CHANGES IN DRY WEIGHT, CHEMICAL COMPOSITION AND VIABILITY OF DEVELOPING SORGHUM CARYOPSES

by

JACK FRANCIS KERSTING

B. S., Kansas State University
of Agriculture and Applied Sciences, 1958

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

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INTRODUCTION

Numerous studies have been conducted on viability and dry weight accumulation of developing caryopses of wheat, oats and barley. Other crops have been studied to a lesser extent. However, information on grain sorghum kernel development, particularly chemical aspects, is lacking. Studies of other crops were directed toward environmental influences on developing kernels (Olson, 1923), time of maximum yield (Frey, et al., 1958) (Grabe, 1956), man's ability to influence different stages of growth resulting in increased yield (Olson, 1923), qualities important in manufacturing consumer goods (McCammon, 1951) and how soon experimental seed may be harvested with assured germination (Scott, 1955) (Frey, et al., 1958). Plant physiologists were particularly interested in determining what changes take place within developing seed and how these changes may affect yield and the following crop.

Information on viability of immature sorghum kernels would be of value to plant breeders since early harvest is advantageous in a breeding program. Likewise, seed producers should find data on time of maximum dry weight accumulation and viability useful. Information on chemical changes associated with seed development is valuable from the standpoint of gaining a better understanding of the basic processes involved in seed development. With the above in mind, an experiment was conducted in 1958 and 1959 with Combine Kafir-60 grain sorghum to study changes in chemical composition, dry weight and viability of developing sorghum caryopses. This thesis reports the results and conclusions from the investigation.

REVIEW OF LITERATURE

Most of the studies of seed maturation in crop plants have considered dry weight, moisture percentage and/or germination. Information involving chemical changes is limited and almost completely concerned with nitrogen. Furthermore, data pertaining to caryopsis development in grain sorghum are not available.

Harlan and Pope (1922) obtained germination of barley caryopses six days after bloom. The average kernel of Hannchen barley, six days after anthesis, contained one-seventh the dry weight at maturity. In a more accurate study in which stigmas were hand pollinated, 90 percent germination was obtained from five-day old seed.

Working with corn, Sprague (1936) observed that air dried samples of 21 through 55 day old seed germinated 100 percent. As the seeds of each harvest were allowed to dry, germination increased and the time required from first germination to final germination of any particular harvest date was decreased. Drying to about 25 percent moisture was necessary before normal germination occurred and varietial differences were noted.

That smooth bromegrass seeds would germinate five days after anthesis was reported by Grabe (1956). Germination was slow hoever, and the seedlings were small and weak. Highest germination percentages and maximum seedling vigor were obtained from seed with maximum dry weight.

Frey et al. (1958) observed that some seeds of oats were capable of germination four days after anthesis. When the dry weight was about two-thirds of maximum, tests gave 90 percent germination. Seed and seedling dry weights were highly correlated (r = 0.97).

Little difference was found by Scott (1955) in germination of winter wheat sampled 11 days after anthesis and at maturity. Seed sampled less than 17 days after anthesis produced plants lacking seedling vigor.

According to Hatcher and Purvis (1945) immature seeds of wheat, rye and barley would readily germinate five days after fertilization and would produce normal sized plants. The kernel size at five days was only 10 percent of fully developed grain.

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

Numerous studies have also been conducted to follow dry weight and moisture percentage trends following anthesis in various crops. Grabe (1956) found maximum dry weight accumulation in smooth bromegrass 17 or 18 days after anthesis when the moisture percentage was on the order of 47 percent. Maximum viability and seedling vigor were noted at this period. Grabe concluded that bromegrass seed may be harvested after maximum dry weight accumulation at high moisture content with no quality damage if proper processing is used.

Actual kernel size of oats was measured by Booth (1929) who found about 82 percent of maximum length at six days after anthesis. About 86 percent of maximum width occurred at three days. Maximum length occurred at 15 days and maximum width at 12 days. Dry matter increased uniformly up to the 15th day.

Olson, (1923) pointed out that dry matter does not increase after moisture content of wheat has dropped to 40 percent.

When the average moisture content for all the kernels on a barley spike is about 42 percent, Harlan and Pope, (1923) noted that dry matter did not further increase.

Wilson and Raleigh, (1929) working with grain quality of oats and wheat found test weight to be greatest from plants that were permitted to mature before harvest. No recognizable difference in 1,000-kernel weight was noted for grain from plants dried in the oven immediately upon harvest, dried in the shock in regular manner, in the shock with culm bases in water and in bags under the eaves of a building. There was no difference in 1,000-kernel weight of grain attached to the full length plant as contrasted with seed from severed spiklets.

Working in Iowa, Frey et al, (1958) found oats to require about 30 days from flower fertilization to maturity which was 25 to 30 percent moisture in the grain. Maximum dry weight was reached 19 to 25 days after anthesis in 1955 when conditions were conducive to a long maturation period. The following year was hot and dry resulting in maximum dry weight accumulation from 13 to 15 days after anthesis. Water content at near maximum dry weight indicated very little food translocation after 45 percent moisture.

Studying grain sorghum plants, Bartel and Martin, (1938) noted that only 10 to 15 percent of the final dry weight of a grain sorghum plant was produced during the first half of the growing period. The sorghum growth curve indicated a slower increase in early stages and a more rapid increase in later stages of growth than is indicated by the typical sigmoid curve. In agreement with other workers, they found a direct relationship between the log of the weight per seed and the log of weight per seedling 10 to 12 days after planting.

Yield of grain, test weight and dry weight per kernel in winter wheat were determined by Scott, (1955) to be at a maximum when the moisture content was about 40 percent.

That nitrogen percent decreases on approaching maturity is evident from studies by Olson, (1923) with wheat, Wilson and Raleigh, (1929) with wheat and oats, and Booth, (1929) with oats. No information on dry weight, viability and chemical changes associated with caryopses development in grain sorghum was found.

METHODS AND MATERIALS

Combine Kafir-60 male-sterile grain sorghum and its male-fertile counterpart were used in this study. Thus, at sampling time each caryopsis sampled on a given head was of the same age. A block of rows was planted in early June in 20 and 40-inch rows, respectively, in 1958 and 1959. Two male-sterile rows were alternated with a single male fertile row in both years. Each experimental area was thinned to a stand of 240 square inches per plant when the seedlings were four to six inches high. In 1958, cultivation was by hoe, and both field machinery and hand cultivation were used in 1959.

After heading but before anthesis, a sufficient number of heads was bagged with Aldrin-treated paper bags. In 1958, hand pollination was carried out on August 13, 14, 17 and 18 and in 1959 on August 4.

The experimental area was divided into four replications each year and samples were then taken from each replication at three-day intervals. In 1958, 20 harvest dates were used. Due to the several dates of pollination, sampling began August 16 and ended October 14. In 1959, samples were taken on 17 dates and included the interval from August 7 through September 21.

At each sampling date, five or six heads were sampled at random from each replication, placed in plastic bags and taken to the laboratory for hand separation. Samples were placed in a cold chamber maintained at approximately 34°F. prior to hand separation. Each dry weight and moisture percentage sample was comprised of 100 kernels from each replication. This sample was immediately weighed and placed in an oven at 70°C. After drying, the dry weight was recorded and replications one and three and replications two and four were combined and used for nitrogen determination.

Another lot of seed was removed to supply sufficient material for carbohydrate analyses. The same replications were combined, autoclaved for five minutes at five pounds of pressure and placed in the oven for subsequent grinding and chemical analysis.

The heads were then placed on a wire screen and allowed to air dry at room temperature until the next harvest at which time each replication's heads were placed in a marked paper bag and set aside for future use.

All chemical analyses were carried out according to A.O.A.C. (1955) methods. In place of copper reduction, carbohydrate fractions were determined from an aliquot of the solutions boiled in 0.18 percent potassium ferricyanide solution for five minutes and immediately cooled. Optical density was read at 420 mu on a Coleman Jr. Spectrophotometer. Amounts of the individual fractions present were then determined from a standard glucose curve. In both years at earlier sampling dates, sample sizes were adjusted in accordance with the amount of material available.

Six 100-seed samples from each of three replications and four 100-seed samples from the fourth replication in 1958 were obtained after the heads were air dry. Two of the samples were used for laboratory germination, two in the greenhouse emergence and seedling vigor test and two for the field test in 1959. In 1958, the laboratory germination test consisted of two complete sets of seed, one treated with Spergon and the other non-treated. Due to only slight differences in seed treatment in 1958, and the fact that all 1959 seed was treated, only the results with treated seed will be considered in this report. Samples obtained in 1958 were germinated according to procedures outlined by the United States Department of Agriculture (1956). The Kansas State Board of Agriculture Seed Laboratory conducted the germination tests on the 1959 seed.

In order to determine the influence of seed maturation on emergence through soil and on seedling vigor, seed was planted in the greenhouse on December 29, 1958 and October 9, 1959. Galvanized flats four inches deep, 14 inches wide and 20 inches long were filled with a mixture of two-thirds soil to one-third sand and thoroughly moistened. Five trenches, each about three-fourths inch deep, were established lengthwise in each flat. Combine Kafir-60 seed obtained in the field was then planted with 100 seeds per row. A randomized complete block design was employed both years. Individual replications in the field corresponded with respective replications in the laboratory and greenhouse tests. Counts of emerged seedling were made at nine, 12, 15 and 18 days after planting in 1958 and at six, 12 and 18 days in 1959. On the eighteenth day the tops were clipped at the soil surface, bagged and oven dried to determine the dry weight per plant which was used as a measure of seedling vigor. The greenhouse temperature was held as nearly as possible to optimum conditions for sorghum growth (85°F.). Since only manual controls were available, this was extremely difficult. Temperatures in 1959 were higher and more favorable for grain sorghum growth than during the period of the 1958 greenhouse test.

In the spring of 1959, plots were laid out in the field, each consisting of two rows 18 feet long. One hundred seeds per row were dribbled through a hand planter on June 3. Each date of harvest from 15 to 57-day old seed was replicated three times in a randomized complete block design. Emergence was determined 15 days after planting. Three harvests were made of the above-ground plant parts, namely, at 18, 27 and 36 days after planting. At each harvest date, 15 plants were chosen at random from each plot except in the case of 15-day plots where only enough plants were taken to allow sufficient material for all three harvests. These plants were dried at 70°C. and weighed. No additional data were obtained in the field except to note that at time of bloom all plots were at about the same stage of maturity.

All data were subjected to procedures outlined by Snedecor (1956). For making random comparisons between means, L.S.D. values were calculated at the five percent level of probability.

RESULTS AND DISCUSSION

Because of differences in climatic conditions during the two years of the study, data from each year are presented separately. Delayed maturity was probably a result of the rather cool, moist weather encountered in 1958 while 1959 was an ideal grain sorghum year except for a dry period in August. Another difference which may of been a factor in several of the anlyses was poorer seed set obtained in 1958, which resulted in larger seed size. Almost all data were similar for both years, the main difference being the time of occurrence of highs and lows. All the treatment means presented in tables in the appendix, were used to establish the graphs that are used and explained in this thesis.

As shown in Figure I and appendix Table 1, moisture percentage decreased at a uniform rate until nearly 40 percent at which time seed harvested in 1959 was a week or more ahead of 1958 seed in loss of moisture.

Dry weight per 100 kernels, (Figure I and appendix Table 1) increased considerably faster in 1959 than in 1958, probably because of higher temperature. At 30 days after pollination seed dry weight from both years was of the same order of magnitude. However, up to that time 1959 seed was about three days ahead of 1958 seed in dry weight. Maximum dry weight accumulation was observed at 45 days in 1958 and on the 33rd day in 1959. This condition was reached before combine harvesting could be accomplished and was followed by a slight decrease in dry weight as the seed lost moisture. Moisture content at the time of maximum dry weight accumulation was about 23 percent and 31 percent in 1958 and 1959, respectively.

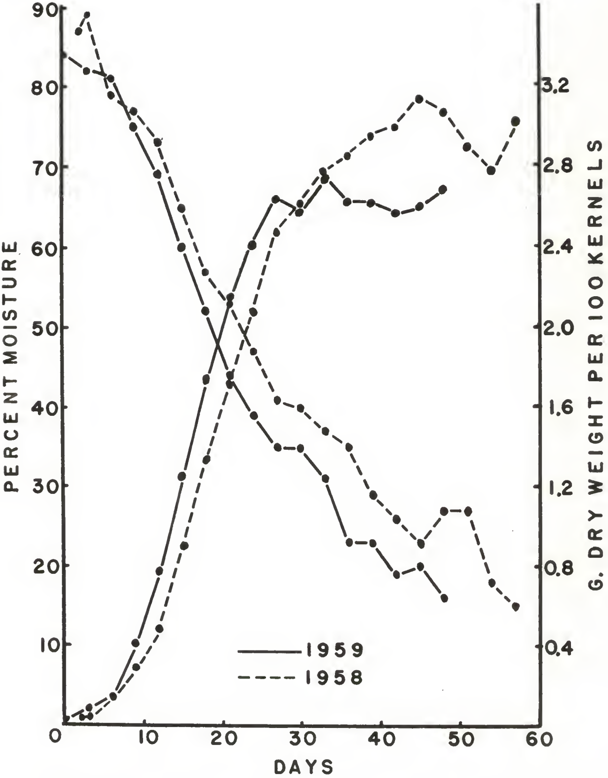

Fig. I. Mean moisture percentage and dry weight per 100 kernels at various stages of maturity of Combine Kafir-60 sorghum grain grown at Manhattan, Kansas in 1958 and 1959.

A possible explanation for increased dry weight at such a low moisture percentage is that the sorghum plant remains green after the seed is ripe, continuing to translocate food materials into the kernel when the kernel moisture percentage is less than that found in small cereal grains when dry weight is at a maximum. Decreases in dry weight after maximum accumulation were probably due to seed respiration. Recent work with soybeans showed loss of dry weight during ripening to be associated with continued high respiration rate of seed under poor drying conditions (Howell, et al., 1959).

Although greenhouse emergence (Figure II and appendix Table 2) was considerably different for the early stages of seed maturation in the two years, viability of near mature and mature seed did not differ greatly. Even though the large increase in emergence in 1959 seed harvested at 12 and 18 days indicated a higher degree of maturity than did the same seed for 1958, it is significant to note that nine-day old seed exhibited no emergence either year. Near-maximum emergence was achieved from 18-day seed in 1959 while near-maximum emergence from 1958 occurred from 33-day seed. Probably much of this difference can be attributed to the environment of the greenhouse and to maturation conditions in the field.

Greenhouse emergence of 15, 30, 45-day seed and seed harvested at maximum dry weight accumulation were compared for the two years in Figure III. It appeared that plants produced from 15-day seed were still emerging at 18 days after planting from 1958 seed, while the same age seed from 1959 was at near maximum emergence 12 days after planting.

Emergence of 30-day seed in 1958 apparently had reached its near-maximum rate 15 days after planting while 30-day seed harvested in 1959 had nearly reached maximum emergence at 12 days after planting. There was little difference in rate of emergence from 45-day old seed and from maximum-dry-weight seed. Both reached near maximum emergence from about nine to 12 days after planting.

Figure III, (appendix Table 3) illustrates the large difference in seedling weights obtained in the two years of the study. This was probably due to differences in the greenhouse temperature during the periods the two tests were conducted. More favorable conditions were obtained in 1959. Germination and emergence were observed shortly after planting in all the samples except the very immature seed. By the time these plants had emerged, they were, in most instances, surrounded by the larger plants and were therefore shaded. If these plants had not been subjected to such strong border effects, seedling vigor values would have no doubt been higher. Near-maximum seedling vigor was not achieved with seed sampled less than 33 days after pollination in 1959, but was reached with 27-day samples in 1958. Again these results are probably due to greenhouse differences. Correlation between seed dry weight and seedling dry weight was significant at the five percent level ($r = 0.89$).

These findings are of importance to seed producers and plant breeders. For the plant breeder who is interested in obtaining as many generations as quickly as possible, these studies show that seed may be harvested considerably before maximum dry weight accumulation without large losses in viability. Seed producers, faced with the problem of

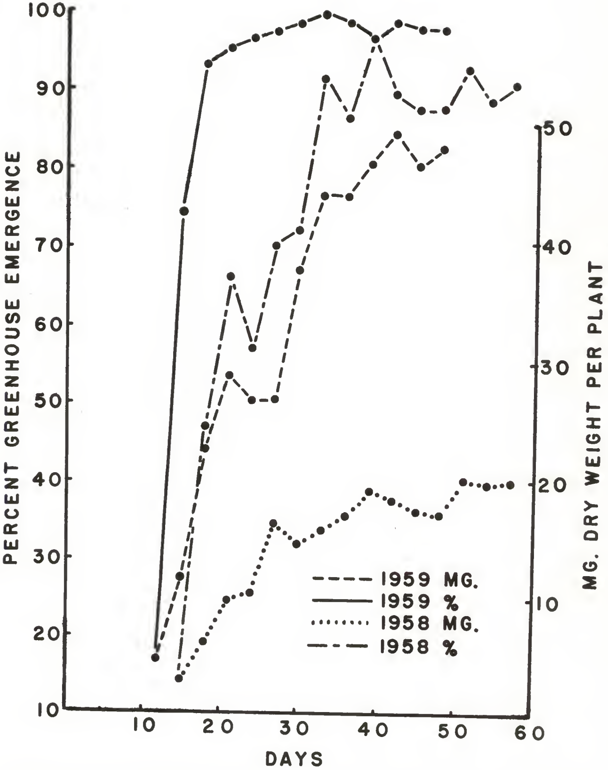

Fig. II. Mean greenhouse emergence percentage and mg. dry weight per plant 18 days after planting Combine Kafir-60 seed harvested at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

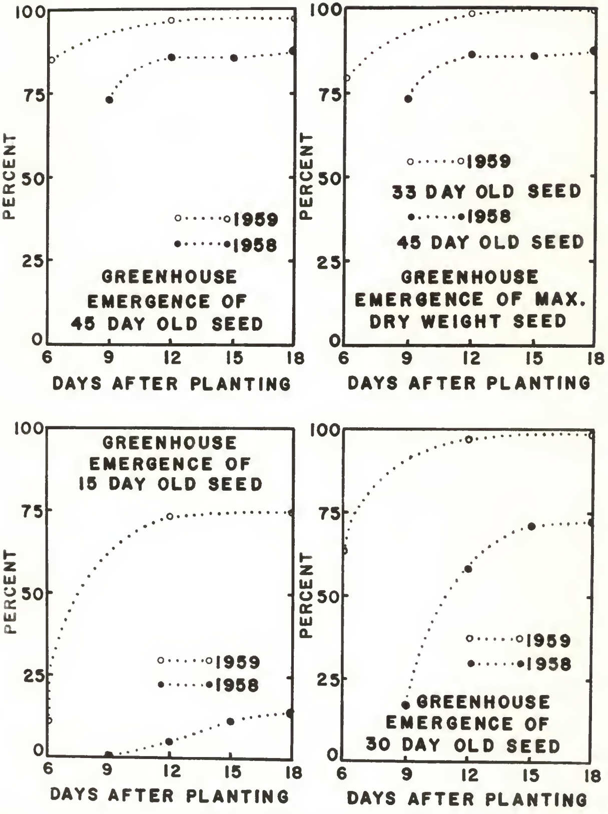

Fig. III. The mean greenhouse emergence of 15, 30, 45-day and maximum dry weight seeds of Combine Kafir-60 counted at various days after planting of 1958 and 1959 seed.

getting their crop to market in time to meet the demands for high quality seed, may find that it is economical to harvest early (near the time of maximum dry weight accumulation) and to use artificial drying to insure a high quality product. Before critical conclusions can be advanced however, data from a wide range of genotypes should be obtained.

Results from laboratory germination tests (Figure IV and appendix Table 4) differed somewhat between the two years. Seed produced in 1958 showed near-maximum laboratory germination from caryopses harvested 18 days after pollination and remained fairly constant thereafter. Rather wide fluctuations were noted from 1959 seed harvested after the 18th day. In general, laboratory germination exceeded emergence in 1958, but in 1959 the difference was reversed as greenhouse emergence through soil exceeded laboratory germination. This difference may be explained in part by a discrepancy in counting live seedlings by the author and the State Seed Laboratory. Greenhouse and laboratory germination values were highly correlated ($r = 0.96^{**}$).

The field emergence test, presented in Figure V and appendix Table 5, was conducted with seed produced in 1958 and planted in the spring of 1959. Small differences in emergence were obtained from seed harvested from 18 days after pollination throughout the rest of the sampling period. These data were from a single emergence count made about 15 days after planting.

Three harvest dates, namely, 18, 27 and 36 days after planting were made from the field emergence trial in order to give some indication of the rate of plant growth from seed of different size. From the results

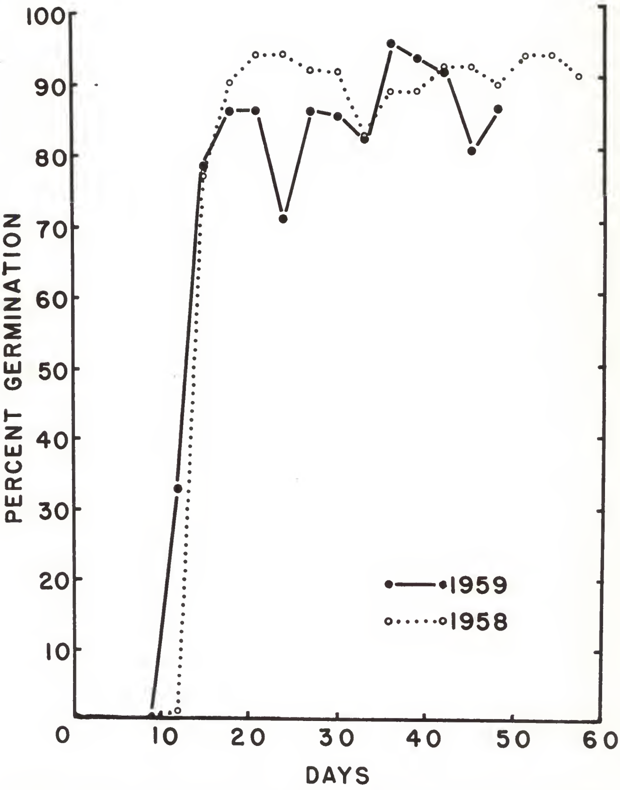

Fig. IV. Mean laboratory germination percentages of Combine Kafir-60 seed harvested at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

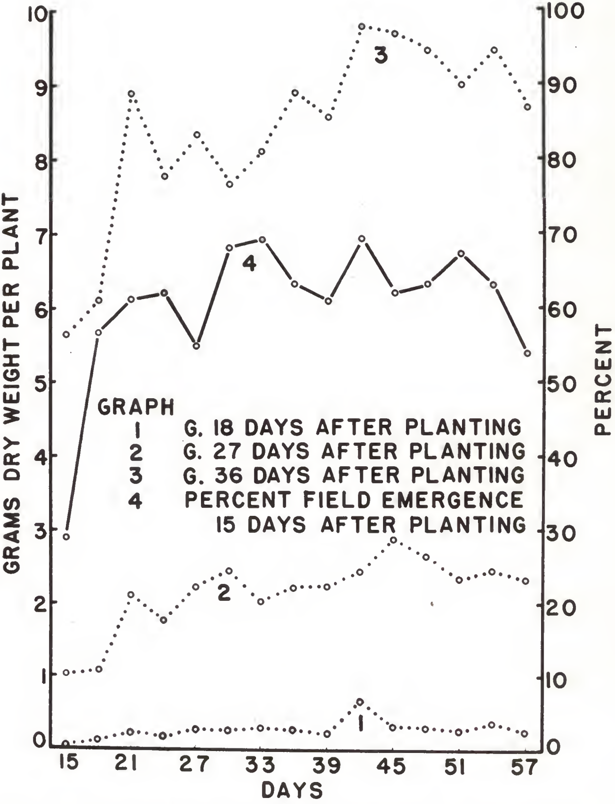

Fig. V. Mean field emergence 15 days after planting 1958 Combine Kafir-60 seed harvested at various stages of maturity, and grams dry weight per plant 18, 27 and 36 days after planting in the field in 1959.

obtained (Figure V and appendix Table 5) it appeared that during the rather restricted growth period employed, plants grown from seeds 21 days old and older did not vary much in dry weight per plant. Plants from seed harvested less than 21 days after pollination were smaller and tended to remain somewhat smaller. All of the plants from the 15-day seed that survived a field cultivation were used in the three harvests. However, all the remaining plants of the other plots were observed at full bloom to show little or no differences in degree of development at that time. The presence of a seed maturity x harvest date interaction indicated the slower rate of development of plants from 15-day seed.

Results of the nitrogen analyses are presented in Figure VI and appendix Table 6. Maximum nitrogen percentage of 2.68 and 3.02 occurred in six and three-day material in 1958 and 1959 respectively while minimum percentage of 2.05 and 1.80 occurred in the 18 and 24 day-old material for the respective years. Once the minimum nitrogen percentages were obtained, little fluctuation was noted thereafter in either year. Expressed in terms of mg. of nitrogen per 100 kernels however, low values were associated with immature seeds. Immediately the nitrogen percentage decreased from 3.5 to 2.0 percent at about 21 days after pollination at which time it increased slightly and thereafter remained fairly constant with only a gradual decrease. These changes in nitrogen percentage were probably associated with the dilution effect of carbohydrate translocation. Milligrams per 100 kernels of nitrogen increased in 1959 until about 30 days after pollination and decreased slightly thereafter. In 1958 nitrogen content increased until 42 days after pollination and then decreased slightly. In both years, these curves approximated the

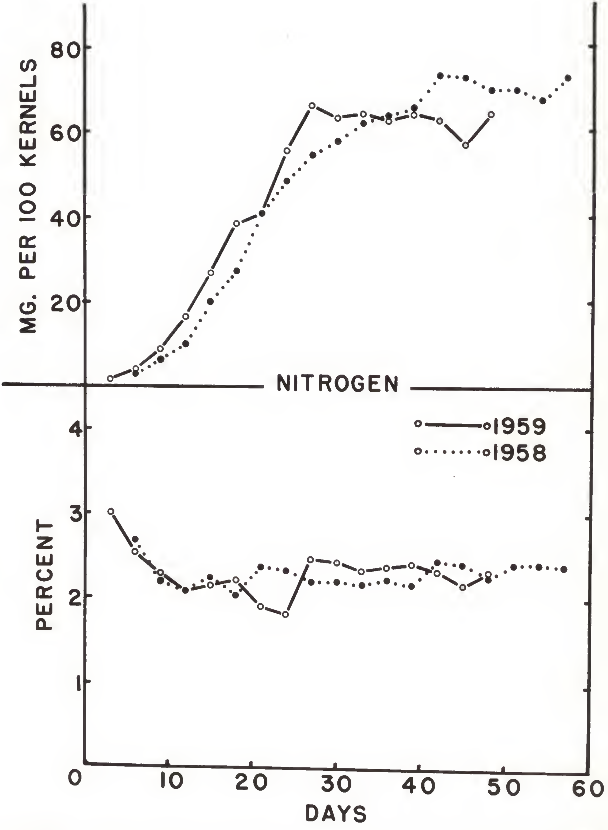

Fig. VI. Mean percentage and mg. per 100 kernels of nitrogen in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

dry weight accumulation curves. Results from both years indicate that nitrogen is moved into the sorghum kernel as long as dry weight is being accumulated and after that time nitrogen content decreases.

As shown in Figure VII and appendix Table 7, percentage of reducing sugars in the younger seeds was relatively high but by 30 days after pollination a fairly constant level was reached. A slight variation in percentage caused considerable fluctuations in mg. of reducing sugars per 100 kernels. In 1958, mg. of reducing sugar per 100 kernels exhibited three distinct peaks while there was only one in 1959. This may have been a result of environmental differences occurring during the two growing seasons, particularly the period of cool temperature encountered in 1958. It is of interest to note that after the final peak in 1958 and the 1959 peak the amount of reducing sugars remained fairly constant.

Total sugar percentages (Figure VIII and appendix Table 8) started low in 1958 but reached a high 12 days after pollination. In 1959 the peak occurred at or before six days after pollination. A possible explanation is that seed development was more rapid in 1959 and total sugar percentage had already reached a maximum before sugar analyses were started. In both years immediately following the maximum total sugar content, percentages decreased and remained fairly constant after about 30 days.

Milligrams of total sugar per 100 kernels in 1959 increased rapidly until about 27 days after pollination. This was followed by a decrease up to 33 days with little variation thereafter. Milligrams of total sugar per 100 kernels in 1958 increased rapidly until 12 days,

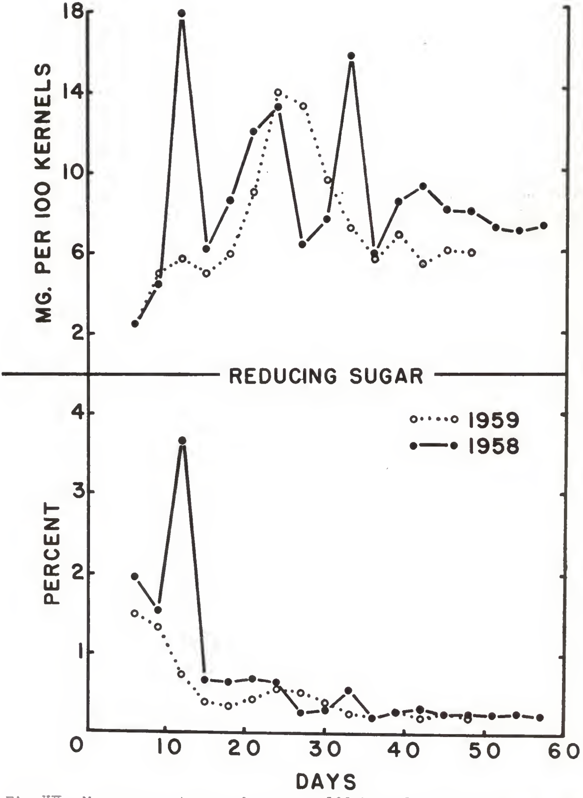

Fig. VII. Mean percentage and mg. per 100 kernels of reducing sugars in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

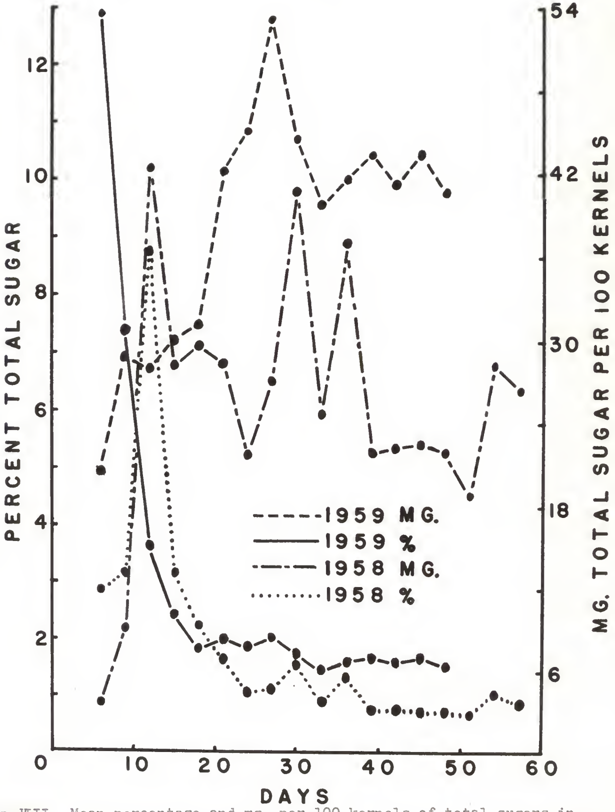

Fig. VIII. Mean percentage and mg. per 100 kernels of total sugars in Combine Kafir-60 seed sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

then decreased until 24 days, thereafter produced two lesser peaks and leveled out at about 23 mg. per 100 kernels at 39 days after pollination.

Nonreducing sugars were determined by the difference between total sugars and reducing sugars. Figure IX and appendix Table 9 illustrates the trend of nonreducing sugars. In general these sugars contributed more to total sugars than did reducing sugars. Nonreducing sugars were more variable that were reducing sugars.

Starch, (Figure X and appendix Table 10) showed a percentage increase in 1958 until 42 days after pollination and then decreased until 48 days, with a slight increase thereafter. Increases in starch percentage in 1959 continued through 33 days and decreased slightly thereafter.

Grams of starch per 100 kernels increased through 33 days in 1959 and through 42 days in 1958. After reaching the maximum in both years, starch content then decreased. Decreasing of the starch content suggests a breakdown to usuable products for embryo respiration and/or production of other compounds. In general, the starch accumulation curves closely followed those for dry matter. Approximately 53 and 68 percent of the total dry matter of maximum dry weight was comprised of starch in 1958 and 1959 respectively.

Acid hydrolyzable carbohydrates are illustrated in Figure XI which was prepared from Table 11. Percentages of acid hydrolyzable carbohydrates for 1959 were nearly constant throughout the entire sampling period. However, in 1958 the percentage started relatively low and equaled the 1959 value at about 12 days after pollination and

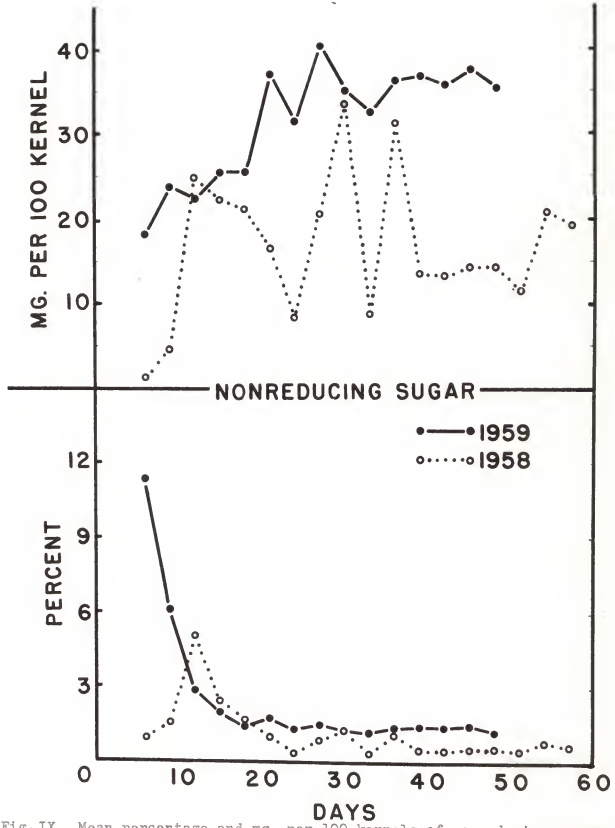

Fig. IX. Mean percentage and mg. per 100 kernels of nonreducing sugars in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

exceeded the remaining 1959 samples. The low percentages at the beginning may have been due to relative differences in maturity.

Grams per 100 kernels of acid hydrolyzable carbohydrates in 1958 seed increased up to the time of near-maximum dry weight, then decreased through the period of maximum dry weight accumulation and reached a maximum at 48 days after pollination and decreased thereafter. An increase in acid hydrolyzable carbohydrates in 1959 through 33 days after pollination was followed by a gradual decrease for the remainder of the harvesting period. Much of the difference in the amount of this fraction for the two years can probably be attributed to larger seed size obtained in 1958.

Diastatic activity was analyzed both years but due to analytical errors the data for 1958 were discarded. Therefore, this report includes information on diastase obtained only in 1959. On a percentage basis there appeared to be little or no difference in diastatic activity due to seed maturation. However, when put on a kernel basis, (Figure XII and appendix Table 12) differences were evident and these variations may help to explain variations found in germination and emergence. A hypothesis is that between 0.2 and 0.5 mg. of glucose produced by diastase is sufficient diastatic activity to initiate some germination. Between 0.5 and 0.75 mg., enough diastase is present to allow essentially complete germination. Further increase in diastase evidently has no great effect on germination and emergence. Diastatic activity increased to some extent throughout the harvest period. However, after about 21 days after pollination further increase was small and a leveling-off tendency was noted. Germination percentage and diastatic activity were significantly associated as shown by correlation ($r = 0.99^{**}$).

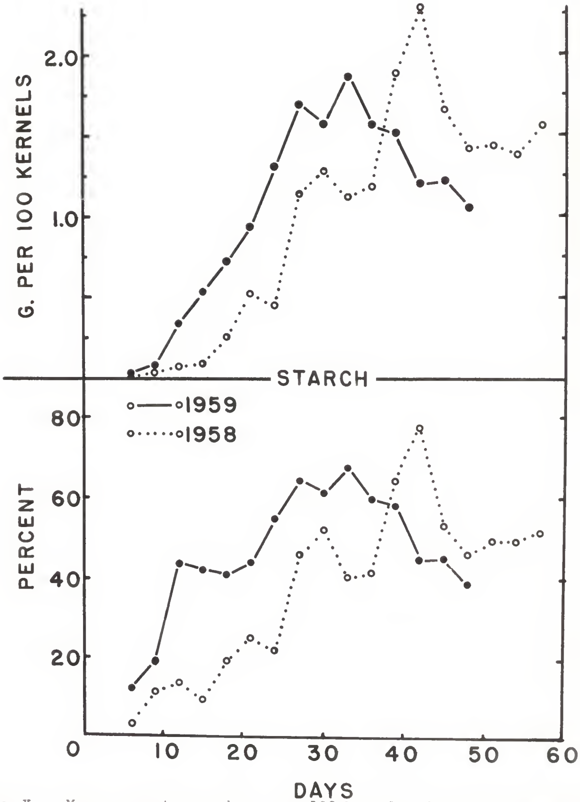

Fig. X . Mean percentage and mg. per 100 kernels of starch in Combine Kafir-60 seed sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

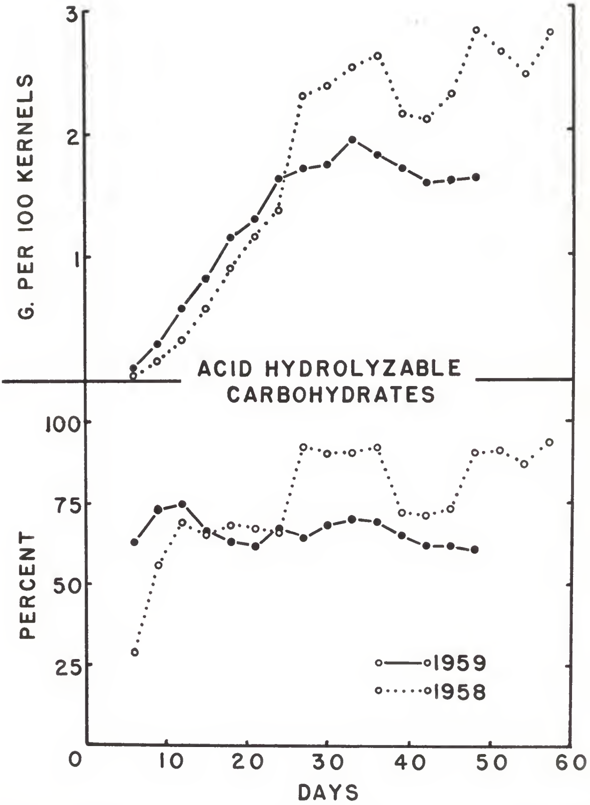

Fig. XI. Mean percentage and mg. per 100 kernels of acid hydrolyzable carbohydrates in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

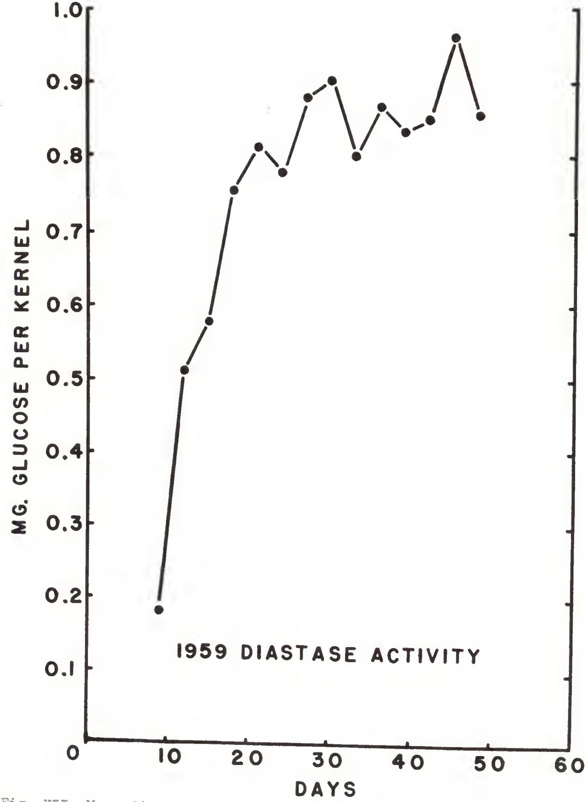

Fig. XII. Mean diastatic activity per kernel, expressed in glucose, of Combine Kafir-60 seed sampled at various stages of maturity at Manhattan, Kansas in 1959.

SUMMARY AND CONCLUSIONS

A study was conducted in 1958 and 1959 to determine changes in dry weight, chemical composition, viability and seedling vigor of grain sorghum caryopses harvested at various stages of maturity.

Male-sterile and male-fertile Combine Kafir-60 were used so the exact age of seed would be known. Head samples were secured every three days from each of four replications and seed samples were removed for analyses. Difference in growing conditions of the two years resulted in more rapid maturation in 1959.

Accumulation of maximum dry weight occurred at about 23 percent moisture and 45 days after pollination in 1958 and at 30 percent moisture and 33 days after pollination in 1959.

Maximum dry weight per 100 kernels was 3.13 and 2.74 grams for the respective years. Following these maximum weights, dry weight decreased slightly.

Unfertilized ovaries contained about 85 percent moisture each year and constantly decreased until approximately the 25 percent level where moisture content of the caryopses tended to fluctuate with environmental conditions.

Milligrams of acid hydrolyzable carbohydrates per 100 kernels, increased steadily throughout the 1958 sampling period, but decreased after maximum dry weight accumulation in 1959. Acid hydrolyzable carbohydrates comprised about 70 percent of the caryopses at the time of maximum dry weight in both years.

Starch percentage increased from 3.44 and 24.3 at six days after pollination in 1958 and 1959, respectively, until near maximum dry weight was accumulated and then decreased thereafter. In 1958, maximum starch was on the order of 77 percent at 42 days while in 1959 it was about 68 percent at 33 days after pollination.

Total sugars increased to a maximum of about 43 mg. per 100 kernels 12 days after pollination in 1958. In 1959 total sugars reached a maximum of about 53 mg. per 100 kernels 27 days after pollination. By the end of the sampling period of 1958, total sugars had decreased to about one half of their maximum value. However, very little decrease, after the maximum, was noted in 1959.

Nonreducing sugars were initially low but increased fairly rapidly in the developing kernels to about 37 mg. per 100 kernels 21 days after pollination in 1959 and thereafter remained nearly constant. In 1959 considerable fluctuation was noted throughout the sampling period. A maximum of about 33 mg. per 100 kernels was reached 30 days after pollination but decreased to about one half by the end of the sampling period. The level of nonreducing sugars considerably exceeded that of reducing sugars.

Percentage of reducing sugars was initially high (about two percent) both years but by 15 days after pollination the value had decreased to 0.5 percent and further decreased until about 0.25 percent at the end of sampling period. Although percent reducing sugar decreased, mg. per 100 kernels increased to about 14 mg. at 24 days after pollination in 1959 and then decreased to about six mg. at 36 days after pollination, thereafter remaining nearly constant. Three distinct peaks occurred in reducing sugar in 1958 but the final amount was similar to that of 1959.

Nitrogen percentage was in excess of 3.00 initially in both years but immediately decreased to a fairly constant range of about 2.1 to 2.4 percent in all material sampled after nine days. Yield of nitrogen increased from less than four mg. at six days after pollination to about 75 mg. per 100 kernels at 42 days in 1958 and nearly 65 mg. per 100 kernels at 27 days after pollination in 1959. Thereafter a slight decrease was noted both years.

Diastatic activity increased rather uniformly from 0.018 mg. per kernel in nine-day old seed to 0.095 mg. per kernel in 45 day-old seed in 1959. These data indicate that germination may occur only after a certain level of diastatic activity has been achieved.

Nine-day old seed failed to germinate in the laboratory either year. Twelve-day seed showed no germination in 1958 and about 33 percent germination in 1959. Germination of 15-day old seed and older ranged from 78 to 94 percent and 71 to 95 percent in 1958 and 1959, respectively.

Results obtained in the greenhouse indicated that younger seeds are slower in emergence through soil than are older seed. In both years the seed maturity x counting date interaction was highly significant. Emergence counts 18 days after planting showed almost no difference from seed 18 days old and older in 1959. Seed 33 days old and older were nearly equal in emergence in 1958.

Dry weight of individual seedlings grown in the greenhouse and harvested 18 days after planting indicated there were three levels of seedling vigor obtained each year. The first, from seed 15 days old and younger weighing about 2.5 mg. per plant; the second, from seeds

18 to 24 days old ranging from 6.1 to 10.2 mg. per plant in 1958 and from 18 to 27-day old seed ranging from 22.1 to 28.7 mg. per plant in 1959; the third, from the remaining seed ranging from 14.5 to 20.0 mg. per plant in 1958 and from 37.0 to 49.0 mg. per plant in 1959. Seed and seedling weights were significantly correlated ($r = 0.89$).

Field emergence results in 1959 from seed harvested in 1958 showed little influence of seed harvested from 18 to 57 days after pollination. Seed harvested 15 days after pollination was significantly lower in emergence than older seed. Dry weight of plants sampled from the field at three growth stages varied little from seed harvested 18 days after pollination and thereafter. The seed age x harvest date interaction was significant at the five percent level of probability.

Results from this study indicate that in a breeding program grain sorghum may be harvested 20 days after pollination with reasonably normal germination and subsequent seedling growth. The findings also suggest that with proper processing grain sorghum seed may be harvested considerably prior to normal harvest for production of high quality seed. Additional experimentation is needed to determine maturity changes of dry matter accumulation and viability of developing caryopses of various genotypes.

ACKNOWLEDGMENT

The writer wishes to extend sincere thanks to Dr. A. W. Pauli who suggested this study, planted the 1958 test and gave further assistance throughout the experiment. Sincere appreciation is also extended to Dr. F. C. Stickler whose supervision and assistance throughout the experimental work of both years helped make this experiment possible, also for his consultation and advice throughout the preparation of this thesis. To Arthur Zech, graduate assistant, for his laboratory analyses of most of the chemical portions of the 1958 material, this author is most grateful. Thanks are also extended to other faculty members who have aided in various phases of this study.

Gratitude is due the many people at the Manhattan Station that rendered assistance toward this study.

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APPENDIX

Table 1. Mean dry weight per one hundred kernels and moisture percentage of grain sorghum seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	Percent moisture 1958	Percent moisture 1959	Grams dry weight per 100 kernels 1958	Grams dry weight per 100 kernels 1959
Unfertilized ovaries[a]	85.4	84.4	0.021	0.020
2	87.1		0.033	
3	88.7	82.1	0.035	0.065
6	79.3	81.4	0.125	0.160
9	77.4	75.6	0.293	0.400
12	72.8	69.4	0.488	0.780
15	64.5	59.9	0.910	1.260
18	56.7	52.0	1.333	1.745
21	52.6	44.1	1.740	2.125
24	47.2	39.4	2.070	2.405
27	41.3	35.0	2.470	2.643
30	40.3	34.6	2.615	2.563
33	37.0	30.7	2.775	2.743
36	34.5	22.9	2.840	2.625
39	29.4	23.2	2.943	2.615
42	25.8	19.3	2.983	2.573
45	23.4	20.6	3.125	2.595
48	26.7	16.1	3.065	2.680
51	27.4		2.890	
54	18.0		2.778	
57	15.0		3.020	
L.S.D. .05 level	2.20	2.36	0.141	0.502

Analysis of variance

Source of variation	D.F.	Means squares 1958	Means squares 1959
Moisture percent			
Total	79, 63		
Replications	3, 3		
Harvest dates	19, 15	2,258.74**	2,129.01**
Error	57, 45	2.4105	2.7542
Dry weight			
Total	79, 63		
Replications	3, 3		
Harvest dates	19, 15	5.609**	3.9753**
Error	57, 45	0.0103	0.1242

a/ Not used in analysis because only one sample was taken.
** Exceeds the 1% level of significance.

Table 2. Mean greenhouse emergence for four counting dates of seed sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Age of seed	Days after planting						
	1958				1959		
	9	12	15	18	6	12	18
9	0	0	0	0	0	0	0
12	0	0	0	0	0	15	17
15	1	5	12	17	11	73	74
18	10	35	47	47	40	94	93
21	30	60	65	66	22	96	95
24	21	48	56	56	33	93	96
27	22	58	70	70	23	94	97
30	17	63	72	72	63	97	98
33	28	83	89	91	79	98	99
36	33	79	86	86	88	97	98
39	54	89	94	95	86	95	96
42	77	88	88	89	90	98	98
45	74	86	86	87	85	97	97
48	44	82	87	87	89	96	97
51	76	91	92	92			
54	74	87	88	88			
57	69	88	90	90			

L.S.D. .05 level 1958 = 11.81, 1959 = 9.00

Combined analysis of variance

Source of variation	D.F.	Mean squares 1958	Mean squares 1959
Total	271, 167		
Replications	3, 3		
Treatment	67, 41	4,400**	5,193**
Seed maturity (S)	16, 13	15,101**	11,362**
Counting dates (C)	3, 2	13,204**	18,490**
S x C	48, 26	491**	1,001**
Error	201, 123	72.7	41.4

** Exceeds the .01 level.

Table 3. Mean mg. dry weight per plant of greenhouse seedlings 18 days after planting Combine Kafir-60 seed harvested at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	1958	1959
9	0.0	0.0
12	0.0	4.4
15	2.5	11.7
18	6.1	22.6
21	9.7	28.7
24	10.2	26.7
27	16.0	26.9
30	14.5	37.9
33	15.5	44.2
36	16.8	44.0
39	19.2	46.9
42	18.4	49.4
45	17.3	46.5
48	17.0	48.1
51	20.0	
54	19.3	
57	19.6	
L.S.D. .05 level	2.94	5.78

Analysis of variance

Source of variation	D.F.	Mean squares 1958	Mean squares 1959
Total	67, 55		
Replications	3, 3		
Harvest dates	16, 13	194.79**	1,123.36**
Error	48, 39	4.296	16.370

**Exceeds the .01 level.

Table 4. Mean germination percentages from Combine Kafir-60 sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	1958	1959
9	0	0
12	0	33
15	78	78
18	90	86
21	94	86
24	94	71
27	92	86
30	91	85
33	82	82
36	89	95
39	89	93
42	92	91
45	92	80
48	89	86
51	93	
54	93	
57	90	
L.S.D. .05 level	9.360	14.89

Analysis of variance

Source of variation	D.F.	Mean squares 1958	Mean squares 1959
Total	67, 111		
Replications	3, 7		
Harvest dates	16, 13	3,627**	5,552**
Error	48, 91	21.708	112.46

** Exceeds the .01 level.

Table 5. Mean dry weight per plant of three harvest dates and mean field emergence percentage from different aged seed grown in 1958 and planted June 2, 1959 at Manhattan, Kansas.

Days after pollination	% emergence 15 days after planting	Grams dry weight per plant at the following days after planting: 18	27	36
15	29	0.06	1.02	5.62
18	55	0.13	1.09	6.11
21	61	0.33	2.13	8.91
24	62	0.20	1.71	7.70
27	55	0.26	2.22	8.31
30	68	0.25	2.42	7.67
33	69	0.27	2.02	8.11
36	63	0.26	2.24	8.87
39	61	0.23	2.27	8.58
42	69	0.66	2.40	9.71
45	62	0.33	2.82	9.69
48	63	0.31	2.64	9.49
51	67	0.27	2.36	8.93
54	63	0.35	2.47	9.42
57	55	0.24	2.31	8.69

L.S.D. .05 level

Source of variation	D.F.	Mean squares
	Emergence	
Total	89	
Replications	5	
Harvest dates	14	578.64**
Error	70	143.57
	Dry weight per plant (3 harvest dates)	
Total	134	
Replications	2	
Treatment	44	38.67**
Maturity stage of seed (S)	14	3.07**
Sampling dates (M)	2	814.66**
S x M	28	1.04*
Error	88	0.563

** Exceeds the .01 level
* Exceeds the .05 level

Table 6. Mean percentage and mg. per 100 kernels of nitrogen in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	Percent nitrogen		Milligrams nitrogen Per 100 kernels	
	1958	1959	1958	1959
2	4.00[a]		1.30[a]	
3	4.00[a]	3.02	1.40[a]	1.93
6	2.68	2.54	3.35	4.05
9	2.21	2.29	6.50	9.19
12	2.09	2.10	10.25	16.42
15	2.25	2.14	20.45	26.87
18	2.05	2.21	27.55	38.50
21	2.39	1.93	41.50	40.97
24	2.34	1.81	48.45	55.66
27	2.21	2.48	54.50	65.91
30	2.21	2.46	57.80	62.97
33	2.19	2.34	62.00	64.22
36	2.23	2.39	63.50	62.53
39	2.19	2.42	64.50	63.17
42	2.46	2.34	73.25	60.39
45	2.42	2.19	72.40	56.80
48	2.28	2.32	69.85	62.14
51	2.42		69.80	
54	2.42		67.05	
57	2.40		72.60	
L.S.D. .05 level	0.161	0.339	4.338	4.135

Analysis of variance

Source of variation	D.F.	Mean squares 1958	Mean squares 1959
Percent nitrogen			
Total	35, 31		
Replications	1, 1		
Harvest dates	17, 15	0.0466**	0.1513*
Error	17, 15	0.0116	0.0507
Milligrams nitrogen/100 kernels			
Total	35, 31		
Replications	1, 1		
Harvest dates	17, 15	1,215.98**	1,132.80**
Error	17, 15	8.4529	7.530

** Exceeds the .01 level

* Exceeds the .05 level

a/ Not used in statistics and graph because it was not replicated.

Table 7. Mean percentage and mg. per 100 kernels of reducing sugars in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	Percent reducing sugars		Milligrams reducing sugars Per 100 kernels	
	1958	1959	1958	1959
6	1.96	1.51	2.46	2.41
9	1.54	1.33	4.52	5.24
12	3.67	0.73	17.89	5.71
15	0.68	0.40	6.24	4.98
18	0.64	0.35	8.60	5.97
21	0.69	0.43	12.00	9.03
24	0.64	0.57	13.32	13.81
27	0.26	0.51	6.42	13.26
30	0.30	0.38	7.68	9.53
33	0.56	0.26	15.68	7.19
36	0.21	0.22	5.96	5.71
39	0.29	0.26	8.54	6.83
42	0.32	0.21	9.34	5.39
45	0.26	0.24	8.12	6.08
48	0.26	0.21	8.00	5.59
51	0.25		7.22	
54	0.27		7.08	
57	0.24		7.25	
L.S.D. .05 level	0.111	0.158	2.040	1.899

Analysis of variance

Source of variation	D.F.	Mean squares	
		1958	1959
	Percent reducing sugars		
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	1.5351**	0.3193**
Error	17, 14	0.0055	0.0109
	Milligrams reducing sugars		
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	29.393**	19.146**
Error	17, 14	1.869	1.567

** Exceeds the .01 level

Table 8. Mean percentage and mg. per 100 kernels of total sugars in Combine Kafir-60 sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	Percent total sugars		Milligrams of total sugar per 100 kernels	
	1958	1959	1958	1959
6	2.86	12.84	3.58	20.57
9	3.12	7.40	9.12	29.09
12	8.75	3.61	42.79	28.23
15	3.14	2.42	28.58	30.39
18	2.24	1.80	29.92	31.44
21	1.64	2.00	28.48	42.51
24	1.05	1.88	21.74	45.28
27	1.10	2.02	27.30	53.38
30	1.57	1.74	41.06	44.59
33	0.90	1.45	24.74	39.72
36	1.31	1.60	37.20	41.93
39	0.75	1.66	22.06	43.55
42	0.75	1.60	22.37	41.30
45	0.72	1.68	22.52	43.60
48	0.72	1.52	22.06	40.75
51	0.65		18.74	
54	1.02		28.23	
57	0.88		26.46	
L.S.D. .05 level	0.320	1.56	5.649	7.0425

Analysis of variance

Source of variation	D.F.	Mean squares 1958	Mean squares 1959
	Percent total sugars		
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	7.366**	19.312**
Error	17, 14	0.0459	1.064
	Milligrams total sugar		
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	185.774**	147.052**
Error	17, 14	14.334	21.559

** Exceeds the .01 level

Table 9. Mean percentage and mg. per 100 kernels of nonreducing sugar in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	Percent nonreducing sugar 1958	Percent nonreducing sugar 1959	Milligrams of nonreducing sugar per 100 kernels 1958	Milligrams of nonreducing sugar per 100 kernels 1959
6	0.90	11.34	1.12	18.16
9	1.57	6.08	4.60	23.85
12	5.08	2.88	24.79	22.56
15	2.46	2.03	22.34	25.39
18	1.60	1.46	21.18	25.47
21	0.95	1.75	16.53	37.10
24	0.40	1.31	8.36	31.51
27	0.84	1.52	20.87	40.12
30	1.28	1.37	33.33	35.05
33	0.33	1.19	8.98	32.53
36	1.10	1.38	31.24	36.23
39	0.46	1.40	13.54	36.73
42	0.44	1.39	13.28	35.91
45	0.46	1.45	14.37	37.53
48	0.46	1.31	14.11	35.07
51	0.40		11.61	
54	0.74		20.83	
57	0.64		19.28	
L.S.D. at .05 level	0.340	1.463	5.371	6.373

Analysis of variance

Percent nonreducing sugar

Source of variation	D.F.	Mean squares 1958	Mean squares 1959
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	2.5732**	14.921**
Error	17, 14	0.0519	0.9299
Milligrams nonreducing sugar			
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	144.037**	89.766**
Error	17, 14	12.959	17.653

** Exceeds the .01 level

Table 10. Mean percentage and mg. per 100 kernels of starch in Combine Kafir-60 seed sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	Percent starch 1958	Percent starch 1959	Grams starch per 100 kernels 1958	Grams starch per 100 kernels 1959
6	3.44	12	0.004	0.019
9	12	19	0.035	0.075
12	14	44	0.069	0.342
15	10	42	0.087	0.531
18	19	41	0.257	0.718
21	25	44	0.527	0.935
24	22	55	0.456	1.311
27	46	64	1.140	1.694
30	52	61	1.273	1.561
33	40	68	1.119	1.854
36	42	60	1.186	1.560
39	64	58	1.881	1.511
42	77	45	2.290	1.150
45	53	45	1.653	1.164
48	46	39	1.415	1.047
51	50		1.430	
54	50		1.379	
57	51		1.552	
L.S.D. .05 level	3.656	5.57	118.7	108.5

Analysis of variance

Source of variation	D.F.	Mean squares 1958	Mean squares 1959
Percent starch			
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	856.27**	485.12**
Error	17, 14	6.01	13.51
Grams starch			
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	1,005,583**	683,917**
Error	17, 14	6,333	5,113

** Exceeds .01 level

Table 11. Mean percentage and mg. per 100 kernels of acid hydrolyzable carbohydrates in Combine Kafir-60 seeds sampled at various stages of maturity at Manhattan, Kansas in 1958 and 1959.

Days after pollination	Percent acid hydrolyzable 1958	Percent acid hydrolyzable 1959	Grams acid hydrolyzable carbohydrates 1958	Grams acid hydrolyzable carbohydrates 1959
6	29	63	0.036	0.100
9	56	73	0.164	0.291
12	69	75	0.338	0.587
15	65	66	0.589	0.829
18	68	63	0.903	1.107
21	67	61	1.163	1.298
24	66	67	1.363	1.621
27	92	64	2.276	1.697
30	90	68	2.367	1.737
33	91	70	2.521	1.933
36	92	69	2.604	1.800
39	72	65	2.131	1.702
42	71	62	2.110	1.595
45	73	62	2.294	1.602
48	91	61	2.798	1.626
51	91		2.633	
54	87		2.460	
57	92		2.792	
L.S.D. .05 level	3.44	3.51	0.141	0.111

Analysis of variance

Source of variance	D.F.	Mean squares 1958	Mean squares 1959
Percent acid hydrolyzable carbohydrates			
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	581.606*	38.343**
Error	17, 14	5.334	5.365
Grams acid hydrolyzable carbohydrates			
Total	35, 29		
Replications	1, 1		
Harvest dates	17, 14	1.8858**	0.6821**
Error	17, 14	0.0089	0.0054

** Exceeds the .01 level

Table 12. Mean diastatic activity per kernel, expressed in glucose, of Combine Kafir-60 sampled at various stages of maturity at Manhattan, Kansas in 1959.

Days after pollination	Milligrams glucose
6	0.018
12	0.049
15	0.056
18	0.074
21	0.080
24	0.077
27	0.087
30	0.089
33	0.079
36	0.086
39	0.082
42	0.084
45	0.095
48	0.085
L.S.D. .05 level	0.0088

Analysis of variance

Source of variation	D.F.	Mean squares
Total	27	
Replications	1	
Harvest dates	13	0.0008230**
Error	13	0.0000329

** Exceeds the .01 level

CHANGES IN DRY WEIGHT, CHEMICAL COMPOSITION
AND VIABILITY OF DEVELOPING SORGHUM CARYOPSES

by

JACK FRANCIS KERSTING

B. S., Kansas State University
of Agriculture and Applied Science, 1958

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

Although seed maturation has been studied in most crop plants, little information is available on caryopsis development in grain sorghum. In order to evaluate chemical changes, dry weight accumulation, viability and seedling vigor of developing grain sorghum seed, a study was conducted in 1958 and 1959 at Manhattan, Kansas.

A sample of hand pollinated seeds from each of four replications of male sterile Combine Kafir-60 pollinated with the fertile counterpart was obtained every three days after pollination.

Maximum dry weight accumulation was found 45 days after pollination at 23 percent moisture in 1958 and at 33 days and 30 percent moisture in 1959.

Milligrams per 100 kernels of starch, total sugars, nonreducing sugars, and nitrogen increased until near maximum dry weight and decreased thereafter. Curves for these components had the same general shape as the dry weight curves.

Percentages of starch increased until maximum dry weight was obtained and then decreased. Total sugar percentages were high initially (9 and 13 percent respectively in 1958 and 1959) but decreased to rather low levels (0.75 and 1.5 percent respectively in 1958 and 1959) at the end of the sampling period. In general the level of nonreducing exceeded that of reducing sugars.

Nitrogen percentage values were nearly identical for both years. Six-day material contained about three percent nitrogen and decreased until 15 days when the level was on the order of 2.25 percent.

Milligrams of acid hydrolyzable carbohydrates per 100 kernels increased throughout the 1958 season, but decreased after maximum dry weight in 1959. Percentage values varied from 28.5 to 92.4 and from 60.7 to 75.2 in 1958 and 1959 respectively.

Diastatic activity per kernel in 1959 showed the same general trend as dry weight accumulation, but did not decrease after the 33rd day.

Emergence in the greenhouse exceeded 90 percent from seed 18 days old and older in 1959, and 86 percent from 33-day and older seed in 1958. Significant decreases in seedling vigor (weight per seedling) were obtained from seed harvested before 21 and 18 days, respectively, in 1958 and 1959. Seed and seedling weights were significantly correlated.

Field emergence of 1958 seed ranged from 55 to 69 percent from 18 through 57-day old seed. Seedling vigor was noted to be least from 18-day old and younger seed.