SUGAR CONTENT OF THE CULM OF FOUR VARIETIES OF SORGHUM IN RELATION TO PHYSIOLOGICAL MATURITY

by

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INTRODUCTION

Forage sorghums have long been a major source of livestock feed in Kansas and certain areas of the Southwestern United States. Until a few years ago, all of the forage sorghums were standard varieties. The discovery of cytoplasmic male sterility in 1954 as reported by Stephens and Holland (5) made it possible to utilize hybrid vigor in the production of sorghums. The sorghum hybrids could be classified as grain, forage, and intermediate or dual purpose types. The concept of an ideal forage sorghum was no longer as distinct as it once was. The forage hybrid, because of its parentage, had a low sugar content of the stalk and produced a large amount of grain in comparison with the typical standard variety which produced less grain and had a somewhat sweeter stalk.

The sterile forage sorghum hybrid was also introduced. It was felt by some persons that the starch normally stored in the caryopses would be in a more available form as sugar in the culm. This concept has been disputed by numerous workers but adequate proof has not been given.

The influence of maturity on the composition of the sorghum plant has been of interest for as long as sorghums have been used for forage and sirup. Collier (3) noted that certain varieties of sorghums had different chemical compositions at the same stage of maturity. He stated that as maturity varied, so did the quantity of the various chemical compounds and that certain varieties failed to vary in the same pattern. In effect, there was a stage of maturity - variety interaction for each variety that determined the chemical composition of the sorghum plant.

The main purpose of this study was to investigate the changes, if any, in the sugar content of the sorghum culm in relation to the maturity of the grain. Four varieties, representing a rather wide range in maturity and type, were used in the study in order to detect any possible varietal differences.

REVIEW OF LITERATURE

The earliest notable work on the sugar content of sorghum was by Collier (3). He reported that in the earlier stages of growth of the sorghum plant the amount of crystallizable sugar (sucrose) was small; but as the plant matured the sucrose rapidly increased until it equalled from 12 to 16 per cent of the juice. At the same time the uncrystallizable sugar (glucose) steadily diminished. He further stated that the specific gravity of the juice and the percentage of solids not sugar regularly increased until the end of the season. He regarded the optimum stage to obtain both quantity and quality of sugar to be when the seed was dry and could be easily split.

Willaman, West, and Spriesterbach (12) studied three varieties of Amber sorgo at eight different stages of maturity. These stages ranged from the emergence of the panicle until the seed was brittle and mature. At the first stage, the reducing sugars were greatly in excess of the sucrose. Reducing sugars decreased, sucrose increased, and at full bloom they were about equal. These trends continued towards maturity and the final non-reducing:reducing sugar ratio was from 7:3 to 9:1, depending upon the variety. They further reported that the removal of the head prior to maturity hastened the production of a maximum amount of sugar in the juice. However, the same amount would be obtained at a later date without the removal of the heads.

Berthelot and Trannoy (2) studied the sucrose, dextrose, and levulose content of the juice of one variety of sorghum at eight stages of growth. These stages were very similar to those chosen by Willaman, West, and Spriesterbach. Berthelot and Trannoy found that the dextrose content was consistently greater than the levulose content and that both reached a minimum at the stage of maturity at which sucrose content was at a maximum.

Ventre, Byall, and Walton (8) divided the sweet sorghum plant into the individual internodes and studied the sirup quality of the juice that came from various parts of the stalk. The starch content and the jellying of the sirup due to starch was greatest in the upper internodes and the number of internodes that caused starch jellying increased with maturity. They observed the same results when they studied the sucrose content and sucrose crystallization. In comparison, dextrose crystallization was most commonly associated with the lower internodes of the culm and the number of these internodes decreased with maturity.

Webster, Davies, and Sieglinger (9) studied a large group of forage sorghums. They found an increase in total solids as the season progressed, but this was accompanied by a drop in the yield of juice. For most varieties there was an optimum stage of maturity when maximum acre yields of juice were obtained, but this stage varied from variety to variety and from season to season. The juice of most varieties contained 14 to 20 per cent solids, except Collier, which was consistently between 20 and 24 per cent. They further stated that the sugar content of the various juices varied from ten to nearly 20 per cent. In all varieties there was an increase in non-reducing sugars and a decrease in reducing sugars as the season progressed. There were large varietal differences in the ratio of the two types of sugar.

Ventre, Byall, and Cattlett (7) concluded that reducing sugars were highest in the immature plant and decreased with maturity as sucrose content increased. Dextrose always exceeded levulose and in some varieties of sorghum, levulose entirely disappeared. In an earlier study, Ventre and Byall (6) had reported that the percentage of dissolved solids, of which total sugar is a part, increased with maturity. The percentage was low in the upper internodes, increased to a maximum in the third or fourth internodes, and then decreased in the lower internodes. Sucrose was also similar in its distribution and with maturity it increased in the same relative proportion in all internodes.

Webster and Heller (10) studied the effect of sugar content of two varieties, Atlas and Dwarf Yellow Milo, on chinch bug resistance. In the early stages of growth, the percentage of solids was higher in Dwarf Yellow Milo than in Atlas. Reducing and total sugars increased steadily in both varieties until the time of heading. Sucrose was almost entirely lacking in the early stages of Atlas, but was always present in small amounts in Dwarf Yellow Milo. They concluded that although Atlas is classified as a sweet sorghum, Dwarf Yellow Milo almost always had as much or more total sugar, and it was only after heading that the sugar content varied to any extent.

As a follow-up study, Webster, Sieglinger, and Davies (11) observed a large number of sorghums which represented a wide range in type. Grain, forage, and intermediate types were included. There was a tendency for all varieties to contain a high percentage of total solids when the plants were extremely small, decrease somewhat, and then increase as heading time approached. The low point of the curve corresponded to the point where accelerated plant growth began. They concluded that sucrose was present in the sweet sorghums in only minute amounts until after heading.

MATERIALS AND METHODS

This study was conducted with four varieties of sorghum: Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088. The varieties represented a rather wide and diverse range in height, maturity, sugar content, and amount of seed produced. Dwarf

Yellow Milo is a 2-dwarf sorghum and has a dry, non-sweet culm. It was used widely at one time for grain production. Pink Kafir is classified as a juicy, non-sweet sorghum and is approximately the same height as Dwarf Yellow Milo. It has been used for both forage and grain. Atlas has long been one of the major forage sorghums in Kansas and is noted for its high yield and its sweet, juicy culm. 54M2088 is a selection from a Collier-Atlas cross, and it has consistently outyielded Atlas at Manhattan. It produces only one-half as much grain as Atlas, but has significantly sweeter juice, blooms three to five days later, and is ten to 12 inches taller. The high sugar content of the culm evidently was inherited from the Collier parent.

The four varieties were planted on the Agronomy Farm on June 1, 1960. Each variety was replicated three times in a radomized complete block design. A heavy rate of seeding was used in order to obtain the necessary stand. The seedlings of all varieties emerged uniformly in approximately four days. The thick stand was thinned accurately to six inches between plants when they were four to six inches in height.

The sorghum varieties were grown on rolling Geary silty clay which was reasonably fertile and deep. Moisture conditions were excellent throughout the entire growing season. A short, droughty period during late June and early July had little effect on the growth of the plants. Daytime temperatures were slightly below average throughout most of the season.

The date of anthesis was noted for each variety when 50 per cent of the inflorescences were in some stage of bloom. The number of days from planting until anthesis for the four varieties were: Dwarf Yellow Milo, 74; Pink Kafir, 74; Atlas, 80; and 54M2088, 83.

The sampling period for each variety began 15 days after 50 per cent bloom and continued at three-day intervals until sufficient plants were no longer available or the freezing temperatures of October 20 killed the remaining plants. Chinch bugs damaged the Dwarf Yellow Milo during July and killed a number of the plants. Consequently, it was impossible to have as many sample dates of this variety as the others.

The sampling for each variety was done at approximately 4:00 p.m. on each sample date to minimize any within-day variation that might have occurred. Three plants were picked individually at random from each replication. To prevent the use of plants that were next to an area of the row that had plants previously removed, alternate plants were always picked. It was hoped that by using this method the amount of border effect on any individual plant would be held to a minimum.

The three plant samples from each replication for each variety were taken to the laboratory. The heads were removed from the peduncles and the leaf sheaths and blades separated from the culms. A small amount of the fresh juice was extracted with a lemon squeezer from the internode portion between the second and third nodes. Several drops of this juice were placed in a refractometer and a reading of the percentage of total solids present was taken.

The culms were chopped into four inch lengths and were then bulked. The green weight was recorded to the nearest gram. The leaves and the heads from each replication were also bulked separately and weighed. The culm samples were autoclaved for five minutes at approximately five pounds pressure to inactivate the enzymes present. The total amount of time from when the plants were cut in the field until the last replication was autoclaved was approximately two hours or less.

The samples were dried at 70° C. until they reached a constant dry weight. The heads and the leaves usually reached this weight in 24 hours, but the culms took as much as 72 hours to dry. The dried culms and the leaves were weighed and ground with a Wiley Junior Mill using a two millimeter mesh screen. A second grinding with a one millimeter mesh screen was necessary to obtain the fineness of the plant material that was required for the chemical analysis.

The oven-dried heads were weighed and then threshed. The pumice that was removed during the threshing process was discarded and the cleaned grain representing the three plants of a single variety from one sample date was weighed. This grain was used in the feedstuff analyses at a later date. Three 100 seed samples were taken from the grain of each sample date and were weighed to the nearest ten-thousandth of a gram. The average weight per 100 seeds was plotted versus the number of days after anthesis and a growth curve was constructed in order to determine the time of physiological maturity, the point at which there was no longer a significant increase in the dry weight of the caryopses.

Sugar analyses were run on the ground culm samples representing the sample dates of nine days before physiological maturity and 12 days after physiological maturity. This gave eight sample dates which covered a period of 21 days. Dwarf Yellow Milo was an exception since there were only six sample dates used.

Sugars were extracted in a Soxhlet extractor for six to eight hours using 80 per cent ethyl alcohol according to the A.O.A.C. method (1). Following clarification, the reducing sugar was quantitatively measured by the use of a Coleman Junior Model 6A Spectrophotometer. The optical density was determined at 420 mu for 2 ml. of each solution after it had been mixed with 3 ml. potassium ferricyanide solution and 3 ml. of water, heated for five minutes in boiling water, and made to an equal volume. Total sugar was determined by adding 5 ml. concentrated hydrochloric acid to 50 ml. of the clarified solution, allowing to stand overnight, neutralizing, and then making to 100 ml. The optical density was then determined in a manner similar to that for the reducing sugar. The optical density readings were recorded and then referred to a standard glucose curve. Results were computed on the basis of grams of sugar per sorghum culm.

Sub-samples of the culm samples and the grain samples from the corresponding sample dates of all four varieties were sent to the Kansas State University Chemistry Service Laboratory for a complete feedstuff analysis. The results of the crude fiber, nitrogen-free extract, and total carbohydrates determinations are presented in this thesis as percentage of the total weight and as grams per culm.

All of the statistical analyses in this thesis were performed according to methods described by Snedecor (3). Fischer's "F test" was used to detect any possible differences among means. The five per cent level of significance was used in the calculation of each least significant difference (LSD).

EXPERIMENTAL RESULTS

Determination of Physiological Maturity

The weights in grams per 100 seeds are given in Table 1. All four varieties showed a definite upward curve in the oven-dry weight of the seed as the plants progressed towards maturity. Dwarf Yellow Milo reached a definite maximum 42 days after bloom, followed by a definite downward trend on two sample dates. Pink Kafir reached maximum dry weight per 100 seeds 36 days after bloom, but on the six sample dates which followed, there was no definite loss of weight. The variation that was encountered from sample date to sample date could have been due to sampling variation and experimental error. Atlas showed a definite increase for each sample date until 42 days after bloom. After this date, the weights had a tendency to stabilize, but on the third and fourth sample dates after physiological maturity, slightly larger weights were recorded. These again were non-significant and were probably due to experimental error. The selection 54M2088 reached maximum dry weight 39 days after bloom, and after this date it consistently had lower weights. The weights did not indicate a definite downward pattern.

Table 1. Weight in grams per 100 seeds of Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 at various three-day intervals after 50 per cent bloom.

Days after 50% bloom	Dwarf Yellow Milo	Pink Kafir	Atlas	54M2088
15	.8239	.6942	.9162	.8196
18	1.1013	.9179	1.1546	1.0540
21	1.4096	1.1629	1.1837	1.3066
24	1.8349	1.4956	1.3271	1.3634
27	2.1182	1.6249	1.5708	1.5790
30	2.2322	1.8342	1.6912	1.7768
33	2.3926	1.8321	1.8245	1.8707
36	2.5498	2.0028*	1.8737	1.8442
39	2.6623	2.0462	1.9328	1.9113*
42	2.9422*	2.1446	1.9967*	1.8484
45	2.8579	2.0206	1.9716	1.8808
48	2.7218	2.1425	2.0094	1.8824
51		2.0953	2.0208	1.8507
54		2.0980	1.9942	1.8895
57			1.9641	
LSD 5%	.0968	.1342	.0532	.0317

* Signifies physiological maturity of the grain.

Culm Weight

The oven-dry weights in grams per culm for each variety on the various sample dates are given in Table 2. The weight per culm generally increased for all four varieties as the plants progressed toward maturity. This increase was not uniform throughout the sampling period and at times tended to give an erratic pattern. This may be attributed to several factors. Probably the most important was the fact that Atlas, 54M2088, and Dwarf Yellow Milo tillered to some extent and the three plants taken at random from a variety on any specific sample date may have had from three to seven culms. Since the tiller culms were always smaller than the main culms, a three-plant sample with three tillers would have had a larger total weight but a smaller per culm weight than a sample with no tillers. Pink Kafir, which had few tillers, showed a relatively smooth curve. The other possible source for the lack of uniformity would be the experimental error.

Table 2. Oven-dry culm weight in grams per culm of Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 at various three-day intervals after 50 per cent bloom.

Days after 50% bloom	Dwarf Yellow Milo	Pink Kafir	Atlas	54M2088
15	35	41	52	103
18	37	33	55	97
21	39	35	56	109
24	38	31	59	109
27	34	32	63	115
30	39	34	57	99
33	41	35	54	111
36	34	38*	59	117
39	37	45	57	109*
42	38*	36	58*	116
45	46	45	67	131
48	45	45	78	121
51		42	79	129
54		53	80	125
57			82	
LSD 5%	7.2	6.7	7.4	13.2

* Signifies physiological maturity of the grain.

The percentages of the oven-dry plant weight contributed by the culms on each sample date are given in Table 3. The results show the same upward trend for all four varieties.

The average Atlas culm increased 30 grams in dry weight during the 42-day sampling period. The increase was erratic, but significant increases did occur at 45 and 48 days after bloom, which was after physiological maturity. Prior to physiological maturity, the culm weight was relatively uniform. The percentage of the total plant weight contributed by the culm was 46.5 per cent at the beginning of the sampling period, decreased to 41.4 per cent at 36 days after bloom, and then increased to 45.9 per cent at the end of 57 days.

Table 3. Percentage of the total plant weight contributed by the culms of Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 at various three-day intervals after 50 per cent bloom.

Days after 50% bloom	Dwarf Yellow Milo	Pink Kafir	Atlas	54M2088
15	36.4	28.1	46.5	61.2
18	32.1	26.2	46.1	59.7
21	30.2	24.9	46.9	57.9
24	25.7	23.7	41.5	59.7
27	23.1	21.6	42.2	58.1
30	22.7	20.6	44.7	58.4
33	22.9	21.2	43.1	57.8
36	22.4	21.4*	41.4	58.4
39	22.4	23.5	43.4	59.4*
42	22.6*	22.8	43.6*	61.7
45	23.6	22.7	44.3	62.8
48	29.2	25.8	44.9	64.2
51		27.5	45.1	63.9
54		26.3	46.5	66.4
57			45.9	

* Signifies physiological maturity of the grain.

The selection 54M2088 was very erratic in its increase in culm weight. It increased from a low of 97 grams on the eighteenth day to a high of 131 grams on the forty-fifth day. There was a significant decrease between the twenty-seventh and thirtieth days and a significant increase between the forty-second and forty-fifth days after bloom. The culm contributed a much larger percentage of the total plant weight in this variety than in any of the others. After a high of 61.2 per cent at the beginning of the sampling period, it decreased to 57.8 per cent on the thirty-third day and then showed a steady increase to 66.4 per cent at the end.

Pink Kafir gave an increase of 22 grams per culm during the 39-day sampling period. A significant increase on the date after physiological maturity was followed by a significant decrease and increase on the next two sample dates, respectively. The culm contributed 28.1 per cent of the total plant weight at the beginning of the period, decreased to 20.6 per cent at the end of 30 days, and then increased to 26.3 per cent at the end.

Dwarf Yellow Milo failed to show a significant increase in culm weight until the forty-fifth day after bloom. Prior to this the weights were erratic with no significant increases or decreases. The culm accounted for 36.4 per cent of the weight of the plant at the beginning of the period, decreased to 22.4 per cent after 36 days, and then increased to 29.2 per cent at 48 days after bloom.

Total Solids

The refractometer readings of total solids present in the juice of the third internodes on each sample date are given in Table 4. Pink Kafir, Atlas, and 54M2088 showed a definite, steady increase in total solids from the beginning to the end of the sampling period. There was not a significant increase in this trend once the grain of Atlas and 54M2088 reached physiological maturity. Pink Kafir did show a significant increase between the third and fourth sample dates following physiological maturity.

Dwarf Yellow Milo reacted differently than did any of the other three varieties. The percentage of total solids was 10.2 per cent at 15 days after bloom and then decreased until it reached a minimum 30 days after bloom. After this date it began a steady increase with a significant increase occurring one sample date after physiological maturity.

Table 4. Refractometer readings of the total solids present in the juice of Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 at various three-day intervals after 50 per cent bloom.

Days after 50% bloom	Dwarf Yellow Milo	Pink Kafir	Atlas	54M2088
15	10.2	2.3	8.5	17.3
18	9.8	2.5	10.4	16.4
21	8.5	2.9	9.9	17.9
24	5.0	3.0	8.8	18.0
27	5.7	3.0	10.2	18.1
30	3.7	3.5	10.7	18.0
33	4.5	3.4	10.3	17.6
36	4.8	4.4*	11.1	19.2
39	5.0	5.5	11.9	18.7*
42	5.8*	6.3	12.5*	19.2
45	6.4	6.1	13.6	19.5
48	10.7	9.6	13.6	19.7
51		9.5	13.7	20.3
54		10.4	13.7	19.6
57			14.2	
LSD 5%	3.7	3.1	ns	ns

* Signifies physiological maturity of the grain.

Reducing and Total Sugar

The grams of total sugar per culm for each variety on the eight sample dates are given in Table 5. In general, Pink Kafir and Dwarf Yellow Milo were low and Atlas and 54M2088 were high in total sugar content.

Pink Kafir showed a significant increase in total sugar content on the sample date following physiological maturity and after that date it remained fairly constant. Dwarf Yellow Milo fluctuated only slightly in total sugar prior to physiological maturity and then had significant increases on the two sample dates that followed. Atlas increased significantly on the date of physiological maturity, stayed relatively constant for two sample dates, and then had significant increases on the last two. 54M2088 showed little change until after physiological maturity, at which time it decreased significantly. This decrease was followed by two consecutive significant increases.

Table 5. Grams of total sugar per culm of Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 at various three-day intervals after 50 per cent bloom.

Days after 50% bloom	Dwarf Yellow Milo	Pink Kafir	Atlas	54M2088
30				44.0
33	4.4	3.4	15.4	43.6
36	3.3	4.8*	19.3	41.5
39	4.5	6.5	18.6	44.3*
42	3.9*	6.7	23.4*	39.5
45	7.5	6.6	21.9	45.8
48	14.1	5.6	21.5	55.1
51		6.0	28.1	53.2
54		6.5	34.0	
LSD 5%	2.7	1.7	2.9	4.0

* Signifies physiological maturity of the grain.

The grams of reducing sugar per culm for each variety on the eight sample dates are given in Table 6. All four varieties showed a gradual, erratic decrease in amount, but in no instance was there a significant decrease between sample dates.

Table 6. Grams of reducing sugar per culm of Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 at various three-day intervals after 50 per cent bloom.

Days after 50% bloom	Dwarf Yellow Milo	Pink Kafir	Atlas	54M2088
30				9.4
33	3.2	2.4	4.8	8.7
36	2.9	2.2*	4.5	8.6
39	3.1	2.3	4.4	8.6*
42	2.5*	1.9	4.4*	8.2
45	2.4	2.0	4.0	8.3
48	2.4	1.7	3.8	7.6
51		1.6	3.9	7.1
54		1.5	3.7	
LSD 5%	ns	ns	ns	ns

* Signifies physiological maturity of the grain.

Growth Curves

The growth curves of the culm, leaf, and grain portions of the four varieties are shown in Figures 1, 2, 3, and 4. The weight of the leaves was relatively constant throughout the sampling period with no significant increases or decreases. Culm weight, which included the weight of the pumice from the heads, increased during the sampling period with significant increases occurring after physiological maturity. Grain weights increased until approximately the time of physiological maturity. After this there was a fairly constant weight maintained with only minor fluctuations until the end of the sampling period.

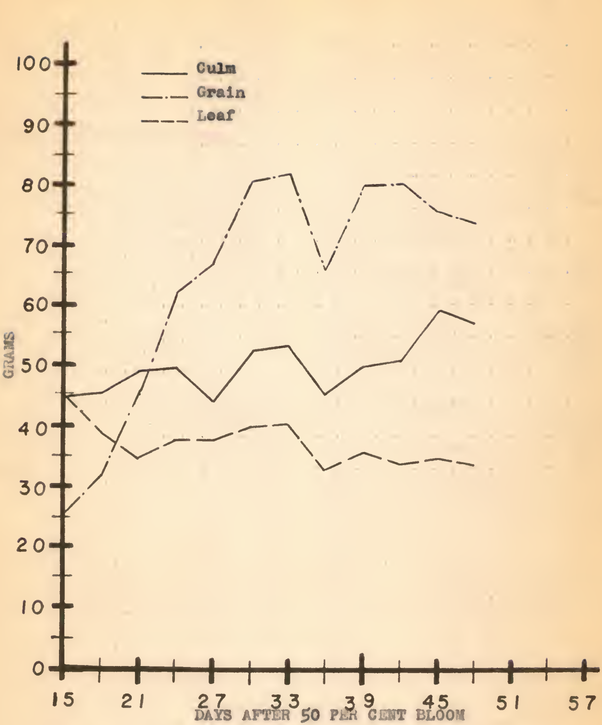

Figure 1. Weight of the culm, leaf, and grain portions of Dwarf Yellow Milo at various three-day intervals after 50 per cent bloom.

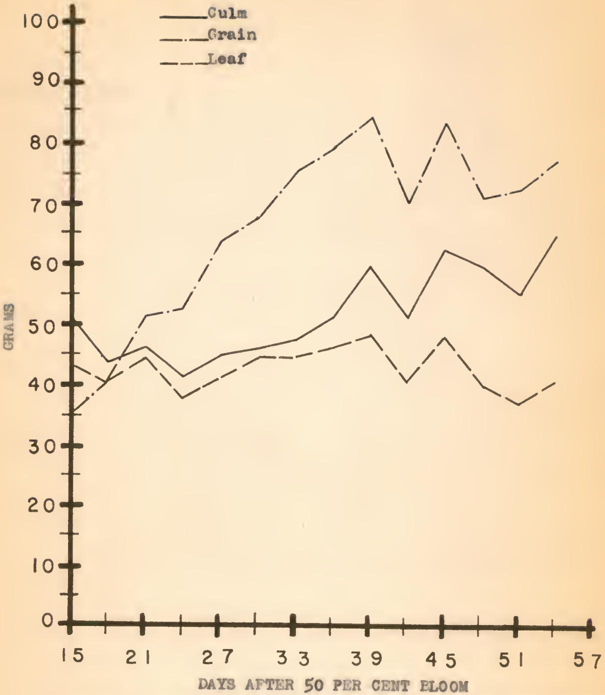

Figure 2. Weight of the culm, leaf, and grain portions of Pink Kafir at various three-day intervals after 50 per cent bloom.

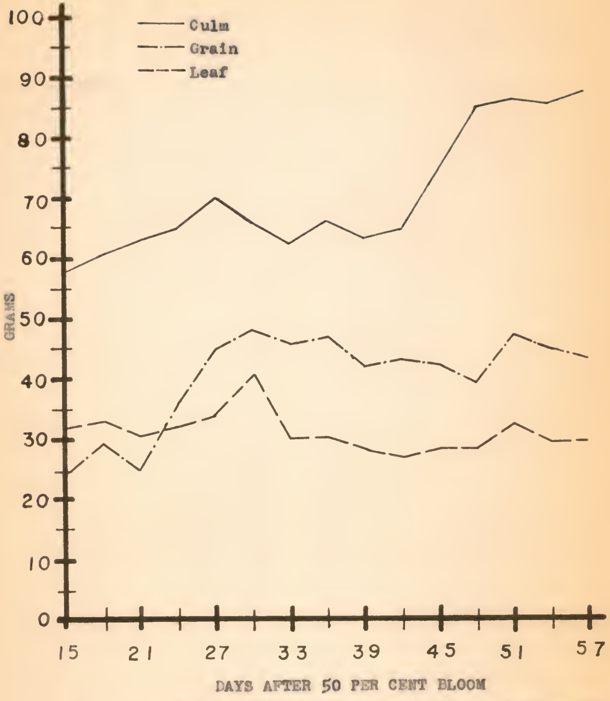

Figure 3. Weight of the culm, leaf, and grain portions of Atlas at various three-day intervals after 50 per cent bloom.

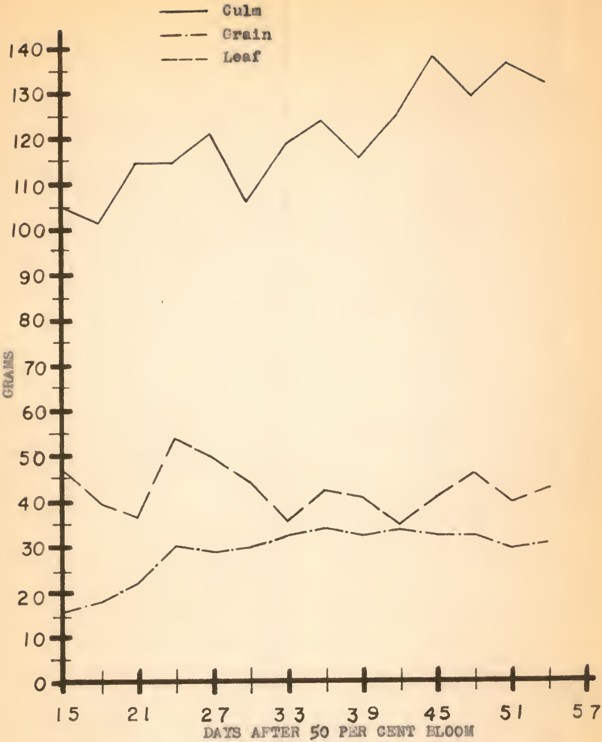

Figure 4. Weight of the culm, leaf, and grain portions of 54M2088 at various three-day intervals after 50 per cent bloom.

Carbohydrates

The percentages and grams of crude fiber, nitrogen-free extract, and total carbohydrates present in the culms and the grain of the four varieties on each of the eight sample dates are given in Tables 7, 8, 9, and 10. As was expected, these data compare fairly well to the data on total sugar per culm. There appeared to be erroneous results in the culm analyses for Pink Kafir on the first and last sample dates and for Atlas on the first sample date. Therefore, these data were not included in the statistical analyses.

The changes in crude fiber and nitrogen-free extract content were relatively minor in Atlas and 54M2088. The percentage of crude fiber in the culm decreased for Atlas and increased for 54M2088, while the percentage of nitrogen-free extract increased for Atlas and decreased for 54M2088 during the sampling period. In terms of grams per culm, both varieties showed an increase in crude fiber and nitrogen-free extract, with significant increases occurring after physiological maturity.

The percentage of crude fiber present in the grain of Atlas and 54M2088 showed an increase until physiological maturity in comparison with the percentage of nitrogen-free extract which varied only slightly. The amount of crude fiber showed a definite increase, but nitrogen-free extract failed to show a significant change. This was not unexpected after the results observed on the weight per 100 seeds in Table 1.

The culms of Pink Kafir and Dwarf Yellow Milo contained a

Table 7. Percentages and grams of crude fiber, nitrogen-free extract, and carbohydrates per culm and head of Dwarf Yellow Milo on six sample dates.

Days after 50% bloom	Culms						Grain					
	Percentage			Grams			Percentage			Grams		
	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates
33	33.27	52.53	85.80	13.6	21.3	34.9	2.03	81.08	83.11	1.3	49.6	50.9
36	32.01	52.43	84.44	10.9	17.8	28.7	2.15	79.94	82.09	1.2	45.0	46.2
39	31.17	54.78	85.95	11.6	20.5	32.1	2.42	79.01	81.43	1.6	54.0	55.6
42*	33.11	51.39	84.50	11.8	18.3	30.1	2.54	78.49	81.04	1.7	52.3	54.0
45	29.12	55.64	84.76	13.4	25.6	39.0	2.29	78.19	80.49	1.5	50.0	51.5
48	25.81	61.95	87.76	11.7	28.2	39.9	2.05	79.04	81.09	1.5	44.6	46.1
LSD 5%	3.02	4.26	ns	ns	6.1	7.4	ns	ns	ns	ns	ns	ns

* Signifies physiological maturity of the grain.

Table 8. Percentages and grams of crude fiber, nitrogen-free extract, and carbohydrates per culm and head of Pink Kafir on eight sample dates.

Days after 50% bloom	Culms						Grain					
	Percentage			Grams			Percentage			Grams		
	Crude fiber	NFE	Carbo-hydrates	Crude fiber	NFE	Carbo-hydrates	Crude fiber	NFE	Carbo-hydrates	Crude fiber	NFE	Carbo-hydrates
33	22.47	70.78	93.25	7.9**	25.0**	32.9**	1.85	81.37	83.22	1.2	54.3	55.5
36*	33.17	52.75	85.92	12.5	19.9	32.4	1.89	80.02	81.91	1.3	56.6	57.9
39	31.71	55.21	86.92	14.4	25.0	39.4	1.84	80.17	82.02	1.4	61.5	62.9
42	31.11	55.69	86.80	11.3	26.2	37.5	2.05	78.80	80.85	1.4	51.7	53.1
45	21.57	53.50	85.07	14.1	23.9	38.0	2.57	76.78	79.35	1.9	58.1	60.0
48	27.30	61.47	88.78	12.4	27.8	40.2	2.41	76.89	79.30	1.6	49.6	51.2
51	26.55	62.57	89.12	11.2	26.5	37.7	2.58	76.52	79.10	1.5	44.9	46.4
54	21.10	72.32	93.42	11.1**	29.1**	40.2**	2.19	78.17	80.36	1.5	55.0	56.5
LSD 5%	2.79	3.06	ns	ns	4.3	6.2	ns	ns	ns	ns	ns	ns

* Signifies physiological maturity of the grain.
** Data was not used in the statistical analysis.

Table 9. Percentages and grams of crude fiber, nitrogen-free extract, and carbohydrates per culm and head of Atlas on eight sample dates.

Days after 50% bloom	Culms						Grain					
	Percentage			Grams			Percentage			Grams		
	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates
33	33.48	51.11	84.60	18.9**	29.0**	47.9**	1.60	83.70	85.30	.5	26.9	27.4
36	21.79	71.55	93.34	11.8	38.9	50.7	1.89	80.45	82.34	.8	31.8	32.6
39	22.29	71.18	93.47	13.1	42.1	55.2	2.33	78.57	80.90	.9	31.7	32.6
42*	21.96	71.76	93.72	12.5	40.9	53.4	2.20	78.44	80.63	.8	28.5	29.3
45	21.27	72.42	93.69	12.4	42.2	54.6	2.48	77.41	79.83	.9	26.6	27.5
48	21.48	72.34	93.81	14.5	48.7	63.2	2.33	76.35	78.68	.9	28.2	29.1
51	21.58	72.43	94.02	15.7	52.6	68.3	2.41	77.21	79.62	.8	25.5	26.3
54	20.60	73.01	93.60	16.3	57.9	74.2	2.10	78.26	80.36	.9	32.6	33.5
LSD 5%	ns	ns	ns	2.1	4.6	5.9	ns	ns	ns	ns	ns	ns

* Signifies physiological maturity of the grain.
** Data was not used in the statistical analysis.

Table 10. Percentages and grams of crude fiber, nitrogen-free extract, and carbohydrates per culm and head of 54M2088 on eight sample dates.

Days after 50% bloom	Culms						Grain					
	Percentage			Grams			Percentage			Grams		
	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates	Crude fiber	NFE	Carbo-hy-drates
30	19.90	74.63	94.54	22.8	85.7	108.5	1.44	79.67	81.11	.3	18.9	19.2
33	20.09	74.75	94.84	19.8	73.9	93.7	1.86	79.29	81.16	.4	16.9	17.3
36	19.70	75.10	94.80	21.9	83.4	105.3	1.67	80.10	81.77	.4	20.9	21.3
39*	20.03	74.55	94.58	23.5	87.5	111.1	1.79	79.75	81.54	.5	23.1	23.6
42	19.69	74.68	94.38	21.6	81.7	103.3	1.86	79.59	81.45	.5	20.1	20.6
45	20.86	73.62	94.49	24.3	85.6	109.9	1.93	79.05	80.98	.5	20.3	20.8
48	21.04	73.38	94.42	27.7	96.1	123.8	1.88	79.16	81.04	.5	23.2	23.7
51	20.79	73.33	94.12	25.1	88.7	113.9	1.56	78.90	80.46	.4	20.0	20.4
LSD 5%	ns	ns	ns	ns	10.1	13.9	ns	ns	ns	ns	ns	ns

* Signifies physiological maturity of the grain.

much higher percentage of crude fiber than did the other two varieties. The percentage decreased and the amount remained relatively constant during the sampling period. The percentage of nitrogen-free extract in the culm increased for both varieties and this showed as significant increases in amount on the same dates as total sugar increased.

Crude fiber in the grain increased, both the percentage and the amount, for Pink Kafir and Dwarf Yellow Milo until physiological maturity. The percentage of nitrogen-free extract remained relatively constant or decreased somewhat. The grams present per head failed to show a significant change, which was similar to the results of Atlas and 54M2088.

DISCUSSION

The results obtained in this study generally agree with previous work performed on the sugar content of sorghum. In all of the previous studies reported, the sorghum plant was studied at various stages of growth and development such as heading, milk stage, hard dough stage, and mature grain stage. The object of this work was to sample at definite regular periods and study the changes that occurred between those sample dates. The sampling in this study was much more intensive, every three days, than if it had been done at previously set stages of plant development. No attempt was made by the author to study the physical state of the developing caryopses. Therefore, it is difficult to give an exact comparison of observed data with previously reported work.

Total sugars increased from the beginning to the end of the 21-day sampling period for all four varieties. Atlas and 54M2088, both classified as sweet sorghums, showed the greatest increase. The results with Pink Kafir and Dwarf Yellow Milo were not so spectacular, but since they are classified as non-sweet sorghums, it was not expected that they show as great an increase in total sugar as the sweet sorghums. Reducing sugars failed to show a significant decrease even though there appeared to be a definite reduction in their amount. The decrease in reducing sugars was relatively small compared to the increase in total sugars. It would be difficult to state whether the reducing sugars were used in the metabolic processes of the plant, causing their reduction, or whether they were simply converted to non-reducing sugars by some ezymatic reaction. Berthelot and Trannoy (2) found the decrease in reducing sugars to be far less than the increase in non-reducing sugars. They theorized that perhaps some of the reducing sugar was converted to non-reducing sugar, but in addition, there would have had to have been new non-reducing sugar synthesized in the leaves.

The pattern of the increase in total sugar for Dwarf Yellow Milo, Pink Kafir, and Atlas lacked uniformity. As previously reported, these three varieties tillered extensively during the 1960 growing season. Willaman, West, and Spriesterbach (12) reported that the sorghum tillers have a composition similar to that of the main culm at the same stage of maturity. However, the tillers are usually seven to ten days later than the main culm in maturity. The ideal conditions would be to remove the tillers as they start to develop, leaving only the main culm to be studied. A plant with several tillers should have a lower amount of total sugar per culm than a plant with no tillers.

The portion of the total plant weight contributed by each component part is of interest. Leaf weight remained relatively constant throughout the entire sampling period and the major changes were in culm and grain weight. At a time 15 days after bloom the culm represented a maximum as far as its share of the total plant weight was concerned. From that maximum until physiological maturity of the grain, the culm weight remained relatively constant, but the grain increased in dry weight. Willaman, West, and Spriesterbach (12) stated that the sorghum plant builds its cellular structure of fiber, protein, and mineral matter during the early part of the growing season. The latter stages of growth consist of the filling of these tissues with carbohydrates (starch in the seed, sugar in the culm). The weight of the grain became relatively stable after physiological maturity, since there were no new carbohydrates being stored in the grain. The carbohydrates that were being synthesized in the leaves were stored in the culm in the form of sucrose. This caused the increase in culm weight after physiological maturity.

Atlas and 54M2088 showed an increase in the amount of crude fiber in the culm as the sampling period progressed, even though its percentage remained fairly constant or slightly decreased. Dwarf Yellow Milo and Pink Kafir, both of which are not forage types, had a higher percentage of crude fiber, but the amount present did not appear to increase after physiological maturity.

The grams of nitrogen-free extract increased after physiological maturity, indicating that the photosynthetic products, of which total sugar is a part, were being stored in the culm rather than the grain.

The question as to the proper stage of development for the harvest of a forage sorghum is still not answered by the results of this study. On strictly a basis of yield, it seems that the longer the sorghum remains in the field, actively carrying on photosynthesis, the greater will be the yield of the harvested plant material. In Atlas and 54M2088, a large portion of this increase is in the form of nitrogen-free extract, which includes total sugar, and lesser portion of the increase is in the amount of fiber. The results of this study did not show a levelling tendency for culm weight and total sugar content. Both were still increasing at the end of the sampling period. It would most certainly be of interest to determine the time or the stage of development of the plant at which the maximum yield and sugar content does occur.

SUMMARY AND CONCLUSIONS

Four varieties of sorghum, Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088, were studied at three-day intervals to evaluate the relationship of physiological maturity of the grain and the sugar content of the culm. The varieties represented a wide range in type.

Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 reached physiological maturity in 42, 36, 42, and 39 days respectively, after 50 per cent bloom. After this date, the weight of the caryopses remained relatively constant or decreased slightly.

The percentage of total solids present in the juice of the culm, as measured with a refractometer, increased throughout the sampling period for Pink Kafir, Atlas, and 54M2088. Dwarf Yellow Milo had a relatively high percentage of total solids at 15 days after bloom, decreased sharply for 15 days, and then began a steady increase as maturity progressed.

The leaf weight per plant was relatively constant throughout the sampling period. The weight per culm showed very little increase until after physiological maturity, at which time significant increases in weight occurred for all four varieties.

The percentage of the total plant weight contributed by the culms of the four varieties was at a maximum 15 days after bloom. This percentage decreased as the head weight increased. As the grain neared physiological maturity and starch was no longer being stored in large amounts in the caryopses, the percentage contributed by the culms began to increase. This increase was maintained until the end of the sampling period.

Reducing sugars failed to show a significant decrease for any of the four varieties during the 21-day sampling period. There was an overall downward trend in the amount present per culm.

Total sugars, which are largely non-reducing or sucrose, increased significantly for all four varieties after physiological maturity.

The feedstuff analyses on the culm and grain portions of the four varieties indicated that the amount of nitrogen-free extract increased in the culm in the same pattern as the total sugar content. Crude fiber content of the culm increased in Atlas and 54M2088, but remained relatively constant in Dwarf Yellow Milo and Pink Kafir. Most of the carbohydrates were already present in the grain nine days prior to physiological maturity, and there were only minor, non-significant changes in nitrogen-free extract and carbohydrates during the 21-day sampling period.

The general conclusions from this study are that prior to physiological maturity of the grain, the products of photosynthesis are translocated to the developing caryopses where they are deposited mainly in the form of starch and to a lesser extent as crude fiber. A decrease in the soluble carbohydrates of the culm could occur if there was a rapid translocation to the head. After physiological maturity of the grain, photosynthesis continues and its products are stored in the culm, primarily in the form of non-reducing sugar or sucrose, and secondly as crude fiber.

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SUGAR CONTENT OF THE CULM OF FOUR VARIETIES OF SORGHUM IN RELATION TO PHYSIOLOGICAL MATURITY

by

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This study was initiated in 1960 to determine the possible relationship between physiological maturity of the grain of sorghum and the sugar content of the culm and its accompanying influence on culm weight. Dwarf Yellow Milo, Pink Kafir, Atlas, and 54M2088 were sampled at three-day intervals, beginning 15 days after 50 per cent bloom and continuing until sufficient plants were no longer available or freezing temperatures killed the remaining plants. Refractometer readings of the juice from the culms were made to obtain some indication of the percentage of total solids present.

Green and oven-dry weights of the leaves, culms, and heads were recorded. Reducing and total sugar analyses were made on the culm portion of each variety, using physiological maturity as the focal point and extending from nine days before until 12 days after this date. A portion of each culm and grain sample of all four varieties was sent to the Chemistry Service Laboratory for a complete feedstuff analysis and the results of the crude fiber, nitrogen-free extract, and total carbohydrates determinations are reported in this work.

The average oven-dry weight per 100 seeds for each variety on each sample date showed that there was a steady increase in grain weight until a certain maximum was reached. After this maximum, the weight decreased or maintained a relatively constant pattern. The date on which maximum dry weight occurred was called physiological maturity. The number of days from bloom until this date were: Dwarf Yellow Milo, 42; Pink Kafir, 36; Atlas, 42; and 54M2088, 39.

The dry weight per culm increased erratically throughout the sampling period with significant increases occurring after physiological maturity. The percentage of the total plant weight contributed by the culm was highest 15 days after bloom. Following this it decreased as physiological maturity approached, then increased to approximately the same high at the end of the sampling period.

Total solids present in the juice of the culm increased regularly throughout the sampling period for all varieties except Dwarf Yellow Milo. It showed a high average refractometer reading 15 days after bloom, decreased to a low 12 days before physiological maturity, and then increased until the end of the sampling period.

Reducing sugars of all four varieties showed a tendency to decrease during the 21-day period, but no significant changes were recorded. Pink Kafir, Dwarf Yellow Milo and Atlas showed significant increases in total sugar after physiological maturity. 54M2088 decreased significantly just after physiological maturity and increased significantly on two consecutive sample dates.

The amount of crude fiber present in the culms of Dwarf Yellow Milo and Pink Kafir remained relatively constant, but percentage-wise it decreased. The percentage of crude fiber changed very little in Atlas and 54M2088, but the amount present increased. Nitrogen-free extract increased in all four varieties in nearly the same pattern as total sugars. Significant increases in grams per culm occurred after physiological maturity in all four varieties.

The amount of crude fiber and nitrogen-free extract in the grain remained relatively constant throughout the 21-day sampling period. It was concluded that the amounts of these two components that were stored in the grain during the nine days prior to physiological maturity were small and difficult to detect.

It is concluded from this study that during the nine days prior to physiological maturity of the grain, the total sugar and carbohydrate content of the culm is relatively stable. After physiological maturity is attained, photosynthesis continues and the carbohydrates synthesized are stored in the culm. A major portion of these stored carbohydrates is in the form of total sugars. Total sugars and culm weight were still increasing at the end of the sampling period.