FREQUENCY OF INTERSPECIFIC CROSSING BETWEEN SORGHUM VULGARE PERS AND SORGHUM HALEPENSE (L.) PERS AND BETWEEN SORGHUM VULGARE PERS AND SORGHUM ALMUM PARODI

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INTRODUCTION

The frequent occurrence of tall off-type plants in fields of hybrid grain sorghum has become a disturbing problem to farmers, seed producers, and sorghum breeders. Many of these off-type plants are outcrosses to sudangrass, Johnsongrass, *Sorghum almum* and other sorghums. The outcrosses to Johnsongrass and *S. almum* produce tall, grassy plants that give a ragged appearance to the sorghum field, cause difficulties in harvest, and produce great concern for seed producers.

The chromosome number, rhizome expression, and fertility of Johnsongrass outcrosses have been studied rather extensively. However, frequency of such outcrossing under field conditions has not been determined. The purpose of this study was to determine the frequency of crossing between *Sorghum vulgare* Pers. and *Sorghum halepense* (L.) Pers. Since *Sorghum almum* Parodi has become prevalent in sorghum producing areas, the frequency of crossing between it and *S. vulgare* was studied. Morphological characteristics of the plants obtained from *S. vulgare* X *S. halepense* and *S. vulgare* X *S. almum* were described.

In addition the chromosome number of several hybrids of *S. vulgare* X *S. halepense* was determined.

REVIEW OF LITERATURE

Numerous natural crosses of sorghum and Johnsongrass have been observed in sorghum fields of Southwestern United States. The frequency of such crosses in sorghum fields may not exceed one plant in 10,000 (Karper and Chisholm, 1936). Under controlled conditions, less than four percent of the available florets set seed when pollinated with S. halepense (Vinall, 1925).

Hybrids between male sterile grain sorghum and S. halepense were described by Hadley (1958). The hybrids were classed into three types. One type had 30 chromosomes and vigorous rhizomes but was sterile; the second had 40 chromosomes, weak rhizomes and was fertile; the third type had 40 chromosomes, weak rhizomes and was male sterile and female fertile. He suggested that the 30-chromosome hybrids could become a weed threat by vegetative reproduction, and if Johnsongrass was available as a male parent, these hybrids could become a source of troublesome seedlings. The fertile, 40-chromosome hybrids were so weakly rhizomatous they could not constitute a perennial weed threat, but could become a source of troublesome seedlings. The male sterile, 40-chromosome hybrids could provide a source of troublesome seedlings if Johnsongrass was present. No information was available on winter survival, but it seemed probable that the 40-chromosome hybrids would not withstand a severe winter. The rhizomes of most of the 30-chromosome hybrids appeared vigorous enough and extended deep enough to survive a severe winter.

Endrizzi (1957) studied the F_1 hybrids obtained from crosses between Sorghum vulgare Pers. and Sorghum halepense (L.) Pers. for chromosome number, meiotic behavior, and vegetative characteristics. The chromosome number for eleven hybrids was determined. One hybrid had 2n = 30, and ten had 2n = 40 chromosomes. The F_1 hybrids were intermediate between their parents in morphological appearance. During the first year of growth there was no apparent morphological difference between the 30-chromosome and the 40-chromosome hybrids. However, during the second year the 30-chromosome hybrids had more tillers than the 40-chromosome hybrids and resembled S. halepense.

When attempting crosses between S. vulgare and (Johnsongrass X 4n Sudangrass), Casady and Anderson (1952) reported the collapse of the florets 15 to 20 days after fertilization. Approximately 30 percent of the emasculated florets produced aborted seed. They concluded the failure was not in fertilization but prior to fertilization. Collapse of florets of cytoplasmic male sterile S. vulgare when fertilized with S. halepense was suggested by Wilhite (1959).

Cooper and Brink (1945) found seed arising from reciprocal matings between tetraploid Lycopersicon pimpinellifolium (2n = 48) and diploid species were abortive and non-functional. They stated this behavior appeared to be characteristic of interspecific crosses between diploids and tetraploids. In 2n X 4n crosses, they suggested, the growth of the endosperm was slow, while cells at the chalazel end became large and vacuolate. Later the endothelium became actively meristematic and filled the space formerly occupied by the endosperm. The embryo grew slowly, became surrounded by the endothelium and died.

In his work with diploid and tetraploid Parthenium argentatum, Powers

(1945) stated that up to 90 percent of the plants produced came from non-reduced egg cells. The production of diploid eggs by normal maize was reported by Bauman (1961).

Cooper and Brink (1944) working with crosses between tetraploid barley and diploid rye reported the collapse of the seed following fertilization. They indicated that the seed enlarged after fertilization, but 4 to 13 days later the seed began to break down, and the cross was completely abortive.

When checking the chromosome number of colchicine-treated and untreated sorghum, Damon (1961) found occasional aneuploid and polyploid sporocytes in untreated plants. His data indicated Martin and Wheatland produced a low frequency of abnormal cells. Redlan and Combine Kafir-60 did not exhibit such abnormalities. He explained these abnormalities as due to the destruction of the walls of adjacent cells during meiosis. He suggested that this phenomenon could also be explained by the failure of cytokinesis at the last mitotic division prior to meiosis.

In the study of chromosome association of S. vulgare Garber (1944) found no variation from 10 bivalent association at metaphase I. Chin (1946), Hadley (1953), and Huskins and Smith (1934) stated that 10 bivalents were most common in S. vulgare but that multivalent associations were found. Cytological evidence presented by Endrizzi and Morgan (1955) suggested that S. vulgare was an allotetraploid.

Quadrivalents were the highest associations found in S. halepense by Garber (1944) and Endrizzi (1957). Hadley (1953) and Huskins and Smith (1934), reported quadrivalents, hexavalents, and octavalents in S. halepense. Support for the allpolyploid nature and presence of two genomes for S. halepense was presented by Endrizzi (1957). Studies have shown a stable number of 40 chromosomes in S. halepense. According to Stebbins (1950) this suggested allopolyploidy and the synaptic behavior implied that there was considerable homology between the genomes.

The origin of Johnsongrass has been discussed by many investigators. The concensus appeared to be that S. halepense was evolved by doubling the chromosomes of a hybrid between S. vulgare and some related 20-chromosome species.

Celarier (1958) proposed that S. halepense may have arisen in Southeast Asia as the result of doubling of the chromosomes of a hybrid between S. propinquum and a 20-chromosome species of the subsection Arundinacea. Endrizzi (1957) proposed S. propinquum was a derivative from S. halepense. He based his hypothesis on the fact that S. propinquum was the only 20-chromosome species with rhizomes.

From data obtained in the cytological study of S. vulgare and S. halepense F_1 hybrids, Hadley (1958) proposed that Johnsongrass arose as a cross between two 20-chromosome species whose chromosome complements were similar. He suggested one parent may be 2(AB) and the other 2(AC), where A, B, and C were genome complements of five chromosomes each. The resulting 40-chromosome hybrid would be expected to have five tetravalents and 10 bivalents at metaphase I.

In the study of the relationship of the 20-chromosome species S. vulgare and S. virgatum, Bhatti (1960) obtained a tetraploid plant by doubling the chromosomes of an F_1 plant. Segregates had strong rhizome tendencies and resembled Johnsongrass. The hybrid had the same cytological behavior as S. halepense. He concluded that S. halepense arose as the result of the doubling of the chromosomes of a natural hybrid between S. vulgare and S. virgatum.

Karyomorphological description of S. propinquum by Magoon and Shambulingappa (1961) indicated the short chromosome was the nucleolar organizer. In the cultivated Eu-sorghums the nucleolar organizer was found to be the long chromosome (Magoon and Shambulingappa, 1960). They suggested that if S. halepense evolved from S. propinquum and a cultivated Eu-sorghum, it should have four nucleolar organizers.

Hybrids of S. vulgare X S. almum were studied by Endrizzi (1957). The hybrids obtained were intermediate between the parents in morphological appearance. He obtained one 30-chromosome hybrid and nine 40-chromosome hybrids. During the first growing season, there were no observable differences in the 30- and 40-chromosome hybrids. The 30-chromosome hybrid resembled S. almum at the end of the second year.

Parodi (1943) in his taxonomic description of S. almum, pointed out that rhizomes, spiklet characteristics, and perennial habit were common to both S. almum and S. halepense. The rhizomes of S. almum were short and ascending, not allowing the plant to spread. In comparison to S. halepense the plants of S. almum were taller, heavier stalked, and had wider leaves, and larger spikelets and caryopses.

There has been considerable discussion concerning the origin of S. almum. Saez (1952) in his cytological study of S. almum, considered S. almum as a possible interspecific hybrid which originated by the fusion of an unreduced egg of a species in the subsection Arundinacea with S. halepense.

According to data obtained by Endrizzi (1957), S. almum arose as a segregate from a cross between S. vulgare and S. halepense. He suggested that most of the genetic complement of S. almum is composed of chromosome segments of S. vulgare.

MATERIALS AND METHODS

The material used in this study consisted of five cytoplasmic male sterile lines of Sorghum vulgare Pers. (Redlan, Wheatland, Martin, Dwarf Redlan, and Combine Kafir-60), and two tetraploid species used as the source of pollen, Sorghum halepense (L.) Pers. (Johnsongrass) and Sorghum almum Parodi (Black Sudan).

The five cytoplasmic male sterile grain sorghum lines were interplanted with Johnsongrass and S. almum in separate isolated blocks. The cytoplasmic male sterile lines were planted in rows, 40 feet long in four replications in a randomized block design, each plot contained five rows. The pollen source was located at the north and south end of the blocks and between replications to insure an adequate pollen supply.

The study was conducted in the Lake Carl Blackwell area to insure the most possible isolation from foreign pollen.

The Johnsongrass in the isolation block used by Wilhite (1959) was clipped prior to seeding of the sterile lines and fertilized with 120 pounds per acre of ammonia nitrate. Martin and Combine Kafir-60 were grown in 1960, while Wheatland, Redlan, and Dwarf Redlan steriles were planted in 1961. The rows were thinned to three plants per foot after the stand was established.

The S. almum block was located approximately 400 yards north and 150 yards west of the Johnsongrass block. This distance from the Johnsongrass block was probably adequate for isolation because the S. almum block was completely surrounded by tall trees. The S. almum was planted in four east-west rows, 40 inches apart at the north and south end of the block and between replications, on June 24, 1961. The two north rows were planted to Columbusgrass, a selection from S. almum made at the Texas Research Foundation, Renner, Texas, and the south rows to unselected S. almum.

The five cytoplasmic male sterile grain sorghum lines were planted in the S. almum isolation block July 1. The plants were thinned July 12 to three plants per foot.

Prior to blooming ten heads in each row of the cytoplasmic sterile lines were selected at random and covered with Aldrin treated bags to determine the amount of selfing. At the same time ten heads in each row were tagged at random to determine the amount of crossing with the tetraploid pollinator. The rows were checked daily for pollen shedders and any plant that appeared to be a shedder was removed. One Wheatland plant in replication II of the S. almum block was found to be a shedder and was not detected until after it had shed some pollen. The plant was marked and an area was marked off to prevent harvesting contaminated plants.

Corn earworms, Heloithus zea (Boddie) and sorghum webworms, Celama sorghiella (Riley), infected the heads at full bloom and hard dough stages. Sevin (1-naphthylmethycarbamate), a commercial wettable powder spray material, was used for control. The wettable powder was applied with a knapsack sprayer attached to an air tank to maintain sufficient nozzle pressure.

The earliest sterile, Dwarf Redlan, began blooming August 14 and the latest sterile, Redlan, completed blooming August 30 in the Johnsongrass block. The Johnsongrass was blooming during this period. In the S. almum block the earliest sterile, Martin, began blooming August 22 and the latest sterile completed blooming September 2. Sorghum almum started blooming August 10 and Columbusgrass August 18. It appeared that S. almum shed pollen in the morning hours.

The plots were harvested October 14 to October 30. The heads were carefully threshed by hand in order to obtain every seed.

On December 12, a random sample of 130 seed was drawn from the 703 obtained from the Johnsongrass block and planted in pots in the greenhouse. On January 5, 1962, a random sample of 224 seed was drawn from the 878 seed obtained from the S. almum block and planted in the greenhouse. The plants were used for observation of morphological characters.

The S. vulgare parents used in this study carried the dominant gene for awnlessness (Sieglinger, Swanson, and Martin, 1934); Martin, Redlan, Dwarf Redlan and Combine Kafir-60 carried the recessive gene for green coleoptile and cloudy midrib, and Wheatland the dominant gene for red coleoptile and white midrib (Swanson and Parker, 1931, and Martin, 1936). The Johnsongrass had white midrib, awns, red coleoptile and was heterozygous for stigma color. The S. almum was heterozygous for midrib color, awns and had red coleoptiles. Sorghum almum was also observed to vary in height and degree of fertility.

The plants Wilhite (1959) grew in the greenhouse were transplanted to a field on the Oklahoma State University Agronomy Farm at Stillwater in 1960, to observe them under field conditions and to determine their ability to survive the winter. Microsporocyte material was collected during the summer and stored in Carnoy's fluid.

Cytological studies were made using the acetocarmine smear technique (Smith, 1947). Microsporocytes at late metaphase I and anaphase I were examined to determine the chromosome number of a plant. Photomicrographs were made when possible to obtain a permanent record.

RESULTS AND DISCUSSION

Frequency of Crossing

The mean number of seeds set per head for each of the female lines when Johnsongrass was the pollen source is shown in Figure 1. Dwarf Redlan had the most seeds with 3.45, Martin had 2.32 seeds and Wheatland set the smallest number of seed per head. The average of five cytoplasmic male sterile lines in the Johnsongrass block was 1.90 seeds per head.

Analysis of variance and Duncan's New Multiple Range test (Duncan, 1955) are presented in Table I. In the 1960 data Martin was significantly higher than Combine Kafir-60 at the 5% level, but not different at the 1% level. In the 1961 data, at the 5% level, Dwarf Redlan was significantly higher than Wheatland and Redlan. There was no significant difference between Redlan and Wheatland.

Using orthagonal comparisons of the varieties grown in 1960 and the varieties grown in 1961, there was no significant difference between the two years.

The number of seed set on bagged heads is presented in Table II. Dwarf Redlan in the S. halepense block had the most seed of the varieties in either block. Martin and Combine Kafir-60 did not set seed

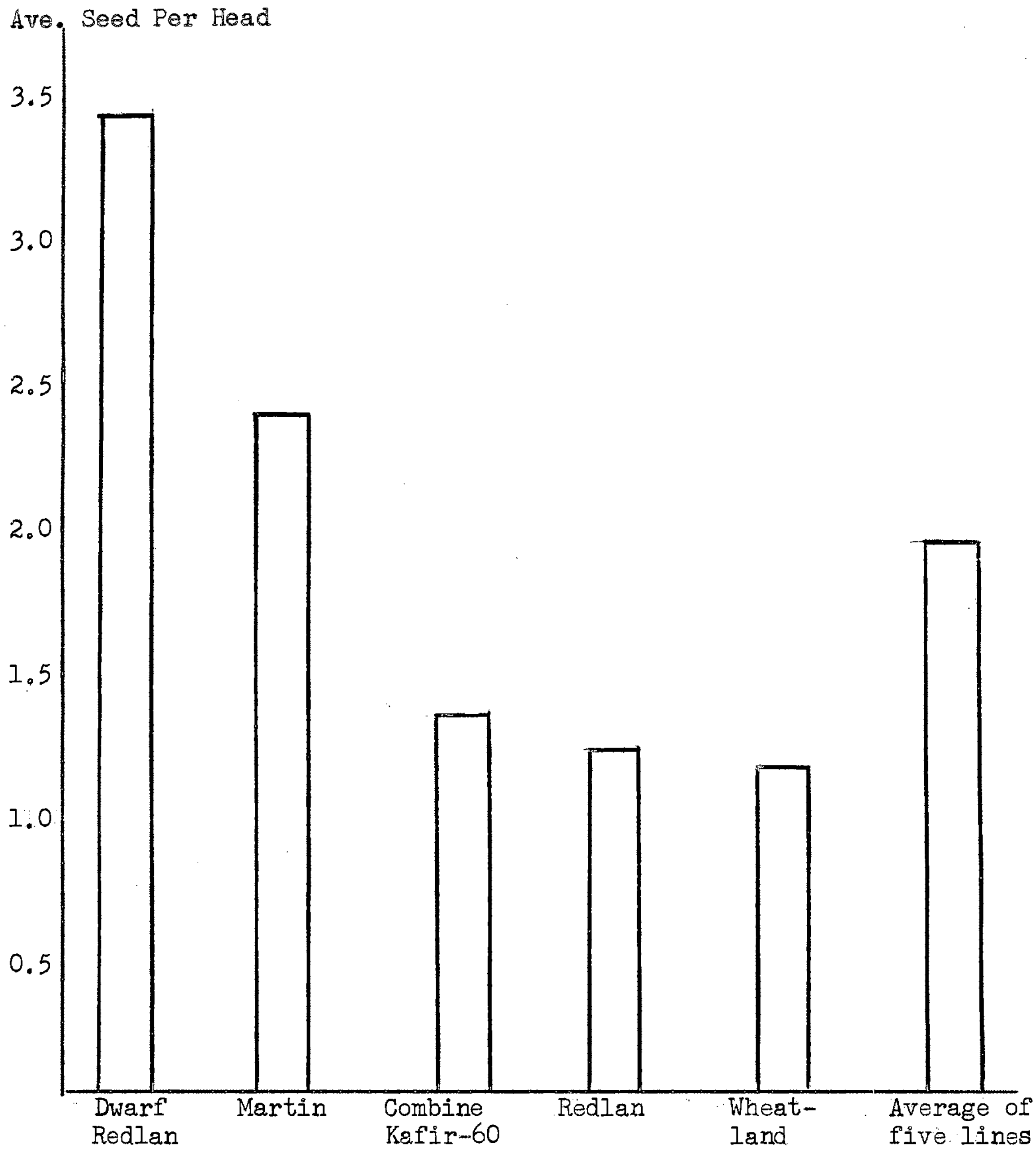


Figure 1. Average Seed Set per Head of Cytoplasmic Male Sterile Lines When Pollinated with S. halepense

TABLE I

ANALYSIS OF VARIANCE FOR NUMBER OF SEED SET PER HEAD OF FIVE CYTOPLASMIC MALE STERILE LINES WHEN POLLINATED WITH S. HALEPENSE

Source	d.f.	S.S.	M.S.	F
Total	99	186.9491		
Reps in Years	6	54.3556		
Varieties	4	77.9406	19.4851	
$Var_{3,5}$ vs. $Var_{1,2,}$ and 4	1	0.269	0.269	.2948
Var_3 vs. Var_5	1	9.312	9.312	10.1859**
Among 1, 2, and 4	2	68.242	34.121	37.3233**
Error	9	8.2278	0.9142	
Rows in Reps X Varieties	80	46.4280	0.5803	

Duncan's New Multiple Range Test

Year		1960	1961	
P		2	2	3
$S_{\bar{x}}$ D	1%	.9835	.9835	1.0391
	5%	.6842	.6842	.7141

Variety	Combine Kafir-60	Martin	Wheatland	Redlan	Dwarf Redlan
Mean	1.3550	2.3200	1.1450	1.2400	3.4550
1%	________	________	________	________	________
5%	________	________	________	________	________

*Significant at the 5 percent level
**Significant at the 1 percent level

TABLE II

NUMBER OF SEEDS SET ON THE BAGGED HEADS

Female	S. almum	S. halepense
Redlan	0	1
D. Redlan	3	13
Martin	0	0
Wheatland	0	10
Combine Kafir-60	0	0

in either block. The seeds set on bagged heads were not considered in the analysis of variance.

The average number of seeds set on each of the varieties where S. almum was used as the pollinator is shown in Figure 2. Dwarf Redlan set the most, 1.70 seeds, and Martin set the least, 0.52 seeds per head. The average for the male sterile lines was 0.88 seeds per head.

Analysis of variance and Duncan's New Multiple Range Test (Duncan, 1955) are presented in Table III. Duncan's test showed Dwarf Redlan was significantly higher than the other four varieties at the 5% level of significance. Martin, Combine Kafir-60, Redlan, and Wheatland were not significantly different.

Dwarf Redlan set the most seed in both isolation blocks. There was no difference between the other four varieties in either isolation at the 1% level of significance. The high seed set on Dwarf Redlan was difficult to explain. It may be noted from the morphological study in the greenhouse that, only one plant from Dwarf Redlan was classed as a self. This was in contrast to the fact that many plants produced from the other four varieties were classified as selfs.

According to Jones and Brown (1951) S. halepense sheds pollen from 10:30 A.M. to 1:30 P.M., and S. vulgare sheds pollen from 4:00 to 10:00 A.M. Sorghum almum was observed to shed pollen during the same time as S. vulgare. On the basis of times of pollen shedding, S. vulgare and S. almum would be expected to cross more frequently than S. vulgare and S. halepense. However, data obtained indicate S. vulgare crossed more frequently with S. halepense than with S. almum. All five lines set more seed in the S. halepense block than in the S. almum block.

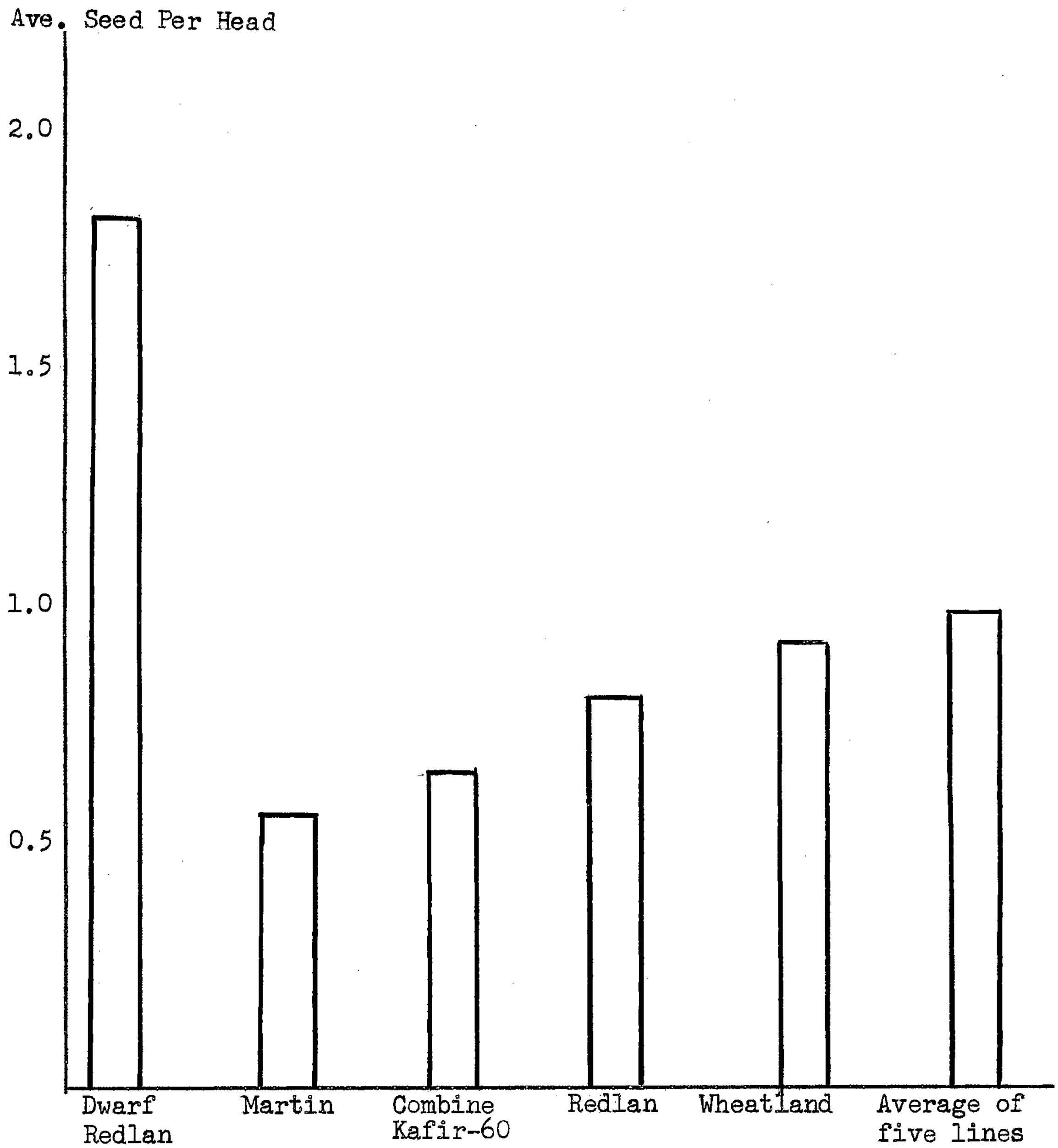


Figure 2. Bar Graph of Average Seed Set Per Head of Cytoplasmic Male Sterile Lines When Pollinated with S. almum

TABLE III

ANALYSIS OF VARIANCE FOR NUMBER OF SEED SET PER HEAD OF FIVE CYTOPLASMIC MALE STERILE LINES WHEN POLLINATED WITH *S. ALMUM*

Source	d.f.	S.S.	M.S.	F
Total	99	43.9516		
Reps	3	8.9516	2.9839	
Varieties	4	18.4106	4.6026	8.443*
Error	12	6.5414	0.5451	
Rows in Reps X Variety	80	10.0480	.1256	

Duncan's New Multiple Range Test

P		2	3	4	5
$S_{\bar{x}}D$	5% level	.5082	.5329	.5494	.5546

Variety	Martin	Combine Kafir-60	Redlan	Wheatland	Dwarf Redlan
Means	0.5200	0.5900	0.7200	0.8550	1.7050
5% level	————	————	————	————	————

(At the 5% level, one line underscores Martin, Combine Kafir-60, Redlan and Wheatland; a separate line underscores Dwarf Redlan.)

*Significant at the 5 percent level

On the basis of three pounds of grain sorghum planted per acre, 20,000 seeds per pound, and 1,500 florets per head, the data obtained in the isolation blocks was projected to plants per acre. Dwarf Redlan X Johnsongrass, with 3.45 seeds per head in the isolation block, would produce approximately 160 off-type plants per acre. Martin X S. almum, with 0.52 seed set per head in isolation, would produce about 23 off-type plants per acre.

Morphological Study

The 130 seeds from the S. halepense block, planted in the greenhouse produced 104 plants that reached anthesis. Morphological observations were made based on the following factors: (1) awned versus awnless, (2) white, dry midrib versus cloudy, juicy midrib, (3) open, grassy head versus compact, grain-type head, (4) male sterile versus male fertile, and (5) rhizomes versus no rhizomes.

The classification of the 104 plants, with the parents, may be found in Table IV. The plants with open head, white midrib, awns, and rhizomes were classed as S. vulgare X S. halepense F_1 hybrids. The plants with compact head, cloudy or white midrib, awnless, and no rhizomes were classed as selfs or outcrosses to another grain sorghum. Many of the plants classified as F_1 hybrids had narrow leaves resembling S. halepense. The F_1 hybrids were generally taller than either parent and many had rhizome development that was as vigorous as S. halepense. All the seeds planted from Dwarf Redlan crosses produced F_1 type plants.

From 224 seeds planted in the greenhouse, from the Sorghum almum

TABLE IV

SUMMARY OF MORPHOLOGICAL CHARACTERISTICS OF S. VULGARE, S. HALEPENSE AND THEIR SUSPECTED F_1 HYBRIDS

Parents or Suspected Hybrids	Number of Plants	Days to Bloom	Average Height (inches)	Head Type	Fertile or Sterile	Midrib Color	Awned or Awnless	Rhizomes or Number of Tillers
Parents								
Wheatland A	2	93	23	Compact	Sterile	White	Awnless	1 stalk
Redlan A	2	102	36	Compact	Sterile	Cloudy	Awnless	1 stalk
Dwarf Redlan A	1	107	24	Compact	Sterile	Cloudy	Awnless	1 stalk
S. halepense	1	99	40	Open	Fertile	White	Awned	Rhizomes
Suspected Hybrids								
Wheatland X S. halepense	24	96	44	Open	Sterile	White	Awned	Rhizomes
Redlan X S. halepense	30	93	49	Open	Sterile	White	Awned	Rhizomes
Dwarf Redlan X S. halepense	36	93	45	Open	Sterile	White	Awned	Rhizomes
Total	90							
Wheatland X S. halepense	1	98	44	Open	Fertile	White	Awned	Rhizomes
Redlan X S. halepense	1	88	31	Open	Fertile	White	Awned	1 stalk
Total	2							
Wheatland X S. halepense	1	99	22	Compact	Sterile	Cloudy	Awnless	3 tillers
Redlan X S. halepense	4	104	26	Compact	Sterile	Cloudy	Awnless	1 stalk
Total	5							
Wheatland X S. halepense	6	100	27	Compact	Sterile	White	Awnless	1 stalk
Wheatland X S. halepense	1	98	18	Compact	Sterile	White	Awned	1 stalk

block, 186 reached heading. Utilizing the same morphological characteristics used to classify plants from the S. halepense block, these plants were classed into groups as shown in Table V.

The plants with open head, sterile or fertile, white midrib and awns or awnless were classed as F_1 hybrids of S. vulgare X S. almum. Due to the heterozygosity of S. almum, plants with open head, sterile or fertile, cloudy midrib and awns may be classed as F_1 hybrids. The compact head, sterile, white or cloudy midrib, and awnless plants were classed as possible selfs. The compact, fertile, white or cloudy midrib, and awnless plants may be outcrosses to a fertility restoring sorghum or because of the nature of the male parent may be crosses with S. almum. Dwarf Redlan produced only one plant that could not be classed as a hybrid.

Many of the S. vulgare X S. almum hybrids were noted to be producing small rhizomes on April 4. Tillers were defined as branches produced from the base of the plant, and a plant was classed as having rhizomes if shoots were produced other than at the base of the plant.

Comparison of the morphological descriptions of the hybrids produced in the S. almum and S. halepense blocks showed several differences. The S. halepense hybrids had narrower leaves, smaller stalks, and more tillers than the S. almum hybrids. Most of the S. halepense hybrids developed definite rhizomes, while the S. almum hybrids were mostly 2 to 3 tillered. The S. almum hybrids were generally taller than the S. halepense hybrids. However, during the first week in April the S. halepense hybrids developed axillary shoots that were taller than the S. almum hybrids.

Germination percentages of the crossed seeds planted in the

TABLE V

SUMMARY OF MORPHOLOGICAL CHARACTERISTICS OF *S. VULGARE*, *S. ALMUM* AND THEIR SUSPECTED F_1 HYBRIDS

Parents or Suspected Hybrids	Number of Plants	Days to Bloom	Average Height (inches)	Head Type	Fertile or Sterile	Midrib Color	Awned or Awnless	Rhizomes or Number of Tillers
Parents								
Wheatland A	2	81	22	Compact	Sterile	White	Awnless	1 stalk
Redlan A	3	85	36	Compact	Sterile	Cloudy	Awnless	1 stalk
Dwarf Redlan A	2	86	27	Compact	Sterile	Cloudy	Awnless	1 stalk
Martin A	2	79	25	Compact	Sterile	Cloudy	Awnless	1 stalk
Combine Kafir-60	2	87	40	Compact	Sterile	Cloudy	Awnless	1 stalk
Sorghum almum	2	87	53	Open	Fertile	White	Awned	3 tillers
Columbusgrass	2	85	50	Open	Fertile	White	Awned	3 tillers
Suspected Hybrids								
Wheatland X *S. almum*	22	77	46	Open	Sterile	White	Awned	2-3 tillers
Redlan x *S. almum*	10	79	50	Open	Sterile	White	Awned	2-3 tillers
Dwarf Redlan X *S. almum*	17	79	47	Open	Sterile	White	Awned	2-3 tillers
Martin X *S. almum*	18	74	43	Open	Sterile	White	Awned	2-3 tillers
Comb.-60 X *S. almum*	14	79	54	Open	Sterile	White	Awned	2-3 tillers
Total	81							
Redlan X *S. almum*	2	81	35	Open	Sterile	White	Awnless	2 tillers
Dwarf Redlan X *S. almum*	4	81	51	Open	Sterile	White	Awnless	2 tillers
Martin X *S. almum*	2	76	43	Open	Sterile	White	Awnless	2 tillers
Comb.-60 X *S. almum*	1	81	66	Open	Sterile	White	Awnless	3 tillers
Total	9							
Wheatland X *S. almum*	2	71	47	Open	Fertile	White	Awned	1 stalk
Redlan X *S. almum*	5	79	47	Open	Fertile	White	Awned	1 stalk
Dwarf Redlan X *S. almum*	12	75	44	Open	Fertile	White	Awned	1 stalk
Martin X *S. almum*	6	78	48	Open	Fertile	White	Awned	1 stalk
Comb.-60 X *S. almum*	1	100	62	Open	Fertile	White	Awned	1 stalk
Total	26							

TABLE V (Continued)

Parents or Suspected Hybrids	Number of Plants	Days to Bloom	Average Height (inches)	Head Type	Fertile or Sterile	Midrib Color	Awned or Awnless	Rhizomes or Number of Tillers
Redlan X *S. almum*	2	78	51	Open	Fertile	White	Awnless	1 stalk
Dwarf Redlan X *S. almum*	4	80	53	Open	Fertile	White	Awnless	1 stalk
Comb.-60 X *S. almum*	1	89	53	Open	Fertile	White	Awnless	1 stalk
Total	7							
Redlan X *S. almum*	3	78	41	Open	Sterile	Cloudy	Awned	1 stalk
Dwarf Redlan X *S. almum*	1	85	61	Open	Fertile	Cloudy	Awned	2 tillers
Martin X *S. almum*	1	76	47	Compact	Sterile	White	Awned	2 tillers
Wheatland X *S. almum*	9	84	25	Compact	Sterile	White	Awnless	1 stalk
Redlan X *S. almum*	1	86	34	Compact	Sterile	White	Awnless	1 stalk
Martin X *S. almum*	2	81	35	Compact	Sterile	White	Awnless	1 stalk
Comb.-60 X *S. almum*	3	85	31	Compact	Sterile	White	Awnless	1 stalk
Total	15							
Redlan X *S. almum*	4	86	32	Compact	Sterile	Cloudy	Awnless	1 stalk
Martin X *S. almum*	4	81	28	Compact	Sterile	Cloudy	Awnless	1 stalk
Comb.-60 X. *S. almum*	5	85	36	Compact	Sterile	Cloudy	Awnless	1 stalk
Total	13							
Redlan X *S. almum*	1	82	29	Compact	Fertile	Cloudy	Awnless	1 stalk
Martin X *S. almum*	2	84	31	Compact	Fertile	Cloudy	Awnless	1 stalk
Total	3							
Wheatland X *S. almum*	6	84	27	Compact	Fertile	White	Awnless	1 stalk
Redlan X *S. almum*	5	81	30	Compact	Fertile	White	Awnless	1 stalk
Dwarf Redlan X *S. almum*	1	87	35	Compact	Fertile	White	Awnless	1 stalk
Martin X *S. almum*	2	82	28	Compact	Fertile	White	Awnless	1 stalk
Comb.-60 X *S. almum*	3	86	32	Compact	Fertile	White	Awnless	1 stalk
Total	17							

greenhouse are presented in Appendix Table II. The germinations ranged from 61.5% for Dwarf Redlan X S. halepense to 78% for Wheatland X S. almum.

Cytological Study

Results of the cytological study are summarized in Tables VI and VII. Among the 29 hybrids analyzed for chromosome number, only three had the expected 2n = 30 chromosome number while 26 had 2n = 40. Similar results for hybrids between S. vulgare and S. halepense have been reported by Endrizzi (1957), Hadley (1958), and Huskins and Smith (1943). The 40-chromosome hybrids could have resulted from unreduced eggs, although it was not known whether the eggs were the result of abnormal meiosis or were reduced and subsequently doubled during delay in fertilization.

Pairing in the 40-chromosome hybrids was almost as regular as in S. halepense, although the hybrids had a higher frequency of univalents. One Redlan hybrid (Plate I, Figure 6) had an association of 20 bivalents which suggested autosyndesis. In the 40-chromosome hybrids, S. vulgare would be expected to contribute 10 bivalents, and S. halepense 20 univalents. Since there were 10 or more bivalents, two to three trivalents and one to two tetravalents in the hybrids, the 20 univalents from S. halepense may have paired with the S. vulgare bivalents to form some trivalents. They may also have paired within themselves to form bivalents, then paired with the S. vulgare bivalents to form tetravalents. This indicates considerable homology between the S. vulgare chromosomes and S. halepense chromosomes.

In the 30-chromosome hybrids, 10 trivalents or 10 bivalents and 10

TABLE VI

SUMMARY OF MORPHOLOGICAL CHARACTERISTICS, CHROMOSOME NUMBER, AND WINTER RECOVERY OF S. VULGARE X S. HALEPENSE F_1 HYBRIDS

Female Parent	Plant Number	Head Type	Fertile or Sterile	Midrib Color*	Rhizome Expression	Winter Recovery	Chromosome 2n Number
Combine Kafir-60	26	Open	Sterile	White	Rhizomes	Weak	40
Martin	28	Open	Sterile	White	Rhizomes	Weak	40
	29	Open	Sterile	White	Rhizomes	No	40
	31	Open	Fertile	White	Rhizomes	Weak	40
	38	Open	Fertile	White	Rhizomes	No	40
	39	Open	Sterile	White	Rhizomes	No	40
	41	Open	Fertile	White	Rhizomes	No	40
	43	Open	Sterile	White	Rhizomes	No	40
	45	Open	Sterile	White	Rhizomes	No	40
	46	Open	Fertile	White	Rhizomes	Weak	40
	49	Open	Fertile	White	Rhizomes	No	40
	50	Open	Sterile	White	Rhizomes	No	40
Dwarf Redlan	51	Open	Sterile	White	Rhizomes	No	30
	55	Open	Sterile	White	Rhizomes	No	40
	56	Open	Sterile	White	Rhizomes	No	40
	58	Open	Sterile	White	Rhizomes	No	40
Redlan	60	Open	Sterile	Cloudy	No	No	40
	62	Compact	Sterile	Cloudy	No	No	40
	65	Open	Fertile	Cloudy	No	No	40
	69	Open	Sterile	Cloudy	No	No	40
	73	Compact	Sterile	Cloudy	No	No	40
	75	Open	Sterile	Cloudy	No	No	40
	78	Open	Sterile	Cloudy	No	No	40
	88	Compact	Sterile	Cloudy	No	No	40

TABLE VI (Continued)

Female Parent	Plant Number	Head Type	Fertile or Sterile	Midrib Color*	Rhizome Expression	Winter Recovery	Chromosome 2n Number
Wheatland	92	Open	Sterile	Cloudy	Rhizomes	No	40
	94	Open	Sterile	Cloudy	Rhizomes	Weak	40
	95	Open	Fertile	Cloudy	Rhizomes	No	40
	96	Open	Sterile	Cloudy	Rhizomes	No	30
	99	Open	Sterile	Cloudy	Rhizomes	No	30

*Data on midrib color were taken from Wilhite (1959).

TABLE VII

CHROMOSOME ASSOCIATION AT METAPHASE I IN SORGHUM VULGARE, SORGHUM HALEPENSE AND THEIR HYBRIDS

Parents or Hybrids	Plant Number	2n	Ave. Per Cell I	II	III	IV	Cells Studied
Parents							
S. vulgare		20		10.00			20
S. halepense		40	0.60	15.70	2.20	1.00	30
Hybrids							
Wheatland X S. halepense	96	40	2.00	9.50	2.50	2.00	40
Wheatland X S. halepense	99	30	6.00	7.00	2.00	1.00	25
Redlan X S. halepense	88	40		20.00			15
Redlan X S. halepense	69	40	3.00	13.50	2.00	1.00	19
Combine Kafir-60 X S. halepense	26	40	12.00	14.00			20
Dwarf Redlan X S. halepense	62	40	1.50	13.50	2.50	1.00	35
Dwarf Redlan X S. halepense	51	30	8.00	6.00	2.00	1.00	15
Martin X S. halepense	38	40	4.00	11.00	2.00	2.00	25
Martin X S. halepense	29	40	2.00	12.00	2.00	2.00	40
Martin X S. halepense	31	40	5.00	8.33	3.00	2.00	17

Legend for Plate I

Figures 1-6 and 8-10, ca X 3000.

Figure 7, ca X 2200.

Figure 1 Metaphase I of *S. vulgare* var. Combine Kafir-60, 2n = 20.

Figure 2 Metaphase I of *S. vulgare* var. Combine Kafir-60, 2n = 20.

Figure 3 Anaphase I of *S. vulgare* var. Martin X *S. halepense*, 2n = 40.

Figure 4 Metaphase I of *S. vulgare* var. Martin X *S. halepense*, 2n = approximately 120.

Figure 5 Anaphase I of *S. vulgare* var. Martin X *S. halepense*, 2n = 40, lagging bivalent.

Figure 6 Metaphase I of *S. vulgare* var. Redlan X *S. halepense*, 2n = 40, 20 bivalents.

Figure 7 Metaphase I of *S. vulgare* var. Wheatland X *S. halepense*, 2n = 30.

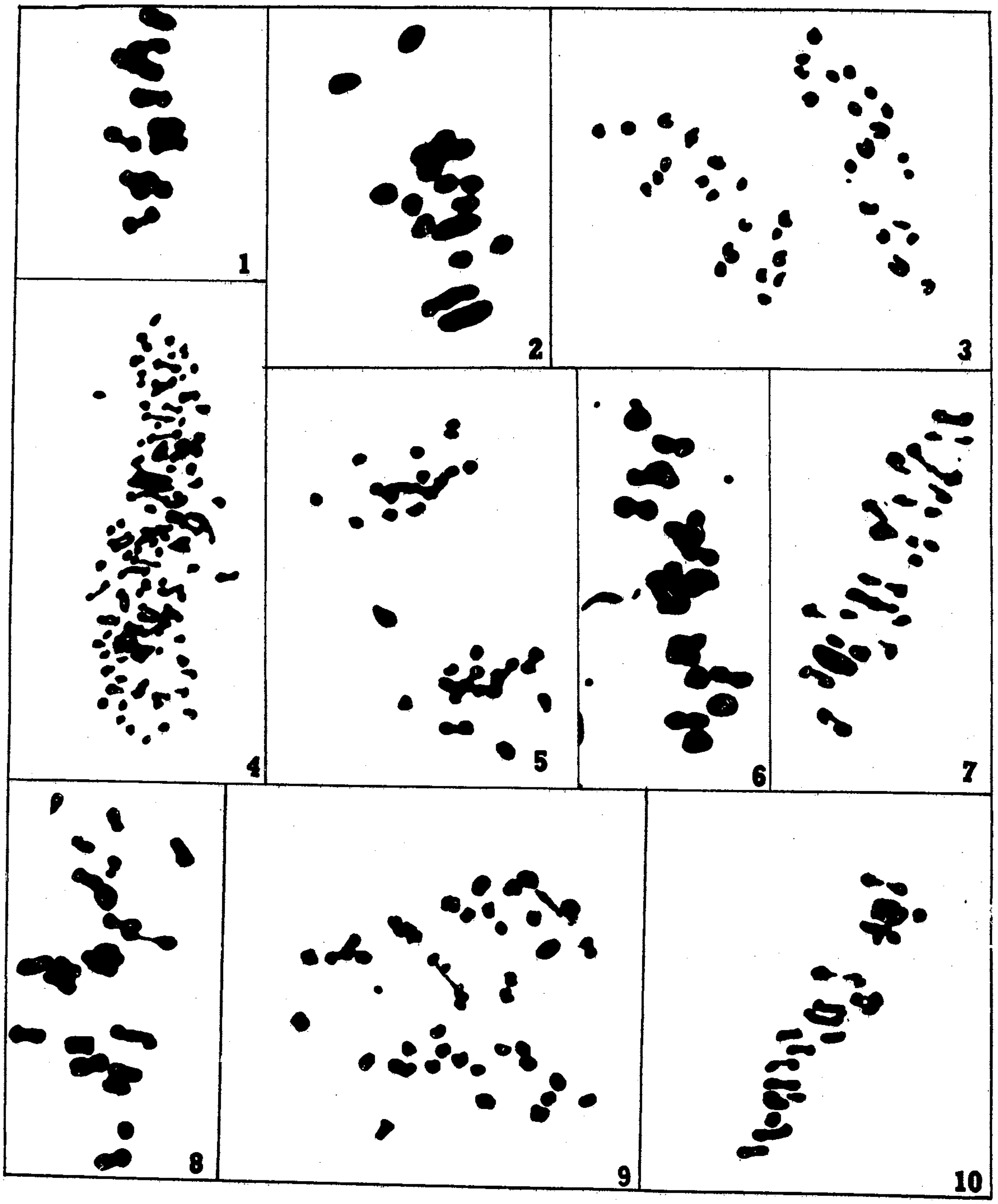
Figure 8 Metaphase I of *S. vulgare* var. Redlan X *S. halepense*, 2n = 40.

Figure 9 Anaphase I of *S. halepense*, 2n = 40, bridge and fragments.

Figure 10 Metaphase I of *S. halepense*, 2n = 40.

(Chromosomes traced with India ink)

PLATE I



univalents would be expected. The 30-chromosome hybrids studied had approximately 6 I + 8 II + 2 III + 1 IV. This association suggested that the chromosomes of S. vulgare and S. halepense were homologous or highly homologous. The fact that there invariably were tetravalents in the hybrids suggested that the chromosomes of S. halepense could at times pair among themselves, i.e., have a certain amount of autosyndesis.

Plate I, Figures 1, 2, 9, and 10 show chromosome associations of the parents and Plate I, Figures 3 to 8 illustrate some of the associations observed in the hybrids. Plate I, Figure 4 is a multiploid microsporocyte in Martin X S. halepense. Plate I, Figure 10 shows several univalents, three trivalents and two tetravalents.

Winter Survival

During the season the hybrids were grown in the field, no differences were observed between the 30- and 40-chromosome hybrids. This observation was based on head type, midrib color, rhizome expression, and fertility or sterility. After the plants had been exposed to the ensuing winter, only a few plants survived. However, no differences were observed between the 30- and 40-chromosome hybrids. According to the data presented in Appendix Table I, the winter temperatures were above normal. Since the hybrid plants survived poorly, they probably would not become a weed problem. However, there were a considerable number of seedling plants that became established the following spring. The persistence of the seedlings was not determined.

Notes on winter survival of the hybrids are presented in Table VI.

SUMMARY AND CONCLUSIONS

A study was conducted of the frequency of interspecific crossing between S. vulgare and S. halepense and between S. vulgare and S. almum. The hybrids obtained were classified into groups based on the following characters: (1) awned versus awnless, (2) white versus cloudy midrib, (3) open versus compact head, (4) rhizomes versus no rhizomes, and (5) sterile versus fertile. A cytological study was conducted on several hybrids obtained from S. vulgare X S. halepense.

Data indicated that there was a degree of receptivity to S. halepense or S. almum pollen among the five cytoplasmic male sterile lines. Dwarf Redlan had a significantly higher seed set than the other lines with an average of 3.45 seeds per head in the S. halepense isolation and 1.70 seeds in the S. almum isolation. Martin had the lowest frequency of seed set in the S. almum block and Wheatland in the S. halepense block.

Morphological data showed several differences between S. vulgare X S. halepense and S. vulgare X S. almum hybrids. Sorghum almum hybrids were taller and had wider leaves in comparison to the S. halepense hybrids. The plants obtained between the tetraploid species and Dwarf Redlan were F_1 hybrid-type with the exception of one plant classed as a self, while the other lines produced many selfs.

The cytological study revealed three plants with 30 chromosomes and 26 with 40 chromosomes. The chromosome associations obtained indicated considerable homology between the genomes of *S. halepense* and *S. vulgare*. No differences were observed among these 30- and 40- chromosome plants with regard to morphological characteristics or winter survival.

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APPENDIX

APPENDIX TABLE I

MEAN MONTHLY TEMPERATURES (°F), OCTOBER 1960 TO APRIL 1961, AGRONOMY FARM, STILLWATER*

Month	1960-61	Average 1931-1961
October	65.1	63.7
November	52.2	49.1
December	38.7	40.6
January	35.8	38.1
February	45.8	45.8
March	53.0	50.3
April	59.6	60.8

*Mean temperatures were computed from Oklahoma Climatological Data, Vol. 69(13) 1960 and Vol. 70(13) 1961.

APPENDIX TABLE II

PERCENT GERMINATION OF F_1 HYBRID SEEDS PLANTED IN THE GREENHOUSE

	Male Parent	
Female Parent	S. almum	S. halepense
Wheatland	78.0	75.0
Redlan	67.5	71.0
Dwarf Redlan	75.0	61.5
Martin	72.0	*
Combine Kafir-60	70.0	64.2**

*Martin F_1 was not planted in the greenhouse
**Seed from the 1960 block was planted

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Master of Science

Thesis: FREQUENCY OF INTERSPECIFIC CROSSING BETWEEN SORGHUM VULGARE PERS. AND SORGHUM HALEPENSE (L.) PERS. AND BETWEEN SORGHUM VULGARE PERS. AND SORGHUM ALMUM PARODI

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