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Genetic Variability for Cottonseed Germination at Favorable and Low Temperatures[1]

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ABSTRACT

Many plant breeders are concerned with developing cotton (*Gossypium hirsutum* L. and *G. barbadense* L.) lines that are adapted for germination and seedling emergence when soil temperatures are low. Seedlings, however, should emerge rapidly over a range of soil temperatures. Little information is available about the association between rapid seedling emergence at favorable and low temperatures. To evaluate this relationship for a broad base of genetic lines, seeds of 18 *G. barbadense* and 12 *G. hirsutum* lines of diverse genetic background were germinated in six experiments at 15 and 25 C. Significant differences in germination properties were found among the genotypes and the temperature × genotype interaction was generally significant. Correlation coefficients for germination parameters of the genotypes at the two temperatures were generally positive but small in magnitude. Germination properties of the cotton lines were associated with geographical area where developed. Generally lines developed for low elevations had better germination properties at both 15 and 25 C than did lines developed for high elevations. The results of this study suggest that potential exists for developing cotton lines with improved germination at low temperatures. Because of the poor correlation between germination at low and favorable temperatures, cotton lines should be evaluated under both conditions.

Additional index words: Gossypium hirsutum, Gossypium barbadense. Rate of germination, Seedling vigor.

SEVERAL factors have stimulated interest in developing cotton (*Gossypium hirsutum* L. and *G. barbadense* L.) lines that germinate and emerge when soil temperatures are low. In areas with short growing seasons, early planting is desirable to extend the growing period. In some regions, late-season insect buildup has encouraged early planting to advance crop development and minimize destructive effects of these pests.

Most cotton cultivars were developed under conditions that did not specifically place great selective pressure for germination and emergence at low soil temperatures. In part, this has occurred because year-to-year variability in weather makes it difficult to consistently evaluate seedling emergence at low soil temperatures. In addition, some plant breeders are reluctant to risk losing valuable germplasm by planting when soil temperatures are low and the probability for seedling survival reduced.

Soil temperatures during planting are extremely variable when compared over locations, planting dates, and years. Thus it is desirable to have cultivars that exhibit rapid field emergence over a wide range of soil temperatures. It is important, therefore, to know how well seeds of cotton lines selected for germination at favorable temperatures germinate at low temperatures and vice versa.

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The optimal temperature for cottonseed germination and emergence is between 30 and 35 C with a minimal temperature of about 12 C (Camp and Walker, 1927; Ludwig, 1932; Marani and Dag, 1962; Wanjura and Buxton, 1972a, b). Little work has been reported on genetic variability of seed germination at low temperatures or of the relationship between germination at favorable and low temperatures. Ludwig (1932) and Marani and Dag (1962) evaluated seeds of lines of both *G. hirsutum* and *G. barbadense* for germination at 12 C. They reported variability within each species and that *G. barbadense* lines generally germinated better at this low temperature than did *G. hirsutum* lines.

The objectives of the work reported here were to evaluate cotton lines of diverse genetic background for germination at low and favorable temperatures, to determine the relationship between germination at these two temperatures, and to determine if the location at which genotypes were developed influenced seed germination properties.

MATERIALS AND METHODS

Six experiments were conducted, using a total of 18 genotypes of *G. barbadense* and 12 genotypes of *G. hirsutum*. With the exception of M-8 in the last two experiments, seed for each experiment were collected from comparative yield trials in Arizona and had similar environmental backgrounds. The M-8 seed was produced in Mississippi. *G. barbadense* seed of released cultivars and advanced experimental lines were furnished through the courtesy of C. V. Feaster, research agronomist, ARS, USDA, Phoenix, Ariz. All experiments were conducted in the laboratory between March and May following the year that the seeds were harvested from the field. The seedlots were acid-delinted in concentrated sulfuric acid. *G. barbadense* lines were exposed to the acid for 4 min while *G. hirsutum* lines were exposed 8 min. Seed were rinsed in tap water for 6 min; floating seeds, seeds with cracked hulls, seeds with light-colored seedcoats, and abnormally small seeds were discarded. These seeds normally show poor germination properties (Ferguson and Turner, 1971; Marani and Amirav, 1970; and Bartee and Krieg, 1972). Seeds were germinated in the dark in temperature-controlled water baths at either 15 ± 1 or 25 ± 1 C.

The first two experiments were with *G. barbadense* genotypes harvested from Phoenix (Exp. I) and Safford (Exp. II), Arizona in 1971 and contained common genotypes. The entries included two commercial cultivars, 'Pima S-3' and 'Pima S-4,' and eight experimental lines. The third experiment included 12 *G. barbadense* genotypes harvested from Phoenix in 1972. The entries were similar to Exp. I and II except that three new experimental lines and one commercial cultivar, 'Pima S-5,' were added and two experimental lines were deleted. Exp. IV contained 10 *G. barbadense* lines grown in Phoenix in 1973. The entries differed from Exp. III in that six experimental lines were deleted and four new lines were added. The fifth experiment included 11 genotypes of *G. hirsutum* grown in Phoenix in 1971 plus M-8 from Mississippi. These genotypes are of diverse genetic backgrounds and were developed at different locations. Seeds from seven of the entries grown in Phoenix in 1971 were re-evaluated in the sixth experiment.

Twenty-five seeds were germinated with the micropyle down on two germination sheets (26 $\times$ 29 cm). A third sheet was placed over the seeds and 60 ml of tap water were added. The sheets were loosely rolled and two rolls were placed in a plastic bag (26 $\times$ 30 cm) attached to a rack to hold the open end above the water level in the water bath. All experiments were in a completely randomized design with four replicates in Exp. I, II, and VI, eight in Exp. III, six in Exp. IV, and five in Exp. V. For each experiment, analyses of variance were determined for each temperature separately and then a combined ANOV was calculated for the two temperatures.

Seeds were germinated for 4 days at 25 C and 8 days at 15 C. Percent germination was determined by counting seedlings with undamaged radicles (normal radicle tips and no cortex damage) longer than 1 cm. Axes of germinated seedlings were removed at the junction with the seed micropyle. The severed plant axes and remaining seedling parts were oven-dried at 70 C and weighed. The weight of the plant axes was expressed as a percentage of the total dry wt and is referred to as % transfer. This value gives an indication of the vigor or rate at which germinating seedlings were developing. Christiansen (1962) described a method to assay seedling vigor by expressing the % cotyledon dry wt in relation to total seedling wt. However this method requires that seedcoats be removed before germination which is time-consuming and may affect germination.

To characterize seed germination into a single term, germination index (GI) was determined as follows:

$$GI = \frac{(\%\ \text{germination})\ (\%\ \text{transfer})}{(\text{length of germination, days})\ (100)}$$

RESULTS AND DISCUSSION

Percent germination may not sufficiently predict performance of germinating seedlings under field conditions, especially if seedlings must emerge from deep plantings when soil temperatures are low. The rate of development (% transfer) may be as important as the number of seeds that are viable. For this reason a measure such as GI which includes both of these parameters may be more meaningful.

Significant variation in genetic expression was noted for the three germination parameters in all experiments at 25 C and was generally observed at 15 C as seen in Tables 1, 2, and 3. At the low temperature, differences in % transfer were not statistically significant in Exp. II, III, and VI; differences in GI were not significant in Exp. II and VI. A relatively large range was observed among genotypes in these cases, but the coefficient of variation was higher at 15 C than at 25 C, which partially accounts for the lack of significance.

Environmental conditions under which seeds are developed can greatly influence seed germination properties (Peacock and Hawkins, 1970; Quisenberry and Gipson, 1974). However because of the similar environmental background of the lines in each test (except M-8), differences found here are believed to represent primarily genetic expression. Although plants from which seeds were harvested were open-pollinated, past experience has shown that outcrossing is at most only a few percent because of the insect control program followed. In addition, seeds were harvested from the center two rows of four row plots which should have minimized pollination from other lines.

When Exp. I and II were analyzed in a combined ANOV, the experiment $\times$ genotype interaction was highly significant for all three germination parameters. Safford (Exp. II) is 500 m higher in elevation than Phoenix (Exp. I) and has lower summer temperatures. This shows the desirability of identifying the environmental background of seeds when comparisons of genetic potential are made. In these experiments, many of the *G. barbadense* experimental lines had germination parameters that were significantly improved over the commercial cultivars. Among the *G. hirsutum* cultivars, 'AZ 64,' 'Deltapine 16,' 'Stoneville 213,' and 'Lockett 4789A' generally had better germinations parameters than the remaining lines.

Table 1. Summary of % germination from six experiments

	G. barbadense								*G. hirsutum*			
	Exp. I		Exp. II		Exp. III		Exp. IV		Exp. V		Exp. VI	
	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C
No. of entries	10		10		12		10		12		7	
% germination												
Max value	91.5	97.0	60.0	92.0	91.0	96.5	95.4	98.0	70.0	95.2	70.2	89.0
Min value	70.0	77.0	27.0	66.0	50.0	78.0	70.3	70.7	29.2	50.4	35.0	47.0
Mean	77.8	88.6	49.4	84.5	70.7	88.1	86.5	90.7	52.3	80.7	58.9	72.9
Mean squares												
Genotype (G)	517**	177**	356*	209**	975**	204**	581**	440**	902**	910**	527*	1,038**
Temp (T)	2,311**		24,570**		14,491**		916**		24,160**		2,758*	
T X G	110		70		480**		132*		330*		443*	
CV (Error b), %	11.1		14.0		11.9		9.2		18.8		18.6	

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Table 2. Summary of % dry wt transfer to seedling axis from six experiments.

	G. barbadense								*G. hirsutum*			
	Exp. I		Exp. II		Exp. III		Exp. IV		Exp. V		Exp. VI	
	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C
% transfer												
Max value	10.2	20.5	4.1	21.0	9.9	12.7	6.4	16.3	7.4	20.1	10.3	14.1
Min value	4.0	11.2	2.1	15.9	7.4	9.6	3.9	11.0	4.2	11.1	8.8	7.1
Mean	6.5	16.4	3.4	19.1	8.7	11.0	5.2	14.6	6.3	15.9	9.5	10.8
Mean squares												
Genotype (G)	13.9**	2.65**	2.1	9.8**	53.8	9.1**	5.3**	24.8**	4.8**	37.1**	1.4	24.8**
Temp (T)	1,978.1**		4,980.2**		253.0**		2,697.4**		24,160.1**		23.8**	
T X G	26.8**		3.0**		2.7		10.6		350.0**		10.5**	
CV (Error b), %	14.2		10.9		18.1		12.5		12.1		14.1	

** Significant at 0.01 probability level.

Table 3. Summary of germination index from six experiments.

	G. barbadense								*G. hirsutum*			
	Exp. I		Exp. II		Exp. III		Exp. IV		Exp. V		Exp. VI	
	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C	15 C	25 C
G I												
Max value	1.02	4.92	0.31	4.75	1.13	2.93	0.76	3.95	0.54	4.36	0.88	3.06
Min value	0.37	2.17	0.07	2.65	0.47	2.10	0.45	1.98	0.16	1.87	0.39	0.95
Mean	0.64	3.66	0.21	4.06	0.78	2.43	0.55	3.34	0.42	3.23	0.71	2.05
Mean squares												
Genotype (G)	0.17**	2.33**	0.02**	1.35**	0.25**	0.87**	0.12**	2.87**	0.07**	3.91**	0.10	2.32**
Temp (T)	183.30**		296.20**		130.50**		232.15**		283.01**		25.05**	
T X G	1.24**		0.56**		0.32**		1.14**		1.77**		1.00**	
CV (Error b), %	17.1		14.2		16.6		14.3		21.3		27.6	

** Significant at 0.01 probability level.

Low temperature significantly reduced all three germination parameters in each experiment. A significant temperature × genotype interaction was generally noted for the germination parameters in all experiments except for % germination in Exp. I and II, and % transfer in Exp. III. The reason for differences in significance of the T × G interaction among experiments probably relates mostly to genotype substitution.

Table 4 presents the correlation coefficients between the two temperatures for % germination, % transfer, and GI. Data were averaged over replications before these determinations were made. The coefficients for each experiment are generally positive but not significant with the magnitude tending to be largest for % germination and smallest for % transfer. Pooled correlation coefficients were calculated after adjusting the experiments to common means. These coefficients are low, but significant, for % germination and GI.

The generally low correlation coefficients and significant genotype × temperature interactions show that there was not a close association between germination response to low and favorable temperatures. Therefore the probability is low that a line selected for rapid germination at a favorable temperature will germinate well at a low temperature and vice versa.

The germination parameters showed a marked association with the geographical area where developed as shown in Tables 5 and 6. Data in Table 5 are averaged for all entries in the first four experiments. Each of these experiments contained three entries, including Pima S-3, developed at El Paso, Texas. The remaining entries in these experiments, including Pima S-4 and Pima S-5, were developed at Phoenix. These two locations differ in elevation and summer temperatures. El Paso is at 1300 m and has cooler temperatures than Phoenix, which is at 380 m.

Table 4. Correlation coefficients for cotton seeds germinated at 15 and 25 C.

Experiment	% germination	% transfer	GI
I	0.62	−0.09	0.13
II	0.73*	0.63	0.88**
III	0.25	0.64*	0.52
IV	0.51	0.16	0.09
V	0.61*	0.17	0.44
VI	0.46	0.49	0.51
Pooled	0.54**	0.19	0.39**

*,** Significant at 0.05 and 0.01 probability levels, respectively.

Lines developed at high elevation might be expected to have improved germination parameters at low temperatures over lines developed at low elevation. As seen in Table 5, however, the opposite was true. The reason for this unexpected response is not readily apparent. Because of later planting dates, selection pressure for germination and emergence during low soil temperatures may have been less at El Paso than at Phoenix. In addition, the Phoenix climate, where most of the seed was produced, may be more favorable for lines developed at Phoenix than those developed at El Paso. This was suggested when Exp. I and II were compared. Lines harvested at Safford (Exp. II), an intermediate elevation, showed no statistical effect of location of development for seed germination at 15 C. When the same entries were evaluated from Phoenix grown seeds (Exp. I), differences were significant and in agreement with the data of Table 5. Little research on the importance of genetic × environmental interactions on seed germination has been reported in the literature.

Lines developed at Phoenix had the highest values for each of the three germination parameters at 25 C. Cotton grown at Phoenix is exposed to a wide range of temperatures from cool springs to hot summers. It seems likely that enzyme systems of lines adapted to this area would respond favorably to a wide range of temperatures.

Table 6 shows the response of the *G. hirsutum* lines from Exp. V by the state in which they were developed, except that M-8 grown in Mississippi was not included. The three lines developed in Mississippi were Deltapine 16, Stoneville 213, and M-8 Superokra. The lines from Arizona were 'Anderson-Clayton 1764,' AZ 64, and an experimental line, Arizona 6704. Those developed in Texas included Lockett 4789A, 'Dunn 56C,' 'Dunn 118,' 'Dunn 119,' and 'Tamcot 23.' At both temperatures, the Mississippi lines generally had the highest germination parameters. The Arizona lines were generally the lowest at 15 C, and the Texas lines lowest at 25 C. The Anderson-Clayton line germinated poorly at both temperatures. If it were eliminated, the Arizona lines responded similarly to the Mississippi lines. Lines adapted to Mississippi have generally shown good adaptation to the low elevations in Arizona. Most of the lines from Texas are adapted to the High Plains where temperatures are relatively low.

As was found for the *G. barbadense* lines, *G. hirsutum* entries adapted to high elevations generally had the lowest germination parameters at each germination temperature. The same explanation given earlier for results with the *G. barbadense* lines probably applies here.

Table 5. Seed germination parameters of *G. barbadense* lines.

	Germination temperature					
	15 C			25 C		
Where developed	% germ.	% trans.	G I	% germ.	% trans.	G I
Phoenix	73.3 a*	6.3 a	0.60 a	89.7 a	15.4 a	3.46 a
El Paso	66.6 b	5.5 b	0.46 b	83.7 b	14.3 b	3.00 b

* Values within a column followed by different letters are significantly different at 0.05 probability level based on L.S.D. calculated from a pooled variance.

Table 6. Seed germination parameters of *G. hirsutum* lines.

	Germination temperature					
	15 C			25 C		
Where developed	% germ.	% trans.	G I	% germ.	% trans.	G I
Mississippi	60.2 a*	6.5 a	0.50 a	90.4 a	17.0 b	3.89 a
Arizona	42.5 b	6.0 a	0.34 b	81.1 b	18.6 a	3.82 a
Texas	53.2 a	6.0 a	0.40 b	78.7 b	13.7 c	2.69 b

* Values within a column followed by different letters are significantly different at the 0.05 probability level bated on L.S.D.

This study has shown that potential exists for developing cotton cultivars with greater seedling vigor during low soil temperatures. This appears to be especially important at high elevations where growing seasons are short. Development of cultivars with these traits offers the potential of extending the growing season and increasing yields in these areas. Improved cultivars that germinate rapidly at low temperatures might be used to advance the maturity of the crop to minimize late-season insect damage and reduce the need for irrigation water in the late summer of irrigated regions. Cultivars selected for rapid germination and emergence at low temperatures should be evaluated for germination at favorable temperatures.

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