



Seed weight, seed vigor index and field emergence in six upland cotton cultivars

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Abstract

In regions where a short growing season is combined with low soil temperatures at sowing, field emergence and stand establishment is one of the most critical stages in cotton production. This study evaluates the relations between seed weight, seed vigor index and field emergence on 6 upland cotton (*Gossypium hirsutum* L.) genotypes, grown at Alentejo (Portugal). Leaf area per cotyledon, cotyledons to total leaf area and to total dry weight ratios were also analyzed. Seed vigor index, the sum of cold and standard germination tests, showed significant differences between genotypes, and different year to year soil temperatures had a significant impact on seedling emergence. No significant correlations were found between field emergence and seed weight or seed vigor index. However, poor positive linear relationships were found between seed weight and seed vigor index, as well as between standard test and field emergence. Probably, the expected impact of seed quality on field emergence was overlapped or confused by the influence of other factors (soil crusting) than temperature physical stress exerted over seeds. Cotyledons per total leaf area and dry weight represent important proportions of the entire plants during the relatively long seedling period often observed in the cotton crop grown on marginal spring weather conditions.

Key words: Cotton, genotypes, seed germination, seed weight, seed index, field emergence, cotyledons.

Introduction

In an economically successful cotton (*Gossypium hirsutum* L.) production program ¹, field emergence is one of the most delicate periods being frequently responsible for stand failures, poor stands and low yields ². Soil temperature, moisture and physical impedance above the seed are the most common physical factors limiting cotton germination and growth during emergence ³. Seed quality and cold tolerance could lead to better emergence, faster seedling growth, earlier maturity and possibly increased yield ⁴. In Andalusia (Spain) and Alentejo (Portugal) regions, with short growing seasons, low spring temperature is a major constraint to early plantings, and the use of plastic cover has been highly spread to overcome this problem, but abandoned due to the high cost in the last years.

Seed vigor index, given by the sum of cold and standard germination tests, is considered a reliable indicator of seed quality and behavior in the field, combining seeds ability to germinate under cold temperatures and speed of germination under optimal temperatures ^{5,6}. In a four year study with seed lots of different qualities, the highest field emergence percentages, although highly variable among lots qualities, were always obtained with the highest seed vigor indices ⁷. A minimum value of 140 was suggested ⁵ as the lower limit of seed vigor index to use a seed lot under prevailing low temperature conditions during field planting. This value corresponds to the lower limit of the class *good* used by seed sellers ⁸. However, no seed vigor index data of the main upland cotton cultivars used in Andalusia and Alentejo regions are available.

Good positive relations have also been found between seed weight, seed vigor index and field cotton emergence performance

under adverse conditions ^{1,9,10}. However, in an Australian region with a short growing season combined with low soil temperatures at planting date, no significant correlation was observed between seed index and the number of days from sowing to 80% of the final emergence ⁴. Good relations between seed characteristics and field emergence performance could be useful and a major tool for growers in order to choose the most adequate cultivar and seed lot to achieve good standings in marginal areas with low soil temperature. Also no results are known about the relations between seed characteristics and field emergence performance in the cotton production regions of Spain and Portugal.

Soon after emergence, cotyledons expand, forming a set of green structures very important to the survival, growth and development of young cotton plants ^{11,12}. Some authors found no chlorosis signs on cotyledons until 35 days after emergence. Senescence symptoms became evident only 45 days after emergence, whereas seed leaves remained attached to the plants at this time ¹¹. The influence of cotyledons persistence was also noted on several cotton morphological (height), growth (leaf area and total dry weight) and production (number of open bolls, immature bolls and fiber production) parameters ¹³.

The objective of this study was to investigate seed behavior under cold and standard germination tests, its emergence on the field, and the possible relations between seed weight, seed vigor index and field emergence data on 6 genotypes of upland cotton mostly used in the southern Iberian Peninsula. Cotyledons persistence, area and dry weight, as well as their proportion on the whole above-ground plant, were also investigated.

Material and Methods

Seed germination tests and field emergence performance experiments were carried out using 2002 and 2003 acid delinted seed lots of six upland cotton genotypes: 'Carmen', 'Celia', 'Crema', 'Flora', 'Lacta' and 'Sonia' (Table 1). The cold germination test (chamber controlled temperature at 18°C with initial and final normal seedling counts at Day 7 and 20) and the standard germination test (chamber controlled temperature at 30°C with initial and final normal seedling counts at Day 4 and 8) were conducted in moist paper towels, according to the American Association of Official Seed Analysts rules^{14, 15} in a growth chamber (Fitoclima S600PL, Concessus, Portugal). Seed vigor index was calculated by the sum of the germination percentages registered at the fourth day at 30°C and at the seventh day at 18°C^{5, 6}. Seed index (weight of 100-seeds) was also determined using three random samples per genotype seed lot.

Seeds were sown on 19 April 2002 and 20 March 2003, at 5 cm deep and 1 m row-width (18 seeds m⁻²), at the experimental field of Comenda Experimental Center, Caia, Alentejo, Portugal (38°54'N, 7°03'W, 169 m altitude), where soil was sandy Xerofluvent, Fluvent, Entisol. A randomized complete block design was used with three replications in plots of 10 m x 5 m. Seedling emergence was counted at full expanded cotyledon stage. Weekly harvests of the above ground plants were made on 7, 14, 21 and 28 June and 5 July, in order to determine cotyledons and total leaf areas, as well as cotyledons and total plant dry weights. Cotyledons and true leaves were digitally photographed and their area measured using the Image Tool for Windows version 3.0, developed by the University of Texas, Health Science Center, San Antonio. Dry weight was determined after drying the samples for 48 h at 100°C. The relative importance of the cotyledonal apparatus was determined in an area basis, by the ratio of cotyledon area/total plant leaf area, and in a dry weight basis, by the ratio of cotyledon dry weight/total plant dry weight.

A soil crust of 2-3 cm thick was observed in both years, probably due to unstable structure and poor organic matter content¹⁶. Soil temperature at 5 cm depth was registered with soil sensors and hourly data loggers (Spectrum Technologies, Inc.), in order to evaluate the influence of this major growth environmental factor on the emergence results (Fig. 1). Soil water content was monitored with watermark soil moisture sensors and loggers (Spectrum Technologies, Inc.) and maintained in adequate thresholds for seed imbibing and seedling growth using drip irrigation.

No yearly differences were detected in the germination tests, seed index values, or cotyledon and true leaf areas and seedling dry weights, so means and statistics were calculated and presented using both year data. One-way ANOVA was performed, and Tukey's honestly significant difference multiple comparison procedure was used to make pair-wise comparisons. Regression

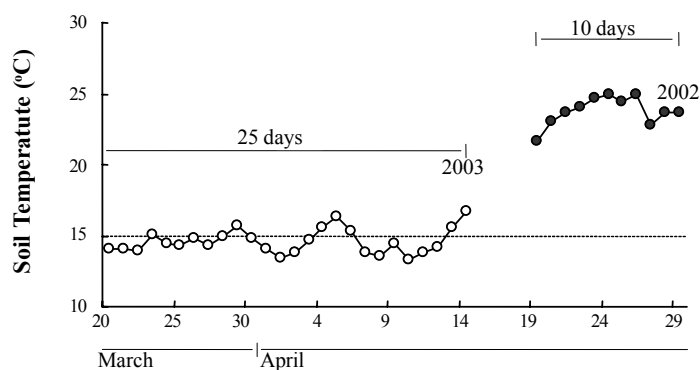


Figure 1. Soil temperature (°C) registered in 2002 and 2003 at Comenda Experimental Center, Caia, Alentejo, Portugal (38° 54' N, 7° 03' W, 169 m altitude) during sowing-emergence period.

analysis was calculated in order to analyze relationships between seed index, seed vigor index and field emergence data, as well as for cotyledon dry weight/total dry weight ratio versus days after sowing. All statistical analysis was performed with SPSS for Windows standard version 9.0.

Results and Discussion

Germination: At 30°C, 24 hours after the beginning of the experiment, most of the seeds were well hydrated and white radicle tips could be seen protruding from the seed coat, as reported by other authors^{12, 17}. In the opposite, in the experiment at 18°C, hydration was evident only after 2-3 days, and at the fourth day all the seeds still did not have germinated.

There were significant differences between genotypes in germination on the fourth day (standard test), the germination percentage in 'Lacta' being lower than in 'Carmen' and 'Sonia' and that in 'Crema' being significantly lower than in 'Carmen' (Fig. 2). On the eighth day after the beginning of the standard test experiment, there was a significant difference between 'Carmen' and 'Lacta', but the germination percentages for all the other genotypes were not different (Fig. 2). These results indicate a relatively slower germination rates of 'Crema' and 'Lacta' at the first germination steps (time as constraint factor), showing the former to have some recover ability between the fourth and the eighth day after hydration, once its germination percentage reached similar values as those of the four other genotypes. To the opposite, germination percentage of 'Lacta' remained until the end of the experiment lower than the germination percentages of all other genotypes.

There were no significant differences between genotypes in the germination percentages of the two standard counting days (4 and 8). Although rather large differences were detected in some genotypes (in 'Crema' and 'Lacta' more than 16.7%), these differences were not significant (0.05 < P < 0.10). These results demonstrate that the speed of seed germination at optimal temperatures can be well estimated with any one of the two counting dates, with a tendency for worse estimates on seeds of worse germination ability at those temperatures.

Three years results of standard test (86-93%) obtained with 'Deltapine 90' commercial seeds were higher than our results obtained with 'Celia', 'Crema', 'Flora' and 'Lacta'⁹. On the other hand, our germination result (100%) for 'Carmen' was higher

Table 1. Description of varieties.

Genotype	Growing season	Precocity index (%) ²	Leaf type	Origin
Carmen (Sicala V2) ¹	medium-late	87	normal	CSIRO (Australia)
Celia (Sicala 40)	early-medium	93	normal	CSIRO (Australia)
Crema 111 (KC311) ¹	medium	86	normal	Stoneville (USA)
Flora (Sicot 41)	medium	89	normal	CSIRO (Australia)
Lacta (Siokra V-17)	medium	90	okra	CSIRO (Australia)
Sonia (Sicot 70)	medium late	87	normal	CSIRO (Australia)

¹ Solely 'Carmen' and 'Crema' cultivars are responsible for more than 46,000 hectares of cotton crop in south Spain per year.

² Percentage of first harvest on total seed-cotton yield (E_g precocity index²⁶).

than the upper limit, while germination of ‘Sonia’ (88.9%) was comprehended in that interval⁹. Although unavailable absolute values, our results for ‘Crema’ and ‘Lacta’ corresponded to lower seed density classes⁹.

Cold germination test on the seventh day revealed significant differences between genotypes, the mean values of ‘Celia’ and ‘Sonia’ being higher than that of ‘Crema’ (Fig. 2). On the twentieth day after the beginning of the experiment (cold test) no significant differences were found between genotypes, and the germination percentages of all the genotypes included in the interval were between 75 and 86% (Fig. 2). Cold test results of commercial seed obtained by other author’s (52-73%)⁹ were very similar to our results obtained with ‘Carmen’, ‘Flora’, ‘Lacta’ and ‘Sonia’. On the contrary, in the present study, cold germination results of ‘Crema’ (30.6%) and ‘Celia’ (77.8%) were lower and higher than their lower and upper limits, respectively. The TAMU rapid germination test for cottonseed used in ‘Acala SJ-1’ and ‘Stoneville 213’ cultivars resulted in higher germination rates than those attained in both temperatures tested here¹⁷. In fact, TAMU test generally produces higher results than the standard germination test¹. In the cool test no significant differences were found in the germination percentages between the two standard counting days (7 and 20) for each genotype, although the absolute differences were detected, for instance, differences greater than 20 and 40% in ‘Carmen’ and ‘Crema’, respectively (Fig. 2).

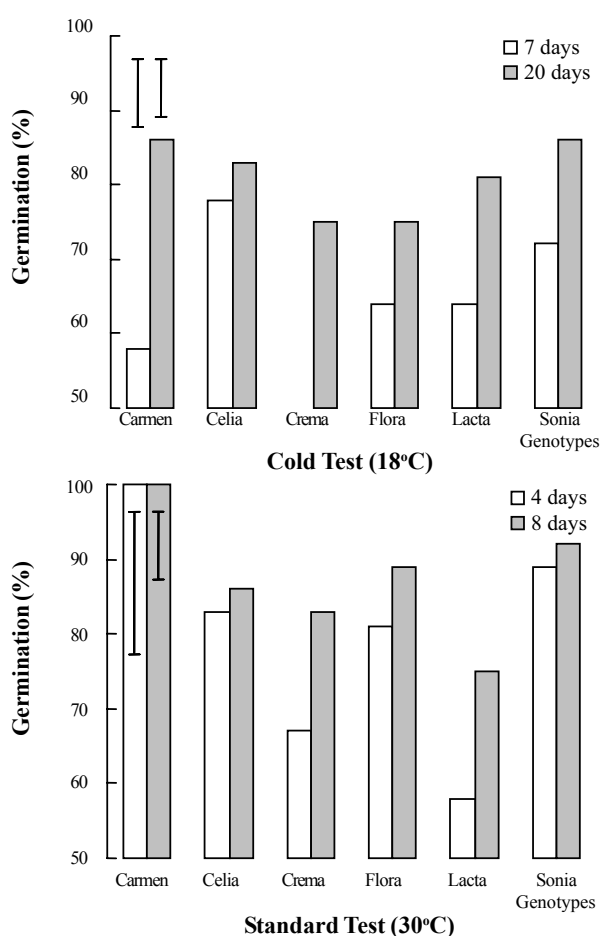


Figure 2. Seed germination (%) under standard (after 4 and 8 days at 30°C) and cold (after 7 and 20 days at 18°C) germination tests of 6 upland cotton genotypes (2002 and 2003 seed lots). Vertical bars represent standard error of the means (n=36).

The different results obtained at 30°C (4 days) and 18°C (7 days) in the present study stand out three main behavior tendencies (0.05<P<0.10) induced by lowering germination temperature: the worsened performances of ‘Carmen’ and ‘Crema’ (-41.6 and -36.1%), intermediate behavior of ‘Flora’ and ‘Sonia’ (-17%) and an inverted behavior of ‘Lacta’ (+5%), which signifies for this genotype a greater impact of available time for seed germination than the respective temperature conditions. The two former genotypes are apparently the most sensitive in response to changing of the time to temperature constraint factor.

Commercial classification of the seed vigor index in the present study varied from the extremes of *excellent* (‘Celia’ and ‘Sonia’, >160) and *poor* (‘Crema’, <120), with *fair* (‘Lacta’, >120 and <140) and *good* (‘Carmen’ and ‘Flora’, >140 and <160) in the mean terms (Table 2). Accordingly with these results, qualities of ‘Crema’ and ‘Lacta’ seeds (seed vigor index lower than 140) will not advice their use under the mean spring weather conditions of south Portugal. Inclusively, cold test germination result of ‘Crema’ (30.6%) is below the inferior limit of 50% recommended by some authors as the minimum percentage yet adequate for sowing at lower temperature sites⁵.

Table 2. Vigor index, seed lots classification and seed index of 6 upland cotton genotypes.

Parameter	Genotype						SE ¹
	Carmen	Celia	Crema	Flora	Lacta	Sonia	
Seed vigor index	158a ²	161a	97b	144a	122ab	161a	12.62
classification	Good	Excellent	Poor	Good	Fair	Excellent	-
Seed index (g)	10.09d	11.13a	9.82e	10.31c	9.08f	10.45b	0.04

¹ SE, standard error of the means. ² Means with the same letter in a line are not significantly different by the Tukey test (P<0.05).

In spite of the relatively small differences in absolute values between genotypes, seed index results were significantly different, varying from 9.08 g (‘Lacta’) to 11.13 g (‘Celia’) (Table 2). Probably the smallest unit leaf area of the okra genotypes is extensible to the cotyledonal leaves, resulting in lighter seeds observed in ‘Lacta’. In spite of the poor linear regression R² between seed weight and seed vigor index, calculated regression coefficient was significant at 5% level, showing a positive correlation between seed index and seed germination speed and ability to germinate under cold temperatures^{9,10} (Fig. 3).

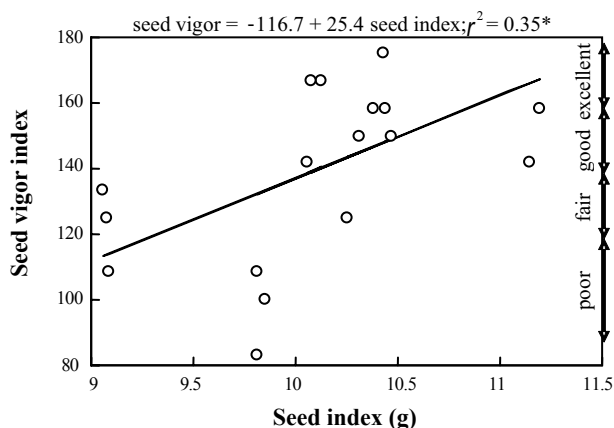


Figure 3. Observed values and fitted linear regression between seed index (g) and seed vigor index of 6 upland cotton genotypes.

In fact, the two cultivars with highest seed index ('Celia' and 'Sonia') were the ones that reached the highest seed vigor index (*excellent*). On the opposite, the two genotypes with lowest seed index ('Crema' and 'Lacta') were the ones that reached the lowest seed vigor indices (*poor* and *fair*). The linear regression shown in Fig. 3 states that for each 0.1 g increment of seed index the correspondent seed vigor index increased about 2.5%.

Field emergence: Emergence results of the field trials differed during experimental years (Table 3), probably being induced by different soil temperatures per annum (Fig. 1). In 2003, when sowing date was one month earlier than in 2002, seeds experienced lower soil temperatures during all the emergence period, inclusively below the t_0 of 15.5°C rule-of-thumb minimum temperature¹⁸. The consequences of the relatively adverse environmental conditions, added to the observed 2-3 cm thick soil crust, become evident at two levels: the duration of the emergence period and the number of emerged seedlings. In fact, in 2003 planting-emergence period lasted as much as 25 days, while in 2002 the same phase lasted only 10 days. Those planting-emergence durations can be classified as *unacceptable* and *excellent*, in 2003 and in 2002, respectively¹⁹.

Table 3. Seedling emergence (seedlings m⁻²) of 6 upland cotton genotypes.

Genotype	Year		Mean
	2002	2003	
Carmen	10.8a ¹	7.3ab	9.1A
Celia	11.0a	6.7b	8.9A
Crema	10.2a	7.2ab	8.7A
Flora	11.3a	9.8a	10.6A
Lacta	11.7a	8.1ab	9.9A
Sonia	11.3a	8.8ab	10.1A
Mean	11.1A	8.0B	9.5
SE ²	1.32	0.90	0.80

¹ Means with the same letter in a column are not significantly different by the Tukey test (P<0.05). ² SE, standard error of the means.

On the other hand, the number of emerged seedlings in 2002 was 39% larger than that registered in 2003, accordingly with the general postulate that the best emergences occur in years of higher soil temperatures^{20,21}. Emerged seedling data revealed a seeding lost of 38% in 2002 and 56% in 2003, with a two-year mean lost of 47%. In general, seedling survival is inversely related with sowing-emergence duration period²². Sowing-emergence lost results (23-41%) with the higher seed vigor index lots⁷ were very similar to the lost data registered in this study in 2002, while the higher lost observed by those authors (61-72%), obtained with lots of poor seed vigor index, were higher than those observed by us, in both years.

Genotypes responded differently to the low temperatures in 2003, with 'Flora' showing a smaller negative impact on emergence than 'Celia', while no differences were accounted between genotypes in the year of best soil temperatures and on the two-year joint analysis (Table 3). In a strange way, the worst emergence results were verified on 'Celia' in 2003, precisely the genotype that has the highest seed vigor index and seed weight (Table 2). Although no significant correlations (Pearson's R) were found between plant emergence and seed vigor index (P = 0.060) or seed index (P = 0.631) pooled data, it seems that seed vigor index is better

related with field emergence performance than seed weight. In fact, of the two seed vigor index components, standard test result fits better to the field emergence (P = 0.035), although explaining very poorly the emergence variability observed (R² = 0.249) (Fig. 4).

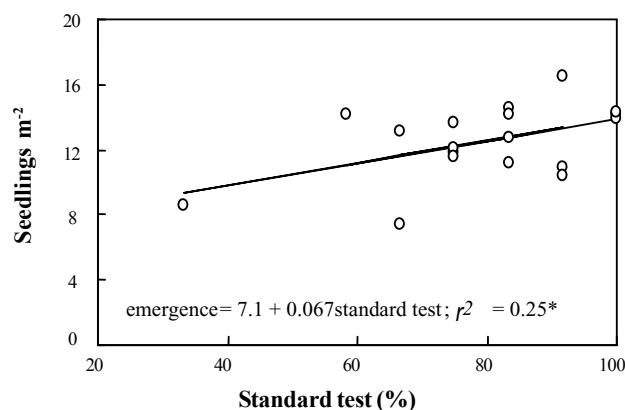


Figure 4. Observed values and fitted linear regression between standard test (%) and field emergence (seedlings m⁻²) of 6 upland cotton genotypes.

Cotyledons: After emergence, and even 60 days after sowing, seed leaves were fully expanded with a dark green, healthy appearance. No chlorosis patches or any other visible senescence signs were detected as late as 50 days after emergence, pointing a longer seedling stage than was registered by other authors who detected chlorosis and senescence symptoms early, 35-45 days after emergence¹¹.

The results of the mean area per cotyledon show differences between genotypes, this parameter being significantly greater in 'Sonia' than in 'Carmen' and 'Lacta' (Table 4). Also values in 'Flora' and 'Crema' were greater than in 'Lacta'. The lowest mean area per cotyledon observed in 'Lacta' is consistent with okra leaf type, confirming the above seed index observations that true leaf morphological characteristic is extendable to the seed leaves. However, no significant relations were found between the area per cotyledon and seed vigor or field emergence results. Only the lower 'Lacta' seed index (Table 2) is consistent with the lower cotyledon area observed in this genotype, result expected once more than 60% of seed weight proportion is accounted by cotyledons²³. Thus, the lower seed reserves available in 'Lacta' seeds, mainly represented by cotyledon tissues, could have been the major constraint to seed germination at favorable temperatures (Fig. 2) and on seed vigor evaluation in its whole (Table 2). However, this apparently intrinsic shortness of energy supply to seed germination didn't have significant negative consequences on emergence performance under field conditions (Table 3), in which other constraints than temperature exerts their negative effects on seedling emergence and growth.

The overall mean area per cotyledon observed in this work (7.3 cm² cotyledon⁻¹, Table 4) is lower than those observed by Lane and Hesketh¹¹ (10.5 to 12.5 cm²) at a constant temperature of 28°C and by Longer and Oosterhuis¹³ (14.4 cm²) in a growth chamber (30/25°C day/night temperature and 12 hours of light).

Differences were found between genotypes and week of harvest in the ratio of cotyledonal area/total leaf area (Table 5). It is important to underline the high values of this ratio at 49 days after

sowing (about 30-39 days after emergence), which are higher than 40% for all genotypes (near 50% in 'Crema'), except 'Lacta', the okra leaf genotype. The genotype average for the whole harvests was significantly higher in 'Crema' (22%) than in 'Lacta' (18.2%). Ratios of 95, 70, 45 and 30% at 12-14, 18, 22 and 24-28 days after sowing were observed in 'Pima' cotton²⁴. However, the faster reduction of the cotyledonal proportion observed in that study was obtained in a growth chamber (30/25°C day/night temperature and 15 hours of light), with quite better conditions to cotton epicotyl growth and development than those in our open field experiment. As expected, the mean decrease of the cotyledonal area proportion was significantly different between the 5 sampled weeks, greater decreases (12-16 percentile points per week) being evident at younger stages and smaller ones at latter stages (2-7 percentile points per week), on behalf the increased area of main stem leaves (Table 5).

Table 4. Mean area per cotyledon of 6 upland cotton genotypes (cm²) (each value represents 2 years and 5 harvests means).

Genotype	Mean
Carmen	6.9 bc ¹
Celia	7.2 abc
Crema	7.3 ab
Flora	8.0 ab
Lacta	6.1 c
Sonia	8.3 a
Mean	7.3
SE ²	0.500

¹ Means with the same letter in a column are not significantly different by the Tukey test (P<0.05). ² SE, standard error of the means.

Table 5. Cotyledonal area/total leaf area ratio of 6 upland cotton genotypes at 5 harvest times.

Genotype	Days after sowing				
	49	56	63	70	77
	%				
Carmen	42ab ¹	25a	16a	6c	4a
Celia	46ab	29a	13a	10ab	5a
Crema	49a	30a	16a	7abc	8a
Flora	40ab	24a	18a	11a	7a
Lacta	38b	30a	12a	6bc	5a
Sonia	46ab	27a	14a	7abc	6a
Mean	43A	27B	15C	8D	6E
SE ²	8.0	5.6	3.8	2.2	2.4

¹ Means with the same letter in a column are not significantly different by the Tukey test (P<0.05). ² SE, standard error of the means.

In the contrary of that occurred with both previous parameters, the ratio of cotyledonal dry weight/total dry weight showed no differences between genotypes, resembling a conservative specific characteristic. As expected, the fitted values in a weight basis ratio (Fig. 5) at all the harvest weeks were lower than the observed values for the area basis ratio (Table 5), once this one considers no structural tissues, like petioles and stems. Anyway, the results of these ratios, on weight and area basis, confirm that the cotton plant stays in seedling stage for a relatively long period²⁵. During this long period, cotyledonal activity is decisive for the survival and initial growth of the cotton plants, which develop new epicotyls-borne forms very slowly.

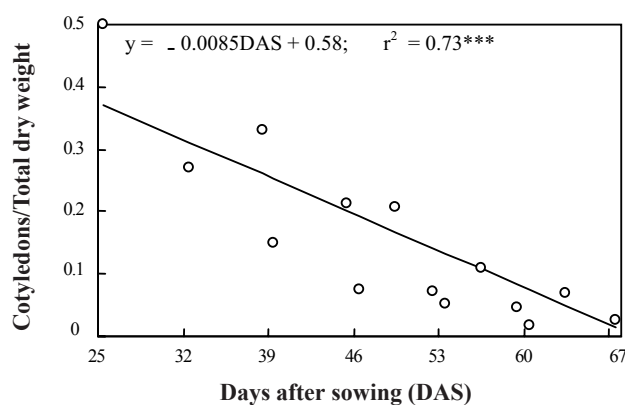


Figure 5. Observed values and fitted linear regression between days after sowing and cotyledons dry weight/total plant dry weight ratio of 6 upland cotton genotypes.

Conclusions

In spite of the reliability of the seed vigor index and seed index as good assessments of seed germination and emergence we have verified that this inference is not directly extendable to field emergence performance^{7,9,10} at least for crusting soils and low soil temperatures⁴. However, we find smooth positive relations between seed index and seed vigor index, and between standard test and field emergence. Anyway, field conditions include other stress effects over seeds than exclusively temperature. Physical impedance and sowing depth and aeration among many other factors have already been stated by many authors as decisive to the emergence duration and field establishment of the cotton crop. It seems that the responses to those other constraints to field emergence can be genetically variable, and can overlap or confound the expected positive impact of seed weight and seed vigor index on field emergence performance. Under Alentejo field conditions, seed leaves remain persistent and apparently healthy during a long initial period, representing high plant proportions, in both area and dry weight basis, until more than 60 days after sowing. Further investigation is needed, in these and other locations, in order to study the relations between emergence duration, seedling survival, plant growth and fiber production in upland cotton grown on South Iberian Peninsula.

References

- ¹Delouche, J.C. 1986. Harvest and post-harvest factors affecting the quality of cotton planting seed and seed quality evaluation. In Mauney, J.R. and Stewart, J.M. (eds). Cotton Physiology. The Cotton Foundation Reference Books 1. Cotton Foundation, Memphis, pp. 483-518.
- ²Christiansen, M.N. and Rowland, R. 1986. Germination and stand establishment. In Mauney, J.R. and Stewart, J.M. (eds). Cotton Physiology. The Cotton Foundation Reference Books 1. Cotton Foundation, Memphis, pp. 535-541.
- ³Wanjura, D.F. and Buxton, D.R. 1972. Hypocotyl and radicle elongation of cotton as affected by soil environment. Agron. J. **64**:431-434.
- ⁴Anderson, W.K. 1971. Responses of five cotton varieties to two field soil temperature regimes at emergence. Cott. Gr. Rev. **48**:42-50.
- ⁵Smith, C.W. and Varvil, J.J. 1984. Standard and cool germination tests compared with field emergence in upland cotton. Agron. J. **76**:587-589.
- ⁶Gregory, J., Hopper, N. and Jividen, G. 1986. Evaluation of several laboratory tests for determining cottonseed quality. Proceedings of the Beltwide Cotton Production Research Conference, National Cotton Council of America, Memphis, pp. 62-63.

- ⁷Wheeler, T.A., Gannaway, J.R., Kaufman, H.W., Dever, J.K., Mertley, J.C. and Keeling, J.W. 1997. Influence of tillage, seed quality, and fungicide seed treatments on cotton emergence and yield. *J. Prod. Agr.* **10**:394-400.
- ⁸Hely, T. 2001. Plant establishment. The first important step for high yield. *DeltaBriefs* **5**(1):3-4.
- ⁹Hofmann, W.C., Kittock, D.L. and Alemayehu, M. 1988. Planting seed density in relation to cotton emergence and yield. *Agron. J.* **80**:834-836.
- ¹⁰Liu, X.L., Yuan, J., Zhang, D., Hao, X.R. and Fan, L.Q. 1994. Effect of seed size on cotton emergence and yield. *China Cottons* **21**(7):16.
- ¹¹Lane, H.C. and Hesketh, J.D. 1977. Cotyledon photosynthesis during seedling growth of cotton, *Gossypium hirsutum* L.. *Amer. J. Bot.* **64**(6):786-790.
- ¹²Purvis, A.C. and Fites, R.C. 1979. Changes in enzyme levels of EMP and pentose phosphate pathways during germination of cotton seed. *Bot. Gaz.* **140**(2):121-126.
- ¹³Longer, D.E. and Oosterhuis, D.M. 1999. Cotton regrowth and recovery from early season leaf loss. *Environ. Exp. Bot.* **41**:67-73.
- ¹⁴Association of Official Seed Analysts 1976. Progress report on seed vigor testing handbook. *AOSA News Letter* **50**:1-78.
- ¹⁵Association of Official Seed Analysts 1983. Seed vigor testing handbook. Contribution **32**:10-11.
- ¹⁶Barradas, G. 2004. Adaptation of 6 Cultivars of *Gossypium hirsutum* L. to the Caia Irrigated Perimeter. Growth Analysis, Yield and Fiber Quality. (In Portuguese, with English abstract). PhD diss., Extremadura University, Badajoz, Spain.
- ¹⁷Powell, R.D. and Morgan, P.W. 1973. A test system for the germination of cotton seed. *Cott. Gr. Rev.* **50**:268-273.
- ¹⁸Gipson, J.R. 1986. Temperature effects on growth, development, and fiber properties. In Mauney, J.R. and Stewart, J.M. (eds). *Cotton Physiology. The Cotton Foundation Reference Books 1. Cotton Foundation, Memphis*, pp. 47-56.
- ¹⁹Kerby, T.A. 1988. Planting When Yield be Highest. University of California Cooperative Extension. *California Cotton Review. Vol. 2.*
- ²⁰Kerby, T.A., Hake, S.J., Hake, K.D., Carter, L.M. and Garber, R.H. 1996. Seed quality and planting environment. In Hake, S. J. *et al.* (eds). *Cotton Production Manual. Publication 3352, Division of Agriculture and Natural Resources, University of California*, pp. 203-209.
- ²¹López-Bellido, L. 2003. Cotton. *Industrial Crops. Mundi-Prensa, Madrid*, pp. 243-436. (In Spanish).
- ²²Wanjura, D.F., Hudspeth, E.B. and Bilbro, J.D. 1969. Emergence time, seed quality, and planting depth effects on yield and survival of cotton (*Gossypium hirsutum* L.). *Agron. J.* **61**:63-65.
- ²³Hopper, N.W. and McDaniel, R.G. 1999. The cotton seed. In Smith, C.W. and Cothren, J.T. (eds). *Cotton. Origin, History, Technology and Production. Wiley Series in Crop Science, John Wiley & Sons, Inc., New York*, pp. 289-317.
- ²⁴Elkinawy, M. 1984. Hormonal changes associated with leaf senescence in cotton (*Gossypium barbadense*). *Physiol. Plant.* **62**:593-598.
- ²⁵Mauney, J.R. 1984. Anatomy and morphology of cultivated cottons. In Kohel, R.J. and Lewis, C.F. (eds). *Agronomy Monograph 24. ASA-CSSA-SSSA, Madison*, pp. 59-80.
- ²⁶Richmond, T.R. and Radwan, S.R.H. 1962. A comparative study of seven methods of measuring earliness of crop maturity in cotton. *Crop Sci.* **2**:397-400.