The *Journal of Cotton Science 15:11–21 (2011)*
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BREEDING AND GENETICS

Evaluation of Cotton Genotypes for Ginning Energy and Ginning Rate

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ABSTRACT

Reducing ginning energy use through cultivar improvement could reduce ginning and energy cost. The objective of this study was to detect genetic variability for ginning energy and ginning rate. Thirty-four conventional and 12 transgenic genotypes were evaluated in 2008 and 2009 for ginning energy requirements and ginning time rate. The experiments were conducted at two sites near Stoneville, Mississippi. Field plots were one row 12.2 m in length and 1.0 m between rows. Ginning efficiency was based on measurements of ginning energy (Wh kg^{-1} lint) and ginning rate (g lint s^{-1}). The mean square values for genotypes were significant for gross ginning energy, net ginning energy, ginning rate, and all other traits studied. The two genotypes with least ginning energy were 'AR 9317-26' and 'Yugo 8' with average ginning energy of 7.5 and 7.9 Wh kg^{-1} lint, respectively. The fastest ginners were 'MD 25' and 'FiberMax 960 B2R' with 3.35 and 3.32 g s^{-1} lint, respectively. Fuzz percent, fiber strength, fiber length, neps, and fineness were highly correlated with ginning energy. Fuzz percent, fibers seed^{-1}, lint percent, boll weight, and neps were highly correlated with ginning rate. The correlations of fuzz percent with ginning energy, r = 0.62, and ginning rate, r = -0.40, appear to be useful tools in improving overall ginning efficiency.

In the history of cotton breeding, improving ginning efficiency was an early target. Ware (1951) suggested the utilization of a black seeded (genotypes where the lint grows free of the seed) *Gossypium hirsutum* L. prior to 1800. One key factor for reducing energy and increasing overall ginning efficiency is to decrease the time required to gin a bale. Gins, today, are looking for every opportunity to improve the bottom line by increasing capacity and efficiency while preserving fiber quality (Valco and Ashley, 2008). Generally, cotton genotypes with low attachment strengths should require less force to pull the fiber from the seed. The resulting separation should require less energy and be faster than cotton with a high strength attachment. Genotypes with high attachment strength tend to reduce gin productivity by increasing power requirements, slowing the system and increasing fiber damage as measured by short fiber content (SFC) and neps. Fiber breakage during ginning could be minimized if the fiber-seed attachment strength were significantly reduced. (Boykin, 2007; Fransen et al., 1984; Griffin, 1984; Porter and Wahba, 1999).

One way to reduce unwanted fiber breakage would be to select cotton genotypes with strong fibers loosely attached to the seed. Smith and Pearson (1941) showed fiber-to-seed attachment strength (or fibers/seed separation force) on any given area of any particular seed varied from about 0.25 g to about 5.5 g. Lyengar (1954) recorded the respective attachment strengths of *G. barbadense* L., *G. hirsutum*, *G. herbaceum*, *G. arboreum* L. at 0.26, 0.41, 0.76, and 0.98 g/fiber, respectively. Chapman (1969) found that Pima S-2 (PI 529162) cotton had a lower fiber-to-seed attachment strength than Pima S-1 cotton and ginned 33 % faster. He pointed out that relatively low fiber-seed tenacity was significantly related to desirable ginning performance, such as greater ginning capacity and greater lint turnout, and to desirable seed and fiber qualities, such as fewer cottonseed linters, higher micronaire readings, fewer neps, and fewer short fibers in the ginned lint. Griffin (1984) indicated that separation force of individual fibers for less fuzzy seeds was 17% lower than the fuzzy control and ginned 23% faster. He further pointed out that the energy required to gin a bale (500 lb lint) was significantly lower for the semi-naked seed strain resulting in 31% energy reduction for fiber seed separation. Bechere et al. (2009) reported that two semi-naked–tufted cotton lines developed through chemical mutagenesis required less energy to gin when compared to the fuzzy genotype, 'FiberMax 958' (PVP 200100208).

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Various researchers have reported genetic differences in fiber attachment and the potential of these genotypes in reducing ginning costs (Table 1). Usually these studies have involved a small number of genotypes that were not diverse and grown in few environments. Often, the various studies gave different conclusions as to what traits contributed to the improved ginning efficiency. More recently, Boykin (2007) showed that differences in gin stand energy for cotton genotypes was likely related to the fiber-seed bond strength. He identified several cotton genotypes with substantially lower energy requirements to gin. These genotypes presumably ginned more gently with less stress on the fiber and less damage. He reported that changes in ginning energy were found to correlate with changes in seed linter content, ginning rate, seed percent, and turnout. Genotypes that used less energy during ginning tended to have higher High Volume Instrument (HVI) fiber strength. Anthony and Griffin (2001) found that individual fiber breakage force equaled 1.8 times the fiber separation force. Based on this result, they concluded the inherent structure of the cotton fiber is such that the ginning process should remove all fibers from seeds without breakage.

Most of the cottons used in this test are under commercial production, obsolete, or new genotypes that have never been under production (Table 2). The transfer of these low fiber-to-seed strength of attachment to conventional cottons would be beneficial to ginners. Ginning efficiency is improved by increasing the ginning rate and/or reducing ginning energy. The rate of ginning might be increased and the energy required for ginning reduced through breeding for low fiber-seed tenacity. The objectives of this research were to evaluate genetic variability for ginning rate and ginning energy requirement among 46 diverse cotton genotypes and correlate ginning traits with 15 other yield component and fiber traits.

Table 1. Some earlier reports on genotype differences in fiber-seed attachment forces and ginning efficiency.

Authors	No. of Genotypes Tested	No. of Environments Used
Griffin, J.C., Jr., 1984	5	1
Anthony, W.S., and R.R. Bridge, 1986	20	1
Anthony, W.S., et al., 1988	5	2
Anthony, W.S. 1989	20	2
Anthony, W.S., and S. Calhoun, 1996	51	2
Anthony, W.S., and S. Calhoun, 1997	49	2
Porter, M.A, and F.T. Wahba, 1999	10	2
Boykin, J.C., 2007	65	2

Table 2. List of 46 diverse cotton genotypes evaluated for ginning efficiency in 2008 and 2009.

Transgenics	Conventional	Strains and Germplasm	Backcross Families	Semi-naked seeds
Deltapine 33B(08)	Acala 1517-99 (08)	AR 9608-08-03 (09)	Deltapine 16 (08, 09)[z]	AR 9317-26 (08, 09)
Deltapine 444BR (08, 09)	Phytogen 72 (08, 09)	DES 119H2 (08)	Deltapine 16 Hairy (09)	Tejas NS (09)
Deltapine 458BR (08)	Sure Grow 747 (08, 09)	JJ1145ne (08,09)	Stoneville 213 (08, 09)[z]	SC 9023 NS (09)
Deltapine 555BR (08, 09)	Stoneville 474 (09)	MD 15 (08, 09)	Stoneville 213 T2 (09)	Yugo 8 (08)
FiberMax 840B2R (08)	Deltapine 50 (08)	MD 51ne Okra (08)	Stoneville 213 t3 (09)	Yugo 216 (08)
FiberMax 960B2R (08, 09)	Deltapine 5415 (08)	TAMcot 98-99ne (08,09)	FiberMax 832 (08, 09)	AR 9317-31 (08, 09)
Phytogen 485WRF (08)	Coker 413 (09)	MD 9-1-1-2 (09)	FiberMax 800 B2RF (08)[y]	
Paymaster 1218BR (08, 09)		MD 25 (09)	DP 90ne (08, 09)[x]	
Paymaster 2167R (08)		TAMcot 182-34 ELS (09)	MD 52ne (08, 09)[x]	
Stoneville 4554B2RF (08, 09)		Deltapine 4-910 (09)		
Stoneville 4892BR (08)		Pee Dee 2-164 (09)		
Stoneville 5599BR (08, 09)		C-6-5 (09)		

Numbers in bracket indicate year(s) genotypes were evaluated.

[z] Deltapine 16 and Stoneville 213 are obsolete genotypes.

[y] FiberMax 800B2RF is a transgenic genotype.

[x] DP 90ne and MD 52ne are near isogenic germplasms.

MATERIALS AND METHODS

Forty-six conventional and transgenic genotypes were planted at two locations each in Stoneville, MS during 2008 and 2009. The two locations differed in soil types. One location had Boskit fine sandy loam, whereas the second location was coarse-loamy, mixed, and fine loam. Genotypes were selected based on earlier observations of ginability, lint yield, and fiber quality. Ginability, in the context of this paper, takes into account the rate and energy of ginning required by a genotype. At the end of the 2008 season, some genotypes were dropped because of their poor performance in ginability and new genotypes were added to the test. Genotypes common between the two years are noted in Table 2. Fourteen genotypes were evaluated only in 2008, 14 only in 2009 and 18 in both 2008 and 2009. The materials were planted in 12.2-m single rows in a randomized complete block design with 1.0 m between rows in two replications in 2008 and four replications in 2009. Planting in 2008 was carried out on 16 May at both locations, and 24 April at one location and 21 April at another in 2009. Planting in 2008 was delayed because of continuous rain during planting time. One hundred thirty-four kg/ha of K_2O and 112 kg/ha of nitrogen were applied at all locations each year. Herbicides, fungicides and insecticides were applied on an as needed basis each year. GINSTAR (Thidiazuron and Diuron) (Bayer CropScience, NC) at the rate of 0.63 kg/ha and SUPER BOLL (Ethephon) (DuPont, DE) at the rate of 1.54 kg/ha were applied as defoliants in both 2008 and 2009.

Fifty randomly selected bolls were hand-picked from each entry. Boykin (2008) reported that a small sample method is a practical tool to predict cultivar differences in gin turnout and most fiber properties. Boykin et al. (2010) also indicated that lab gins offer an effective, convenient screening tool for cotton researchers predicting fiber quality in commercial gins though results for ginning energy and rate were not reported. Data on ginning energy requirements, rate of ginning, HVI and Advanced Fiber Information System (AFIS) fiber quality, fuzz percent, lint percent, fiber seed^{-1}, and boll weight were collected. Ginning efficient genotypes, in the context of this paper, refers to genotypes that gin faster or require less energy to gin.

Ginning energy might be significantly affected by factors such as lint moisture content, seed moisture content, ambient temperature and relative humidity (Anthony, 1989). Attempts were therefore made to standardize these before and during testing. The cotton samples were stored for at least 3 d to equilibrate the moisture content before ginning. Seedcotton was weighed before ginning and the lint was weighed after ginning to determine the lint percent. Fuzz percent was calculated by weighing the fuzzy seed, delinting the sample, and re-weighing the delinted seed. The difference in weight was divided by the weight of the fuzzy seed and multiplied by 100 to give the fuzz percent. HVI quality analyses generated data on micronaire, fiber strength, and fiber length, and AFIS quality analyses generated data on SFC, nep size, nep count, seed coat nep (SCN), fineness and maturity ratio. HVI was performed by the STARLAB INC, at Knoxville, TN, and AFIS analyses were performed at the USDA Crop Genetics Research Unit at Stoneville, MS. The number of fibers per seed was calculated using the relationship: fiber per seed = (Li*10)/ (stdfine/ (1,000,000/Lw)) where Li = Lint index; stdfine (standard fineness) = fineness/maturity ratio; and Lw = Length by weight. (Bourland and Bird, 1983). Lint index is the weight, in grams, of lint from 100 seeds. Fiber bundle strength ($kNmkg^{-1}$) was measured by stelometer as the force required for breaking a bundle of fibers. Micronaire was measured in micronaire units. Fibers were also analyzed for mean SFC and fineness using AFIS (Uster AFIS, 1977). SFC was measured as the percentage by weight of the fibers that were less than 12.7 mm. Fineness was measured as the weight per unit of length ($mg\ km^{-1}$) where smaller values indicate higher degree of fineness.

The cotton was ginned on a 10-saw laboratory gin stand (Continental Eagle, Prattville, AL) to evaluate ginning energy requirements and ginning rate. Power consumed by the gin stand was measured and recorded with a Yokogawa power meter (Yokogawa Corp. America, Newnan, GA). Ginning efficiency was based on measurements of ginning energy ($Wh\ kg^{-1}$ lint) and ginning rate ($g\ lint\ s^{-1}$). Total ginning energy has two components (idle and net), each of which might respond differently to seed lines. Total ginning energy is the power consumption of the gin stand integrated over the time required to gin. Idle energy is the power consumption of the gin stand without the presence of cotton integrated over the time, and net energy is the difference in the total and idle energy.

The 46 genotypes in the test were grouped into four categories based on their ginning energy requirements and speed of ginning: low energy and fast ginners, high energy and fast ginners, low energy and slow ginners, and high energy and slow ginners. These classifications were based on deviations from the mean of the population. For net energy, all cultivars with values lower than the population mean are considered to require “low” ginning energy and cultivars having higher ginning rates than the population mean are classified as “fast ginners”. This type of grouping can assist breeders to identify genotypes for inclusion in their program for the improvement of ginning efficiency.

Statistical analyses of all properties associated with genotypes were performed using Proc GLM (SAS, 2004). The model included the fixed effects year, location within year, rep within location and year, genotype, genotype x year, and genotype x location within year. Year had 1 degree of freedom (df) because there were 2 yr (Tables 3 and 4). Location within year had 2 df as locations were different each year (1 df per year). Rep within location and year had 2 df per location in each year for a total of 8. Genotypes had 45 df, but genotype x year only had 17 df as only 18 cultivars were common between years. Genotype x location within year had 31 df per year for a total of 62. Resulting mean squares were reported in Tables 3 and 4 to show strengths of statistical differences for each variable. To generate least square means for genotype properties averaged over years and location (Table 5), Proc MIXED (SAS, 2004) was used with the same effects listed for the previous model, except that rep within location and year, genotype x year, and genotype x location within year were included as random effects instead of fixed effects thus averaging across this variability. The purpose for using the mixed model was to change some of the fixed effects to random effects to generate least square means for genotype from an unbalanced data set (not all genotypes were included in both years). Because year and location within year were fixed effects, least square means were averaged across these effects. This allowed for simple Pearson correlations between properties associated with genotypes to be generated across years. Correlations of traits using all the 46 genotypes and 41 genotypes, (excluding the semi-naked seed genotypes) were calculated separately to check for the effects of the semi-naked seed trait (Table 7).

RESULTS AND DISCUSSION

Significant differences among the tested genotypes were observed for gross ginning energy, net ginning energy, ginning rate, fuzz percent, fiber seed^{-1}, lint percent, and boll weight (Table 3). HVI (strength, length, and micronaire) and AFIS (nep size, SCN, SFC, fineness, and maturity ratio) also were significantly different among the tested genotypes (Table 4). It appears that genotype effects for all traits are much larger than genotype x environment effects. These large genotype variance components are encouraging because the population of 46 entries had little previous evaluations. These larger effects of the genotypic effects over the genotype x environment effects also indicate that selection for the traits under consideration probably will be effective in relatively few environments. The relatively small genotype x environment effects validated the grouping of all cultivars from both years and fields for subsequent analysis of genotypic variations as well as correlations between traits.

Gross Ginning Energy, Net Ginning Energy, and Ginning Rate. Ginning rates ranged from 2.37 (‘YUGO 216’) to 3.35 (MD 25) g lint s^{-1} (a 29% increase). Net ginning energy ranged from 7.5 (AR 9317-26) to 12.00 (‘TAM 182-34-ELS’) Wh kg^{-1} lint (Table 5, Figure 1). Griffin (1984), Anthony (1989), and Boykin (2007) also reported 31%, 30%, and 30%, differences in ginning energy, respectively, between the genotypes they tested.

Table 3. Mean square values for gross ginning energy, net ginning energy, ginning rate, and other physical parameters for 46 genotypes grown in four environments during 2008 and 2009 at Stoneville, MS.

Source of Variation	df	Gross Ginning Energy (Wh kg^{-1} lint)	Net Ginning Energy (Wh kg^{-1} lint)	Ginning Rate (g lint s^{-1})	Lint %	Fuzz %	Fibers seed^{-1}	Boll weight (g)
Year	1	418.8**	155.5**	4.85**	1.07 x 10^{-3}**	48.87**	9.3 3x 10^{6} **	27.55**
Location (Year)	2	973.8**	14.5**	3.42**	2.08 x 10^{-4}*	9.14**	2.12 x 10^{6} **	0.86**
Rep (Year*Location)	8	222.9**	0.3**	0.57**	2.98 x 10^{-4}**	5.21**	3.67 x 10^{5}	0.18*
Genotype	45	105.9**	5.7**	0.44**	4.63 x 10^{-3}**	40.0**	1.38 x 10^{7} **	1.01**
Genotype*Year	17	22.7*	0.1	0.10**	2.02 x 10^{-4}**	1.25	1.17 x 10^{6} **	0.44**
Genotype*Location(Year)	62	15.1	0.1	0.05	1.31 x 10^{-4}**	1.21	5.14 x 10^{5} **	0.07
Error	248	11.8	0.1	0.04	5.94 x 10^{-5}	1.02	2.61 x 10^{5}	0.07

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level

Table 4. Mean square values for HVI and AFIS quality for 46 genotypes grown in four environments during 2008 and 2009 at Stoneville, MS.

Source of Variation	df	Strength (cN tex^{-1})	Length (mm)	Micronaire	Nep_um^z	SCNcnt^y	SFCw^x	Fine^w (millitex)	Maturity Ratio^v
Year	1	0.29	2.60 x 10^{-3}*	7.23**	2780.59**	196.02**	177.23**	7837.04**	9.60 x 10^{-2}**
Location (Year)	2	9.57**	5.37 10^{-3}**	3.35**	2163.57**	2.26	1.01	1071.92**	2.08 x 10^{-3}**
Rep (Year*Location)	8	6.15**	1.16 x 10^{-3}**	0.15**	354.70	4.03	1.05	32.94*	6.74 x 10^{-4}**
Genotype	45	40.4**	2.38 x 10^{-2}**	0.85**	928.34**	6.71**	7.69**	446.14**	3.23 x 10^{-3}*
Genotype*Year	17	2.25	6.92 x 10^{-4}	0.22**	404.55	3.63	1.37**	48.68**	2.95 x 10^{-4}*
Genotype*Location(Year)	62	1.37	7.86 x 10^{-4}	0.08*	383.92	2.56	0.58	43.63**	2.52 x $10^{-4\,8}$
Error	248	1.60	6.09 x 10^{-4}	0.06	412.08	2.85	0.52	15.15	1.69 x 10^{-4}

*** Significant at the 0.05 probability level.**

****Significant at the 0.01 probability level.**

z Nep = A small knot of entangled fibers that will not straighten to a parallel position during processing. Nep-um = Nep size.

y SCN = Seed coat fragments that remain in the lint after ginning.

x SFC = Short fiber content. Percent of fibers shorter than ½ in.

w Fine = fineness, a relative measure of size, diameter, linear density or weight per unit length.

v MR= maturity ratio, the degree of cotton fiber wall development relative to the diameter of the fiber.

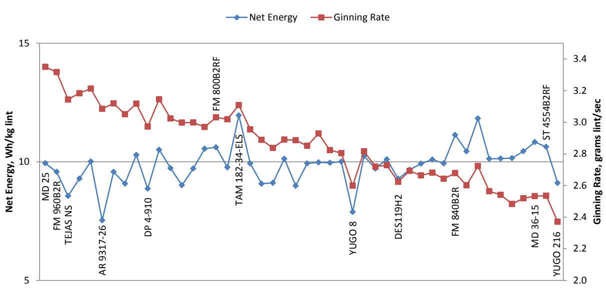

Figure 1. Gross ginning energy, net ginning energy, and ginning rate data for the 46 genotypes grown in the ginning efficiency test at Stoneville during 2008 and 2009.

Relationships between gross ginning energy, net ginning energy, and ginning rate are illustrated in Figure 2. As gross ginning energy increased, net ginning energy increased and ginning rate decreased. The semi-naked seed group is shown to have lower net ginning energy and ginning rates when compared to the rest of the genotypes. When the tested genotypes were categorized into four groups based on their relationship to mean ginning energy and ginning rate, 13 of the tested genotypes fell into the first group, which has the desired combination of low net energy and high ginning rate. The group that required high energy to gin and also ginned slower included 17 genotypes. Genotypes with the low energy and fast ginning requirements as a group took about 14% less energy and ginned 19% faster than genotypes in the high energy and slow ginner group (Table 5). Four genotypes with some level of the semi-naked seed trait: AR 9317-26, 'Tejas NS', 'SC 9023 NS 57-13-2-1', and 'AR9317-31' have the desired combinations of low ginning energy plus high ginning rate. However, two semi-naked seed genotypes, Yugo 8 (PI 655688) and Yugo 216 were slow ginners and it took significantly higher gross energy to gin these two genotypes when compared to the other semi-naked seed genotypes. Some fuzzy seeded commercial genotypes such as 'ST 5599BR' (PVP 200300279), FM 960B2R (PVP 200500109), 'PM 1218BR' (PVP 20000213) and 'SG 747' (PVP 9800118) were also in the favorable first group. These commercial genotypes, in addition to their low ginning net energy and fast ginning rates, have higher lint percent and higher fiber seed^{-1}. The genotypes with low net ginning energy and ginned faster had significantly lower gross energy, fuzz percent, and fiber length. Eighty percent of the tested semi-naked seed genotypes, 42% of transgenic, and 43% of conventional genotypes fell within this group. Figures 4 and 5 illustrate the ginning efficiency of two lines: AR 9317-26 (a "good" ginner) and 'MD52ne' (PI 634930) (a "bad" ginner). The area under the curve (power x time) is the energy required to gin the sample. AR 9317-26 has less area under the curve as compared to MD52ne.

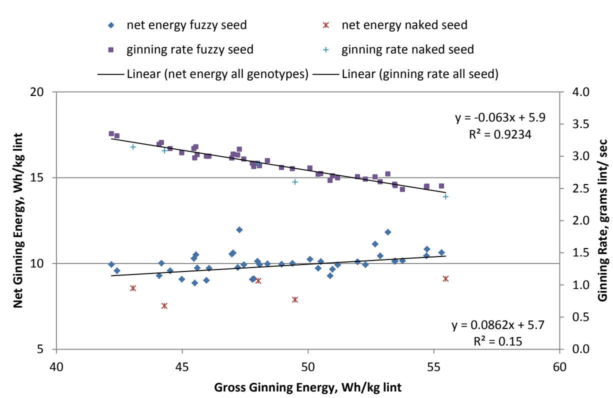

Figure 2. Relationships between gross ginning energy, net ginning energy, and ginning rate for 46 cotton genotypes grown at Stoneville, MS in 2008 and 2009.

Table 5. Least square means for ginning energy, ginning rate, and other characteristics averaged over years and locations for four genetic types grown at Stoneville, MS.

Cultivar/Group	Gross Ginning Energy (Wh kg^{-1} lint)	Net Ginning Energy (Wh kg^{-1} lint)	Ginning Rate (gm lint s^{-1})	Lint %	Fuzz %	Fibers $Seed^{-1}$	Boll Wt (gm)	Fiber Strength (cN tex^{-1})	Fiber Length (mm)	Nep_ um[z]	SCNpg[y]	SFCw[x]	Fine[w] (millitex)	MR[v]
(1) LOW NET ENERGY, FAST GINNERS														
AR 9317-26	44.3	7.5	3.09	0.35	6.4	10436	4.8	18.7	28.4	612.3	3.0	4.6	183.7	0.93
Tejas NS	43.0	8.6	3.14	0.36	6.7	12285	4.9	21.4	29.0	626.4	2.3	4.1	179.7	0.96
DP 4-910	45.5	8.9	2.97	0.40	12.9	13380	4.7	19.3	28.2	631.3	3.5	4.5	195.6	0.96
SC 9023NS 57-13-2-1	48.0	9.0	2.89	0.36	8.2	12257	4.7	20.5	29.0	611.4	3.1	4.8	171.6	0.93
AR 9317-31	46.0	9.0	3.00	0.40	6.9	12028	4.4	19.1	28.7	625.1	2.9	6.0	178.8	0.93
DP 444BR	45.0	9.1	3.05	0.42	10.5	14199	4.7	20.6	28.4	624.8	3.5	5.1	180.9	0.95
PM 2167R	47.8	9.1	2.89	0.40	10.0	13188	4.7	20.7	26.2	630.2	5.0	5.7	183.1	0.94
ST 5599BR	44.0	9.3	3.18	0.42	11.0	15594	5.1	21.1	28.7	623.7	3.5	7.0	184.5	0.97
FM 960B2R	42.5	9.6	3.32	0.40	10.5	14529	5.1	22.6	30.0	632.4	3.2	5.7	180.8	0.97
Coker 413	44.5	9.6	3.12	0.42	11.8	13748	4.7	21.0	28.7	629.4	4.5	5.0	177.7	0.94
PM 1218BR	46.0	9.7	3.00	0.42	11.8	15809	5.1	19.0	27.2	625.3	4.1	5.4	195.1	0.97
SG 747	45.5	9.7	3.02	0.41	14.7	13337	4.7	18.9	28.7	634.5	3.7	5.5	183.8	0.93
TAM 98-99ne	47.3	9.8	3.02	0.39	11.7	12514	4.8	22.5	29.2	631.1	3.9	4.0	193.4	0.99
GROUP 1 MEAN	45.3	9.2	3.10	0.40	10.2	13331	4.8	20.4	28.5	626.0	3.6	5.2	183.7	1.0
(2) HIGH NET ENERGY, FAST GINNERS														
DP 555BR	47.5	9.9	2.96	0.45	12.8	13273	4.4	20.1	28.7	620.9	2.9	7.5	172.8	0.94
MD 25	42.3	10.0	3.35	0.41	10.6	14051	5.4	24.2	30.5	625.1	3.8	4.5	182.0	0.99
MD 51NEOK	48.5	10.0	2.93	0.39	11.9	12656	4.9	20.8	29.0	626.9	3.7	4.8	183.9	0.98
MD 15OP	44.3	10.0	3.21	0.38	10.6	13494	4.8	29.0	31.5	626.4	3.4	3.4	165.3	0.98
DP 16 HAIRY	48.0	10.1	2.89	0.38	14.9	13794	5.3	19.8	29.0	628.6	4.1	6.2	174.0	0.94
JJ1145ne	45.5	10.3	3.12	0.42	12.1	14614	5.0	20.4	30.2	628.0	3.5	5.9	177.4	0.94
FM 832	45.5	10.5	3.15	0.39	12.4	13733	5.3	24.7	31.2	628.7	3.9	4.5	169.7	0.98
ST 474	47.0	10.6	2.97	0.42	13.5	14403	4.5	20.3	27.9	621.4	4.3	5.3	185.1	0.95
FM 800B2RF	47.0	10.6	3.03	0.38	12.1	13369	4.9	22.5	31.2	643.2	5.2	4.1	170.1	0.97
TAM 182-34-ELS	47.3	12.0	3.11	0.35	11.3	13325	5.8	25.2	35.3	672.7	6.6	4.4	161.7	0.97
GROUP 2 MEAN	46.3	10.4	3.07	0.40	12.2	13671	5.0	22.7	30.5	632.0	4.1	5.1	174.2	0.96
(3) LOW NET ENERGY, SLOW GINNERS														
YUGO 8	49.5	7.9	2.60	0.35	7.2	9358	4.0	19.6	27.9	606.9	3.0	4.9	185.4	0.95
YUGO 216	55.5	9.1	2.37	0.34	10.2	11539	4.2	18.3	26.4	634.4	2.5	6.6	179.4	0.92
AR 9608-08-03ne	47.8	9.1	2.84	0.42	10.6	11390	3.8	22.9	29.5	620.9	2.5	4.8	184.2	0.98
DES119H2	51.0	9.3	2.62	0.37	12.7	11202	4.3	21.2	28.2	635.2	5.7	5.2	188.9	0.95
C-6-5	51.0	9.7	2.69	0.35	13.3	12555	5.2	21.3	29.0	617.4	3.8	5.7	169.0	0.93
DP 16	50.5	9.7	2.72	0.41	13.4	12382	4.4	19.3	28.7	620.4	3.6	6.3	177.0	0.93
GROUP 3 MEAN	51.0	9.1	2.60	0.40	11.2	11404	4.3	20.4	28.3	622.5	3.5	5.6	180.7	0.94
(4) HIGH NET ENERGY, SLOW GINNERS														
AC 1517-99	48.0	9.9	2.85	0.41	13.0	14602	4.9	19.6	27.7	622.4	2.7	6.2	185.1	0.94
DP33B	51.3	9.9	2.66	0.40	14.4	11404	4.8	20.4	28.4	640.7	4.0	5.9	184.4	0.95
ST 213 SM2	52.3	9.9	2.64	0.37	14.9	12649	4.6	19.8	28.7	619.2	2.5	6.2	174.5	0.92
PHY 485WRF	49.0	10.0	2.82	0.41	12.0	12922	4.4	20.8	28.2	645.7	6.0	5.5	182.1	0.94
9-1-1-2	49.5	10.0	2.81	0.38	11.2	12044	4.5	21.0	30.0	615.8	2.6	5.6	174.7	0.95
St 213	50.5	10.1	2.73	0.38	14.5	12631	4.9	19.5	28.2	641.0	4.8	6.0	179.6	0.93
ST 213 sm	52.0	10.1	2.68	0.37	13.7	12408	4.6	20.4	29.7	636.2	3.9	5.8	179.6	0.95
DP 458BR	53.5	10.1	2.56	0.39	14.5	11238	4.6	20.7	29.2	630.9	2.2	6.6	187.6	0.96
DP 50	53.5	10.2	2.54	0.36	15.0	11599	4.9	18.9	29.7	642.9	4.5	6.9	187.4	0.94
DP 5415	53.8	10.2	2.48	0.38	12.8	10889	4.7	20.3	29.2	631.9	3.5	4.7	185.4	0.95
ST 4892BR	50.0	10.3	2.82	0.41	12.7	13869	4.7	20.4	28.4	639.2	5.7	4.6	185.6	0.95
DP 90ne	53.0	10.5	2.60	0.38	12.5	11096	4.3	22.5	29.2	627.5	3.3	4.8	177.4	0.97
PD 2-164	54.8	10.5	2.52	0.36	13.7	13012	4.6	22.3	29.0	634.6	4.5	5.4	170.0	0.94
ST 4554B2RF	55.3	10.6	2.54	0.40	15.2	13234	4.7	20.0	28.2	635.4	4.2	7.1	174.8	0.92
MD52ne	54.8	10.8	2.53	0.37	13.3	10706	4.3	25.0	30.0	638.9	3.7	4.1	180.8	0.99
FM 840B2R	52.8	11.1	2.68	0.38	12.6	12622	4.8	22.2	32.0	644.9	3.0	4.3	166.4	0.95
PHY 72	53.3	11.8	2.72	0.38	12.4	12826	4.6	24.3	30.5	653.8	5.3	4.4	173.1	0.97
GROUP 4 MEAN	52.3	10.4	2.70	0.40	13.4	12338	4.6	21.1	29.2	635.4	3.9	5.5	179.3	0.95
LSD (0.05)	5.6	0.4	0.37	0.02	1.3	1260	0.8	1.4	0.5	21.4	2.2	1.4	8.0	0.02

[z] **Nep-um= Nep size.**

[y] **SCNpg = Seed coat fragments that remain in the lint after ginning.**

[x] **SFC = Short fiber content. Percent of fibers shorter than ½ in.**

[w] **Fine = fineness, a relative measure of size, diameter, linear density or weight per unit length.**

[v] **MR= maturity ratio, the degree of cotton fiber wall development relative to the diameter of the fiber.**

Lint Percent, Fuzz Percent, Boll Weight, and Fibers Seed^{-1}. No difference in lint percent was observed between the different groups. Percent fuzz ranged from 6.4 to 15.2%. In general, an increase in fuzz percent resulted in an increase in net ginning energy and a decrease in ginning rate. Most of the genotypes within the semi-naked seed group had the lowest fuzz percent and ginned faster with lower net energy (Figure 3). The high energy, slow ginner genotypes as a group had significantly higher fuzz percent (13.9%) than the low energy, fast ginner genotypes (10.3%) (Table 5). The genotypes with the best ginning efficiency (AR 9317-26 and Tejas NS) also had the lowest fuzz percent (6.4 and 6.7%), respectively. Boll weight ranged from 3.8 to 5.8 g. Generally, genotypes with low net ginning energy had less fiber seed^{-1} as compared to the genotypes with higher net ginning energy (Table 5).

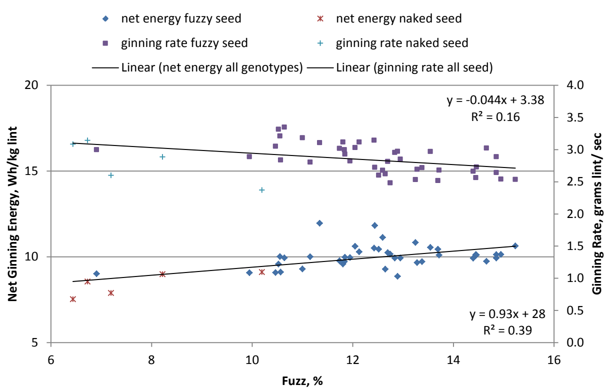

Figure 3. Relationships between fuzz percent, net ginning energy, and ginning rate for 46 cotton genotypes grown at Stoneville, MS in 2008 and 2009.

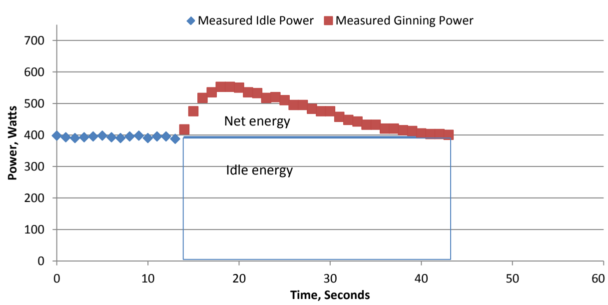

Figure 4. Gin stand power requirement for 91 g lint from AR 9317-26 grown at Stoneville, MS in 2008 and 2009. Energy equals power multiplied by time, or the area under the curve. Total energy equals net energy plus idle energy.

HVI and AFIS Fiber Quality. The low energy, fast ginning genotypes as a group had lower fiber strength, fiber length, nep size, nep number, SFC, and higher fineness than the high energy, low ginner rate group (Table 5). AR 9317-26 had significantly lower fiber strength than most of the tested genotypes. It also has one of the lowest values for nep size, SCN size, and SFC. The lowest nep counts were recorded for FM 960B2R and Tejas NS (both low energy/fast ginners) and 'MD 51NEOK' (PI 566941) and 'MD 15OP' (PI 642769) (both high energy/fast ginners). SCN size was lowest for FM 960B2R, followed by MD 15OP, Tejas NS, and AR 9317-26. Tejas NS had the lowest number of SFC, followed by MD 15OP and 'TAM 98-99ne' (PI 636491). It should be noted that these are high ginning efficiency genotypes. Three of the genotypes with the highest fineness values ('DP 4-910', PM 1218BR, and TAM 98-99ne) had high ginning efficiency.

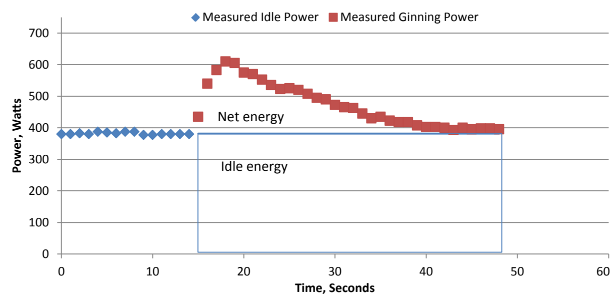

Figure 5. Gin stand power requirement for 82 g lint from MD 52ne grown at Stoneville, MS in 2008 and 2009. Energy equals power multiplied by time, or the area under the curve. Total energy equals net energy plus idle energy.

Comparison Between Different Genetic Types. The comparisons among the different genetic types were not significant and appeared to be random at best. The exception to this is the semi-naked seed group. This group was significantly different than the transgenic, conventional, strains/germplasm, backcross families for net ginning energy, fiber strength, fiber length, fuzz percent, fibers seed^{-1}, nep size, and SCN. The backcross families group comprises lines created by the backcross procedure to select for specific traits such as hairiness and fiber strength (Table 6), which are controlled by few genes (Endrizzi et al., 1984; Meredith, 2005a). The 'Stoneville 213' (PI 529229) and 'Deltapine 16' (PI 529251) families involve hairiness versus smooth leaf traits. There is little difference in net ginning energy and ginning rate indicated in either family (data not shown). The cultivar Deltapine16 hairy showed a significant probability difference at the 0.05 level for ginning energy, but there was no significant difference among the Stoneville 213 entries. The differences within the Deltapine 16 and Stoneville 213 families were not sufficiently large to warrant a special breeding program to enhance ginning energy and ginning rate.

Table 6. Genetic comparisons between recurrent parents and their near isogenic backcross derived lines for ginning energy, ginning rate, lint percent, fuzz %, fibers/seed, micronaire, 2.5 span length, strength, and short fibers.

Families and genetic types	Net ginning energy (Wh kg^{-1} lint)	Ginning rate (g lint s^{-1})	Lint (%)	Fuzz (%)	Fibers $seed^{-1}$ (no)	Mic	Strength (cN tex^{-1})	2.5 % span length (mm)	Short fiber (n) (%)
Hairiness:									
DPL 16 sm	9.7	2.72	41**	13.4	12382	4.6*	193	28.7	18.3
DPL 16 Hairy	10.1*	2.89	38	14.9*	13794*	4.5	198	29.0	19.2
Stv 213	10.1	2.73	38	14.5	12631	4.6	195	28.2	17.7
Stv 213 sm2	9.9	2.64	37	14.9	12649	4.8	204	29.7*	17.7
Stv 213 SM2	9.9	2.66	40**	14.4	11404	4.3	198	28.7	18.6
Transgenics:									
FiberMax 832	10.5	3.15	39	12.9	13733	4.4	247**	31.2	15.2**
FiberMax 800 B2RF	10.6	3.03	38	12.1	13309	4.2	225	31.2	13.7
Fiber Strength:									
MD 90ne	10.2	2.48	38	12.8	10889	4.9	225	29.2	14.8
MD 52ne	10.6**	2.54	40	15.2**	13234**	4.9	250**	30.0**	13.5
LSD (0.05)	0.4	0.37	0.02	1.3	1260	0.3	14	0.5	2.9

*and ** indicate statistical significances of the 0.05 and 0.01 probability levels respectively.

The population involving 'FiberMax 832' showed no significant differences for either ginning energy or ginning rate. However, fiber strength was significantly larger for FiberMax 832 than that for 'FiberMax 800 B2RF'. Boykin (2007) reported that genotypes that use less energy during ginning tended to have higher HVI fiber strength. This small sample and review of other transgenic and non-transgenic entries suggest that the currently used transgenic genotypes have little effect on ginning energy and ginning rate. Blanche et al. (2006) indicated few differences between transgenic genotypes and their conventional recurrent parents. However, they indicated that transgenics had larger seeds and lower lint percentage than their conventional recurrent parents.

The last population involved 'MD90ne' and its BC_7 equivalent MD 52ne. MD 52ne (Meredith, 2005a) has been shown to have about 10% higher bundle strength, 22% less short fibers, and 7% longer fiber length. Fiber strength differences between the two near isolines were controlled by a small number of genes, 1.23 (± 0.16) (Meredith, 2005b). In this study, fiber bundle strength was 11% higher, SFC was 10% less, and fiber length 3% more than the recurrent parent MD 90ne. The results in Table 6 show similar results for strength, length, and SFC. In addition, ginning energy for MD 52ne was significantly higher than that for MD 90ne. Also detected was that MD 52ne's average fuzz content was 13.3% compared to 12.8% for MD 90ne. MD 52ne also had 21.5% higher number of fibers/seed. Apparently, selecting for this type of higher strength gene also contributes to greater fuzz content and number of fibers/seed. In contrast there was no significant association detected between fiber strength and fuzz percent, (r = -0.06) among the total number of entries.

Trait Associations/Correlations. Traits associations are useful tools for plant breeders because they can indicate a predictive relationship that can be exploited in practice. Selection for one characteristic will result in a progress for all positively correlated and regress of all negatively correlated characteristics.

Net ginning energy was positively correlated with fuzz percent (r = 0.62, P = 0.01), boll weight (r = 0.32, P = 0.05), fiber strength (r = 0.46, P = 0.01), and fiber length (r = 0.60, P = 0.01) (Table 7). Net ginning energy was negatively correlated with fineness (r = -0.45, P = 0.01). Boykin (2007) and Chapman (1969) also reported a strong and positive relationship between ginning energy and fuzz percent. Increased fiber-seed bond strength might have resulted in more lint remaining on the seed. Contrary to the results of this study, Boykin (2007) and Chapman (1969) suggested that fiber length did not appear to influence ginning energy and furthermore, ginning energy increased as HVI strength decreased. A significant negative association was observed between net ginning energy and micronaire when the semi-naked seed types were dropped. Chapman (1969) reported that micronaire readings were significantly higher with low fiber-seed tenacity. This follows the negative trend between micronaire and ginning energy in our test. AFIS maturity ratio appeared to have no effect on net ginning energy. Contrary to this result, Boykin (2007) reported that ginning energy significantly decreased with AFIS maturity ratio. Our results indicated lint percent, fibers seed^{-1}, nep count, and number of SFC had no effect on net ginning energy. However, according to Boykin (2007), ginning energy is increased with decreased lint percent. Chapman (1969) also reported that lint percent increased with low fiber-seed tenacity.

Ginning energy was positively correlated with AFIS nep size (r = 0.70, P = 0.01) and SCN count (r = 0.46, P = 0.01) (Table 7). It was speculated that more energy was required for the saw to pass through and remove entangled fibers. Boykin (2007) also reported an increase of ginning energy with AFIS nep count, nep size, SCN count, and SCN size. Chapman (1969) also found that nep numbers decreased with low fiber-seed tenacity**.** Fuzz percent (r = -0.40, P = 0.01) and nep count (r = -0.45, P = 0.01) were two components that significantly and negatively affected ginning rate (Table 7). The more fuzz on the seed and neps in the lint, the slower the cotton gins. Strong and positive associations between ginning rate and fibers seed^{-1} (r = 0.61, P = 0.01), lint percent (r = 0.39, P = 0.01), boll weight(r = 0.53, P = 0.01), fiber strength (r = 0.30, P = 0.05), and maturity ratio (r = 0.34, P = 0.05) were also observed. Micronaire, length, nep size, SCN, SFC, and fineness appear to have no significant effect on ginning rate. Other interesting correlations observed in Table 7 are the positive and highly significant correlations between fuzz % and SFC; fibers seed^{-1} and lint % and boll weight; lint % and micronaire; boll weight and length; strength and length and maturity ratio; length and nep size and maturity ratio; nep size and SCN; nep count and SFC. Negative and significant correlations also were observed among strength and SFC and fineness; length and fineness; nep count and maturity ratio; and SFC and maturity ratio.

Table 7. Pearson Correlation coefficients between various parameters for the genotypes in the 2008 and 2009 ginning efficiency study at Stoneville, MS. (For first row P = 0.01 when r = 0.38 and P = 0.05 when r = 0.29. For 2nd row P = 0.01 when r = 0.40 and P = 0.05 when r = 0.31).

	Gin. Rate	Fuzz %	Fibers/ seed	Lint %	Boll wt	Mic	Str.	Len	Nep _um	NepPg	SCNpg	SFCn	Fine	MR
Net ginning Energy[z,y]	-0.15 -0.22	0.62** 0.32*	0.26 -0.08	0.08 -0.39	0.32* 0.28	-0.29 -0.42**	0.46** 0.42**	0.60** 0.65**	0.70** 0.65**	0.09 0.15	0.46** 0.35	0.05 -0.16	-0.45** -0.55**	0.24 0.15
Ginning Rate		-0.40** -0.58**	0.61** 0.70**	0.39** 0.43**	0.53** 0.47**	0.03 -0.01	0.30* 0.28	0.28 0.23	-0.11 -0.13	-0.45** -0.47**	0.03 0.01	-0.24 -0.17	-0.05 -0.05	0.34* 0.35*
Fuzz %			0.18 -0.19	0.21 -0.25	0.12 0.02	0.04 0	-0.06 -0.31*	0.05 -0.12	0.37* 0.14	0.33* 0.45**	0.27 0.05	0.41** 0.32*	-0.01 0.03	-0.11 -0.37*
Fibers/sd				0.56** 0.45**	0.57** 0.53**	0.04 0.03	0.08 -0.05	0.06 -0.08	0.09 -0.14	-0.15 -0.15	0.21 0.09	0.19 0.12	-0.05 0	0.07 -0.03
Lint %					-0.07 -0.26	0.43** 0.47**	-0.09 -0.30	-0.18 -0.42**	-0.1 -0.39*	-0.14 -0.17	0.01 -0.24	0.23 0.17	0.29 0.37*	0.13 -0.01
Boll Weight						-0.26 -0.33*	0.25 0.19	0.47** 0.43**	0.31* 0.28	-0.02 0	0.27 0.24	0.02 0.04	-0.26 -0.26	0.17 0.13
Mic							-0.30* -0.36*	-0.53** -0.60**	-0.19 -0.25	-0.31* -0.33	-0.12 -0.16	-0.06 -0.06	0.87** 0.88**	0.29 0.28
Strength								0.69** 0.67**	0.31* 0.27	-0.37* -0.36*	0.21 0.14	-0.53** -0.61**	-0.48** -0.50**	0.68** 0.66**
Length									0.50** 0.53**	-0.08 -0.06	0.22 0.15	-0.26 -0.29	-0.61** -0.64**	0.44** 0.40**
Nep_um										0.14 0.17	0.68** 0.70**	-0.09 -0.25	-0.21 -0.22	0.20 0.15
NepPg											0.1 0.09	0.59** 0.61**	-0.16 -0.18	-0.62** -0.63**
SCNpg												-0.16 -0.27	-0.09 -0.09	0.08 0
SFCn													-0.02 -0.02	-0.55** -0.64**
Fine														0.17 0.17

[*] Significant at the 0.05 probability level.

[**] Significant at the 0.01 probability level.

[z] First rows are correlations between all 46 genotypes.

[y] Second rows are correlations of 40 genotypes (excluding the 6 naked seed genotypes).

In Table 7, the first row indicates correlations for all 46 genotypes, whereas the second row indicates correlations for the 40 genotypes, excluding the six semi-naked seed genotypes. Correlations between net energy and fuzz percent decreased from 0.62 to 0.32 when the semi-naked seed genotypes were removed from the group. Correlations between net ginning energy and SCN count went from highly significant (r = 0.46**) to nonsignificant (r = 0.35) when the semi-naked seed group is omitted. Semi-naked seedness, however, did not have significant effect on the correlations between net ginning energy and traits such as ginning rate, fibers seed^{-1}, lint percent, nep count, SFC, and maturity ratios. No effects on the correlation of net ginning energy with strength, length, and fineness were observed when the semi-naked seed group was taken out from the group. Moreover, correlations of ginning rate with all other parameters were not affected by the semi-naked seed genotypes as a group (Table 7).

CONCLUSION

There appeared to be a large amount of genetic variability for ginning rates and ginning energy requirements among the tested genotypes. Furthermore, ginning rate appeared to be related to desirable ginning performances such as higher fibers seed^{-1}, higher lint percent, higher boll weight, and higher maturity ratio. Ginning rate was also negatively associated with fuzz percent and number of neps. Because of its ease in measurement, the positive correlation of fuzz percent with ginning energy and the negative correlation with ginning rate can be a useful tool in improving overall ginning efficiency. Genotypes that ginned faster and required less net energy to gin had in general lower nep size, nep count, and SFC when compared to genotypes that required higher net energy and ginned slower. More work has to be done to confirm these conclusions in commercial situations.

ACKNOWLEDGMENT

This research is part of the National Program 301 (Plant Genetic Resources, Genomics and Genetic Improvement) and is funded through ARS Project Number 6402-21000-033-00D.

DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S Department of Agriculture.

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