The *Journal of Cotton Science 7:23–38 (2003)*
http://journal.cotton.org, © The Cotton Foundation 2003

BREEDING & GENETICS

Lint Yield, Lint Percentage, and Fiber Quality Response in Bollgard, Roundup Ready, and Bollgard/Roundup Ready Cotton

Laval M. Verhalen*, Bruce E. Greenhagen, and Robert W. Thacker

ABSTRACT

Transgenic cotton (*Gossypium hirsutum* L.) with the Bollgard (BG) genes, the Roundup Ready (RR) gene, or both (BG/RR) has been grown commercially since 1996, 1997, and 1997, respectively. Because genes used in the past for one purpose have often had unforeseen effects on nontargeted traits, these experiments were conducted with cotton across several genetic backgrounds to determine whether the BG, RR, and BG/RR genes have an effect on lint yield, two measures of lint percentage, and five fiber quality traits. Replicated field trials were conducted as if for conventional (i.e., nontransgenic) cotton at two irrigated locations in Oklahoma over 2 years. The BG genes were stable for lint yield across genetic backgrounds, but the RR gene was not. BG significantly increased lint yield across genetic backgrounds in three of four experiments (from 6.7 to 11.8%) with an average of 6.2% over all four. In one background, RR decreased lint yield in two experiments (from -7.3 to -22.2%), but increased it (12.7%) in another. RR increased yield (10.5%) in another background in one experiment, but had no influence in two other backgrounds. Clearly, RR can reduce lint yield in some backgrounds in some environments. BG/RR increased lint yield by 2.5 and 16.8% in two backgrounds over four experiments. In BG/RR, higher yields associated with BG apparently overcame the occasional deficits associated with RR by 7.2 to 9.6%. BG/RR increased lint yield by 8.6 and 9.0% above RR in two backgrounds over four experiments. In another background, the increase was not significant. BG/RR (like BG) often increased lint yield in individual experiments, but caused no significant yield reductions. BG reduced picked lint percentage (-0.7%) and fiber fineness (-0.1 to -0.2 micronaire units). RR increased pulled lint percentage (0.8%), had a neutral or negative effect (-0.3 to -1.0 mm) on fiber length, and showed a neutral or positive effect (0.2 to 0.4 units) on fineness. BG/RR reduced fiber length (-0.3 to -0.8 mm), length uniformity (-0.7 to -1.1%), strength (-8.9 kN m kg^{-1}), and elongation (-0.2 to -0.4%), but it increased fineness (0.1 units). Relative to RR, BG/RR had a neutral or negative influence on picked lint percentage (as much as -1.2%), fiber length uniformity (-0.1 to -0.7%), fineness (-0.4 units), and strength (-10.3 kN m kg^{-1}). Traits not mentioned above were mixed in the direction of their response or were too small to be of statistical significance or practical value.

L. M. Verhalen and B. E. Greenhagen, Department of Plant and Soil Sciences, Oklahoma State University, 368 Agric. Hall, Stillwater, OK 74078; R. W. Thacker, Southwest Res. and Ext. Center, Rt. 1, Box 15, Altus, OK 73521.
*Corresponding author (lmv@mail.pss.okstate.edu)

Transgenic cotton cultivars with the BG genes, derived from *Bacillus thuringiensis* var. *kurstaki* (Perlak et al., 1990), were developed and first released in 1996 as 'NuCOTN 33B' and 'NuCOTN 35B' by Delta and Pine Land Company for picker harvest (Jones et al., 1996). The primary incentive for those releases was to reduce the damage to cotton caused by lepidopterous insect pests (Perlak et al., 1990). Planting BG cotton diminishes, but does not eliminate, the requirement for insecticide applications (Mahaffey et al., 1995; Benedict et al., 1996) and lowers that cost of cotton production, but seed costs are higher than in conventional cotton, and a technology fee increases the cost of transgenic cotton production still further.

Cotton with the BG genes displays resistance to the tobacco budworm [*Heliothis virescens* (F.)] (Benedict et al., 1991, 1996; Jenkins et al., 1991, 1997), bollworm [*Helicoverpa zea* (Boddie)] (Perlak et al., 1990; Benedict et al., 1991, 1996; Williamson and Deaton, 1991), cabbage looper [*Trichoplusia ni* (Hübner)] (Perlak et al., 1990; Benedict et al., 1991, 1996), pink bollworm [*Pectinophora gossypiella* (Saunders)], cotton leafperforator (*Bucculatrix thurberiella* Busck), saltmarsh caterpillar [*Estigmene acrea* (Drury)] (Wilson et al., 1992), beet armyworm [*Spodoptera exigua* (Hübner)] (Perlak et al., 1990; Wilson et al., 1992), and fall armyworm [*S. frugiperda*

(J. E. Smith)] (Williamson and Deaton, 1991). Of these insects, the bollworm and beet armyworm are the least sensitive to BG, and the cabbage looper is the most sensitive (Perlak et al., 1990). The durability of the efficacy of BG against some of the lepidopterous insects is in doubt. Research from Arizona (Moulton and Dennehy, 2001) demonstrated that natural beet armyworm populations were different in susceptibility to BG by more than 28 fold. Selection experiments were also conducted over three generations with three populations of the beet armyworm, and resistance to BG increased in those populations by 32, 298, and 716%, respectively, which indicates a genetic basis for that resistance (Moulton and Dennehy, 2001). Nonlepidopterous insects are generally unaffected, but BG cotton is apparently more attractive to the sweetpotato whitefly [*Bemisia tabaci* (Gennadius)] (Wilson et al., 1992) and the tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)] [Hardee, as cited by Jenkins et al. (1995)]. With the reduction of insecticides applied to BG (as compared to conventional) cotton, secondary pests such as the green stink bug [*Acrosternum hilare* (Say)], southern green stink bug [*Nezara viridula* (L.)], and brown stink bug [*Euschistus servus* (Say)] may become more economically important (Turnipseed et al., 1995).

Transgenic cotton cultivars with the RR gene, derived from *Agrobacterium* spp. (Nida et al., 1996), were developed and first released in 1997 as ‘PM 2200 RR’ and ‘PM 2326 RR’ by Paymaster Cottonseed Research for stripper harvest (Sheetz and Speed, 1997). Picker-harvested cotton cultivars with the RR gene (i.e., ‘PM 1215 RR’, ‘PM 1220 RR’, ‘PM 1244 RR’, ‘PM 1330 RR’, and ‘PM 1560 RR’) were also developed and first released in 1997 by Paymaster Technology Corp. (Williams et al., 1997). Cultivars with RR allow glyphosate [*N*-(phosphonomethyl)glycine] to be applied over-the-top in seedling cotton (Johnson, 1996). Culpepper and York (1998) demonstrated that several glyphosate systems for weed control in RR cotton used fewer herbicide applications and less total herbicide than traditional weed control programs, but the glyphosate systems produced equivalent yields and net returns.

The 10 “most troublesome” weeds in Oklahoma are field bindweed (*Convolvulus arvensis* L.), common cocklebur (*Xanthium strumarium* L.), Texas panicum (*Panicum texanum* Buckl.), morningglory (*Ipomoea* spp.), pigweed (*Amaranthus* spp.), johnsongrass [*Sorghum halepense* (L.) Pers.], yellow nutsedge (*Cyperus esculentus* L.), silverleaf nightshade (*Solanum elaeagnifolium* Cav.), devil’s-claw [*Proboscidea louisianica* (Mill.) Thellung], and red sprangletop [*Leptochloa filiformis* (Lam.) Beauv.](Webster, 2001). Many of these weeds are also serious problems in other states. The label indicates that glyphosate controls six of the above weeds: field bindweed, common cocklebur, Texas panicum, morningglory, pigweed, and johnsongrass in the seedling (i.e., without rhizomes) stage (Anonymous, 2001). The supplemental label for glyphosate application in RR cotton states that 1.9 L/ha “will burndown or suppress the growth” of yellow nutsedge, silverleaf nightshade, and johnsongrass with rhizomes; but that additional preharvest applications may be necessary in the fall for adequate control (Anonymous, 1999). Two of the most troublesome weeds in Oklahoma, devil’s-claw and red sprangletop, are not addressed by either label. Weed scientists in Oklahoma have determined that devil’s-claw (D. S. Murray, personal communication, 2001) and red sprangletop (J. C. Banks, personal communication, 2002) are controlled by glyphosate. Murray (personal communication, 2001) demonstrated that rates higher than recommended are required to effectively control yellow nutsedge, silverleaf nightshade, and field bindweed in Oklahoma. He has also observed erratic control of larger morningglory plants with glyphosate. Culpepper and York (1998) in North Carolina found that a single application of glyphosate did not adequately control most weed species. Two treatments of glyphosate or one of glyphosate followed by a postemergence directed application of cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} plus MSMA (monosodium salt of methylarsonic acid) were similar in effectiveness to the standard weed control programs, but three applications of glyphosate were not more effective than two.

Transgenic cotton cultivars with both the BG and RR genes (i.e., ‘PM 1220 BG/RR’, ‘PM 1244 BG/RR’, ‘PM 1330 BG/RR’, and ‘PM 1560 BG/RR’) were developed and first released in 1997 by Paymaster Technology Corp. for picker harvest (Williams et al., 1997). Producers growing these cultivars would not be forced to decide before planting whether insect or weed control was their priority, which would dictate the transgenic cultivar to grow. With both genes present, both classes of pest could be addressed in the same season.

The transgenic cotton cultivars identified previously were all derived by the backcross breeding method (Jones et al., 1996; Sheetz and Speed, 1997; Williams et al., 1997), which transferred the BG or RR genes or both into preexisting, highly adapted cultivars (used as recurrent parents). Almost all transgenic cotton cultivars released since that time have also been the products of backcross breeding (e.g., Sheetz, 1998; Legé, 1999; McCall and Robinson, 2000; Calhoun, 2001). The number of backcrosses used in their development is not always specified, but when given, they are usually three (e.g., Sheetz and Speed, 1997) or four (e.g., Sheetz, 1998). With three and four backcrosses, the transgenic cultivar is on the average 93.8 and 96.9%, respectively, the same genetically as its recurrent parent, except for the backcrossed gene or genes (Fehr, 1987). Therefore, comparisons between a transgenic cultivar and its recurrent parent are a powerful method to determine the effect(s) of the transferred gene(s) on nontargeted traits. Multiple effects on a plant are commonly observed in plant breeding after the insertion of one or two qualitative genes. For examples in cotton, see Andries et al. (1969) for okra leaf, Andries et al. (1970) for super okra leaf, Hosfield et al. (1970) for glandless, Meredith et al. (1973) for nectariless, and Wilson and George (1986) for smoothleaf.

Experiments were conducted at two irrigated locations in Oklahoma for 2 years to determine whether BG, RR, and BG/RR had positive, neutral, or negative effects on cotton lint yield, lint percentage, and fiber quality.

MATERIALS AND METHODS

Replicated field studies were conducted in 1998 and 1999 near Altus, OK, on a Hollister clay loam (a fine, smectitic, thermic Typic Haplustert) and near Tipton, OK, on a Tipton silt loam (a fine-loamy, mixed, superactive, thermic Pachic Argiustoll). Planting dates at Altus were 28 May and 4 June in 1998 and 1999, respectively. Planting dates at Tipton were 27 May 1998 and 2 June 1999.

Cultivars in the 1998 tests were the recurrent parents and their related transgenics that were available in sufficient seed quantities to be included in these experiments. Delta and Pine Land Company (Scott, MS) was the source for all seed. The cotton cultivars were 'PM 1215' (plus BG and RR versions of it), 'PM 1220' (plus RR and BG/RR), 'PM 1244' (plus RR and BG/RR), and 'DP 5415' [plus BG, which is the same as NuCOTN 33B (Jones et al., 1996)]. The same cultivars plus 'DP 5415 RR', PM 2326 RR, and 'PM 2326 BG/RR' were tested in 1999. The recurrent parent for the latter two cultivars was 'Paymaster HS 26' (Sheetz and Speed, 1997; Sheetz, 2000).

A split-plot arrangement of treatments was used with genetic backgrounds randomly assigned to whole plots and individual cultivars sharing that background randomly assigned to the subplots within the whole plots. Whole plots were arranged in a randomized complete block design with 10 replications. Subplots were single rows 9.1 m long and 1.0 m apart. Plant populations were typical for commercial fields in the area. The split-plot arrangement and large number of replications were used to increase the precision of comparisons to be made within genetic backgrounds (Little and Hills, 1978).

Cultural practices were used on each experimental area as necessary. Fertilizer was applied in February or March each year as 112 kg ha^{-1} of 46-0-0. The amount of added N at Tipton was actually higher because nitrates are naturally present in the well water used to irrigate at that location. An estimated 9.0 kg ha^{-1} of N is added per irrigation to the soil at that location. To counteract possible excess N at Tipton, mepiquat chloride (1,1-dimethylpiperidinium chloride; Pix, BASF Corp., Research Triangle Park, NC) was applied to those experiments on 30 July 1998 and on 2 Aug. 1999. Approximately 10 cm of water were applied per irrigation at each location. The Altus experiments were irrigated seven times in 1998 and five times in 1999. At Tipton, five irrigations were applied in 1998, and four irrigations were applied in 1999.

Because the effects of BG were to be determined relative to nontransgenic cotton, these experiments were treated for insect control with the same chemicals and at the same time as in surrounding conventional cotton. Insecticides were applied when insect pests in the conventional cotton reached economic threshold levels as defined for Oklahoma (Karner, 1998). Insecticides were applied 15 times in 1998 and seven times in 1999 at Altus. At Tipton, there were eight applications in 1998 and six in 1999. The insecticides applied are not listed because they were applied uniformly over the experimental areas and have no relevance to BG vs. non-BG comparisons. Five of the applications at Altus in 1998 were for the bollworm-tobacco budworm, beet armyworm, or both, and one at Altus in 1999 was for the bollworm-tobacco budworm. None of the applications at Tipton in either year were for lepidopterous insects.

Because the effects of RR were to be compared with conventional cotton, these experiments were treated for weed control in the same manner as in surrounding nontransgenic cotton, i.e., glyphosate was not applied over-the-top of seedling cotton. Each experiment received a preplant incorporated and a preemergence herbicide. At Tipton in 1999, the plots also received a postemergence herbicide to control late-season weeds. The herbicide treatments in each experiment were supplemented by mechanical cultivation and by hand hoeing. The herbicides applied are not listed because they were applied uniformly over the experimental areas and have no bearing on RR vs. non-RR relationships.

Harvest-aid chemicals were not utilized in the 1998 experiments. In 1999 at Altus, a defoliant mixture of tribufos (*S,S,S*-Tributyl phosphorotrithioate; Def 6, Bayer CropScience, Research Triangle Park, NC) plus ethephon [(2-chloroethyl) phosphonic acid] and cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid; Finish, Rhône-Poulenc Ag Co., Research Triangle Park, NC] plus a crop oil concentrate (Agridex, Helena Chemical Co., Memphis, TN) were applied on 21 October. At Tipton in 1999, ethephon and cyclanilide plus a nonionic adjuvant (Kinetic; Helena Chemical Co., Memphis, TN) were applied on 9 November.

A few days prior to harvest, 15-boll samples were taken from each plot to estimate picked and pulled lint percentages and to measure fiber quality. Cotton was harvested with a mechanical stripper (modified for small-plot work) at Altus on 17 Nov. 1998 and on 29 Oct. 1999 and at Tipton on 2 Dec. 1998 and 17 Nov. 1999. In 1998 at Tipton, two plots were treated as missing for lint yield due to a harvesting error. Plot weights of stripped cotton were multiplied by the corresponding pulled lint percentages to convert them into lint weights per plot, which were then converted into kilograms per hectare. Fiber from each boll sample was sent to the International Textile Center at Lubbock, TX, to obtain High Volume Instrument (HVI) measurements using the Uster 900A system. Fiber length and strength measurements were converted into millimeters and kilonewton meters per kilogram, respectively. Conversions were not necessary for fiber length uniformity, fineness, and elongation.

Because BG, RR, and BG/RR cultivars were not available for each of the genetic backgrounds tested, the experimental design was unbalanced. To eliminate that imbalance when making comparisons, analyses were conducted on data subsets of all BG cultivars vs. their respective recurrent parents, all RR cultivars vs. their recurrent parents, all BG/RR cultivars vs. their recurrent parents, and all BG/RR cultivars vs. the RR entries in the same backgrounds. Because additional entries were available for evaluation in 1999, an imbalance also resulted between years at both locations. Two plots were lost due to a harvesting error at Tipton in 1998; therefore, an imbalance existed between locations in that year. Because of those complications, each of the four experiments was analyzed separately for each subset using PROC GLM (SAS Institute, release 6.03, Cary, NC) with the appropriate instructions for a split-plot. Statistical significance was determined at the 0.10, 0.05, and 0.01 levels of probability.

RESULTS AND DISCUSSION

Lint Yield. In the analyses of the "BG vs. Recurrent Parent" subset, no interactions between whole plots (i.e., genetic backgrounds) and subplots (i.e., the transgene vs. none) were significant. Thus, no evidence was found in these experiments that BG's influence on lint yield was affected by genetic background. Therefore, BG may be treated as a constant relative to lint yield. Whole plots were significant for lint yield in all four experiments ($P \leq 0.01$ at Tipton in 1998 and 1999; $P \leq 0.05$ at Altus in 1998; $P \leq 0.10$ at Altus in 1999) indicating that the two backgrounds in these comparisons (i.e., PM 1215 and DP 5415) were different in yield. The difference in whole plots was of minimal interest because any conventional experiment comparing cultivars could have provided that same information. On the other hand, differences in whole plots provide some assurance that BG was tested over a range of expression for lint yield. Subplot effects, the primary concern of this paper, were significant for BG in three of the four experiments ($P \leq 0.01$ at Altus in 1998 and Tipton in 1999; $P \leq 0.05$ at Tipton in 1998).

Lint yield responses to BG, RR, and BG/RR, shown as a percentage of the corresponding recurrent parent (or RR), are summarized in Table 1. Presenting the data in this manner [rather than as actual yields for each entry, after Moser et al. (2001)] results in smaller tables that are more easily interpreted as to direction of response, magnitude of difference, and degree of statistical significance. Because none of the interactions were significant for "BG vs. Recurrent Parent", the effects of BG in each experiment were

Table 1. Lint yield of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Lint yield (% of recurrent parent or RR)[z]			
	1998		1999	
	Altus	Tipton	Altus	Tipton
BG vs. Rec. Parent				
Across backgrounds[y]	110.6***	111.8**	95.5	106.7***
RR vs. Rec. Parent				
PM 1215	101.5	100.5	96.8	99.0
PM 1220	92.7*	77.8***	112.7**	98.0
PM 1244	104.5	108.2	110.5***	105.6
DP 5415	–	–	99.0	97.7
BG/RR vs. Rec. Parent				
PM 1220	102.0	95.1	111.7**	101.1
PM 1244	117.9**	113.2	123.8***	112.4**
BG/RR vs. RR				
PM 1220	110.0***	122.2**	99.1	103.1
PM 1244	112.9**	104.5	112.0***	106.4*
PM 2326	–	–	102.8	104.6

[z] Means were 1060, 1210, 1310, and 1360 kg ha^{-1} for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively. *, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

[y] Genetic backgrounds in these analyses were PM 1215 and DP 5415.

averaged across backgrounds. In three of the four experiments, BG significantly increased lint yield from 6.7 to 11.8% compared with its recurrent parent (Table 1). Averaged across the four environments, an estimated lint yield increase of 6.2% was associated with BG. This yield advantage of BG cotton could have derived from the "subthreshold protection" hypothesized by Ihrig and Mullins (2001).

Williamson and Deaton (1991) obtained lint yields in BG cotton (sprayed or unsprayed) that were 3.1 to 19.1% greater than the sprayed recurrent parent control. Wilson et al. (1994) reported that six of nine BG lines produced yields 13.1 to 29.7% higher than their recurrent parent. Of the three remaining lines, one (designated as T-62) had significantly less yield (-13.3%). In our literature search, this was the only BG line to yield significantly less than its respective recurrent parent. Jenkins et al. (1995) compared BG lines with their recurrent parents in four genetic backgrounds in tests not infested with the tobacco budworm and calculated a yield advantage for BG ranging from 0.6 to 19.5% (the latter estimate was on the DP 5415 background included herein) with an average of 9.1%. Benedict et al. (1996) showed that two of seven BG lines had yields 11.6 and 12.5% greater than their recurrent parents. In 11 experiments with low lepidopteran pressure, Kerby et al. (1995) obtained the same lint yield for NuCOTN 35B compared with its recurrent parent and a 11.3% increase in yield for NuCOTN 33B compared with its recurrent parent. In 52 tests, Jones et al. (1996) found that NuCOTN cultivars not treated for lepidopteran pests had 14.7 to 20.6% higher yields than their treated recurrent parent. Williams et al. (1997) did not observe any differences in yield between BG cottons and their recurrent parents from five genetic backgrounds (including PM 1215, also used here). When the tobacco budworm was suppressed with insecticides, BG provided an average 5.7% advantage in lint yield in Delta and Pine Land lines from three backgrounds, including DP 5415 (Jenkins et al., 1997). They measured a 51.1% advantage when the budworm could not be controlled. Moser et al. (2001) noted that lint yields from six of nine BG lines were 8 to 15% higher than their respective recurrent parents, which included NuCOTN 33B (on the DP 5415 background) with an 8% yield advantage.

In the “RR vs. Recurrent Parent” subset for lint yield, whole plots by subplots interactions were significant in three of four experiments ($P \leq 0.01$ at Tipton in 1998; $P \leq 0.05$ at Altus in 1998 and 1999), and whole plots were significant in two experiments ($P \leq 0.01$ at Altus in 1999; $P \leq 0.05$ at Tipton in 1999). The significant interactions indicate that RR behaves differently on some backgrounds than it does on others. Thus, backgrounds must be evaluated separately for the RR gene. In this paper, if one or more experiments within a subset expressed a significant interaction, effects on individual backgrounds were calculated in all experiments to avoid oversimplification of the data.

The RR gene decreased lint yield of PM 1220 in two experiments (from -7.3 to -22.2%), but increased it (12.7%) in another (Table 1). An increase of 10.5% was associated with the RR gene for PM 1244 in one of four trials. Significant responses in lint yield were not detected in PM 1215 or DP 5415. This data indicates that the RR gene can reduce lint yield on some backgrounds in some environments, so potential cultivars with the RR trait should be extensively evaluated prior to release.

In similar comparisons, the first two RR releases by Paymaster Cottonseed Research produced yields 7.3 and 8.1% greater than their respective recurrent parents (Sheetz and Speed, 1997). Williams et al. (1997) compared the first five RR releases by Paymaster Technology Corp. with their corresponding recurrent parent and reported a significant yield loss (-11.6%) in the ‘PM 1560’ background, but no differences for PM 1215, PM 1220, PM 1244, and one other line. An RR release developed by Sheetz (1998) had 9.0% greater yield than its recurrent parent. One RR cultivar developed by McCall and Robinson (2001) was not significantly different in yield from its recurrent parent. Moser et al. (2001) determined that only one of 10 RR cultivars had significantly lower yield (-9%) than its corresponding recurrent parent.

In the “BG/RR vs. Recurrent Parent” subset, the interaction between whole plots and subplots for lint yield was significant in three of four experiments ($P \leq 0.05$ at Altus in 1998; $P \leq 0.10$ at Tipton in 1998 and Altus in 1999) and significant for whole plots in two experiments ($P \leq 0.05$ at Altus in 1998; $P \leq 0.10$ at Tipton in 1998). Compared with their recurrent parents, the yield of PM 1220 BG/RR was increased in one experiment by 11.7% and of PM 1244 BG/RR in three of four experiments by 12.4 to 23.8% (Table 1). Yield was not significantly decreased for either background. Means across the four experiments showed yield increases of 2.5 and 16.8% for PM 1220 and PM 1244, respectively, compared with their recurrent parents. Comparing corresponding values of PM 1220 in the “RR vs. Recurrent Parent” subset with those in the “BG/RR vs. Recurrent Parent” subset showed yield increases in the latter subset ranging from -1.0 to 17.3% with an average increase of 7.2% for BG. The same comparisons for PM 1244 gave a range from 5.0 to 13.4% with an average of 9.6% advantage for BG. Apparently, the yield increases associated with BG overcame the occasional deficits associated with RR.

Comparisons for lint yield between BG/RR cultivars and their recurrent parents have been made by others. Williams et al. (1997) described a significant yield loss (-13.7%) for BG/RR compared with its recurrent parent for PM 1560 (the same background was significantly reduced by RR), but not for PM 1220, PM 1244, and one other cultivar. In two recent BG/RR releases, Sheetz (2000) reported a 5.1% increase in lint yield in PM 2326 relative to its recurrent parent, but no differences in the other cultivar. Moser et al. (2001) compared BG/RR entries with their respective recurrent parents and found that four of 10 significantly increased lint yield by 8 to 16%.

The authors reasoned that testing “BG/RR vs. RR” could serve as an independent, direct comparison on three additional backgrounds (to those in the “BG vs. Recurrent Parent” subset) for the effects of BG vs. non-BG cotton on lint yield (and other traits). Interactions between whole plots and subplots were significant in two of four experiments ($P \leq 0.10$ at Tipton in 1998 and Altus in 1999), and whole plots were significant at Altus in 1999 ($P \leq 0.01$). Significant increases in yield associated with the BG in BG/RR were observed in two of four experiments for PM 1220 and in three of four for PM 1244 (Table 1). Lint yield was not different for PM 2326 in two experiments. Mean increases in lint yield of 8.6 and 9.0% were estimated for the PM 1220 and PM 1244 backgrounds, respectively. As for “BG vs. Recurrent Parent” and for “BG/RR vs. Recurrent Parent”, BG/RR often increased lint yield in individual experiments above its check (RR) and caused no significant reductions in yield. To the authors’ knowledge, no one has previously conducted “BG/RR vs. RR” comparisons.

Likewise, testing "BG/RR vs. BG" could have served as an independent, direct comparison for the effects of RR vs. non-RR cotton, but paired cultivars with those traits in the same genetic background were not included in these experiments.

Picked Lint Percentage. Picked lint percentage is a component of lint yield that is important to cotton producers who harvest with mechanical pickers. Because this and subsequent traits were determined from boll samples taken prior to harvest, the harvesting error at Tipton in 1998 did not affect degrees of freedom in their analyses. Significant interactions between whole plots and subplots were detected in one or two experiments per subset (e.g., the "BG vs. Recurrent Parent" analyses) with significant whole plot effects in one to four experiments per subset. Picked lint percentage responses to BG, RR, and BG/RR are summarized in Table 2. Responses were expressed as deviations from the recurrent parent (or RR) and provide the direction of the effect, its magnitude, and its degree of statistical significance. This is the same technique used for fiber properties by Moser et al. (2001).

In analyses of "BG vs. Recurrent Parent", picked lint percentage was reduced by BG in two of four experiments for PM 1215 and in three for DP 5415 (Table 2). Using algebraic mean deviations (i.e., positives and negatives were allowed to cancel each other), picked lint percentages declined -0.7% across both backgrounds. The tendency for BG to negatively affect lint percentage while simultaneously increasing lint yield indicates that BG had positive effects on the other yield components (i.e., boll size, boll number per unit area, or both). The effects of BG on lint percentage in the literature are mixed. Six of nine BG lines evaluated by Wilson et al. (1994) had 0.7 to 2.1% higher picked lint percentage than their recurrent parent, and one was significantly lower (-1.3%). Benedict et al. (1996) reported increases of 1.5 to 2.6% in three of seven BG lines. Williams et al. (1997) did not observe any significant responses from five backgrounds (including PM 1215). Across 22 locations, Kerby et al. (1995) showed declines of -0.3 to -0.5% in picked lint per-

Table 2. Picked lint percentage of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Picked lint percentage (deviations from recurrent parent or RR in %)[z]			
	1998		1999	
	Altus	Tipton	Altus	Tipton
<u>BG vs. Rec. Parent</u>				
PM 1215	0.1	-1.1	-1.2***	-0.6**
DP 5415	-1.7***	-0.8**	-0.5*	0.1
<u>RR vs. Rec. Parent</u>				
PM 1215	-0.4	-0.2	-0.4	-0.8**
PM 1220	0.6	-0.1	0.5*	1.0**
PM 1244	1.6***	1.2*	0.1	0.2
DP 5415	–	–	0.4	0.9
<u>BG/RR vs. Rec. Parent</u>				
PM 1220	0.3	-0.8**	0.4**	0.5**
PM 1244	-0.1	-0.1	-0.7	-0.7*
<u>BG/RR vs. RR</u>				
PM 1220	-0.3	-0.7	-0.1	-0.5
PM 1244	-1.7***	-1.3*	-0.8**	-0.9**
PM 2326	–	–	0.3	-0.3

[z] Means were 40.1, 40.1, 42.2, and 38.4% for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively. *, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

centage in the NuCOTN cultivars compared with their corresponding recurrent parents. Jenkins et al. (1997) obtained an average response of -1.3% across three genetic backgrounds from Delta and Pine Land (including DP 5415) when the tobacco budworm was controlled and a response of -0.3% when it was not.

For the "RR vs. Recurrent Parent" subset, the RR gene had a negative effect on PM 1215 in one of four experiments, positive responses for PM 1220 and PM 1244 in two of four trials, and no significant response for DP 5415 in two experiments (Table 2). Williams et al. (1997) found that picked lint percentage increased by 1.1% on one background, but not on four others (including PM 1215, PM 1220, and PM 1244). McCall and Robinson (2001) reported a significant loss of -0.5% in 'ST 4793R' compared with its recurrent parent.

In the "BG/RR vs. Recurrent Parent" subset analyses, BG/RR resulted in two positive and one negative responses in PM 1220 and one negative response in PM 1244 (Table 2). Williams et al. (1997) showed a negative effect of BG/RR for picked lint percentage in one background, but not in three others (including PM 1220 and PM 1244).

Comparisons of "BG/RR vs. RR" functioned as a measure of the effects of BG vs. non-BG on lint percentage across three additional backgrounds. BG resulted in significant negative responses for PM 1244 in all four tests with an average loss of -1.2% (Table 2). Effects on the PM 1220 and PM 2326 backgrounds were not significant.

Pulled Lint Percentage. Pulled lint percentage is a component of lint yield corresponding to the previous trait, but this trait is important to cotton producers who harvest with mechanical strippers. Significant interactions for whole plots with subplots were observed in the "BG vs. Recurrent Parent" and "BG/RR vs. RR" subsets in one and two experiments, respectively, but not in the other two subsets. Whole plot mean squares were significant in two to four experiments per subset. Responses to BG, RR, and BG/RR are summarized in Table 3 as deviations from the recurrent parent (or RR).

In the "BG vs. Recurrent Parent" subset, the BG genes resulted in two significant positive responses for PM 1215 and one negative response for DP 5415 in the four environments (Table 3). Algebraic mean deviations were 0.2% for PM 1215 and -0.3% for DP 5415. Opposite signs and relatively small magnitudes do not inspire confidence that a trend was present.

Because whole plots by subplots interactions were not significant in the "RR vs. Recurrent Parent" analy-

Table 3. Pulled lint percentage of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Pulled lint percentage (deviations from recurrent parent or RR in %)[z]			
	1998		1999	
	Altus	Tipton	Altus	Tipton
BG vs. Rec. Parent				
PM 1215	0.5**	-0.6	-0.2	0.9***
DP 5415	-0.8*	0.1	-0.7	0.3
RR vs. Rec. Parent				
Across backgrounds[y]	0.9***	0.2	0.7***	1.2***
BG/RR vs. Rec. Parent				
Across backgrounds[x]	-0.1	0.1	0.9***	0.4
BG/RR vs. RR				
PM 1220	-0.7*	-0.4	-0.4*	-0.2
PM 1244	-1.4***	-0.2	0.4	-0.9
PM 2326	–	–	1.1**	0.0

[z] Means were 31.6, 30.5, 32.9, and 30.1% for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively. *, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

[y] Genetic backgrounds in these analyses were PM 1215, PM 1220, and PM 1244 in both years and DP 5415 in 1999.

[x] Genetic backgrounds in these analyses were PM 1220 and PM 1244.

ses, estimates were averaged across backgrounds. Significant positive responses were associated with the RR gene in three of four experiments with an algebraic overall mean deviation of 0.8% (Table 3). Sheetz and Speed (1997) reported that the releases, PM 2200 RR and PM 2326 RR, were 1.0 and 2.0% higher in pulled lint percentage, respectively, than their corresponding recurrent parents. Sheetz (1998) also noted that 'PM 2145 RR' had a 1.0% higher lint percentage than its recurrent parent.

Lack of significant interactions for the "BG/RR vs. Recurrent Parent" subset permitted the averaging of effects across backgrounds. A significant positive response associated with BG/RR was observed in only one of four experiments (Table 3). The overall algebraic mean deviation was 0.3%, which was too small to be of practical importance. Sheetz (2000) observed a 1.0% increase in pulled lint percentage for "BG/RR vs. Recurrent Parent" in two cultivar releases.

Analyses of "BG/RR vs. RR" revealed negative responses associated with the BG genes for PM 1220 in two of four experiments and for PM 1244 in one of four (Table 3). A positive change was noted for PM 2326 in one of two experiments. Algebraic mean deviations across the four tests were -0.4 and -0.5% for PM 1220 and PM 1244, respectively. Across the 1999 experiments, those mean deviations were -0.3, -0.7, and 0.6% for PM 1220, PM 1244, and PM 2326, respectively.

Fiber Length. Interactions between whole plots and subplots were significant for fiber length in two or three experiments per subset. Whole plot effects were significant in two to four experiments per subset. Table 4 summarizes the effects of BG, RR, and BG/RR on fiber length expressed as deviations from its recurrent parent (or RR).

Comparisons in the "BG vs. Recurrent Parent" subset were positive in one of four experiments for PM 1215 and were mixed (two positive, one negative) for DP 5415 (Table 4). In related studies, Wilson et al. (1994) reported that four of nine BG lines had significantly longer fiber (0.7 to 1.1 mm) than their nontransgenic parent, and four had significantly shorter fiber (-0.6 to -1.3 mm). Benedict et al. (1996) obtained negative responses (-0.8 to -1.6 mm) for BG in four of seven lines relative to its recurrent

Table 4. Fiber length of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Fiber length (deviations from recurrent parent or RR in mm)[z]			
	1998		1999	
	Altus	Tipton	Altus	Tipton
BG vs. Rec. Parent				
PM 1215	0.0	0.5**	0.5	0.3
DP 5415	1.0***	-0.3	0.3*	-0.5**
RR vs. Rec. Parent				
PM 1215	-0.8**	0.0	-0.3	0.0
PM 1220	0.0	-0.3	-0.3	0.0
PM 1244	-0.8***	-0.8	-1.5***	-1.0***
DP 5415	–	–	-0.3	0.0
BG/RR vs. Rec. Parent				
PM 1220	-0.3	0.3	-0.5***	-0.8***
PM 1244	-0.3	-0.8*	-1.3***	-0.8***
BG/RR vs. RR				
PM 1220	-0.3	0.5	-0.3	-0.8**
PM 1244	0.5***	0.0	0.3	0.3
PM 2326	–	–	-0.8***	-0.8*

[z] Means were 27.4, 27.7, 27.2, and 27.7 mm for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively.
*, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

parent. Moser et al. (2001) derived significant differences in three (one positive for DP 5415, two negative) of 10 comparisons. No significant differences in fiber length between BG and their recurrent parents were reported by Kerby et al. (1995) and Jones et al. (1996) on two backgrounds (including DP 5415), by Williams et al. (1997) on five (including PM 1215), and by Kerby et al. (2000) on seven (including DP 5415) in small plots.

In “RR vs. Recurrent Parent”, RR had significant negative effects on PM 1215 in one experiment and on PM 1244 in three experiments (Table 4). Algebraic mean deviations of -0.3 and -1.0 mm were calculated for PM 1215 and PM 1244, respectively. The trait had no effect on PM 1220 and DP 5415. Sheetz and Speed (1997) observed no significant differences in fiber length between two RR cultivars and their respective recurrent parents. Williams et al. (1997) reported a significant negative response (-0.8 mm) in the PM 1244 background, but no effects on PM 1215, PM 1220, and two others. Sheetz (1998) noted a significant loss (-0.8 mm) in a later RR release (in the PM 2326 background), as did McCall and Robinson (2001) in one of their releases (-0.5 mm). In small plot experiments, Kerby et al. (2000) calculated an average -0.1 mm decline in fiber length attributable to RR across seven backgrounds (including DP 5415). Moser et al. (2001) observed three negative responses, ranging from -0.4 to -0.8 mm, in RR among 10 paired comparisons. The DP 5415 background was included in their study, but was not significant.

Two negative responses in the PM 1220 background and three negative responses in PM 1244 were associated with the BG/RR genes in four experiments of the “BG/RR vs. Recurrent Parent” subset (Table 4). Algebraic mean deviations were -0.3 and -0.8 mm for PM 1220 and PM 1244, respectively. No significant differences in fiber length between BG/RR and their recurrent parents were reported by Williams et al. (1997) across four backgrounds (including PM 1220 and PM 1244) and by Kerby et al. (2000) across seven backgrounds in small plots. Sheetz (2000) described a -0.8 mm loss in one of his BG/RR cultivar releases, but not in the other. Five of 10 comparisons between BG/RR and their recurrent parents were significant ranging from -0.3 to -0.8 mm (Moser et al., 2001).

Comparisons of “BG/RR vs. RR” resulted in one negative response in four experiments for PM 1220, one positive response in four experiments for PM 1244, and two negative responses in two experiments for PM 2326 (Table 4). As in “BG vs. Recurrent Parent”, the results for fiber length were mixed.

Fiber Length Uniformity. Interactions of whole plots by subplots were significant for fiber length uniformity in one or two experiments (of four) per subset, and whole plot effects were significant in one to four per subset. The effects of BG, RR, and BG/RR on uniformity are presented as deviations from the recurrent parent (or RR) in Table 5.

When comparing “BG vs. Recurrent Parent”, no significant responses were measured in the PM 1215 background (Table 5). One positive and one negative response were associated with BG on DP 5415, so the effect of BG on length uniformity was not convincing. In the only other paper to discuss length uniformity (but using a different measure of it), Benedict et al. (1996) showed that five of seven BG lines were superior to their recurrent parent.

In the “RR vs. Recurrent Parent” subset, RR was positive in one experiment in the PM 1215 background and negative in two experiments in the PM 1244 background (Table 5). There were no effects on the PM 1220 and DP 5415 backgrounds.

In the “BG/RR vs. Recurrent Parent” tests, significant negative effects were associated with BG/RR in PM 1220 and PM 1244 in three and two experiments, respectively (Table 5). Mean deviation losses were -0.7 and -1.1% in those respective lines, demonstrating some consistency.

One significant negative effect each was associated with PM 1220 and PM 1244 in the “BG/RR vs. RR” subset (Table 5). None were found in PM 2326. Mean losses for PM 1220 and PM1244 were -0.7 and -0.1%, respectively.

Fiber Fineness. Interactions between whole plots and subplots were not significant for fiber fineness (i.e., micronaire) in the “BG/RR vs. Recurrent Parent” analyses, and one or two interactions were noted in the other subsets. Whole plot effects were significant in three to four experiments per subset. The effects of BG, RR, and BG/RR on fineness are presented as deviations from the recurrent parent (or RR) in Table 6.

Responses in “BG vs. Recurrent Parent” were negative in PM 1215 in one of four experiments and in DP 5415 in three of four (Table 6). Algebraic mean deviations across the four experiments were -0.1 and -0.2 units for PM 1215 and DP 5415, respectively. These differences are the same general magnitude and direction reported for the NuCOTN cultivars by

Table 5. Fiber length uniformity of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Fiber length uniformity (deviations from recurrent parent or RR in %)[z]			
	1998		1999	
	Altus	Tipton	Altus	Tipton
BG vs. Rec. Parent				
PM 1215	-0.5	-0.2	0.3	0.2
DP 5415	1.1*	-0.8	0.1	-0.7**
RR vs. Rec. Parent				
PM 1215	0.5	0.7*	-0.4	0.0
PM 1220	-0.4	0.0	-0.1	0.3
PM 1244	-0.9*	-0.5	-1.7***	-1.0
DP 5415	–	–	0.1	-0.5
BG/RR vs. Rec. Parent				
PM 1220	-1.1**	0.0	-0.8*	-0.9*
PM 1244	-0.5	-1.7***	-1.3**	-0.8
BG/RR vs. RR				
PM 1220	-0.7	0.0	-0.7	-1.2**
PM 1244	0.4	-1.2*	0.4	0.2
PM 2326	–	–	-0.7	0.2

[z] Means were 83.0, 83.5, 83.9, and 83.9% for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively. *, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

Kerby et al. (1995) and Jones et al. (1996). Significant differences for BG compared with its recurrent parent were not observed for five genetic backgrounds (including PM 1215) (Williams et al., 1997) and for seven backgrounds (including DP 5415) in small plots (Kerby et al., 2000). On the other hand, Wilson et al. (1994) showed six of nine BG lines were 0.3 to 0.8 units higher in micronaire than their recurrent parent. Benedict et al. (1996) reported that three of seven BG lines were significantly different from their recurrent parent by -0.3, 0.3, and 0.5 units. Moser et al. (2001) reported that four of nine differences in micronaire between BG and its recurrent parents were significant (two positive, two negative). The absolute size of those differences ranged from 0.1 to 0.2 units. The DP 5415 background was included in the latter study, but was not significantly different from its recurrent parent.

Comparisons of "RR vs. Recurrent Parent" were not significant in the PM 1215 and DP 5415 backgrounds (Table 6). Significant positive effects were associated with RR in the PM 1220 background in one of four experiments and for PM 1244 in all four experiments. Algebraic mean deviations in the PM 1220 and PM 1244 backgrounds were 0.2 and 0.4 units, respectively. Sheetz and Speed (1997) described one of their two RR cultivar releases as having significantly higher micronaire (0.2 units) than its recurrent parent. Williams et al. (1997) also reported higher micronaire for one background (PM 1244) by 0.3 units, but not for PM 1215, PM 1220, and two others. In later RR releases, Sheetz (1998) reported no effect on micronaire, whereas McCall and Robinson (2001) described a -0.1unit reduction. Kerby et al. (2000) detected no significant differences between RR and their recurrent parents in micronaire in small plot trials across seven backgrounds (including DP 5415). Moser et al. (2001) observed two significant comparisons of -0.2 and -0.4 units among 10 cultivar pairs. The DP 5415 background was included in their tests, but it was not significantly different from its recurrent parent.

Across backgrounds, "BG/RR vs. Recurrent Parent" was significant in three of four experiments with

Table 6. Fiber fineness (micronaire) of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Fiber fineness (deviations from recurrent parent or RR in micronaire units)[z]			
	1998		1999	
	Altus	Tipton	Altus	Tipton
BG vs. Rec. Parent				
PM 1215	0.1	-0.2	-0.2**	0.0
DP 5415	-0.3**	-0.4***	-0.2*	0.0
RR vs. Rec. Parent				
PM 1215	0.1	0.1	-0.1	0.2
PM 1220	0.2	0.0	0.2**	0.3
PM 1244	0.5***	0.3**	0.4***	0.4**
DP 5415	–	–	0.0	0.2
BG/RR vs. Rec. Parent				
Across backgrounds[y]	0.3***	-0.2	0.1*	0.1*
BG/RR vs. RR				
PM 1220	0.0	-0.2	0.0	-0.1
PM 1244	-0.2**	-0.4*	-0.4**	-0.4**
PM 2326	–	–	0.0	-0.2

[z] Means were 4.9, 5.0, 5.4, and 5.0 micronaire units for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively. *, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

[y] Genetic backgrounds in these analyses were PM 1220 and PM 1244.

an algebraic mean deviation of 0.1 units (Table 6). No significant response to BG/RR was reported by Williams et al. (1997) in four backgrounds (including the two tested here) nor by Sheetz (2000) in two backgrounds. Kerby et al. (2000) calculated an average reduction of -0.1 units in small plot studies across seven backgrounds. Moser et al. (2001) observed significant differences of -0.3, -0.1, and 0.1 units in three of 10 comparisons.

Significant responses for "BG/RR vs. RR" were present for micronaire in the PM 1244 background, but not in PM 1220 or PM 2326 (Table 6). Micronaire was negative in all four experiments for PM 1244 and averaged -0.4 units.

Fiber Strength. Interactions between whole plots and subplots were not significant for fiber strength in the "BG/RR vs. Recurrent Parent" comparisons; two or three were significant in each of the other subsets. Whole plot effects were significant in two or three of the four experiments per subset. The effects of BG, RR, and BG/RR on fiber strength are presented as deviations from the recurrent parent (or RR) in Table 7.

Comparisons of "BG vs. Recurrent Parent" were significant for fiber strength in only one of four experiments for the DP 5415 background and in none for PM 1215 (Table 7). Jones et al. (1996) and Kerby et al. [1995, 2000 (in small plots)] did not observe a significant difference between DP 5415 and NuCOTN 33B (its BG version), as well as other Bollgard and recurrent parent pairs (on one, one, and six other backgrounds, respectively). Williams et al. (1997) described a significant loss of strength in one background, but not in PM 1215 and three others. Moser et al. (2001) listed five of nine comparisons that were significant (one positive, four negative). One of those not significant was the DP 5415 background. Wilson et al. (1994) reported that eight of nine BG lines had significantly stronger fiber than their recurrent parent, and Benedict et al. (1996) reported the same for one of seven.

Differences between "RR vs. Recurrent Parent" were not significant in the PM 1215 and PM 1220 backgrounds (Table 7). A negative response was associated with RR in two of four experiments with an average loss of -9.6 kN m kg^{-1} for PM 1244. The

Table 7. Fiber strength of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Fiber strength (deviations from recurrent parent or RR in kN m kg^{-1})^{z}			
	1998		1999	
	Altus	Tipton	Altus	Tipton
BG vs. Rec. Parent				
PM 1215	-4.9	5.9	0.0	-3.9
DP 5415	12.8**	-3.9	4.9	-3.9
RR vs. Rec. Parent				
PM 1215	0.0	4.9	7.8	-4.9
PM 1220	2.9	0.0	6.9	-1.0
PM 1244	-17.7***	-7.8	-9.8*	-2.9
DP 5415	–	–	15.7***	15.7***
BG/RR vs. Rec. Parent				
Across backgrounds^{y}	-12.8***	-4.9	-6.9**	-10.8***
BG/RR vs. RR				
PM 1220	-10.8***	-5.9	-14.7***	-9.8
PM 1244	0.0	3.9	2.9	-7.8
PM 2326	–	–	-8.8	-6.9

^{z} Means were 248.2, 258.0, 262.9, and 260.9 kN m kg^{-1} for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively. *, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

^{y}Genetic backgrounds in these analyses were PM 1220 and PM 1244.

RR gene was positive in both tests with an average gain of 15.7 kN m kg^{-1} for DP 5415. No effects on fiber strength were observed for RR by Sheetz and Speed (1997), Williams et al. (1997), Sheetz (1998), Kerby et al. (2000), and McCall and Robinson (2001) on two, five (including PM 1215, PM 1220, and PM 1244), one, seven (including DP 5415), and one backgrounds, respectively. Moser et al. (2001) detected fiber strength losses associated with RR on two of 10 backgrounds, but no loss was detected in DP 5415.

Across backgrounds, BG/RR was significantly lower than the recurrent parents in fiber strength in three of four experiments with an average loss of -8.9 kN m kg^{-1} (Table 7). Williams et al. (1997) and Kerby et al. (2000) in small plots observed no significant responses in fiber strength to BG/RR across four (including PM 1220 and PM 1244) and seven (including DP 5415) backgrounds, respectively. One of Sheetz's (2000) two BG/RR cultivars lost strength relative to its recurrent parent. Moser et al. (2001) reported significant differences on four of 10 backgrounds (one positive, three negative).

In the PM 1220 background, BG/RR was significantly lower in fiber strength than RR in two of four experiments with an average loss of -10.3 kN m kg^{-1} (Table 7). Responses in the PM 1244 and PM 2326 backgrounds were not significant.

Fiber Elongation. Whole plot by subplot interactions for fiber elongation were not significant in the "RR vs. Recurrent Parent" subset, but they were significant in one or two experiments in the other subsets. Whole plots were significant in two or three of the four experiments per subset. The effects of BG, RR, and BG/RR on fiber elongation are presented as deviations from the recurrent parent (or RR) in Table 8.

Comparisons of "BG vs. Recurrent Parent" were not significant in the PM 1215 background, but were in two of four experiments for DP 5415 (Table 8). Because one response was positive and the other negative, a trend was not evident. Wilson et al. (1994) detected two of nine BG lines that were statistically different from their recurrent parent (0.6 and 0.7% higher).

Table 8. Fiber elongation of Bollgard (BG), Roundup Ready (RR), and BG/RR cotton under irrigation at Altus and Tipton, Oklahoma in 1998 and 1999

Genetic background	Fiber elongation (deviations from recurrent parent or RR in %)[z]			
	1998		1999	
	Altus	Tipton	Altus	Tipton
BG vs. Rec. Parent				
PM 1215	-0.1	0.0	-0.3	-0.1
DP 5415	0.3**	0.0	-0.2**	-0.2
RR vs. Rec. Parent				
Across backgrounds[y]	0.1	0.1	-0.2**	0.0
BG/RR vs. Rec. Parent				
PM 1220	-0.4***	0.0	-0.5***	-0.6***
PM 1244	-0.1	0.0	-0.1	-0.5**
BG/RR vs. RR				
PM 1220	-0.6**	0.0	-0.4**	-0.7***
PM 1244	-0.3	-0.2	0.0	-0.3***
PM 2326	–	–	0.2*	0.3*

[z] Means were 7.2, 7.2, 7.8, and 7.2% for Altus (1998), Tipton (1998), Altus (1999), and Tipton (1999), respectively. *, **, *** = significant differences between paired means at $P \leq 0.10$, 0.05, and 0.01, respectively, according to Fisher's protected LSD test.

[y] Genetic backgrounds in these analyses were PM 1215, PM 1220, and PM 1244 in both years and DP 5415 in 1999.

Across backgrounds, the "RR vs. Recurrent Parent" comparison was significant in only one (-0.2%) of the four experiments (Table 8) and was nonexistent when averaged across all four experiments (0.0%). Sheetz and Speed (1997) in their first two RR releases reported a 0.2% increase in elongation in one cultivar, but no significant differences in the other. In a later release, RR increased elongation by 0.6% (Sheetz, 1998).

When comparing "BG/RR vs. Recurrent Parent", significant loss in elongation was observed in three of four experiments in the PM 1220 background and in one of four experiments for PM 1244 (Table 8). Mean losses on those backgrounds were -0.4 and -0.2%, respectively. Neither of Sheetz's (2000) BG/RR releases differed in elongation from their respective recurrent parent.

For "BG/RR vs. RR", significant losses were detected in three of four experiments for PM 1220 and in one of four for PM 1244 with overall averages of -0.4 and -0.2%, respectively (Table 8). In PM 2326, the response was positive in both experiments, averaging 0.3%.

CONCLUSIONS

The BG genes were stable for lint yield across genetic backgrounds, but the RR gene was not. Relative to its recurrent parent, BG increased lint yield by an average of 6.2%. Depending upon genetic backgrounds and environments, RR decreased lint yield (as much as -22.2%), increased it (up to 12.7%), or had no significant effect. Because RR severely restricted lint yield on some backgrounds in some environments, caution should be exercised in choosing an RR cultivar. The lint yield increases associated with BG apparently overcame in BG/RR the occasional deficits associated with RR. BG/RR (like BG) often increased lint yield in individual experiments, but caused no significant yield reductions. BG also influenced picked lint percentage and fiber fineness. RR affected pulled lint percentage, fiber length and fineness. BG/RR impacted fiber length, length uniformity, fineness, strength, and elongation. Relative to RR, BG/RR altered picked lint percentage, fiber length uniformity, fineness, and strength. Traits not mentioned above relative to BG, RR, and

BG/RR were mixed in the direction of their response or were too small to be of statistical significance or practical value.

ACKNOWLEDGMENTS

The authors wish to thank J. C. Banks, Don S. Murray, and Jonathan M. Shaver, Oklahoma State Univ., for their reviews of this paper and for their many helpful suggestions toward its improvement. Financial support for this research was provided by the Oklahoma Agricultural Experiment Station. Published with the approval of the Director of the Oklahoma Agricultural Experiment Station.

REFERENCES

Andries, J.A., J.E. Jones, L.W. Sloane, and J.G. Marshall. 1969. Effects of okra leaf shape on boll rot, yield, and other important characters of upland cotton, *Gossypium hirsutum* L. Crop Sci. 9:705-710.

Andries, J.A., J.E. Jones, L. W. Sloane, and J.G. Marshall. 1970. Effects of super okra leaf shape on boll rot, yield, and other characters of upland cotton, *Gossypium hirsutum* L. Crop Sci. 10:403-407.

Anonymous. 1999. Roundup UltraMAX™ herbicide: Supplemental labeling for cotton with the Roundup Ready® gene in-crop applications (EPA Reg. No. 524-512) [Online]. Monsanto Company, St. Louis, MO. Available at http://www.greenbook.net/ASP/free.asp (verified 8 May 2002).

Anonymous. 2001. Roundup UltraMAX™ RT herbicide (EPA Reg. No. 524-512) [Online]. Monsanto Company, St. Louis, MO. Available at http://www.greenbook.net/ASP/free.asp (verified 30 May 2003).

Benedict, J.H., D.W. Altman, E.S. Sachs, W.R. Deaton, and D.R. Ring. 1991. Field performance of cotton genetically-modified to express insecticidal protein from *Bacillus thuringiensis* III. College Station, TX. p. 577. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 6-10 Jan. 1991. Natl. Cotton Counc. Am., Memphis, TN.

Benedict, J.H., E.S. Sachs, D.W. Altman, W.R. Deaton, R.J. Kohel, D.R. Ring, and S.A. Berberich. 1996. Field performance of cottons expressing transgenic CryIA insecticidal proteins for resistance to *Heliothis virescens* and *Helicoverpa zea* (Lepidoptera: Noctuidae). J. Econ. Entomol. 89:230-238.

Calhoun, D.S. 2001. ST 2454R-Stoneville's new Roundup Ready variety for the stripper market. p. 34. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Culpepper, A.S., and A.C. York. 1998. Weed management in glyphosate-tolerant cotton [Online]. J. Cotton Sci. 2:174-185. Available at http://www.jcotsci.org/1998/issue04/weed/art01/article.pdf.

Fehr, W.R. 1987. Principles of cultivar development. Vol. 1. Theory and technique. McGraw-Hill, Inc., New York, NY.

Hosfield, G.L., J.A. Lee, and J.O. Rawlings. 1970. Agronomic properties associated with the glandless alleles in two varieties of upland cotton. Crop Sci. 10:392-396.

Ihrig, R., and W. Mullins. 2001. A case for the subthreshold advantage of Bollgard cotton. p. 858-862. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Jenkins, J.N., J.C. McCarty, Jr., R.E. Buehler, J. Kiser, C. Williams, and T. Wofford. 1997. Resistance of cotton with δ-endotoxin genes from *Bacillus thuringiensis* var. *kurstaki* on selected lepidopteran insects. Agron. J. 89:768-780.

Jenkins, J.N., J.C. McCarty, Jr., and T. Wofford. 1995. Bt cotton a new era in cotton production. p. 171-173. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Jenkins, J.N., W.L. Parrott, and J.C. McCarty. 1991. Field performance of transgenic cotton containing the B.t. gene. p. 576. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 6-10 Jan. 1991. Natl. Cotton Counc. Am., Memphis, TN.

Johnson, E.M. 1996. Roundup Ready™ gene in cotton. p. 51. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Jones, K., T. Kerby, H. Collins, T. Wofford, M. Bates, J. Presley, J. Burgess, B. Beuhler, and R. Deaton. 1996. Performance of NuCOTN with Bollgard™. p. 46-48. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 9-12 Jan. 1996. Natl. Cotton Counc. Am., Memphis, TN.

Karner, M. 1998. Cotton insect control-1998. Current Rep. CR-7162. Rev. ed. Oklahoma State Univ. Coop. Ext. Serv., Stillwater, OK.

Kerby, T., B. Hugie, K. Howard, M. Bates, J. Burgess, and J. Mahaffey. 2000. Fiber quality comparisons among varieties for conventional, Bollgard® and Roundup Ready® versions. p. 484-488. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Kerby, T., T. Wofford, J. Presley, J. Thomas, M. Bates, and J. Burgess. 1995. Field performance of transgenic Bt cotton in multiple locations across the Belt. p. 574-576. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Legé, K.E. 1999. New early-maturing transgenic varieties from Sure-Grow: SG125B/R, SG125R, SG501B/R, SG585B, and SG585R. p. 64-65. *In* Proc. Beltwide Cotton Conf., Orlando, FL. 3-7 Jan. 1999. Natl. Cotton Counc. Am., Memphis, TN.

Little, T.M., and F.J. Hills. 1978. Agricultural experimentation: Design and analysis. John Wiley & Sons, Inc., New York, NY.

Mahaffey, J.S., J.R. Bradley, Jr., and J.W. Van Duyn. 1995. *B.t.* cotton: Field performance in North Carolina under conditions of unusually high bollworm populations. p. 795-798. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

McCall, L.L., and M.R. Robinson. 2000. New early- to mid-season transgenic varieties from Stoneville Pedigreed Seed Company. p. 113. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

McCall, L.L., and M.R. Robinson. 2001. ST 4793R - A new mid-season Roundup Ready® variety from Stoneville Pedigreed Seed Company. p. 32-33. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Meredith, W.R., Jr., C.D. Ranney, M.L. Laster, and R.R. Bridge. 1973. Agronomic potential of nectariless cotton. J. Environ. Qual. 2:141-144.

Moser, H.S., W.B. McCloskey, and J.C. Silvertooth. 2001. Performance of transgenic cotton varieties in Arizona. p. 420-423. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Moulton, J.K., and T.J. Dennehy. 2001. Beet armyworm resistance to CrylAc. p. 989-991. *In* Proc. Beltwide Cotton Conf., Anaheim, CA. 9-13 Jan. 2001. Natl. Cotton Counc. Am., Memphis, TN.

Nida, D.L., K.H. Kolacz, R.E. Buehler, W.R. Deaton, W.R. Schuler, T.A. Armstrong, M.L. Taylor, C.C. Ebert, G.J. Rogan, S.R. Padgette, and R.L. Fuchs. 1996. Glyphosate-tolerant cotton: Genetic characterization and protein expression. J. Agric. Food Chem. 44:1960-1966.

Perlak, F.J., R.W. Deaton, T.A. Armstrong, R.L. Fuchs, S.R. Sims, J.T. Greenplate, and D.A. Fischhoff. 1990. Insect resistant cotton plants. Bio/Technology 8:939-943.

Sheetz, R.H. 1998. Paymaster Cottonseed variety, PM 2145 RR. p. 44-45. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

Sheetz, R.H. 2000. Paymaster stripper cotton varieties PM 2280 BG/RR and PM 2326 BG/RR. p. 106-107. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Sheetz, R.H., and T. Speed. 1997. Paymaster Cottonseed cotton varieties PM 2200 RR and PM 2326 RR. p. 39. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 7-10 Jan. 1997. Natl. Cotton Counc. Am., Memphis, TN.

Turnipseed, S.G., M.J. Sullivan, J.E. Mann, and M.E. Roof. 1995. Secondary pests in transgenic Bt cotton in South Carolina. p. 768-769. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Webster, T.M. 2001. Weed survey-Southern states, 2001: Broadleaf crops subsection (Cotton, peanut, soybean, tobacco, and forestry). Proc. South. Weed Sci. Soc. 54:244-259.

Williams, C., J. Mitchell, M. Swindle, and D. Albers. 1997. Paymaster's picker type transgenic cotton varieties for 1997. p. 40-41. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 7-10 Jan. 1997. Natl. Cotton Counc. Am., Memphis, TN.

Williamson, D.R., and W.R. Deaton. 1991. Field performance of cotton genetically-modified to express insecticidal protein from *Bacillus thuringiensis*. VII. Loxley, AL. p. 577. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 6-10 Jan. 1991. Natl. Cotton Counc. Am., Memphis, TN.

Wilson, F.D., H.M. Flint, W.R. Deaton, and R.E. Buehler. 1994. Yield, yield components, and fiber properties of insect-resistant cotton lines containing a *Bacillus thuringiensis* toxin gene. Crop Sci. 34:38-41.

Wilson, F.D., H.M. Flint, W.R. Deaton, D.A. Fischhoff, F.J. Perlak, T.A. Armstrong, R.L. Fuchs, S.A. Berberich, N.J. Parks, and B.R. Stapp. 1992. Resistance of cotton lines containing a *Bacillus thuringiensis* toxin to pink bollworm (Lepidoptera: Gelechiidae) and other insects. J. Econ. Entomol. 85:1516-1521.

Wilson, F.D., and B.W. George. 1986. Smoothleaf and hirsute cottons: Response to insect pests and yield in Arizona. J. Econ. Entomol. 79:229-232.