THE ROLE OF HOST PLANT RESISTANCE IN LYGUS MANAGEMENT

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Abstract

This review covers reasons why more attention should be given to *Lygus spp*. HPR. Two changes have occurred in growing cotton that places a higher priority on developing cotton varieties with resistance to *Lygus spp*. than in previous years. The use of transgenic Bt has at present, greatly reduced the need for the use of insecticides to control the budworm-bollworm complex. Insecticides applied for these insects also reduced *Lygus* populations. Second, insecticides that once were effective in controlling *Lygus* are no longer effective. A third reason for using (HPR) is that use of another control method increases the effectiveness and longevity of use of other insect control measures.

Frego bract, okra leaf, glandless, and ultra plant smoothness increase susceptibility. Some types of smoothleaf cottons are tolerant to *Lygus* as judged by the wide use of these type varieties. Also, many hirsute (hairy) varieties are very susceptible to *Lygus*. Two traits that have been shown to be of great help in reducing *Lygus* populations are nectariless and earliness. Ten studies showed nectariless cotton reduces *Lygus* an average of 49%. Nectariless has no known deleterious effects on yield or fiber properties. Under heavy *Lygus* pressure it has consistently produced higher and earlier yields than nectaried varieties. Earliness is valuable in producing a crop quickly, thus escaping late season insect buildups and weather losses.

No one has shown that the *Bt* transgene increases susceptibility to *Lygus*. The genetic background a trait is placed into also influences the expression of that HPR trait. It would be advantageous to the cotton grower if nectariless, earliness, some forms of smoothleaf, and Bt. were combined in a modern conventional-transgenic breeding program.

Discussion

There was a time when many entomologists did not consider plant bugs, *Lygus* species, and related insects as major cotton pests. Other entomologists believed that while plant bugs could cause square shedding, the cotton plant would compensate and no yield loss would occur; and even in some cases the plant would overcompensate for early square losses and result in increased yields. While these views in general have changed, both breeders and entomologists did not believe breeding for resistance was necessary, since the usual insecticide applications for other insects was sufficient to control plant bugs. The added burden of selecting for an additional trait also apparently discouraged breeding for resistance.

Two recent changes in cotton culture have placed more emphasis on the need to utilize host plant resistance (HPR) to control plant bugs. First, the use of transgenic Bt varieties that at present are excellent in controlling the tobacco budworm, *Heliothis virescens,* and are good in controlling bollworms, *Helicoverpa zea*, (Jenkins et al., 1997). In 1997, it was estimated that about 19% of USA cotton was Bt (Anonymous, 1997). Second, plant bugs have developed resistance to many of our commonly used insecticides (Snodgrass, 1996). There is still another reason HPR should be given a higher priority in breeding and management, and that is that a combination of plant bug control measures compliments all components of insect control, and increases the likelihood that transgenics and/or new insecticides will be effective over a longer period of time.

Jenkins and Wilson (1996) in their review of HPR for cotton listed six traits that have varying effects on plant bug populations and yield. Four traits, glabrous (extreme smoothness), pilose (extreme hairiness), okra-leaf, and frego bract resulted in increased susceptibility. Another characteristic, earliness, interacts with plant bug control measures from both genetic and management strategies. Another question "Are transgenic Bt varieties more sensitive to plant bugs?" has recently been questioned by many growers. All of these topics will be covered in this review. This review does not attempt to site all publications on *Lygus* HPR, but will use a good sample of research to illustrate the prevailing results of various HPR issues. Jenkins and Wilson (1996) listed three species referred to as plant bugs. These are tarnished plant bug, *Lygus lineolaris* (TPB), western plant bug, *Lygus hesperus* (WPB), and fleahopper, *Pseudomatoe celis*. While the clouded plant bug, *Neurocolpus nubilus*, is sometimes mentioned as a pest, this review will focus primarily on *Lygus* as influenced by the traits given in Table 1.

Pubescence (Glabrous, Hirsute, Pilose, Smoothleaf, etc.)

Many genes control total pubescence characteristics of cotton. Lee (1985) listed five loci, the t_1 locus with at least six alleles, the t_2 locus has six, and the t_3 locus has three and the t_4 and t_5 loci each bearing two alleles. To complicate pubescence genetics further, several genes show interloci (epistasis) interactions. Pubescence characteristics that vary on the plant are location of hairs, hair diameter, hair density, amount of branching of hairs, angle of growth, glandular or nonglandular, and age of hairs at senescence. The large number and complexity of pubescence inheritance often results in confusion when it is characterized and related to TPB susceptibility. The t_1 and t_2 loci impart extreme susceptibility to TPB (Laster and Meredith, 1974). The t_3 loci, when homozygous, produces smoothness, but less than

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that of t_1 and t_2 varieties. On many t_3,t_3 varieties, numerous hairs surround the terminal and juvenile squares giving them some protection from TPB for about 10 days. This varies depending on weather conditions and genetic background. Laster and Meredith (1974) reported two varieties with t_3,t_3 genotype that were intermediate in sensitivity to TPB. They also found that one hirsute variety, 'Coker 201', was very sensitive to TPB. The results taken from Jones et al. (1983), shows that 'Stoneville 213', which is very hairy (t_3^h,t_3^h), and 'Deltapine 16', which has t_3 smoothness have about the same tolerance to TPB. Meredith (unpublished data) compared hairy 'DES 119' with genotype t_3^h,t_3^h with smooth DES with genotype t_3,t_3 in eight tests. In 1992 and 1993, when TPB was not a problem, the average of hairy and smoothleaf isolines was 909 and 898 lbs. lint acre^{-1}, respectively; a yield difference of 11 lbs. In 1994, when we were unable to control TPB, the yields for hairy and smoothleaf was 1030 and 989 lbs. lint acre^{-1}, respectively; or a difference of 41 lbs. The interaction between smooth and hairy isolines was not significant. These studies and the successful use of many t_3,t_3 smoothleaf varieties show that some types of smoothness in appropriate genetic backgrounds can possess sufficient tolerance to TPB.

Jenkins et al. (1977) evaluated 249 cotton lines for TPB resistance. They detected 30 resistant lines of which 27 were very hirsute and three were smoother than average. However, many hairy cottons in this study were very susceptible to TPB. Frequently, hairy cottons which were bred and selected in areas where TPB are not a problem are found later to be very susceptible to TPB. Several cotton varieties fit this pattern.

The conclusion from these studies is that the type of smoothness and hairiness and the genetic background they are placed in determine susceptibility, tolerance, or resistance to TPB.

Okraleaf, Frego Bract, Gossypol Content

Jones, (1982) in his review of the use of open-canopy cottons reported that in their Louisiana studies, okraleaf and super okraleaf were more attractive to TPB, often having twice as many TPBs as normal leaf isolines. Jones et al. (1983) reported that the frego bract lines developed to reduce boll weevils (*Anthonomus grandis grandis*) populations had about four times more TPB than Stoneville 213 and Deltapine 16 (Table 2). The frego bract lines' yield was 13% less than the checks. Laster and Meredith (1974) reported that frego bract was the most susceptible to TPB of any cotton they evaluated. Low gossypol levels produced by the glandless genes gl_2 and gl_3 and high gossypol lines, both indicate that resistance to plant bugs is related to high gossypol levels (Jenkins and Wilson, 1996). More information on these traits will be given in the section on pyramiding traits (combining traits) and HPR breeding.

Nectariless

A review on the nectariless traits' impact on cotton insects was presented by Meredith (1978). Nectaries are located on the midrib and sometimes on other prominent leaves of upland cotton. Also, there are three outer involucral nectaries and three inner involucral nectaries located between the calyx and involucre. Nectar secreted by the nectaries attracts and furnishes food and moisture for many beneficial and harmful insects. The source of the nectariless trait is the wild tetraploid species from Hawaii, *Gossypium tomentosum*. Meyer and Meyer (1961) described the nectariless trait and its inheritance when it was transferred to upland cotton. The presence of two recessive genes, ne_1, and ne_2, results in the nectariless trait. Holder (1967) determined that ne_1 and ne_2 were linked to the glandless trait (no gossypol) genes, gl_2, and gl_3, respectively.

It has been well documented, as shown in Table 3, that the nectariless trait reduces both the TPB and WPB. These 10 studies show reductions ranging from 26.2 to 66.6% with an average of 48.8%. Schuster et al. (1976) reported that in laboratory studies TPBs raised on nectariless cottons averaged 0.9 eggs/female and 11.3 eggs/female on nectaried cotton. Generally, when cages confine TPB, the reductions are greater than in field studies. It may be that the ability of TPB to migrate in open fields allows them to find more food sources. As indicated in the review by Meredith (1978), nectariless also results in decreased populations and damage by tobacco budworms, bollworms, cotton leaf worm *(Alabama argillacea)*, cabbage looper (*Trichoplusia ni*), and fleahoppers. Wilson (1982) also reported significant reductions in pink bollworm (*Pectinophora gossypiella*) numbers and damage.

Of importance is the effect nectariless has on predatory insects of cotton pests. Meredith et al. (1973) did not detect any differences in lady beetles (*Hippodamia convergens*) and big eyed bugs (*Geocoris* spp.) for nectaried and nectariless isolines. However, Schuster et al. (1976) showed that with early season sampling in Texas, nectariless reduced fleahoppers 60.5% and total natural predators 34.8%. Their late season sampling resulted in reductions in fleahoppers of 12.6% and natural enemies 34.4%. In Mississippi, Schuster et al. (1976) reported fleahoppers were reduced in both 1973 and 1974 by 58.2 and 69.4%, respectively. In the same studies, TPB were reduced by 63.8 and 69.4%, respectively. Total predators were reduced 29.1 and 27.0% in 1973 and 1974, respectively. Scott et al. (1988) reported similar results in natural enemies. Utilizing this data involving 14 and 18 growers in 1981 and 1982, respectively, using both nectaried and nectariless fields; nectariless reduced TPB adults and nymphs 37.6% and total predators 27.2%. The major reductions in predaceous insects were *Geocoris* spp. (33.1%) and *Nabes* spp. (44.0%). In general, most studies measuring both target insects and their natural enemies have shown a greater reduction in target insects than in the natural enemies; thus not inhibiting the use of IPM strategies.

Yield, yield components, and fiber properties of three BC_6F_4 nectariless cottons and their recurrent variety parents are given in Table 4 (Meredith et al. 1973). In this study, conducted at six locations in 1971, a variety x nectariless interaction was detected. Nectariless 'Stoneville 7A' produced lower yields than its nectaried recurrent parent did. Nectariless 'Deltapine Smoothleaf' produced higher yields and no difference in yield was detected for 'Dixie King' isolines. The significant variety x nectariless interaction implies that the genetic background a trait is placed into, has a major impact on the efficient use of that trait. The average yield of nectaried and nectariless was 1081 and 1077 kg ha^{-1}, respectively. Nectariless tended to be earlier in maturity than its nectaried parents. The only fiber property that was effected by nectaried vs. nectariless comparisons was 2.5% span length with average lengths of 1.19 and 1.18 inches, respectively. This degree of shortness, less than 1%, should not be a problem in a breeding program. The study by Meredith et al. (1973) was conducted with a full season insecticide program.

McCarty, et al. (1983) conducted a series of studies from 1978-80 to determine the effects of early season and no early season control on nine nectaried and nine nectariless cottons and their possible interactions with nectariless. Table 5 shows the yield of three commonly used commercial nectaried varieties and similar nectariless types. With early season control of TPB there was little difference in the yield of nectaried and nectariless types; yields were 1001 and 1004 kg ha^{-1} lint, respectively. However, without early season insect control, nectariless produced significantly higher yields than nectaried varieties. The average lint yield loss for nectaried cottons was 151 kg ha^{-1} and that for nectariless was 77 kg ha^{-1}. In these studies nectariless was earlier than nectaried cottons. From the yield stability analyses they concluded that the nectariless trait had wide adaptability.

Earliness

Earliness has the benefit of escaping the late season insect buildups and weather, and offers growers a more profitable way to manage cotton than does full season cottons. Earliness can be achieved by early season insect control and other management practices, and the use of early maturing varieties. Bridge and McDonald (1987) reported that early maturing varieties began to be used in the late 1970s. They state "The percentage of early maturing varieties increased significantly from 1978 to 1986 in the Mid-South and Texas." In 1978 early maturing varieties accounted for an average of 16.7% of six mid-south states cotton. In 1986, for the same six states, the average for early maturing varieties was 89.5%. Bridge and McDonald (1987) also reported that from 1959 to 1986, the average number of increased earliness in days from planting to final harvest (regression of earliness on years) was 1.2, 2.5, 1.3, and 2.4 days per year for Stoneville and Sumner, MS; College Station, TX; and Florence, SC, respectively. Accompanying these increases in earliness, yields were also increased up until about 1984.

Norman and Henneberry (1987) reported that short season production generally requires less input for insect control and has higher yield than conventionally grown cotton in the Lower Rio Grande Valley of Texas. Insecticide use ranged from 0 to 24% less and yields ranged from 0 to 25% greater in short season system fields compared to conventional plantings. While earliness is not an HPR trait *per se,* it does offer aid by escaping problems in the control of insect pests and also less use of insecticides.

Combinations of Traits, Pyramiding, and/or Stacked Genes

As mentioned earlier in this manuscript, the genetic background in which a trait(s) are placed has an effect on that trait's usefulness. As indicated in Table 2, the intrusion of the nectariless trait (Jones, 1983) into frego bract strains resulted in considerable reduction as related to TPB damage. In Table 5, ultra smooth 'Coker 420's' yield was increased by nectariless, 75 lbs. lint $acre^1$ with early season insect control while other varieties showed little yield difference for nectaried and nectariless comparisons. In Table 6, results of combinations of traits from McCarty et al. (1983) study are given. Nectariless had a major positive effect in reducing TPB yield losses when combined with the glandless trait; a loss of only 15 lbs. lint per acre. With okraleaf, which had also been backcrossed into Stoneville 7A, the nectariless trait had little effect on yield performance when grown with and without early season insect control. Jones, et al. (1988) reported that the Stoneville 213 genetic background was more favorably responsive to open canopy traits than the MD 65-11 genetic background. Okraleaf was the superior leaf shape on the LA 213 genetic background, ranging in yield from 98 to 126% of normal leaf. Sub-okra was the superior leaf shape on the MD 65-11 genetic background ranging in yield from 81 to 112% of normal leaf.

Milam et al. (1982) developed five improved frego bract lines that out yielded the Stoneville 817 frego check. These strains were earlier in maturity and were nectariless. Jones et al. (1989) reported a frego bract nectariless strain that had exceptional adaptability across environments.

Combining traits into one improved variety, pyramid breeding, and stacked genes are all terms used to describe combining traits or characteristics into a new improved cotton. This has long been the goal of plant breeders. Progress in breeding for *Lygus* spp. resistance is no exception to this objective.

Use of Transgenic Gene from *Bacillus Thuringiensis* (*Bt*)

In the last several years, the most discussed new technology has been the use of transgenic *Bt*. Jenkins et al. (1997) have clearly shown that *Bt* produces excellent resistance to the tobacco budworm and good resistance to the bollworm. The budworm/bollworm complex has generally been the most destructive and most responsible for insecticide use of any insect in the Mississippi Delta and much of the Midsouth. *Bt* also gives excellent control of the pink bollworm (Wilson, et al., 1982).

With respect to *Lygus* management, many growers and consultants believe *Bt* is more sensitive to *Lygus* than conventional varieties. Hardee and Bryan (1997) summarized the results in Table 7 from a two-year study. The bottom row of Table 7 shows that the sum total of adults and nymphs observed by three sampling methods was 30.0 for *Bt*, 29.3 for non-Bt, and 21.7 for nectariless. These results show no consistent trend for *Bt* vs. non-*Bt*, but the nectariless trait reduced TPB by 27.7% of that for the *Bt* variety and 25.9% less for the non-*Bt* variety. Wilson et al. (1992) reported the average number of WPB for non-*Bt* Coker 312, mean of three *Bt* lines, and nectariless MD51ne to be 13.3, 15.0, and 8.2, respectively. Meredith (1997) presented results from a one-year study at Stoneville conducted in 1996. Three insect control regimes were used; a complete budworm-bollworm and TPB control regime; budworm-bollworm control only, no TPB control; and complete TPB control, but no budworm-bollworm control. Since no bollworm/budworm populations occurred, it yielded 2.2% (not significant) higher than the complete program, it was not included in the summary. Note the yield loss for first harvest and total yield for *Bt* vs. non-*Bt* parents is almost identical; 85 vs. 87 lbs. per acre. Lint acre^{-1} for first harvest, respectively; and 145 and 147 lbs. lint acre^{-1} for total yield, respectively. Also note that Stoneville 474 lost no yield due to TPB. This stability of yield, probably is one reason for its grower popularity in the Midsouth and may be related to the extreme hairiness of Stoneville 474.

Collectively, the three studies cited show no trend that *Bt* transgenics are any more or less susceptible to TPB than non-*Bt* varieties. Since *Bt* fields receive less insecticides, it should be expected that more TPB will be in *Bt* fields. This begs the question of one of the primary objectives of this conference, "How do we manage *Bt* cotton for *Lygus*?"

Summary

This review shows several HPR methods for reducing *Lygus* populations and their damage. Some, but not all, forms of pubescence (hairiness), can reduce *Lygus* and their damage. Some, glabrous (smoothleaf) have good tolerance to *Lygus*. By far the most consistent trait to suppress *Lygus* has been the nectariless trait. At least 10 studies show reductions in *Lygus* due to this trait and several have shown that the nectariless trait has no deleterious agronomic effects and produces significantly higher yields than nectaried cottons when *Lygus* populations are high. The best breeding method to utilize the benefits of nectariless is through conventional breeding and not the backcross method.

Many breeders do not like to work F_2 populations because of the low frequency of nectariless plants, 6.25%. However, a random sample of F_2,F_3 plant to progeny rows will show over 50% of the time for either a 15:1 or 3:1 nectariless plants segregation in the F_3. Bulk breeding in environments with little out crossing will result in an increase of nectariless plants. In the F_2, F_3, and F_4 generations one would expect 6.25, 14.1, and 19.1% nectariless plants. The easiest method to produce nectariless populations is to cross nectariless x nectariless which produces only nectariless progenies.

Earliness is well documented as a practical way to escape insect and weather cotton losses and to reduce dependency on insecticides. *Lygus* is one of the major insects that fill the void created in *Bt* cotton. As of this date no nectariless *Bt* varieties have been released to growers. The combination of earliness, pubescent type, nectariless, and *Bt* through conventional breeding methods offers a great potential for protecting the crop, increasing yields, reducing dependency on insecticides, and reducing cost of production in a friendly environment.

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Table 1. Traits and characteristics of cotton that influence plant bug susceptibility.

Trait	Increases	Decreases
Glabrous	S	
Pilose	S	
Okraleaf	S	
Frego	S	
High Gossypol		R
Nectariless		R
Earliness		R
Bt	?	

R indicates increased resistance
S indicates increased susceptibility
? depends on variety background

Table 2. Effect of tarnished plant bug on flower damage and yield[1].

Variety	% Flower Damage	Yield lbs. Lint/Acre	% of Checks
Stoneville 213	14	1135	100
Deltapine 16	16	1127	100
Frego Nectariless	47	1092	97
Frego Nectaried	64	987	87

[1]Table is a summary of research by Jones et al., 1983

Table 3. Effect of the nectariless trait on populations of Lygus in cotton[1].

Year	Reference	% Reduction
1972	Meredith et al.	55.6
1973	Meredith et al.	56.8
1973	Schuster and Maxwell	63.6
1974	Laster and Meredith	43.2
1976	Schuster et al.	66.6
1984	Bailey et al.	64.7
1988	Scott et al.	37.6
1997	Hardee and Bryan	29.7
1992	Benedict et al.[1]	26.2
1992	Wilson et al.[1]	43.7
Average		**48.8**

[1]Reduction % of Lygus hesperus; all others are L. lineolaris.

Table 4. Average yield, yield components, and fiber properties of three BC_6F_4 nectariless cottons and their recurrent varieties as determined from six environments.

Variety Type	Total Lint kg	1st Harvest ha^{-1}	Lint %	Boll Wt. g	Seed Wt. G	Span Length 50%	in 2.5	T_1	Mic.
Nectaried	1081	557	34.6	6.4	13.3	0.58*	1.19*	18.8	4.7
Nectariless	1077	584	34.6	6.3	13.1	0.57	1.18	18.5	4.7

Data from Meredith et al., 1973

Table 5. Average yield (kg ha^{-1}) of three commercial varieties and similar nectariless lines when grown with and without early season insecticide control of tarnished plant bugs.[1]

	Type of Early Season Insect Control		
Variety Type	With	Without	Difference
DPL 61	1064	876	188
DPL 7146 ne[2]	1044	946	98
STV 213	1057	904	153
STV 825 ne[2]	1011	1002	9
Coker 420	883	769	114
Coker 420 ne[2]	958	832	126
Averages			
Nectaried	1001	850	151
Nectariless	1004	927	77

[1] Data from McCarty et al. (1983), average of 18 tests (3 yrs. And 6 locations).
[2] ne = nectariless

Table 6. Average yield (kg ha^{-1}) of three nectaried and nectariless lines when grown with and without early season control of tarnished plant bugs.[1]

	Type of Early Season Insect Control		
Variety Type	With	Without	Difference
STV 7A-glandless	822	751	131
STV 7A-glandless ne[2]	844	829	15
HGBR8[3]	910	782	128
HGBR8 ne[2]	950	863	87
STV 7A okraleaf	1008	906	102
STV 7A okraleaf ne[2]	1046	927	119

[1] Data from McCarty et al., 1983, average of 12 tests (2 yrs. And 6 locations).
[2] ne = nectariless
[3] HG – High gossypol

Table 7. Average number of tarnished plant bugs observed by three methods at Stoneville, MS.[1]

	Type Variety		
Type Observation	Bt	Non-Bt	Nectariless
Visual–Adults	1.5	1.3	1.3
Nymphs	2.7	2.0	1.6
Drop Cloth–Adults	2.9	3.4	2.6
Nymphs	13.5	15.4	9.8
Sweep Nets–Adults	5.5	4.2	3.4
Nymphs	4.1	3.0	3.0
Total – Adults	9.7	8.9	7.3
Nymphs	20.3	20.4	14.4
Adult + Nymphs mean	30.0	29.3	21.7

[1]Data is a summary of a 2-year study by Hardee and Bryan, 1997

Table 8. First harvest (Sept. 4) and total lint yield $acre^{-1}$ for four Bt varieties, their four recurrent parent varieties, and Stoneville 474; when grown with a budworm/bollworm TPB insecticide control program and only a budworm/bollworm program.[1]

	Sept. 4 harvest			Total yield by Oct. 11, 1996		
Variety	TPB Control	No TPB Control	Differ-ence	TPB Control	No TPB Control	Differ-Ence
DPL 33B	614	453	161**	1324	1142	182**
DPL 35B	441	431	10	1191	1062	129**
DPL 20B	572	463	109*	1259	1143	116*
PM 1220B	582	521	61	1236	1084	152**
Average	552	467	85**	1252	1108	145**
DPL 5415	331	272	59	1079	903	176**
DPL 35	451	345	106*	1063	943	120*
DPL 20	584	487	97	1089	983	106*
PM 1220	621	534	87	1262	1076	186**
Average	497	410	87**	1123	976	147**
STV 474	627	672	-45	1172	1171	7
LSD 0.05	98	98		97	97	

[1] Data from 1996 study by Meredith, presented at MS Agric. Expo 1997
*, ** indicates statistically different than transgenic TPB control mean