From Conventional Host Plant Resistance (HPR) to Transgenic Crops

- Know the three main categories of traditional HPR categories … nonpreference, antibiosis, and tolerance
- What does it mean to describe resistance mechanisms as oligogenic versus polygenic … in which category would Bt crops fall?
- What is a “virulent” biotype?
- What are the 4 approaches to delaying the development of virulent biotypes that overcome resistance mechanisms?
- Why put Bt genes into plants when Bt sprays already provided some effective insect control?
- Into what US crops have Bt genes for insect resistance been inserted?
- What are the main approaches to preventing the development of virulent biotypes (insecticide resistance) in response to Bt crops?

Some history

- 1792: ‘Underhill’ wheat reported to show some resistance to Hessian fly
- 1830s: ‘Winter Majetin’ apples reported to be resistant to woolly apple aphid
- 1860s: C.V. Riley grafted European grapes on American rootstocks resistant to grape phylloxera (introduced from N. America) (also introduced downy mildew … led to “Bordeaux mix” fungicide)
- 1914: At Kansas State University R.H. Painter began breeding efforts for the scientific development of cultivars resistant to Hessian fly. Painter is widely recognized as the “Father of Host Plant Resistance.”
- Important targets for HPR have included Hessian fly, greenbug, spotted alfalfa aphid, wheat stem sawfly, and European corn borer … and many others

References on traditional host plant resistance to insects

- Basics of Insect Resistance to in Plant Breeding
  - http://www.agriinfo.in/default.aspx?page=topic&superid=3&topicid=2144
- Plant Breeding for Insect Resistance
  - http://www.agriinfo.in/default.aspx?page=topic&superid=3&topicid=2143
- Teetes, G. 1996. Plant Resistance to Insects: A Fundamental Component of IPM
  - (http://ipmworld.umn.edu/teetes)
- Radcliffe, R.H. 2000. Breeding for Hessian Fly Resistance in Wheat.
  - (http://ipmworld.umn.edu/ratcliffe-hessian-fly)

Basics of Insect Resistance to in Plant Breeding

- Morphological Factors
  - Hairiness (cotton and beans), color (red versus green cabbage), solid stem (wheat stem sawfly) toughness of tissues (cotton)
- Physiological Factors
  - Osmotic concentrations, gummy exudates
- Biochemical Factors
  - High silica content in rice (stem borer), benzyl alcohol in wheat and barley (greenbug), gossypol and tannins in cotton (bollworm and others), saponin in alfalfa (aphids), DIMBOA in corn (corn borer), others.
  - Primary metabolites
    - Enzymes, hormones, carbohydrates, lipids, proteins, and phosphorous compounds
  - Secondary metabolites
    - “Token” odor and taste stimuli (terpenes, flavonoids, coumarins, alkaloids)

Host suitability

- Nutritional quality
- Absence of toxic compounds
- Components that allow normal development and fecundity

Plant Breeding for Insect Resistance

- Nonpreference (= antixenosis)
  - Deters pest before colonization … see discussion in this reference
- Antibiosis … … see discussion in this reference
  - Toxic metabolites, absence or imbalance of essential nutrients, inhibitory enzymes
  - Results are death, abnormal growth rates, failure to pupate, etc.
- Tolerance
  - Insect develops and causes injury (but little or no damage); plants yield normally anyway

Nonpreference

- Chemical
  - Attractive chemicals absent (reduction or absence of cucurbitacins in cucurbits)
  - Repellent chemicals present
- Morphological
  - Hairs / pubescence deters leafhoppers (soybean), favors *Heliothis* (cotton). Hooked hairs (trichomes) on beans deter leafhoppers and corn borers. Silk tip characteristics influence corn earworm in corn.

Antibiosis

- Examples include
  - DIMBOA in corn
  - Low amino acid levels in peas
  - Resistance mechanisms in wheat against Hessian fly
  - Induced resistance as a result of injury and subsequent phytoalexin production in soybean
  - (and now Bt transgenic crops)

Tolerance

- Soybeans to defoliators (but do cultivars differ as a result of selections in breeding programs?)
- Corn to corn earworm (long silk channels), corn rootworm (root re-growth after feeding injury), and corn borer (thick, strong stalks)

Genetic basis for resistance

- Oligogenic: major gene (one or a few)
  - Examples include resistance to Hessian fly and greenbug in small grains.
- Polygenic: many genes
  - Non Bt corn varieties with resistance / tolerance to European corn borer
- ~~Cytoplasmic:~~
  - ~~A factor in plant disease resistance, but not a known factor in insect resistance~~

Insects evolve in response resistant varieties

- ‘Virulent’ biotypes … insects that are resistant to the plant’s resistance mechanisms
  - Brown planthopper in rice
  - Hessian fly in wheat
  - Corn rootworms to Bt corn?
  - Many other examples make HPR breeding an ongoing endeavor

Deployment of resistance genes to postpone biotype development

- Sequential cultivar release
  - Use until failure, switch to next gene … use it until you lose it
- Pyramiding
  - Combine multiple resistance genes (against one pest) in the hybrid or cultivar … ~ the same as mixtures of insecticides
- Gene rotation
  - Use cultivars with one gene in one season, then a different resistance gene the next … ~ the same as rotations of insecticides
- Crop multilines
  - Different resistance genes in different plants of the same crop within a single field of area … ~ the same as mosaics for insecticides

TABLE 9.7 Interaction of Genes for Resistance in Wheat Cultivars with Virulence Genes in Biotypes of the Hessian Fly, *Mayetiola destructor* (Say)[a]

Wheat Cultivar and Gene(s) for Resistance	Biotype and Gene(s) for Virulence									
	Great Plains (none)	A (s)	B (s, m)	C (s, k)	D (s, m, k)	E (m)	F (k)	G (m, k)	J (s, m, a)	L (s, m, k, a)
Turkey (none)	S	S	S	S	S	S	S	S	S	S
Seneca (H_7, H_8)	R	S	S	S	S	R	R	R	S	S
Monon (H_3)	R	R	S	R	S	S	R	S	S	S
Knox 62 (H_6)	R	R	R	S	S	R	S	S	R	S
Arthur 71 (H_5)	R	R	R	R	R	R	R	R	S	S

[a]Adapted from Gallun and Khush 1980, with permission of John Wiley & Sons, Inc.
[b]R = resistant; S = susceptible.

Hessian fly biotypes are listed across the top. Turkey (a susceptible variety) is – perhaps obviously – susceptible to all biotypes. Listed biotypes overcame one or more genes that conferred resistance as a sequence of genes were bred into other varieties. Biotype L has overcome all of these antibiosis resistance mechanisms.

Table 5. Resistance rating of wheat entries to Hessian fly populations from Alabama, Idaho, Illinois, Indiana, Maryland, Mississippi, North Carolina, Virginia, and Washington

Hessian fly population	Wheat entry (resistance gene)							
	9811[a] (*H*13)	17960[a] (*H*13)	9547[a] (Unknown)	Blueboy (None)	Monon (*H*3)	Magnum (*H*5)	Caldwell (*H*6)	Seneca (*H*7*H*8)
Southeast								
HE-AL	R	R	S	S	S	S	S	R
MR-AL	R	R	S	S	S	S	S	S
TA-AL[b]	R	—	S	S	S	S	S	S
WA-AL[b]	R	—	S	S	S	R	S	R
PR-MS[c]	R	—	MR	S	S	S	R	S
Mid-Atlantic								
CA-MD	MR	MR	S	S	S	S	S	S
LN-NC[b]	R	—	MR	S	S	S	R	S
NK-VA	MR	S	S	S	S	S	S	S
Midwest								
AX-IL[b]	R	—	S	S	S	S	S	S
PO-IN	R	R	MR	S	S	S	S	S
TP-IN	R	R	S	S	S	S	S	S
Northwest								
NP-ID	R	R	R	S	MR	R	R	R
DU-WA-1	R	R	MR	S	S	MR	S	R
Laboratory Colony								
Bio. 'L'	R	R	S	S	S	S	S	S

Resistance ratings: R = 90–100% resistant plants; MR = 76–89%; S = 0–75%. Ratings are based on nontransformed mean values shown in parentheses in Table 4.
[a] INW9811, CI 17960-1-1-2-4-2-10 and P9547B1-12, respectively.
[b] Insufficient seed of CI 17960 available for testing against these populations.

Journal of Economic Entomology, Volume 93, Number 4, August 2000, pp. 1319-1328.

More considerations for host resistance in IPM

- Possible costs of resistance
  - Yield
    - Resistant plants may devote too much energy to defense mechanisms or otherwise be lower yielders
  - Response to other insects or pathogens
  - End-use characteristics
    - Texture, flavor, consumer demands (Honeycrisp vs. Goldrush apples)
- Nature of antibiotic or antixenotic compounds
  - Endophytes in fescue; weevil-resistant alfalfa

Overall summary …

- Traditional breeding methods (selection, crossing, backcrossing, etc.) have been used to successfully produce crops with resistance to certain insects
  - Time consuming
  - Not always without “costs” in terms of yield, crop quality
  - Not all crops, not all insects
  - Resistance generally is not immunity … and that’s ok
  - Breeding programs are ever-ongoing because virulent biotypes develop
- And … back to microbial biological control, spray applications of *Bacillus thuringiensis* can be used to control certain insects … European corn borer on corn, for example (at least partially)

So … why put *Bacillus thuringiensis* genes into plants to create transgenic plants resistant to insects?

- *Bt kurstaki* (one of the subspecies that is toxic to Lepidoptera larvae) has been used as an insecticide applied to plant surfaces since the 1960s
  - Fermentation product formulated as liquids, wettable powders, and dusts
  - Formulated products contain bacterial spores and crystalline protein toxins
- Limitations:
  - Short residual on plants (degraded by ultraviolet light
  - Must be ingested by larvae to kill them
  - Insects that feed only a little or not at all on plant surfaces before tunneling into stalks, fruit, etc. usually are not controlled (codling moth in apples, corn earworm in sweet corn)

Some history … Mycogen first developed a transgenic system for Bt in the 1980s early 90s

- Inserted gene for Bt toxin production into *Pseudomonas syringae*, then heat-killed these bacteria, resulting in a thicker wall that better protected the toxin from U-V degradation
  - Products: MVP (against Lep larvae) and M-Trak (against Colorado potato beetle larvae)
  - 3 to 5 days residual stability instead of 1-2 days for earlier formulations
  - No living transgenic organism released into the environment

Next steps moved genes for toxin production into plants

- Transgenic crops in the US include:
  - Bt corn
    - First for European corn borer resistance, now also for resistance to other Leps and corn rootworm resistance
  - Bt potatoes
    - for Colorado potato beetle resistance (no longer marketed)
  - Bt cotton
    - For tobacco budworm and cotton bollworm resistance)

Transgenics in HPR

- "Transgenic" organisms contain genes taken from another species by means of molecular techniques.
- In Bt corn, Bt cotton, and Bt potatoes, genes that direct Bt toxin production have been inserted into plants so that seeds (or seed pieces) carry the instructions for plants to produce Bt toxins for insect resistance (host plant resistance to insects).
- Although crop yields and effectiveness of insect control vary among Bt hybrids and transgenic technologies, Bt plants generally are very effective for controlling target insects – especially European corn borer.
- Issues that still spark disagreement include:
  - human toxicity / allergenic response (real or feared)
  - "escape" of the Bt genes into wild plants
  - insect resistance to Bt toxins ... Resistance management proposals rely on the use of an untreated "refuge“
  - Potential threat to nontarget organisms (monarchs, specific parasitoids, etc.)
- These issues influence consumer decisions and therefore market and export opportunities.

So let’s look at corn …

http://www.msuent.com/assets/pdf/28BtTraitTable2016.pdf

Table 2. Bt corn trait packages, with spectrum of control and refuge requirements. Updated April 2016

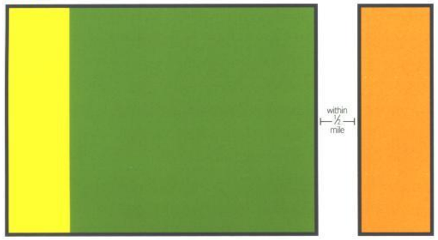
Trait Family Product	Bt protein(s)	Insects controlled or *suppressed* Above-ground	In soil	Herbicide tolerance	Refuge %, placement for the MIDWEST
AGRISURE					
Agrisure 3010, 3010A	Cry1Ab	ECB SWCB *CEW FAW SB*	---	GT LL	20% structured ½ mile
Agrisure 3000GT, 3011A	Cry1Ab mCry3A	ECB SWCB *CEW FAW SB*	RW	GT LL	20% structured w/in, adj
Agrisure Viptera 3110	Cry1Ab Vip3A	BCW CEW ECB FAW SB SWCB TAW WBC	---	GT LL	20% structured ½ mile
Agrisure Viptera 3111	Cry1Ab mCry3A Vip3A	BCW CEW ECB FAW SB SWCB TAW WBC	RW	GT LL	20% structured w/in, adj
Agrisure 3122 E-Z Refuge	Cry1Ab Cry1F mCry3A Cry34/35Ab1	BCW ECB FAW SB SWCB WBC *CEW*	RW	GT	5% RIB
Agrisure Viptera 3220 E-Z Refuge	Cry1Ab Cry1F Vip3A	BCW CEW ECB FAW SB SWCB TAW WBC	---	GT	5% RIB
Agrisure Duracade 5122 E-Z Refuge	Cry1Ab Cry1F mCry3A eCry3.1Ab	BCW ECB FAW SB SWCB WBC *CEW*	RW	GT	5% RIB
Agrisure Duracade 5222 E-Z Refuge	Cry1Ab Cry1F Vip3A mCry3A eCry3.1Ab	BCW CEW ECB FAW SB SWCB TAW WBC	RW	GT	5% RIB
HERCULEX					
Herculex 1 (HX1)	Cry1F	BCW ECB FAW SB SWCB WBC *CEW*	---	LL	20% structured ½ mile
Herculex RW (HXRW)	Cry34/35Ab1	---	RW	RR2 (most)	20% structured w/in, adj
Herculex XTRA (HXX)	Cry1F Cry34/35Ab1	BCW ECB FAW SB SWCB WBC *CEW*	RW		20% structured w/in, adj
OPTIMUM					
Intrasect (YHR)	Cry1F Cry1Ab	BCW ECB FAW SB SWCB WBC *CEW*	---	LL RR2	5% structured ½ mile
AcreMax (AM)	Cry1F Cry1Ab	BCW ECB FAW SB SWCB WBC *CEW*	---	LL RR2	5% RIB
[a] Leptra (VYHR) [b] AcreMax Leptra (AML)	Cry1F Cry1Ab Vip3A	BCW CEW ECB FAW SB SWCB TAW WBC	---	LL RR2	[a] 5% structured ½ mile [b] 5% RIB
AcreMax RW (AMRW)	Cry34/35Ab1	---	RW	LL RR2	10% RIB
AcreMax1 (AM1)	Cry1F Cry34/35Ab1	BCW ECB FAW SB SWCB WBC *CEW*	RW	LL RR2	10% RIB (RW) + 20% structured ½ mile (ECB)
TRIsect (CHR)	Cry1F mCry3A	BCW ECB FAW SB SWCB WBC *CEW*	RW	LL RR2	20% structured w/in, adj
[a] Intrasect TRIsect (CYHR)	Cry1F Cry1Ab	BCW ECB FAW SB	RW	LL RR2	[a] 20% structured w/in, adj

Resistance Management

- High-dose expression
- Refuges to allow survival of homozygous susceptible individuals and their mating with homozygous resistant individuals
  - Proximity to Bt crop
  - Timing of planting

Additional Examples of Separate Refuge Configurations

Block



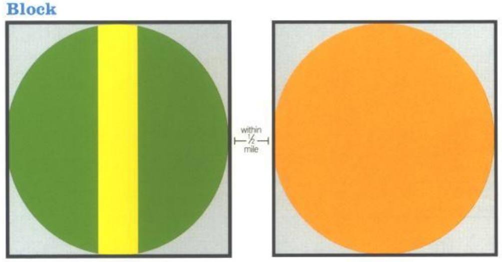
YieldGard Plus

Corn Rootworm Refuge
(e.g., YieldGard Corn Borer corn or YieldGard Corn Borer with Roundup Ready corn)

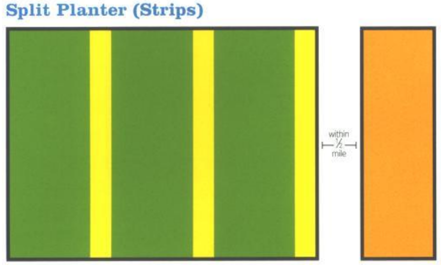
Corn Borer Refuge
(e.g., Roundup Ready corn or conventional corn)

Corn refuge within ½ mile (¼ mile preferred) of YieldGard Plus and minimum of 20% non-B.t. corn borer corn

Block

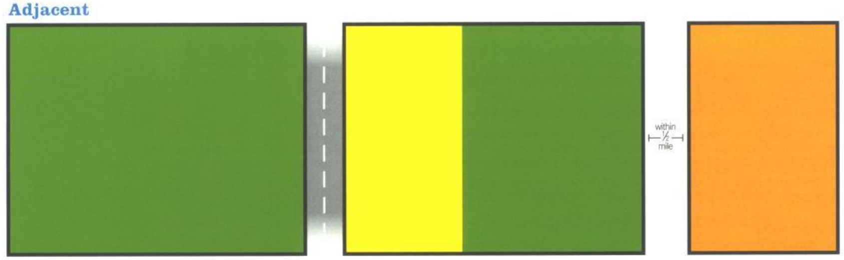


Split Planter (Strips)



Minimum of 6 rows (12 rows preferred)

Adjacent



We don’t know this in advance

Factors influencing resistance development

Fraction of population treated	% effectiveness	Dominance of resistance allele	Initial allele frequency	Generations to resistance (allele frequency = 50 %)
.80	95	0.00	0.001000	324
.80	95	0.05	0.001000	31
.80	95	0.10	0.001000	20
.80	100	0.00	0.001000	258
.80	100	0.05	0.001000	25
.80	100	0.10	0.001000	17
.90	100	0.00	0.001000	118
.90	100	0.05	0.001000	13
.90	100	0.10	0.001000	10
.95	95	0.00	0.001000	115
.95	95	0.05	0.001000	13
.95	95	0.10	0.001000	9
.95	100	0.00	0.001000	60
.95	100	0.05	0.001000	8
.95	100	0.10	0.001000	6
.99	100	0.00	0.001000	15
.99	100	0.05	0.001000	4
.99	100	0.10	0.001000	3

From a model developed by James Mallett, then of Mississippi State University

A rootworm Bt corn scenario if high-dose assumptions are met …

- In the fall of 2016, 7 million western corn rootworm eggs are laid per acre in land that will be planted to corn in 2017. 1 million survive to start feeding on the roots of corn in 2017.
- Initial gene frequency for resistance to the pertinent Bt Cry toxin is 0.002.
- Resistance is completely recessive (rr survives field rates; Sr does not; SS does not.
- Control of susceptible insects in the Bt acreage is 100 percent. No other mortality occurs in resistant or susceptible genotypes after they begin feeding on corn roots (not realistic, but not biased either, and it makes calculations easier).
- In each acre planted, there is a 25 percent non-Bt (rootworm) refuge.

The eggs laid in the fall of 2016 hatch in our ¾ acre of Bt corn and ¼ acre of refuge in the spring of 2017.

Genotype	Number of eggs in the 0.75 acre in which Bt corn has been planted	Number of eggs in the 0.25 acre in which nonBt corn has been planted (refuge)	Total number of r alleles
rr	3	1	8
Sr	2,994	998	3992
SS	747,003	249,001	0
Total	750,000	250,000	4,000

1 million individuals each have 2 alleles for the Bt resistance/susceptibility trait (2 million alleles). 4,000 / 2 million = 0.002

Survival in our 1 acre of corn …

Genotype	Number of survivors in the 0.75 acre in which Bt corn was planted	Number of survivors in the 0.25 acre in which nonBt corn was planted (refuge)	Total number of r alleles in the survivors of each genotype
rr	3	1	8
Sr	0	998	998
SS	0	249,001	0
Total	3	250,000	1,006

250,003 individuals survive. Each has 2 alleles for the Bt resistance/susceptibility trait (500,006 alleles) 1,006 r alleles divided by 500,006 total alleles = ______________.

- The frequency of the r allele was 0.002 before selection. What is the frequency of the r allele in this 1 acre after 1 generation of selection? Express the answer at the 6th decimal place.

Frequency = _______________

- What would the r allele frequency be after 1 generation of selection if the entire 1 acre had been planted to Bt rootworm corn?

1.000 (though only 4 individual survivors)

- Refuges have worked very well in maintaining the effectiveness of Bt corn against Lepidopteran pests (esp. European corn borer)
- Rootworms …?
  - Depends on inter-mating of susceptible and "resistant" individuals, and that may not be occurring
  - Depends on true "high-dose" exposures

Tabashnik, B.E., and F. Gould. 2012. Delaying Corn Rootworm Resistance to Bt Corn. J. Econ. Entomol. 105: 739-1106.

Transgenic crops producing Bacillus thuringiensis (Bt) toxins for insect control have been successful, but their efficacy is reduced when pests evolve resistance. To delay pest resistance to Bt crops, the U.S. Environmental Protection Agency (EPA) has required refuges of host plants that do not produce Bt toxins to promote survival of susceptible pests. Such refuges are expected to be most effective if the Bt plants deliver a dose of toxin high enough to kill nearly all hybrid progeny produced by matings between resistant and susceptible pests. In 2003, the EPA first registered corn, *Zea mays* L., producing a Bt toxin (Cry3Bb1) that kills western corn rootworm, Diabrotica virgifera virgifera LeConte, one of the most economically important crop pests in the United States. The EPA requires minimum refuges of 20% for Cry3Bb1 corn and 5% for corn producing two Bt toxins active against corn rootworms. We conclude that the current refuge requirements are not adequate, because Bt corn hybrids active against corn rootworms do not meet the high-dose standard, and western corn rootworm has rapidly evolved resistance to Cry3Bb1 corn in the laboratory, greenhouse, and field. Accordingly, we recommend increasing the minimum refuge for Bt corn targeting corn rootworms to 50% for plants producing one toxin active against these pests and to 20% for plants producing two toxins active against these pests. Increasing the minimum refuge percentage can help to delay pest resistance, encourage integrated pest management, and promote more sustainable crop protection.

Resistance to Bt Corn by Western Corn Rootworm (Coleoptera: Chrysomelidae) in the U.S. Corn Belt

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http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1176&context=ent_pubs

ABSTRACT. Transgenic Bt corn hybrids that produce insecticidal proteins from the bacterium *Bacillus thuringiensis* Berliner have become the standard insect management tactic across the U.S. Corn Belt. Widespread planting of Bt corn places intense selection pressure on target insects to develop resistance, and evolution of resistance threatens to erode benefits associated with Bt corn, such as reduced reliance on conventional insecticides. Recognizing the threat of resistance, the U.S. Environmental Protection Agency requires seed companies to include an insect resistance management (IRM) plan when registering a Bt trait. The goal of IRM plans is to delay Bt resistance in populations of target insects. One element of IRM is the presence of a non-Bt refuge to maintain Bt-susceptible individuals within a population, and growers are required to implement IRM on-farm by planting a refuge. Field-evolved resistance has not been detected for the European corn borer, *Ostrinia nubilalis* (Hubner), even though this species has been exposed to Bt proteins common in U.S. corn hybrids since 1996. The IRM situation is unfolding differently for Bt corn targeting the western corn rootworm, *Diabrotica virgifera virgifera* LeConte. In this article, we examine the scientific evidence for *D. v. virgifera* resistance to Bt rootworm traits and the cropping system practices that have contributed to the first reports of field-evolved resistance to a Bt toxin by *D. v. virgifera*. We explain why this issue has developed, and emphasize the necessity of an integrated pest management approach to address the issue.

Key Words: Bt corn, western corn rootworm, insect resistance management, IPM, refuge

https://jipm.oxfordjournals.org/highwire/markup/62988/expansion?width=1000&height=500&iframe=true&postprocessors=highwire_figures%2Chighwire_math%2Chighwire_inline_linked_media%2Chighwire_embed%2Chighwire_oup_table_images

Table 1.

Representative list of Bt corn hybrids that produce insecticidal proteins from the bacterium *Bacillus thuringiensis*

Trade name	Bt protein(s)	Bt event(s)	Insects controlled (bold) or suppressed (italics)		Herbicide tolerance	Refuge %, field placement in the MIDWEST
			Above-ground	In soil		
Agrisure trait family						
Agrisure CB/LL	Cry1Ab	Bt11	**ECB** *CEW FAW SB*	–	LL	20% within half mile
Agrisure GT/CB/LL	Cry1Ab	Bt11	**ECB** *CEW FAW SB*	–	GT LL	20% within half mile
Agrisure RW	mCry3A	MIR604	–	**CRW**	–	20% in field/adjacent
Agrisure GT/RW	mCry3A	MIR604	–	**CRW**	GT	20% in field/adjacent
Agrisure CB/LL/RW	Cry1Ab mCry3A	Bt11 MIR604	**ECB** *CEW FAW SB*	**CRW**	LL	20% in field/adjacent
Agrisure 3000GT	Cry1Ab mCry3A	Bt11 MIR604	**ECB** *CEW FAW SB*	**CRW**	GT LL	20% in field/adjacent
Agrisure Artesian 3011A	Cry1Ab mCry3A	Bt11 MIR604	**ECB** *CEW FAW SB*	**CRW**	GT LL	20% in field/adjacent
Agrisure Viptera 3110	Cry1Ab Vip3A	Bt11 MIR162	**BCW CEW ECB FAW WBC SB**	–	GT LL	20% within half mile
Agrisure Viptera 3111	Cry1Ab mCry3A Vip3A	Bt11 MIR604 MIR162	**BCW CEW ECB FAW WBC SB**	**CRW**	GT LL	20% in field/adjacent
Agrisure 3122 E-Z Refuge	Cry1Ab Cry1F mCry3A Cry34/35Ab1	Bt11 TC1507 MIR604 DAS-59122-7	**BCW ECB FAW WBC** *CEW SB*	**CRW**	GT	5% in the bag
Trade name	**Bt protein(s)**	**Bt event(s)**	**Insects controlled (bold) or suppressed (italics)**		**Herbicide tolerance**	**Refuge %, location in the MIDWEST**
			Above-ground	**In soil**		
Agrisure Viptera 3220 E-Z Refuge	Cry1Ab Cry1F Vip3A	Bt11 TC1507 MIR162	**BCW CEW ECB FAW WBC SB**	–	GT	5% in the bag
Agrisure Duracade 5122 E-Z Refuge	Cry1Ab Cry1F mCry3A eCry3.1Ab	Bt11 TC1507 MIR604 5307	**BCW ECB FAW WBC** *CEW SB*	**CRW**	GT	5% in the bag
Agrisure Duracade 5222 E-Z Refuge	Cry1Ab Cry1F Vip3A mCry3A eCry3.1Ab	Bt11 TC1507 MIR162 MIR604 5307	**BCW CEW ECB FAW WBC SB**	**CRW**	GT	5% in the bag

Transgenic methods for host plant resistance

- Advantages
  - Speed
  - Specificity of genetic change
  - Phenomenal increase in possible genetic sources of resistance
- Disadvantages
  - Scientific and public concern about nontarget impacts and human health, respectively
    - Subsequent export and domestic market concerns
  - Pest biotypes that overcome resistance
  - Panacea attitude
- Efficacy … in corn, substantial differences for resistance to Lepidopteran larvae and corn rootworm larvae

- Know the three main categories of traditional HPR categories … nonpreference, antibiosis, and tolerance
- What does it mean to describe resistance mechanisms as oligogenic versus polygenic … in which category would Bt crops fall?
- What is a “virulent” biotype?
- What are the 4 approaches to delaying the development of virulent biotypes that overcome resistance mechanisms?
- Why put Bt genes into plants when Bt sprays already provided some effective insect control?
- Into what US crops have Bt genes for insect resistance been inserted?
- What are the main approaches to preventing the development of virulent biotypes (insecticide resistance) in response to Bt crops?