Lessons from Global Patterns of Resistance to Bt Crops for Sustainable Pest Management

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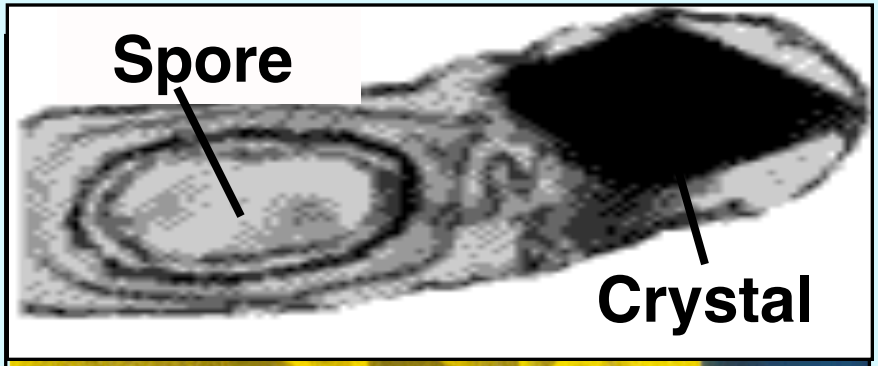
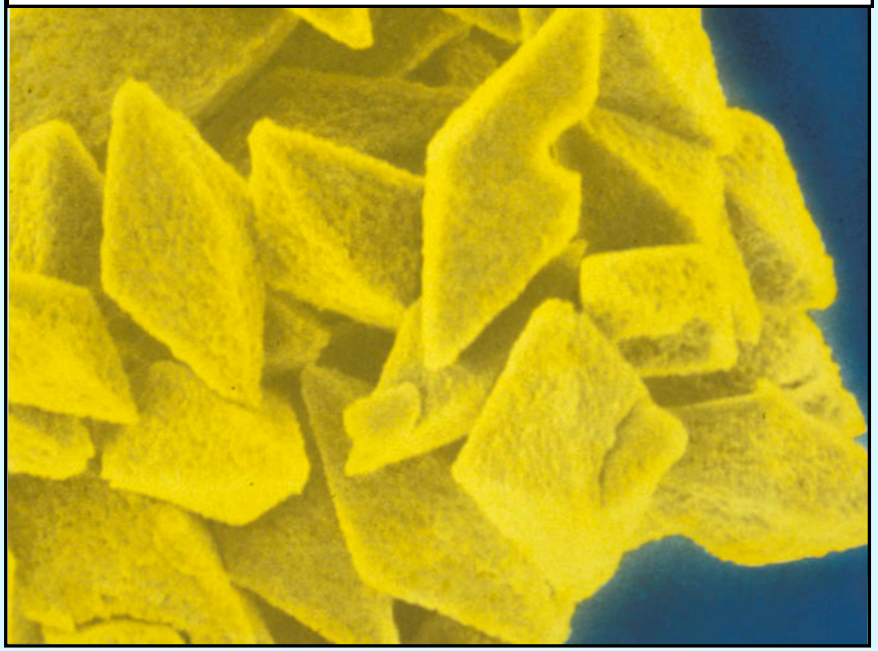
AZ Cotton Growers Association, AZ Cotton Research & Protection Council,
AZ Pest Management Center, Cotton Inc., Cotton Foundation, Dow, Monsanto, USDA-APHIS

Bacillus thuringiensis

- Natural, widespread bacterial pathogen of insects
- Used in sprays for >80 years to control disease vectors, forest & crop pests -- especially in organic agriculture
- Not harmful to most non-target organisms including beneficial insects & people
- Genes encoding Bt proteins engineered into crops





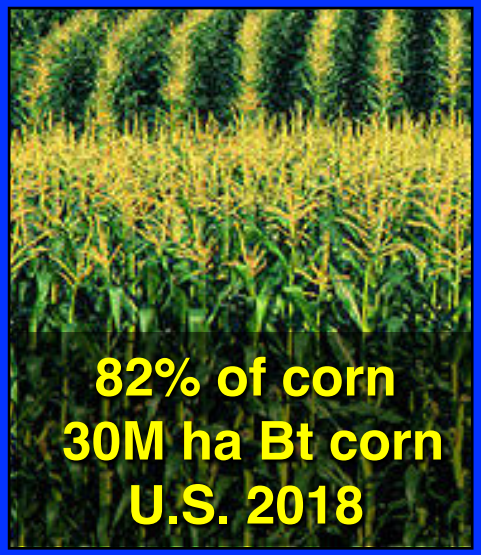
Bt crystalline (Cry) proteins

Benefits of Bt crops

- Effective against target insect pests
- Kill boring pests
- Little or no toxicity to most other species
- Reduce broad-spectrum insecticide use
- Economic, environmental & health benefits

European corn borer
Ostrinia nubilalis

Global Adoption of Bt Crops



93% of cotton
11M ha Bt cotton
India 2017

Million ha

120
100
80
60
40
20
0

1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

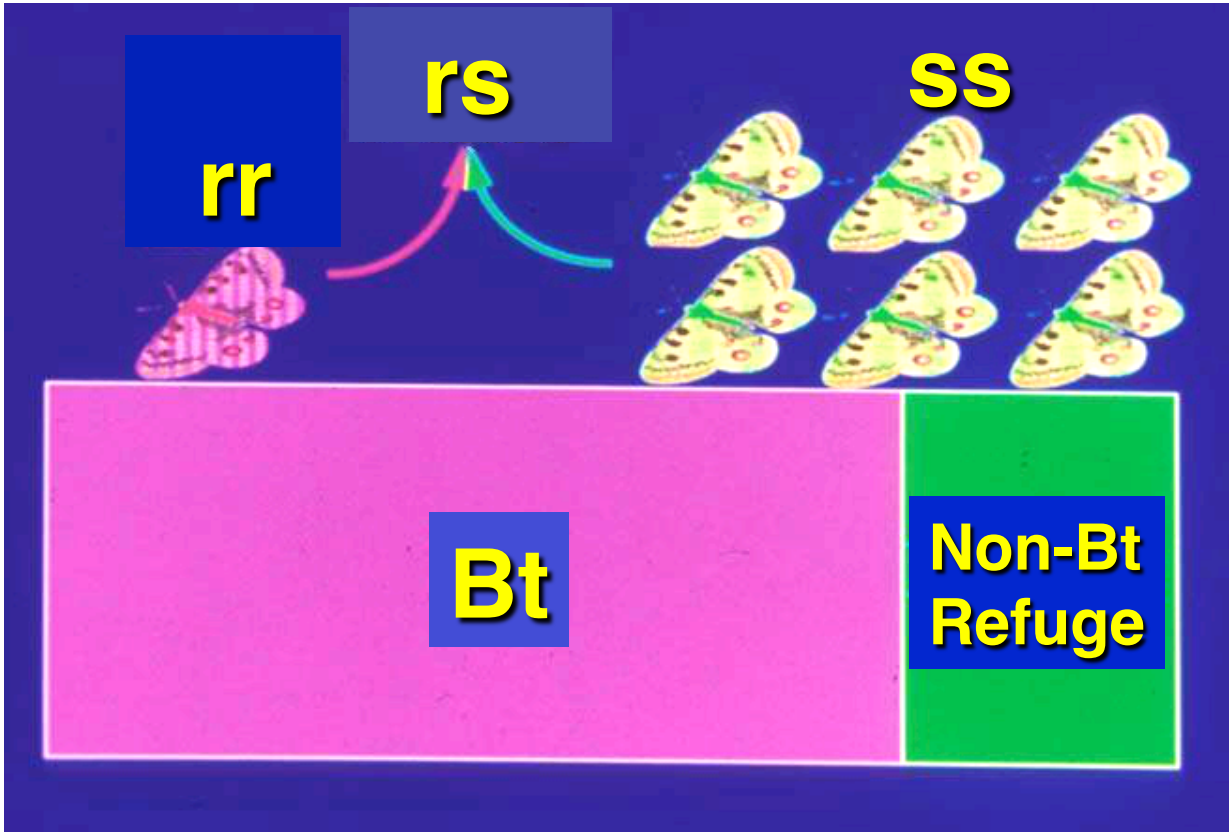
James (2017) ISAAA Brief 53, USDA ERS (2018)

Can we apply evolutionary principles and knowledge about resistance to make Bt crops more sustainable?

Refuge Strategy: Ideal Conditions

Resistance is recessive

- r alleles rare
- only extremely rare rr survive on Bt crop
- rr mate with ss to produce rs
- rs killed by Bt



Taylor & Georghiou JEE 1979
Tabashnik & Croft Environ Ent 1982
Gould Annu Rev Ent 1998

Refuge Theory Predicts

Resistance evolves slower if:

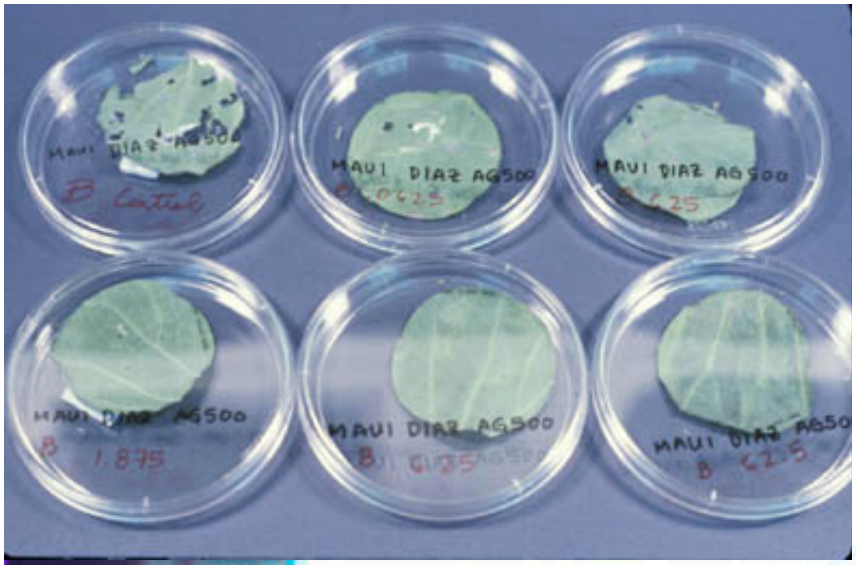
1) resistance is recessive

2) low initial frequency

3) abundant refuges of non-Bt host plants

Lab Bioassays for Bt Resistance

- Collect insects from field
- Rear progeny in lab
- Test larvae on food treated with toxin or on Bt plant material
- Record mortality (diagnostic concn)



Field-Evolved Resistance to Bt Crops: Field Monitoring Data by Case

- **Case: 1 pest species vs. 1 toxin in 1 country**
- **43 cases: 16 pest species, 11 countries, 10 toxins**
- **>40 papers**

Tabashnik & Carrière Nature Biotech (2017), JEE 2019 Chandrasena et al. PMS (2017), Smith et al. JEE (2017), Grimi et al. PMS (2018) & others




Field-evolved practical resistance to Bt crops: 1996-2016

D. v. virgifera
Cry3Bb, mCry3A corn
eCry3.1Ab, Cry34/35Ab corn

S. albicosta
Cry1F corn

P. gossypiella
Cry1Ac, Cry2Ab cotton

H. zea
Cry1Ac cotton
Cry2Ab cotton
Cry1Ab corn
Cry1A.105 corn

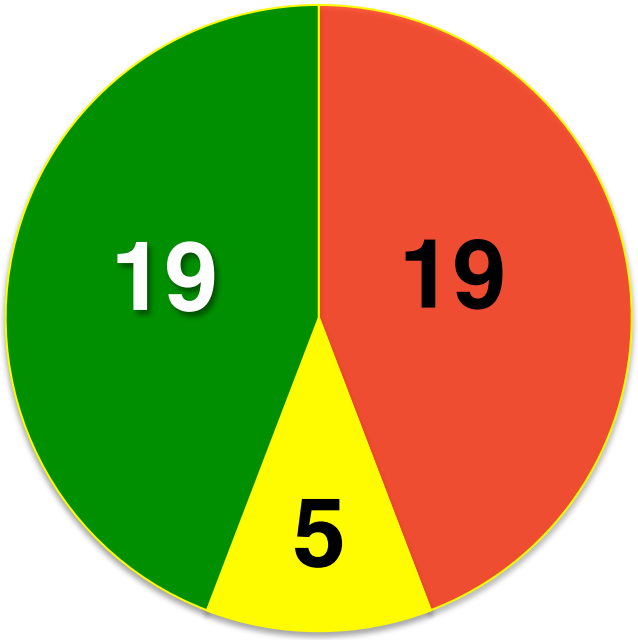
S. frugiperda
Cry1F, Cry1Ab corn

D. saccharalis
Cry1A.105 corn
Cry1F corn

B. fusca
Cry1Ab corn

Van Rensburg SAJPS 2007, Storer et al. JEE 2010, Dhurua & Gujar PMS 2011, Farias et al. Crop Prot 2014, Monnerat et al. PLOS One 2014, Gassmann et al. PNAS 2014 & JEE 2016, Huang et al. 2014, Yano et al. PMS 2015, Dively et al. PLOS ONE 2016, Omoto et al. PMS 2016, Jakka et al. Sci Reports 2016, Zukoff et al. JEE 2016, Chandrasena et al. PMS 2017, Smith et al. JEE 2017, Tabashnik & Carrière Nature Biotech 2017, Grimi et al. PMS 2018, Naik et al. PMS 2018 and others

Field-Evolved Resistance to Bt Crops

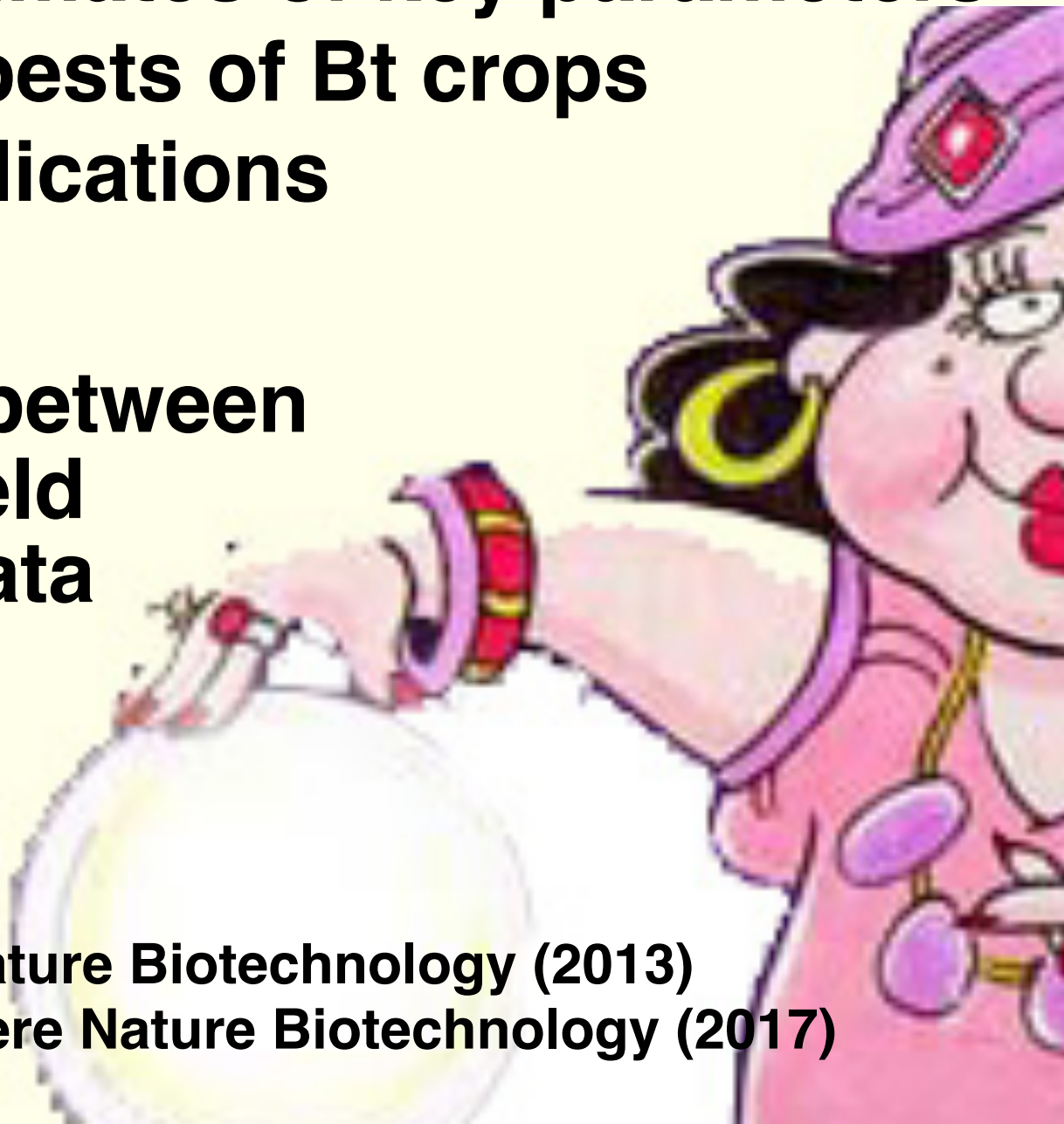


2018: 43 cases

B. fusca	Corn	Cry1Ab	S. Africa
D. saccharalis	Corn	Cry1A.105, Cry1F*	Argentina
D. v. virgifera	Corn	Cry3Bb, mCry3A	USA
D. v. virgifera	Corn	eCry3.1Ab, Cry34/35Ab	USA
H. zea	Cotton	Cry1Ac, Cry2Ab	USA
H. zea	Corn	Cry1Ab, Cry1A.105	USA
P. gossypiella	Cotton	Cry1Ac, Cry2Ab	India
S. albicosta	Corn	Cry1F	Canada*, USA
S. frugiperda	Corn	Cry1F	Argentina*, USA
S. frugiperda	Corn	Cry1F, Cry1Ab	Brazil
D. saccharalis	Corn	Cry1Ab	USA
H. armigera	Cotton	Cry1Ac	China, India*
H. zea	Corn	Vip3Aa	USA*
O. furnacalis	Corn	Cry1Ab	Philippines
C. includens	Soybean	Cry1Ac	Brazil
D. grandiosella	Corn	Cry1Ab	USA
E. biplaga	Cotton	Cry1Ac	S. Africa*
H. armigera	Cotton	Cry1Ac, Cry2Ab	Australia
H. punctigera	Cotton	Cry1Ac, Cry2Ab	Australia
H. virescens	Cotton	Cry1Ac, Cry2Ab	USA
H. virescens	Cotton	Cry1Ac	Mexico
H. zea	Corn	Vip3Aa	Brazil*
O. nubilalis	Corn	Cry1Ab	Spain
O. nubilalis	Corn	Cry1Ab, Cry1F	USA
P. gossypiella	Cotton	Cry1Ac	China
P. gossypiella	Cotton	Cry1Ac, Cry2Ab	USA
S. frugiperda	Corn	Vip3Aa	Brazil
S. nonagroides	Corn	Cry1Ab	Spain

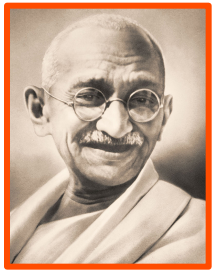
Empirical estimates of key parameters for 16 major pests of Bt crops from >40 publications

Good match between theory and field monitoring data



Tabashnik et al. Nature Biotechnology (2013)
Tabashnik & Carrière Nature Biotechnology (2017)

Pink Bollworm Resistance to Bt Cotton in the World's Top 3 Cotton-Producing Countries



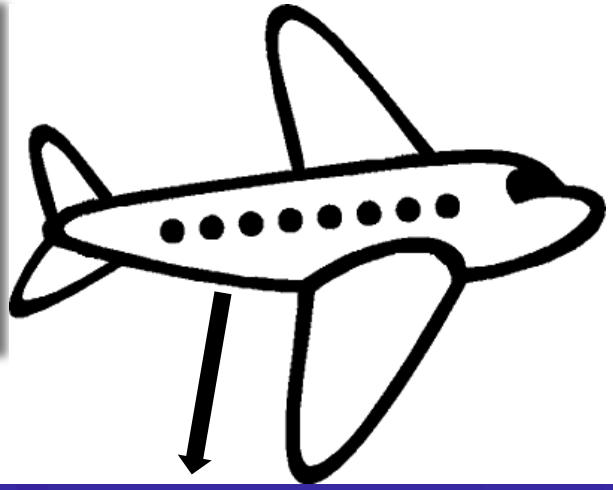
India Resistant after 6 years, refuges not planted

USA Not resistant after 23 years, eradicated

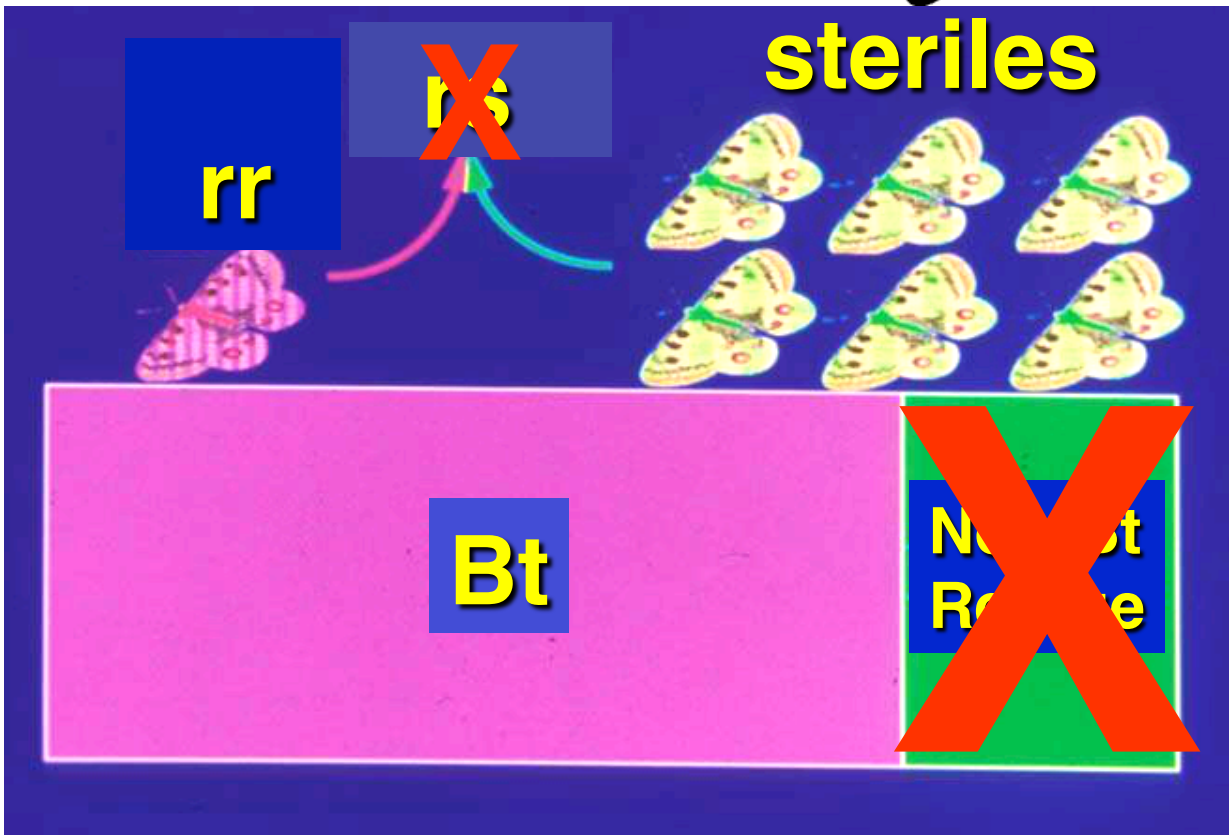
China Resistance reversed by increasing refuges

Bagla 2010 Science, Dhurua & Gujar Pest Man Sci 2011
Tabashnik et al. 2010 Nature Biotechnology & 2019 JEE
Wan et al. PLoS ONE 2012, PNAS 2017

Sterile Insect Technique + Bt Cotton Ideal Conditions



- r alleles rare
- rr mate with steriles
- No fertile progeny



Impact of Bt cotton + sterile releases

- Pink bollworm declared eradicated from U.S. (October 19, 2018)
- Insecticide use reduced
- Economic, environmental, health benefits