Eastern Filbert Blight: The Search for Resistance

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Topics to be covered:

- Field assessment of clonal germplasm for response to EFB in New Jersey
- Identifying new sources of resistance
- Determining genetic diversity of sources of resistance
- Inheritance of resistance in progeny
- Rutgers breeding efforts
- Conclusions and future directions

What is our available resistant material for breeding?

10 year assessment of resistance to EFB in New Jersey:

- 190 clonal accessions (cultivars, breeding selections, and wild species) evaluated for response to EFB in Rutgers field trials
  - Study started in 2002
- Plants from Oregon State University, the USDA ARS Clonal Germplasm Repository, the Univ. of Nebraska, Arbor Day Foundation, Grimo Nut Nursery, and John Gordon Nursery
- Study included *C. avellana* as well as:
  - *C. americana*
  - *C. americana x C. avellana*
  - *C. heterophylla*
  - *C. heterophylla x C. avellana*
  - *C. colurna x C. avellana*

Capik, J.M. and T.J. Molnar. 2012. Assessment of host (*Corylus* sp.) resistance to EFB in New Jersey. JASHS 137:157-172

Goals of study

- Collect a solid representation of all currently available sources of resistance to EFB
- Evaluate EFB response in NJ of cultivars and accessions shown to be resistant to EFB in OR
- Study wild species held in NCGR and OSU collections not previously tested
- Validate response of hybrids known to be EFB resistant through anecdotal reports and grower observations in the eastern United States

Plant material evaluated

- 10 cultivars set up in a replicated trial in 2002 (18 trees of each)
  - 2 known susceptible/tolerant
    - 'Barcelona' and 'Tonda di Giffoni'
  - 8 shown resistant in Oregon
    - *C. avellana*
      - 'Gasaway'
      - 'VR20-11' ('Gasaway' offspring)
      - 'Zimmerman' ('Gasaway' offspring)
      - OSU 495.072 (southern Russia sdlg. selection)
      - OSU 408.040 (Univ. of Minnesota sdlg. selection)
    - *C. americana* hybrid OSU 541.147 (related to 'Rush')
    - *C. colurna* hybrid 'Grand Traverse'
    - *C. heterophylla* hybrid OSU 526.041
- Remaining 183 accessions planted in 2004 through 2007 with fewer trees of each
  - 1 to 3 trees of each accession
  - 455 total trees evaluated across study

Experimental design

- Plants were exposed to EFB through natural spread and by field inoculations
  - Diseased wood tied into canopy of each tree yearly
  - Disease pressure increased as study progressed
- All trees evaluated for incidence and severity of EFB in 2012
- For susceptible trees
  - Total number and length of cankers
  - Proportion of disease wood calculated (total amount of cankered wood divided by total shoot growth)
  - Means compared for trees of 2002 trial

Adam Morgan measuring EFB cankers


2002 Replicated trial

Results – *Corylus avellana*

- All 50 susceptible control trees developed EFB (including ‘Tonda di Giffoni’ and ‘Sacajawea’ known to be tolerant in Oregon)
- Of the 18 *C. avellana* cultivars shown to be resistant to EFB in Oregon, only 10 remained free of EFB
- These include:
  - ‘Gasaway’ related: ‘Zimmerman’, ‘Santiam’, ‘Delta’, ‘Epsilon’
  - Others:
    - OSU 408.040 (Univ. of Minnesota sdlg)
    - OSU 495.072 (southern Russia sdlg)
    - ‘Ratoli’ (Spain)
    - ‘Uebov’ (Serbia)
    - Moscow #2 (Russia)

Susceptible *Corylus avellana*

Cultivar name/ accession	Disease incidence	Ave. canker length (cm)	Proportion of diseased wood
Barcelona	18/18	61.9 a	.67 a
Tonda di Giffoni	18/18	24.5 a	.39 b
Gasaway	18/18	14.4 b	.16 c
VR 20-11 (Gas.)	18/18	22.2 a	.16 c
Gamma (Gas.)	1/1	9.0	.01
Jefferson (Gas.)	5/9	13.0	.04
Yamhill (Gas.)	1/1	8.0	.02
Moscow #1	1/2	27	.06
CCOR 187.001	3/3	21.3	.11
OSU 759.007	4/6	2.9	.01

Noticed EFB on Theta in 2013 (small cankers)

Conclusions – *Corylus avellana*

- Most trees found EFB-resistant in Oregon maintained at least a high level of tolerance under field conditions in New Jersey
  - Suggests usefulness of *R*-genes but that the scenario is different in the East compared to Oregon (climate and diversity of fungus)
- Interestingly, around 50% of the plants containing the 'Gasaway' resistance gene developed EFB (although limited amounts) with the others remaining free of disease
  - 'Zimmerman' is a striking example. It is 'Gasaway' x 'Barcelona' but developed no cankers on 18 trees over 12 years of exposure, whereas all 'Gasaway' developed some EFB
  - Results suggests that modifying genes are present that support EFB resistance in addition to major 'Gasaway' gene

Results – *Corylus americana*

- Known to be resistant to EFB with northern accessions very cold hardy
  - Although tiny nut with thick shell
- 49 of 51 accessions remained **free of EFB in our study**
- Includes a diversity of selections made by Shawn Mehlenbacher at OSU in the 1980s (from OSU and USDA collections)
  - Indiana, Mississippi, Minnesota, Wisconsin, North Dakota, Pennsylvania, Nebraska, New Jersey, Michigan, West Virginia, Kentucky, South Dakota, Virginia, Massachusetts, Illinois
- Supports prior (largely undocumented) understanding that *C. americana* is highly resistant to EFB


Corylus americana clones
grafted on *C. avellana* rootstock

Results – *Corylus americana* × *C. avellana* hybrids

- 13 of 23 accessions remained **free of EFB**
- The resistant accessions include:
  - *C. americana* 'Rush' related hybrids:
    - OSU 541.147
    - 'Medium Long'
    - NY 398, NY 616
    - 'Potomac'
    - Grimo 208P
    - Weschcke TP-1
  - Arbor Day Foundation selections (Badgersett origin; 5 of 11): NADF 10-50-, NADF 11-51, NADF 15-74, NADF 25-60, and NADF 11-55

Results – Susceptible *Corylus americana* × *C. avellana* hybrids

Cultivar name/ accession	Disease incidence	Ave. canker length (cm)	Proportion of diseased wood
Reed (Rush hybrid)	1/1	25.5	.28
Skinner	1/1	22.8	.09
NADF 14-30	1/1	29.2	.37
NADF 9-31	3/3	15.5	.11
NADF 13-55	2/2	27.8	.59
NADF 25-146	1/1	15.0	.38
NADF 20-122	2/2	6.8	.05
NADF 11-56	1/1	48.6	.85
OSU 401.014 (res. in Oregon)	2/2	19.5	.26
OSU 532.014 (res. in Oregon)	1/1	14.4	.36

Results – *Corylus americana* × *C. avellana* hybrids

- *C. americana* ‘Rush’ looks to be a promising source of durable EFB resistance
  - research shows likely transmission of single dominant *R*-gene (Molnar and Capik, 2012; Mehlenbacher, unpublished)
- While useful and present in the hybrids, inheritance of EFB resistance from other sources remains unclear
  - Current progenies show less resistance than expected (to be discussed later)
  - More parents need to be used in controlled crosses
  - Studies are underway in a number of places (need to pool data from multiple projects to build consensus on what’s occurring)

Results – *Corylus colurna* hybrids (Turkish tree hazel)

- No pure Turkish tree hazels evaluated, only hybrids with *C. avellana*
- *C. colurna* may be a source of EFB resistance, cold and stress tolerance, and non-suckering growth habit
- All but one hybrid evaluated can be traced back to Gellatly's breeding program in British Colombia
- 8 of 13 accessions remained **free of EFB**
- Resistant accessions include:
  - 'Grand Traverse'
  - 'Lisa'
  - Grimo 186M and Grimo 208D
  - Chinese Trazel #6 and #11 (USDA)
  - TurkTrazel Gellatly #3 (USDA)
  - Rutgers H2R5P21

Nut cluster of 'Grand Traverse'

Clonal study conclusions

- Relatively long-term study demonstrates the existence of a wide diversity of *Corylus* germplasm resistant or tolerant to EFB
- Confirms previous reports that *C. americana* is resistant to the disease
- *C. heterophylla* and *C. fargesii* were also mostly resistant, suggesting EFB resistance also available in Asian germplasm

Clonal study conclusions

- A large number of EFB-resistant interspecific hybrids show the potential for incorporating EFB resistance from wild species through breeding
  - supports the continual development of hazelnuts as a crop in colder and more stressful climates
- Further evidence is provided on the difference in EFB expression in New Jersey compared to Oregon
  - Diversity of fungus as well as different climate and disease pressure
  - Studies are underway to examine this more closely including pyramiding known *R*-genes

Searching for new sources of EFB resistance in European hazelnut

- The European hazelnut, *Corylus avellana*, is typically very susceptible to EFB
- However, highly resistant plants exist on rare occasions (<2% of germplasm)
- The European species has the largest nuts of the genus and other attributes amenable to commercial production
- Using resistant *C. avellana* in breeding can speed the process of developing EFB-resistant plants for NJ and the Mid-Atlantic Region (and other locations)
  - We can grow *C. avellana* here successfully

EFB-resistant plants from Russia, Ukraine, and Poland

- In 2002-2005, seed collections were made across a wide area of Russia (Moscow, Krasnodar, Sochi, Yalta, etc.), Crimea, Ukraine, and Poland
- Collections were made from 66 separate locations or accessions
- Over 3,000 resulting new seedlings were grown in the field at Rutgers

EFB-resistant plants from Russia, Ukraine, and Poland

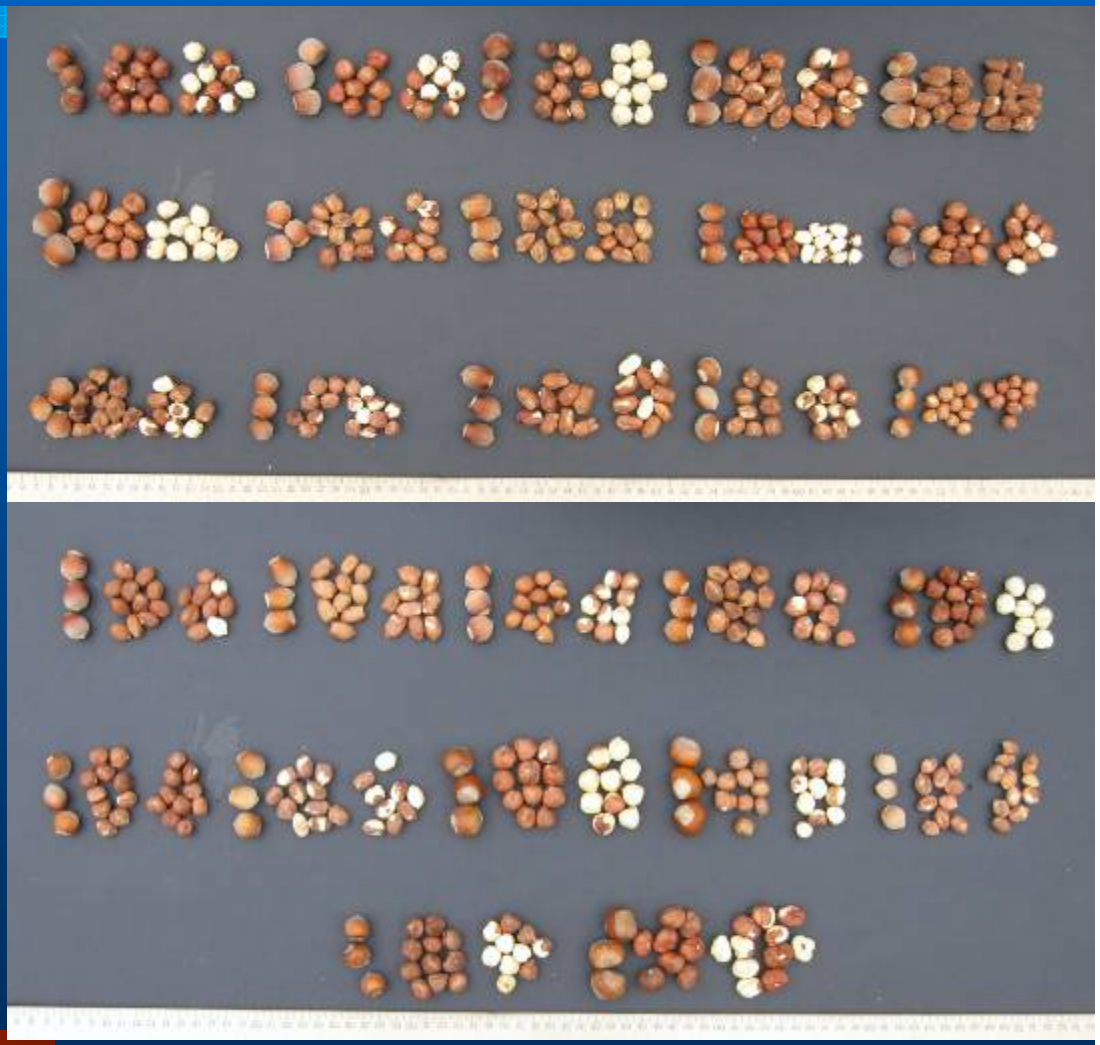
- Trees were exposed to EFB through greenhouse inoculations and then continual field exposure (including field inoculations)
- Most (>95%) were extremely susceptible to EFB and have since died
- However, there were a significant number of survivors
  - A total of 98 trees show no signs of EFB after 8 years+ of exposure
  - A number of the best were propagated and inoculated again with similar results

EFB-resistant plants from Russia, Ukraine, and Poland

- The survivors trace back to many locations each separated by many miles
  - may hold different genes for EFB-resistance (needs further investigation)
- Several progeny look to be segregating for dominant resistant genes
  - 50% resistant and 50% susceptible
- Nut evaluations were done to identify most promising clones

We evaluated nuts and kernel attributes of all the resistant plants to identify those seedlings with best breeding traits

Kernel dimensions,
Kernel weight,
Kernel to shell ratio,
Presence of fiber,
Pellicle removal after roasting,
Presence of defects (mold, twin kernels, etc.)



Identified new EFB-resistant plants that produce excellent quality nuts…

- From our collections from Russia and Ukraine, we identified several EFB-resistant seedlings with commercial quality nuts
- The best are being used in crosses; however, little is known on their genetic background

H3R13P40
Holmskij, Russia

H3R14P26 Simferopol, Crimea, Ukraine

H3R10P88 Yalta, Crimea, Ukraine

‘Santiam’, EFB-resistant OSU

‘Barcelona’ EFB-susceptible, main US cultivar

‘Gasaway’ EFB-resistant, grandparent of ‘Santiam’

Additional *C. avellana* populations are under evaluation

- Large seedling populations from Turkey, Latvia, Moldova, Lithuania, Estonia, southern Italy, and the Republic of Georgia now under evaluation (over 6,000 plants)
- Most are succumbing to EFB in a severe manner
- We expect to see 1-2% survive
  - It's early, but we see healthy plants in populations dying from EFB
  - Hopefully, some will have large, high-quality nuts to add to our breeding pool

Determining genetic diversity of sources of resistance: Collectively, a large number of sources of EFB resistance have been identified…

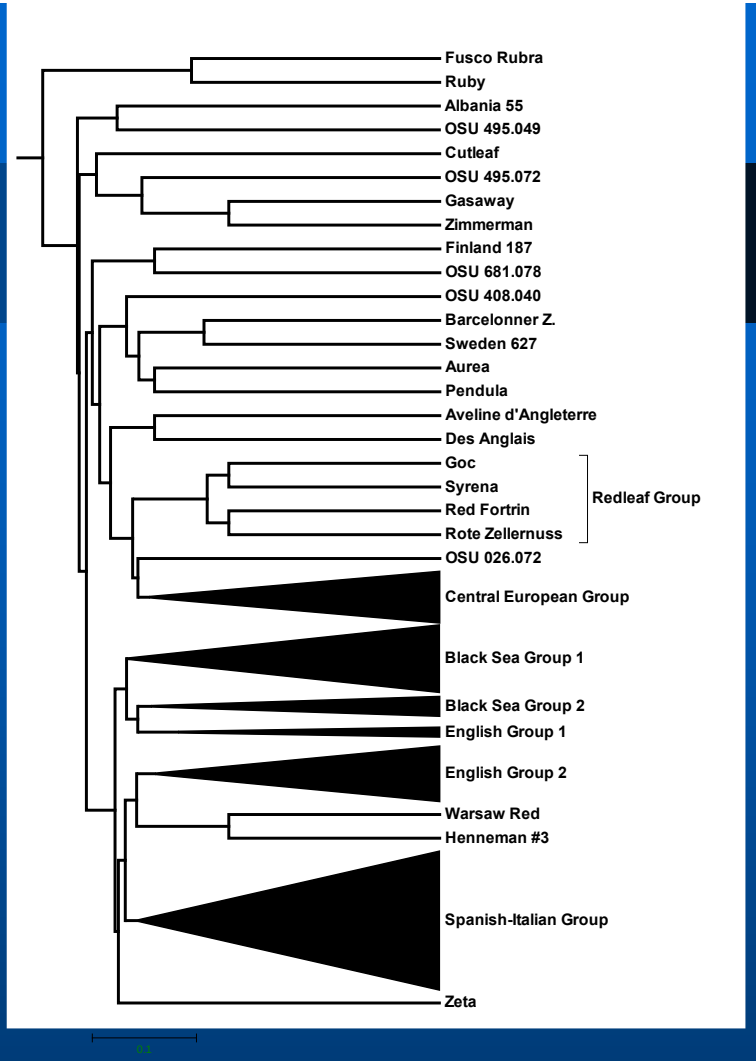
- Resistant plants (clones and seedlings) from early breeding efforts exist ('Rush' and Weschcke-related hybrids, Gellatly, Farris, etc.)
  - Our collection includes around 50 clonal selections from several private North American nurseryman/breeders
  - Few pedigree records available
- Around 20+ additional sources of EFB resistance in European hazelnut have been identified in Oregon
  - Some of these are holding up well in NJ
- Further, as mentioned, we identified around 100 additional resistant seedlings from our wide germplasm collections in Europe
  - Open-pollinated seed (uncertain origins)

Characterization of Resistant Germplasm Using Microsatellite (SSR) Markers

- Unknown germplasm can be problematic in long-term perennial plant breeding programs with goal of developing durable disease resistance while maintaining high genetic diversity
  - Fortunately, molecular tools are now available to help determine relationships and genetic diversity
- Microsatellite markers have been developed and utilized for studying hazelnut germplasm (*Corylus*)
  - Microsatellite, or simple sequence repeat (SSR) markers, due to their abundance, polymorphic nature, and co-dominance, have shown considerable value in fingerprinting accessions, examining relationships, and assessing genetic diversity in hazelnut, including across species

Genetic Diversity Assessment of EFB-resistant germplasm

- Used 17 well-characterized SSR markers (OSU) to assess 348 total accessions, including:
- 106 reference cultivars spanning well-documented world's cultivars and wild species
  - includes 15 EFB-resistant accessions
- 134 resistant/tolerant and 60 susceptible accessions from Rutgers seed-based germplasm collection
- 48 resistant grower selections from North America with uncertain origins
  - Cecil Farris
  - John Gordon
  - Ernie Grimo
  - Arbor Day Foundation



Dendogram from Gökirmak et al. (2009). 270 accessions of *C. avellana* representing world growing regions. We selected 106 plants representing each clade from this study

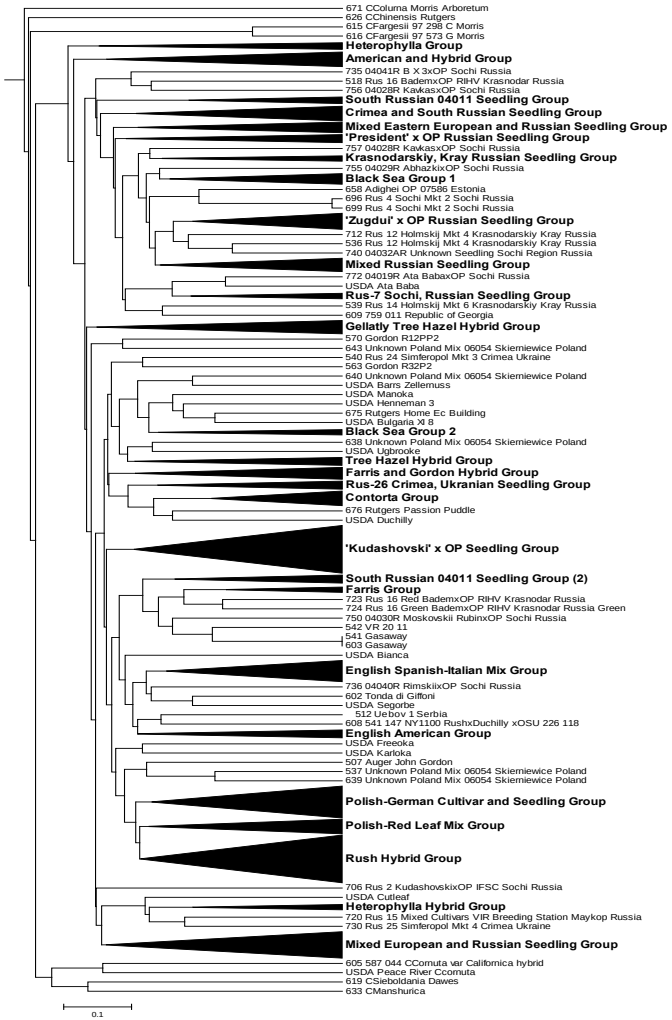
Some technical details…

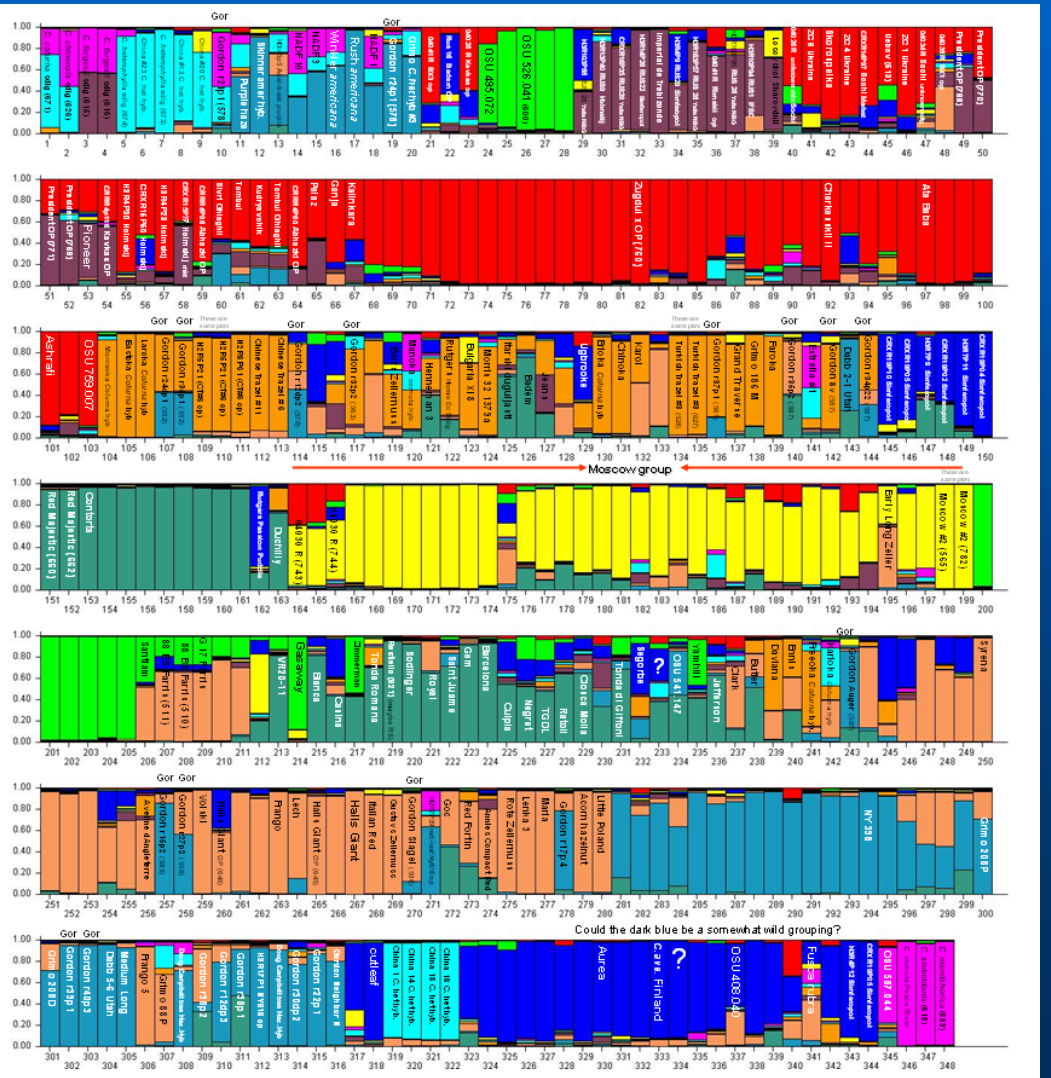
- The numbers of alleles for each locus, allele frequencies, observed heterozygosity, expected heterozygosity, and PIC values were calculated using Powermarker v.3.25a
- UPGMA tree was constructed, and bootstrap values for the tree were calculated
- A Bayesian, model-based clustering method, STRUCTURE 2.3.3 was used to elicit population structure, by assigning each accession to a population or populations, based on 17-locus genotypes

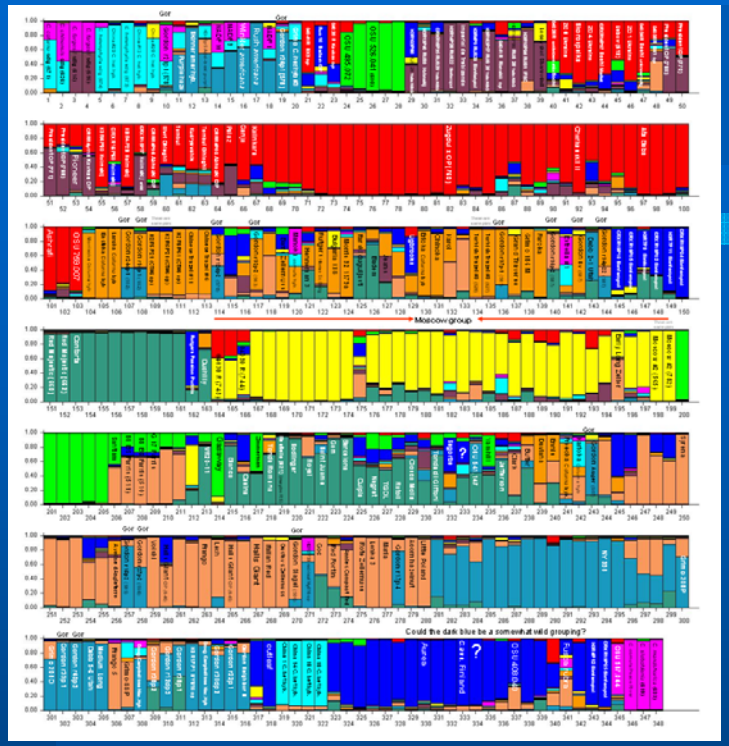
SSR Results…

UPGMA Dendrogram

STRUCTURE output, 11 groups







STRUCTURE analysis, supported by UPGMA and AMOVA, recognized 11 groups represented by colors.
Plants falling between groups are a mix of colors.

Out-group, wild species

C. heterophylla hybrids

C. americana ‘Rush’ group

Black Sea group 1

C. avellana ‘Gasaway’ group

Black Sea group 2

Faroka group

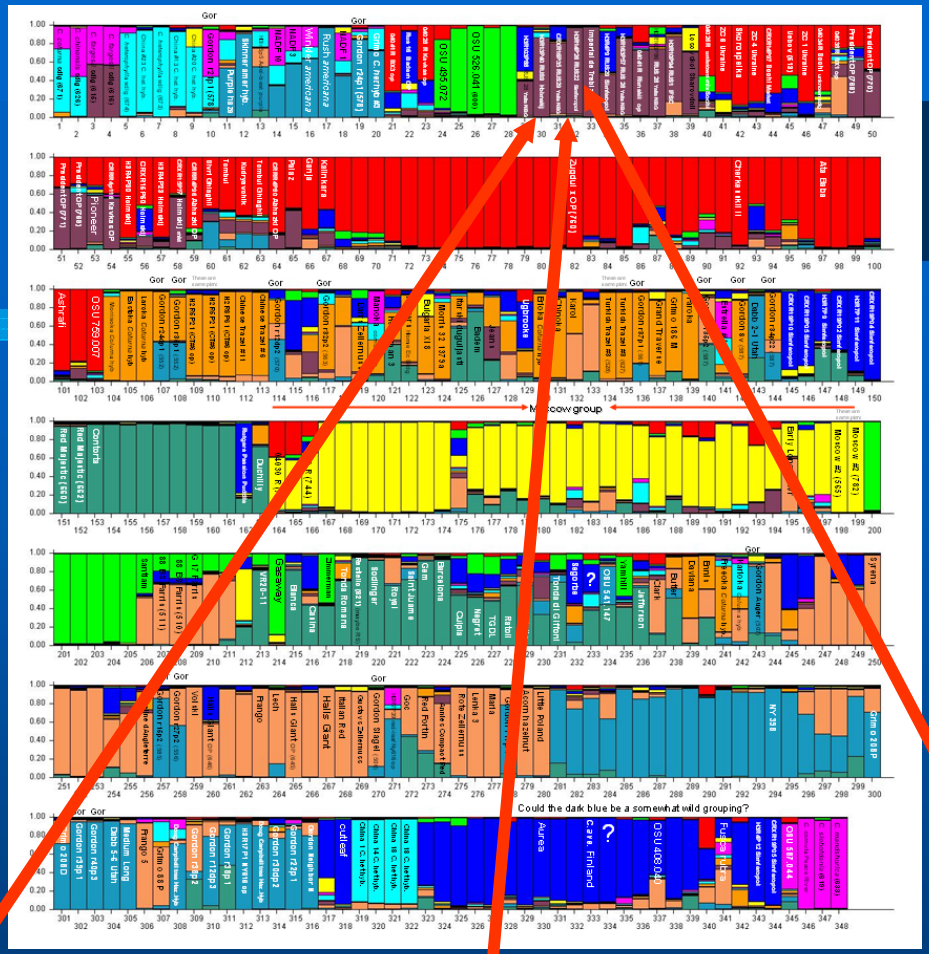
Mixed/wild *C. avellana* group

Spanish-Italian group

Moscow Group

Polish-German Group

How does this apply to breeding program?



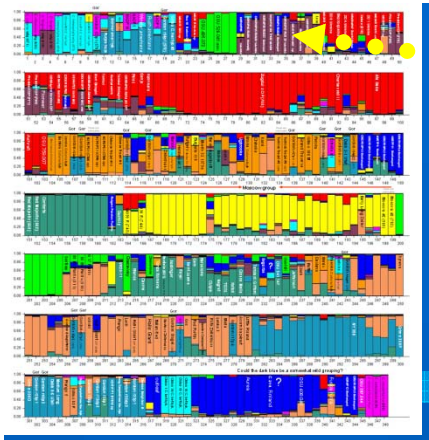
STRUCTURE output confirms very wide diversity of hazelnut accessions

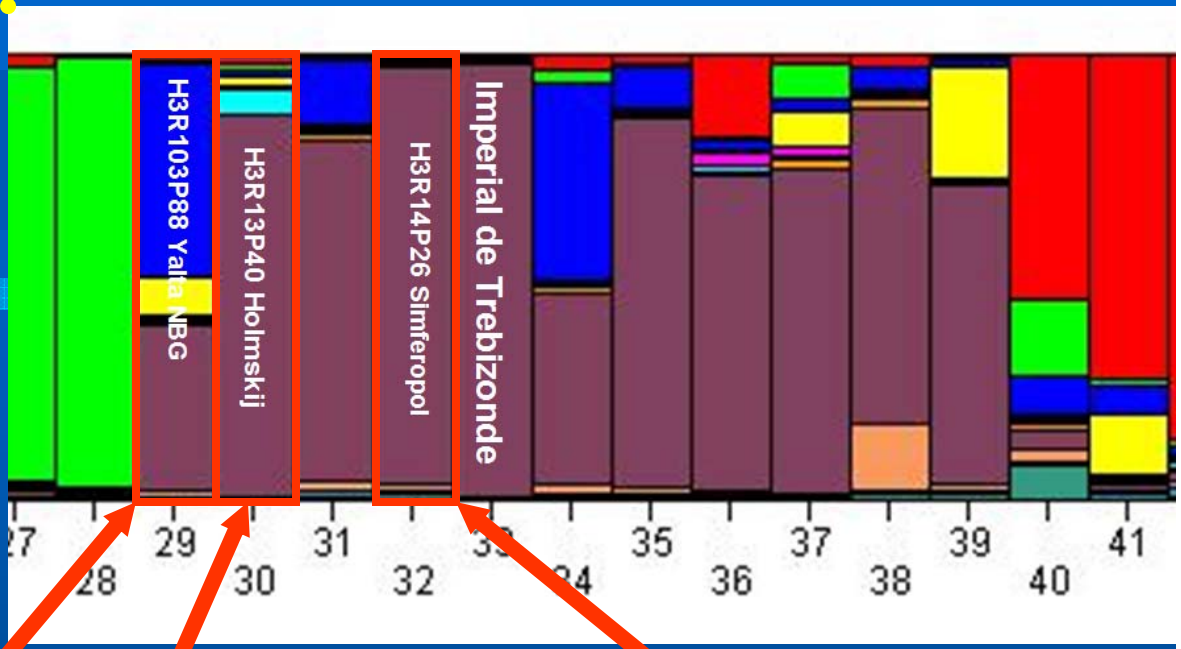
Includes many reference cultivars and already known sources of EFB resistance

H3R13P40
Holmskij, Russia

H3R14P26 Simferopol, Crimea, Ukraine

H3R10P88 Yalta, Crimea, Ukraine



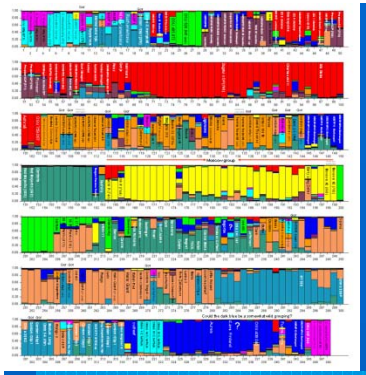


While its disappointing that these plants share a common lineage, there are no other “known” resistant plants in this group (Black Sea Group 2). Could be novel source of resistance?

H3R10P88 Yalta, Crimea, Ukraine

H3R13P40 Holmskij, Russia

H3R14P26 Simferopol, Crimea, Ukraine



Summary of known verses new EFB-resistant accessions

	Known EFB-resistant	New EFB-resistant
1. out-group	3	1
2. Asian C. *heterophylla*	0	6
3. Rush group	8	37
4. Black Sea 1	0	25
5. Gasaway group	4	0
6. Black Sea 2	0	5
7. Faroka group	6	11
8. Mixed/wild group	2	17
9. Spanish-Italian group	7	2
10. Moscow group	1	35
11. Polish-German group	0	8

SSR data provides ability to narrow breeding focus and to remove trees from holdings

The 25 accessions span 10 different seed lots

Of these 25 plants, 5 produce kernels 1.0 grams or larger

Of these 5 plants, 2 have round kernels and blanch well

These best 2 plants in Black Sea Group 1 will be the focus of breeding and mapping efforts. A similar approach will be made in the other populations.

Case study: John Gordon Nursery *Corylus* hybrids

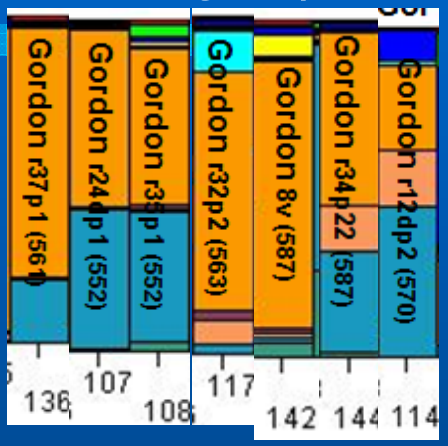
- John Gordon began a hazelnut breeding program in 1963 in Amherst, NY
  - He planted open-pollinated seeds of NY Ag. Experiment Station hybrid selections NY 104 and NY 200 (from the 1950s)
    - *C. americana* 'Rush' x *C. avellana* 'DuChilly'
    - *C. americana* 'Rush' x *C. avellana* 'Hall's Giant'
  - Later, he added seedlings of **'Faroka',** 'Morrisoka', and 'Laroka' (*C. colurna* hybrids) and Gellatly 502 (*C. cornuta* hybrid)
- John harvested nuts off of the best surviving trees to plant successive generations
  - Many thousands of plants cycled through program
  - No records kept on pedigree…

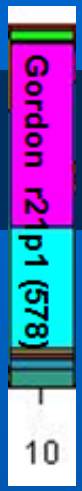
Case study: John Gordon Nursery *Corylus* hybrids

- In 2006, we obtained scions of over 60 plants remaining free of EFB in John's plantings
  - Established 42 in the field
- 40 of 42 accessions remained **free of EFB**
- Some trees appear high yielding and have decent nut quality
  - Goal is to narrow down group to the best few for use in breeding

Summary of Gordon selections

7 were placed in Faroka group



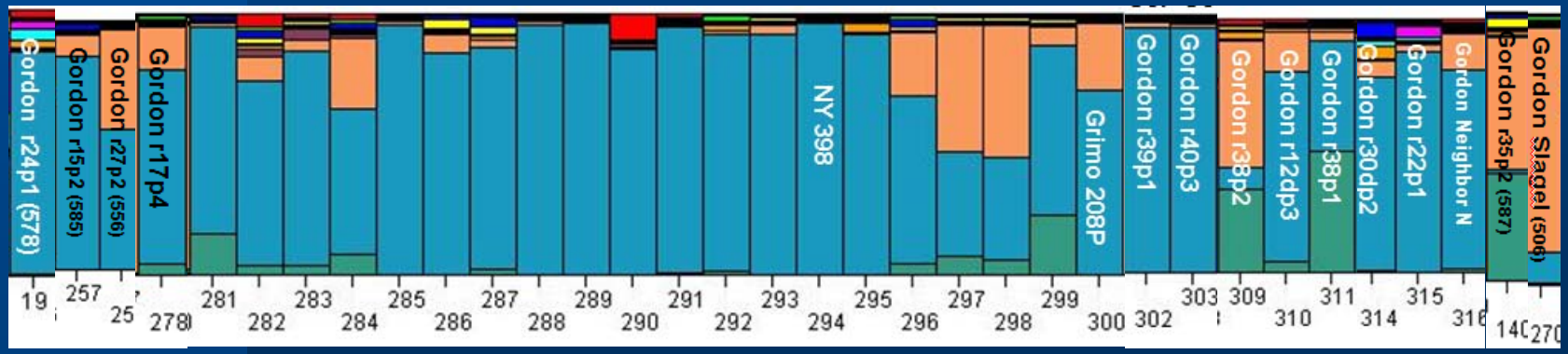


One fell in out group.

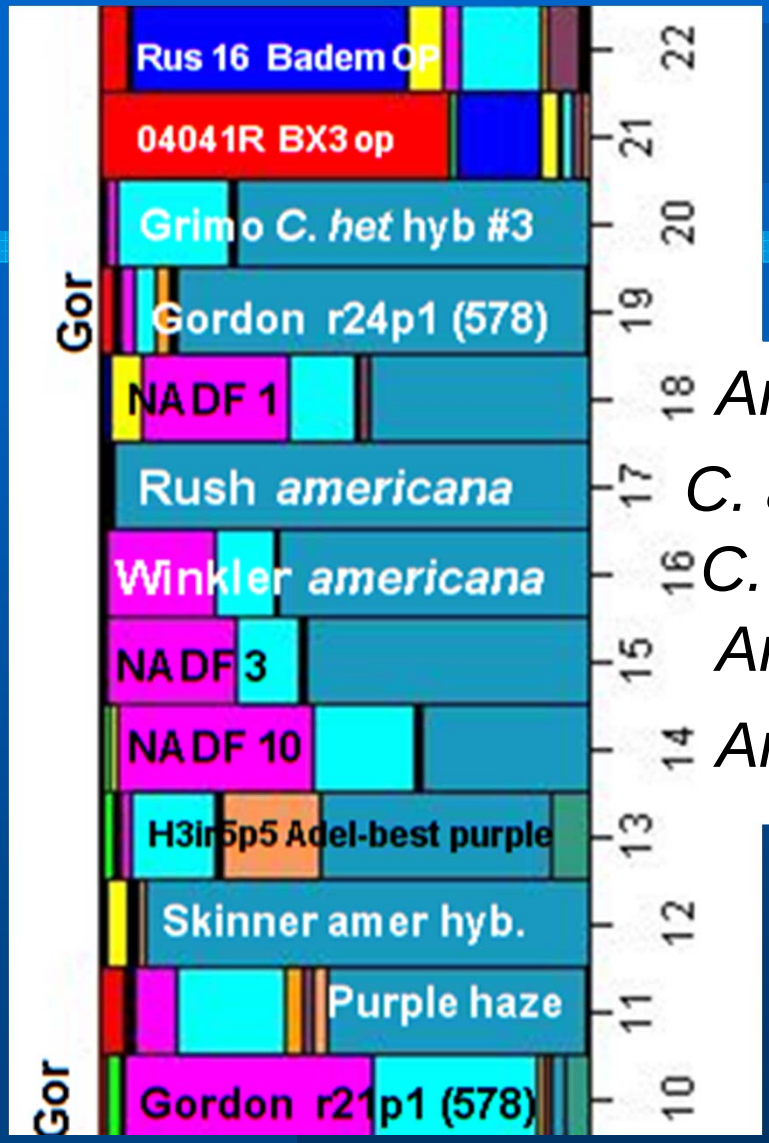
Interestingly, this is one of the two susceptible Gordon plants (tolerant – 2 rating)

Would have been discarded…

Nearly all fall cleanly into the “Rush group” with admixture with Hall’s Giant (Polish-German) group



Arbor Day plants grouped with ‘Winkler’ as expected



Arbor Day Farm #1

C. americana ‘Rush’

C. americana ‘Winkler’

Arbor Day Farm #3

Arbor Day Farm #10

SSR analysis conclusions

- We have access to a wide diversity of *Corylus* germplasm that is resistant or tolerant to EFB
- By utilizing the STRUCTURE analysis and UPGMA Dendrogram in addition to morphological trait assessment, we are able to pick the best plants within the different population groups to use as parents in the breeding program
  - target unrelated breeding parents to help maintain a high level of genetic diversity in our breeding program
- Molecular tools will also be used to map resistance genes to genetic linkage map to help study inheritance and for the future ability to pyramid different *R*-genes
  - Develop markers for marker assisted selection

Inheritance of resistance in progeny We have resistant plants: how will their progeny hold up?

- Controlled crosses made at Rutgers and OSU between resistant and susceptible parents
- Progeny were field planted and exposed to EFB in NJ
  - high field disease pressure and supplemental inoculations
- Evaluate for disease incidence and severity at year 5 and later

Evaluating Disease Response of Progeny

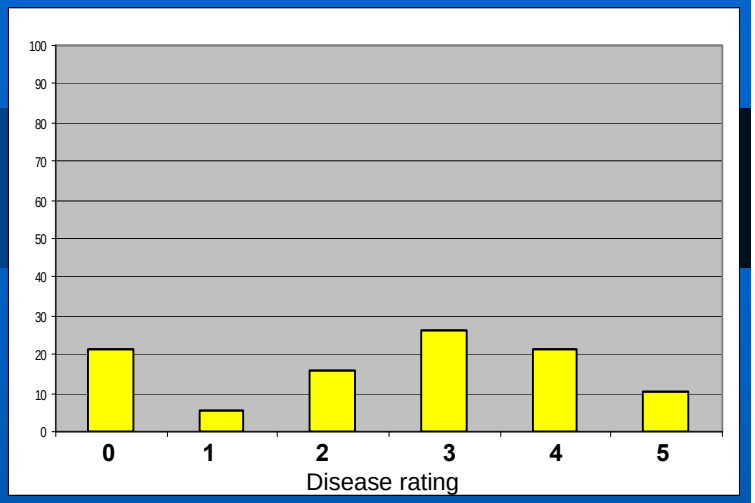
Resistant/tolerant

- 0 = no detectable EFB
- 1 = single canker
- 2 = multiple cankers on single branch

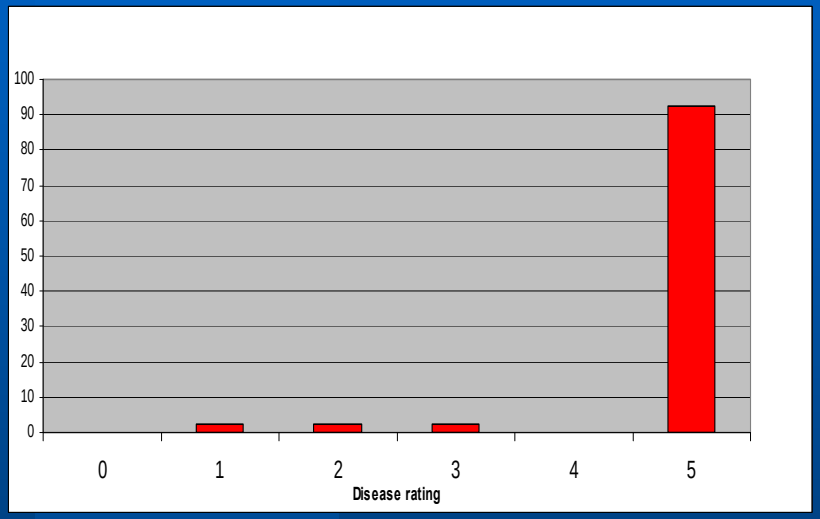
Susceptible

- 3 = multiple branches with cankers
- 4 = greater than 50% of the branches with cankers
- 5 = all branches containing cankers, except for basal sprouts

Progeny-based disease phenotypes suggest modes of inheritance:

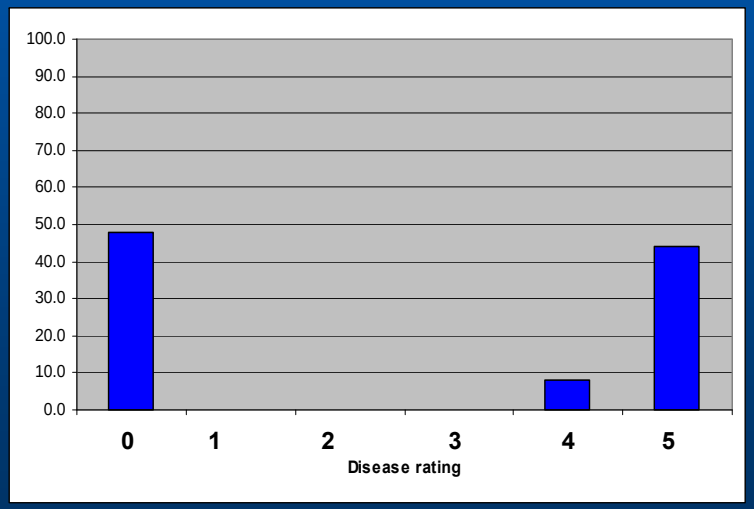


Quantitative resistance (multi-gene; bell-shaped curve)



Few resistant offspring

Visualized by percent of plants in each category



Bimodal segregation indicates dominant R-gene in heterozygous state

Progeny Evaluated

- Resistance sources that were crossed with susceptible *C. avellana*:
  - *C. avellana* 'Gasaway'
  - *C. avellana* OSU 408.040 (from Minnesota)
  - *C. avellana* 'Ratoli' (Spain)
  - *C. americana* 'Rush' (*C. americana)*
  - other *C. americana* sources
  - Badgersett hybrids
  - Others not covered here
    - *C. avellana* 'Culpla' and 'Uebov'
    - *C. colurna* hybrids ('Grand Traverse', Gellatly Chinese Tree Hazel #11, and 'Lisa')

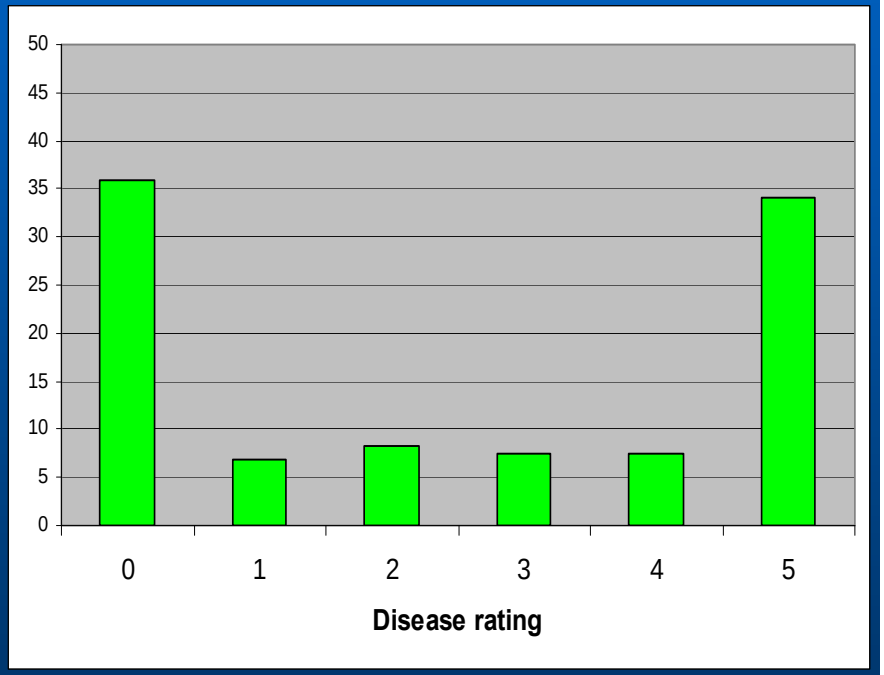
‘Gasaway’-related progeny

- ‘Gasaway’ source of resistance has been widely used in Oregon State Univ. breeding program
- In Oregon, offspring of ‘Gasaway’ segregate in a clear ratio of 1 resistant : 1 susceptible
- In NJ field trials, differential response observed with clones known to hold ‘Gasaway’ resistance gene*
  - ‘Gasaway’, VR 20-11, ‘Gamma', 'Yamhill', ‘Theta’, and 'Jefferson' developed EFB
  - ‘Zimmerman’, ‘Santiam’, 'Delta', and 'Epsilon’ remain free of disease

*Molnar et al., 2010. Plant Disease 94:1265; Capik and Molnar, 2012, JASHS

‘Gasaway’-related progeny: we expected 1 resistant to 1 susceptible segregation pattern

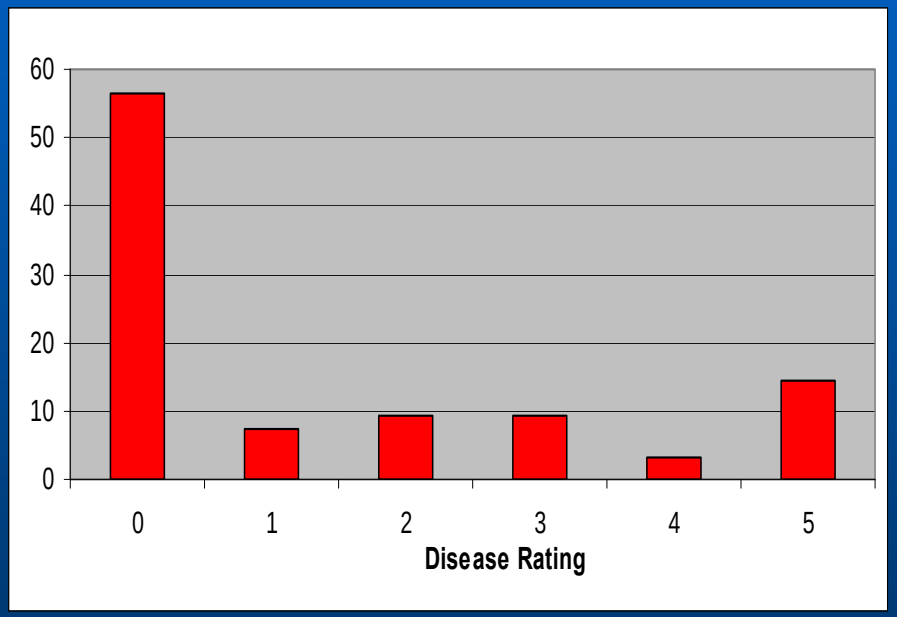
- **11** different progeny evaluated for a total of **279** plants expected to segregate 1 resistant to 1 susceptible seedling (6 years of exposure)
- If considering “0” resistant (n=100) and all other categories susceptible (n=179), data does not fit 1:1 model
  - Chi square test = 22.369, P-value < 0.0001
- However, if 0, 1, & 2 considered resistant (n=142), the progeny closely fit 1 res. : 1 susc. model
  - Chi square test = .090, P-value 0.7647



Pooled ‘Gasaway’ expected 1 resistant :1 susceptible data

‘Gasaway’-related progeny: expected 3 resistant to 1 susceptible segregation

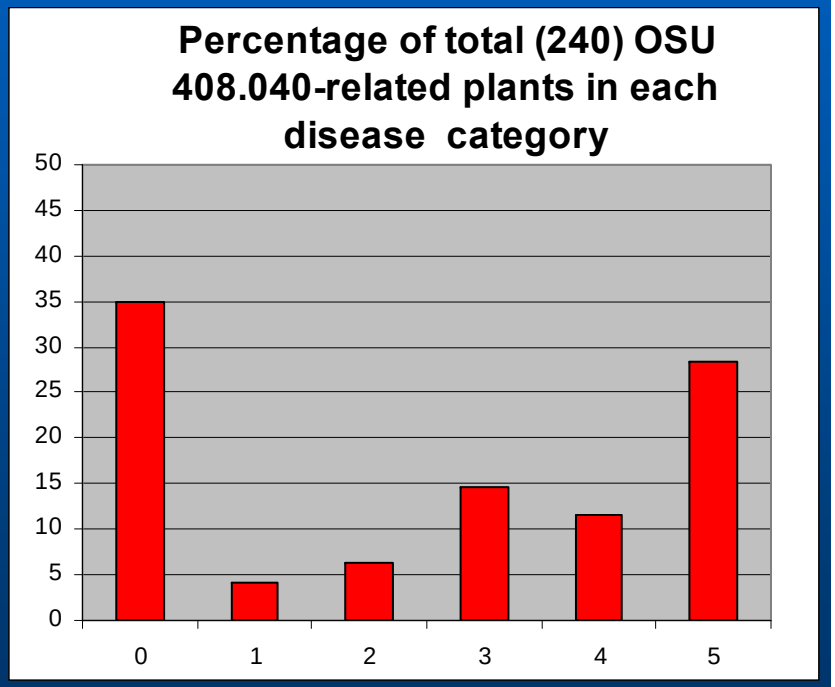
- **7** different progeny for a total of **227** plants expected to segregate 3 resistant to 1 susceptible
  - Crosses between parents both containing ‘Gasaway’ allele
- If considering “0” resistant (n=128) and all other categories susceptible (n=99), data not fit 3:1 model
  - Chi square test = 41.940, *P*-value <0.0001
- However, if 0, 1, & 2 considered resistant (n=166), the progeny now fit 3 res. : 1 susc. model
  - Chi square test = 0.424, *P*-value 0.5148



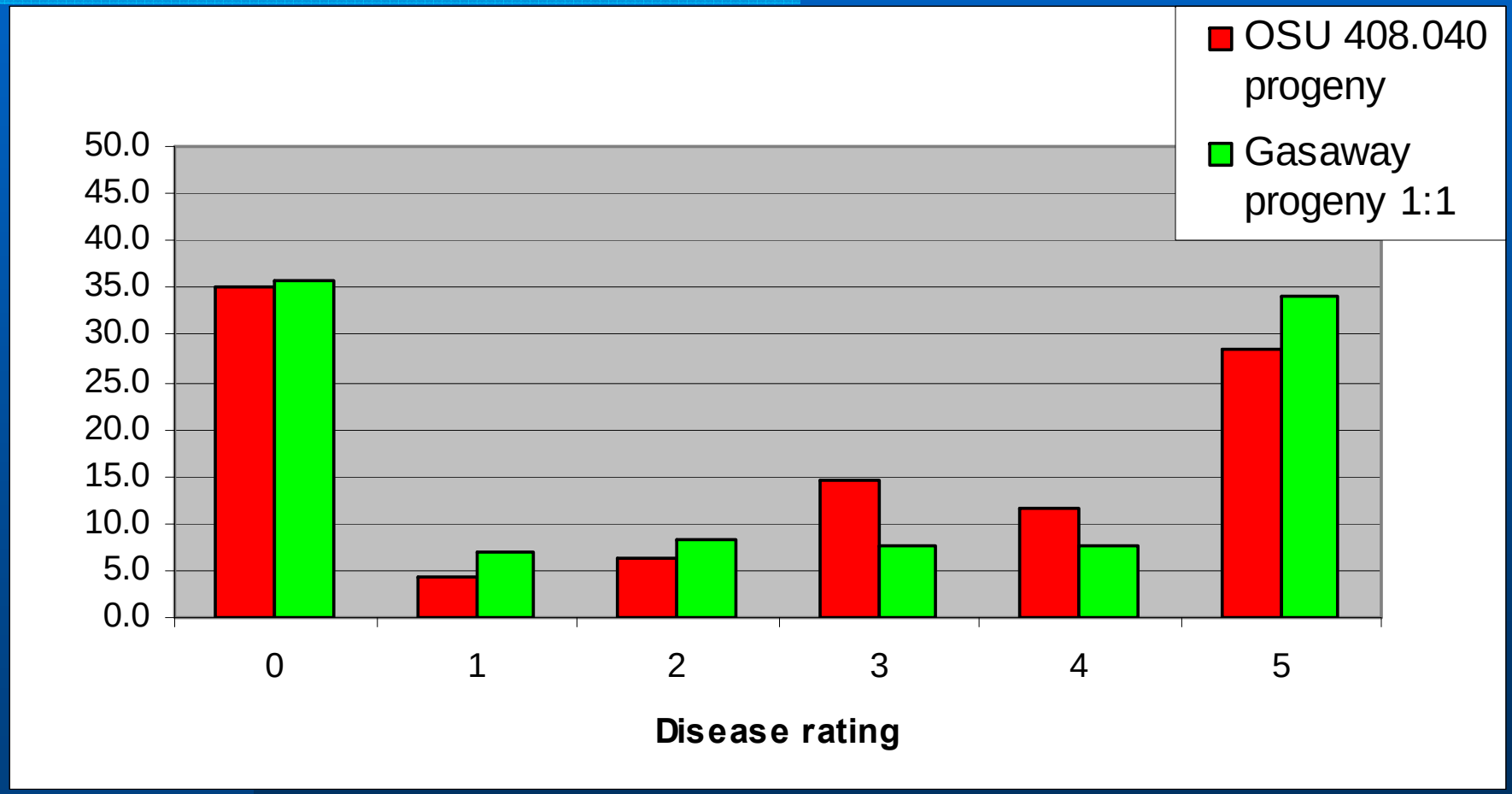
Pooled ‘Gasaway’ expected 3 resistant :1 susceptible data

OSU 408.040-related progeny

- OSU 408.040 selected from seed collected at Univ. of Minnesota
  - Free of EFB in NJ after 10 years (18 trees)
- 7 progeny derived from OSU 408.040 (240 total plants) expected to segregate for 1:1 ratio observed in Oregon
- However, like ‘Gasaway’ progeny, we needed to qualify those rating 0, 1, and 2 as resistant and 3, 4, 5 as susceptible to meet Chi squared test
  - 1 resistant : 1 susceptible (109:131)
  - Chi-square 2.017, *P* value 0.1556



Comparison of OSU 408.040 (n=240) and Gasaway (1:1) (n=279) progenies

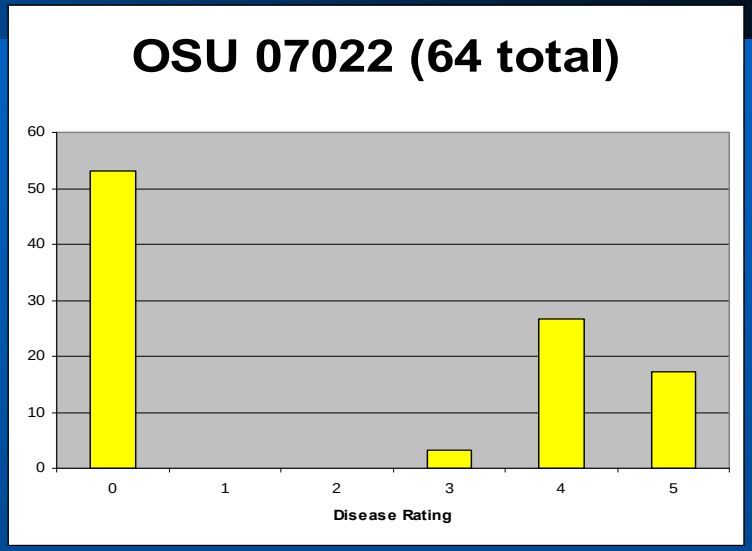


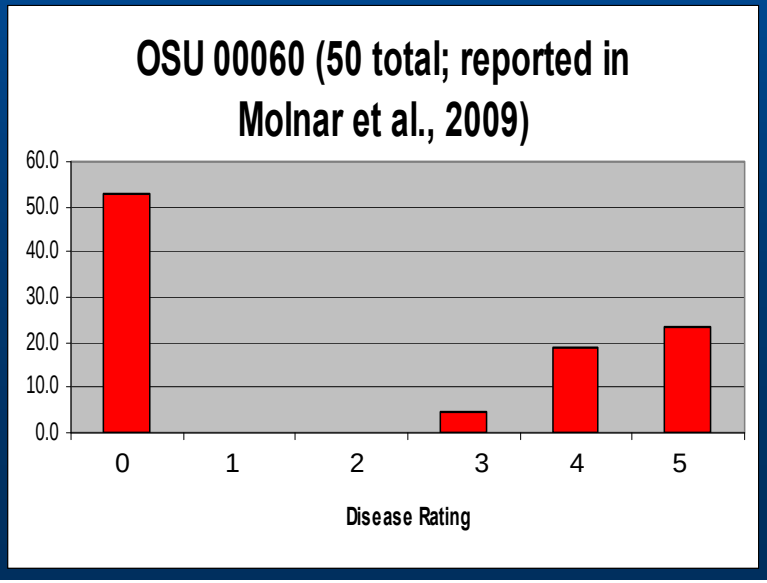
What can we glean from these segregation ratios?

- 'Gasaway' and OSU 408.040 plants may carry same *R*-gene, since patterns reflected in pooled progeny were very similar
  - Mehlenbacher showed they map to same linkage group (LG6)
- The ability to still group the 'Gasaway' and OSU 408.040 progeny into two classes (resistant/highly tolerant and susceptible) in a ratio of 1:1, provides evidence that the single-dominant gene is not breaking down in a traditional sense
  - otherwise we would see a much less predictable response
- These results suggest that the single gene provides a high level of tolerance alone and is acting in concert with other modifying genes
- The modifying genes are either being overcome by different isolates of the fungus or are sensitive to environmental conditions

C. avellana 'Ratoli' progeny

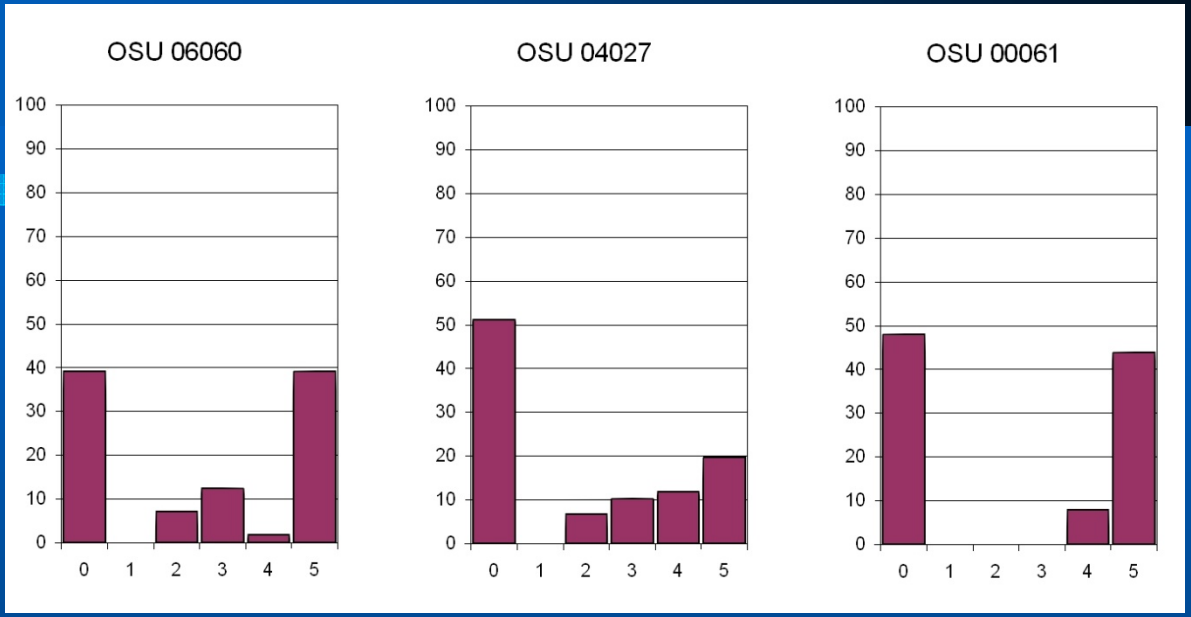
- *C. avellana* 'Ratoli' from Spain, shown in Oregon to segregate 1:1 resistant and susceptible
  - All plants remain free of EFB in NJ after 12 years
- Resistance loci mapped to different linkage group than 'Gasaway' (OSU) (LG7)
- Progeny derived from 'Ratoli' segregated for complete resistance following reports in Oregon
- Different pattern than 'Gasaway'
  - May be a good gene to pyramid with 'Gasaway'





C. americana 'Rush' hybrids

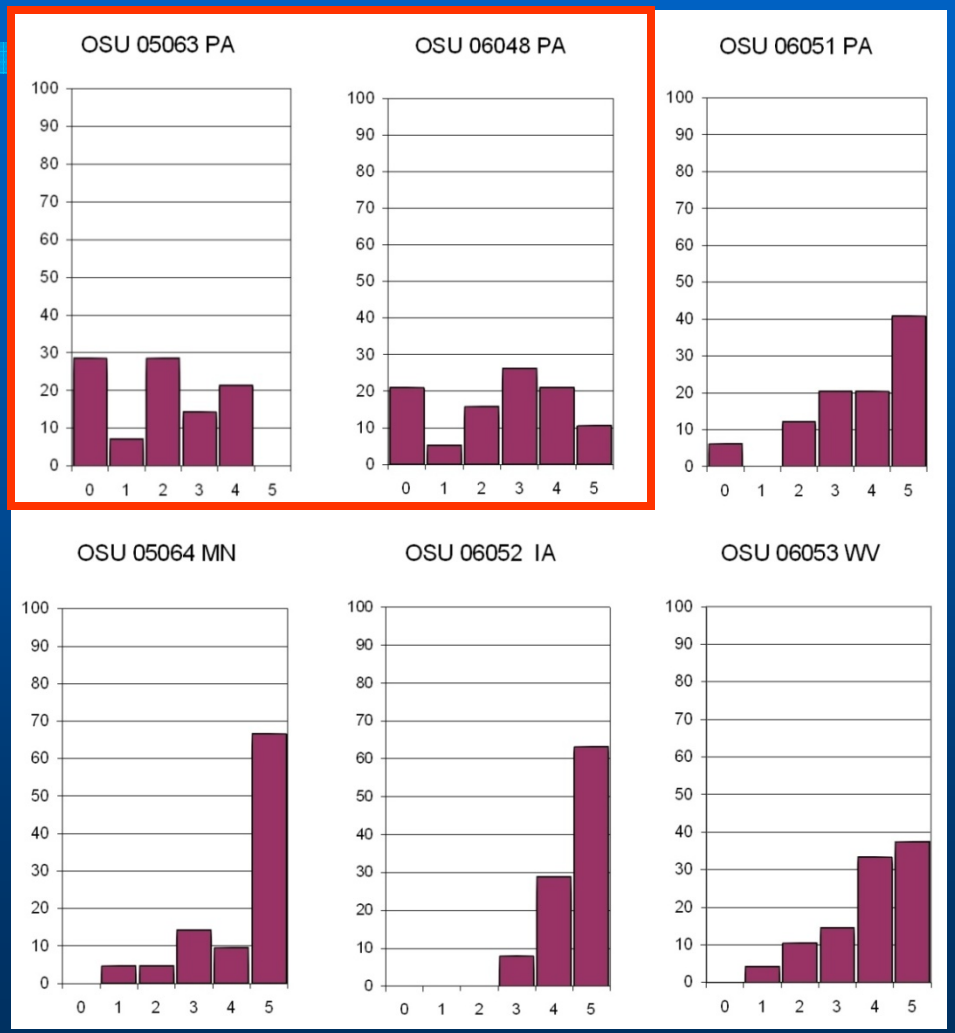
- Plants related to 'Rush' free of EFB for decades (NY 616, etc.)
- Known plants related to 'Rush' have shown no EFB in NJ trials
- Three progeny (total 223 plants) show bimodal segregation suggesting single dominant gene
- Resistance from *C. americana*, thus should be different than 'Gasaway' and 'Ratoli'
  - Mapping underway to see if on different linkage group



Progeny	Parents	Disease response (no. of trees) Resistant	Susceptible	χ2	*P*
OSU 00061	Yoder #5 × OSU 612.015	24	26	0.080	0.773
OSU 04027	OSU 527.070 × OSU 786.091	60	57	0.077	0.782
OSU 06060	OSU 753.054 × OSU 533.029	22	34	2.571	0.109
Pooled data		106	117	0.543	0.461

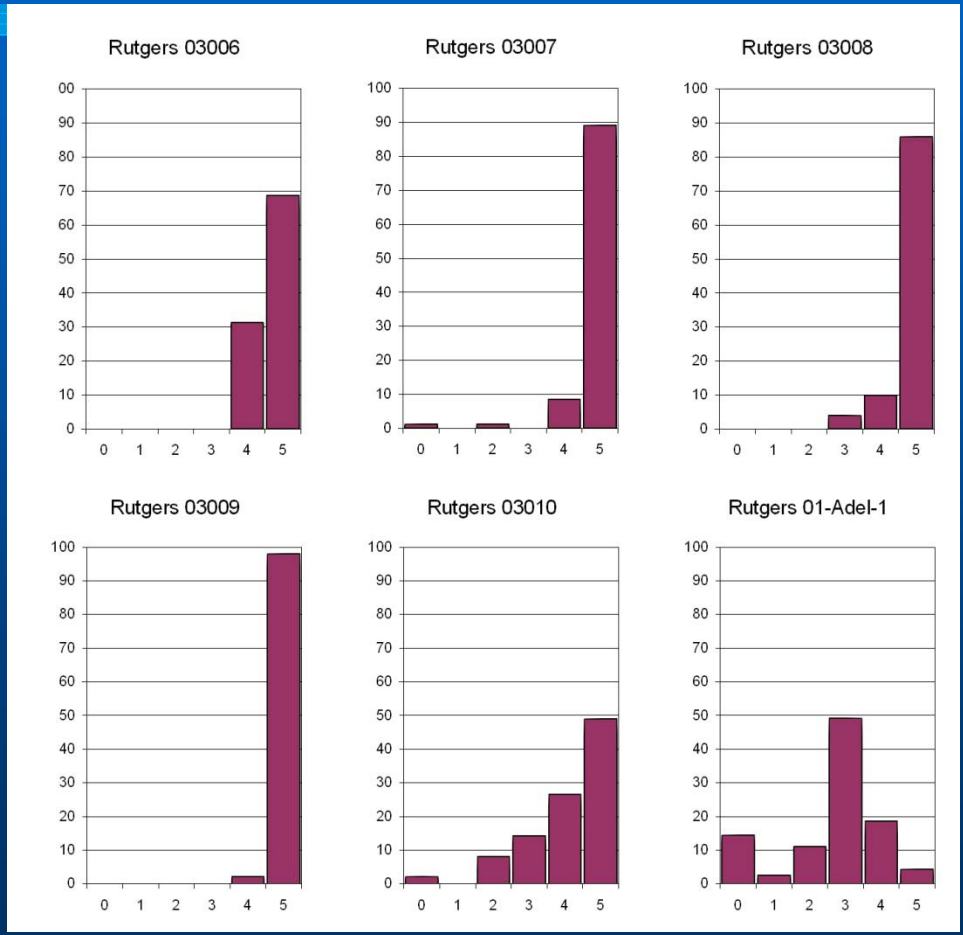
Other *C. americana* progeny crossed with susceptible *C. avellana*

- Two progeny from PA showed segregation for resistance expected for a trait controlled by multiple genes (bell-shaped curve)
- Four progeny showed a significant shift towards susceptible offspring
- Suggests a dominant gene (or genes) for susceptibly may be passed on from *C. avellana*



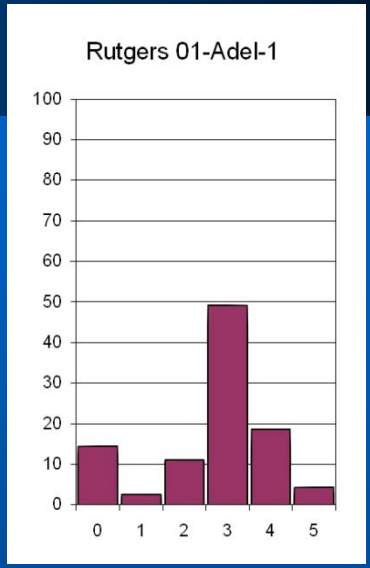
Badgersett hybrid-related progeny

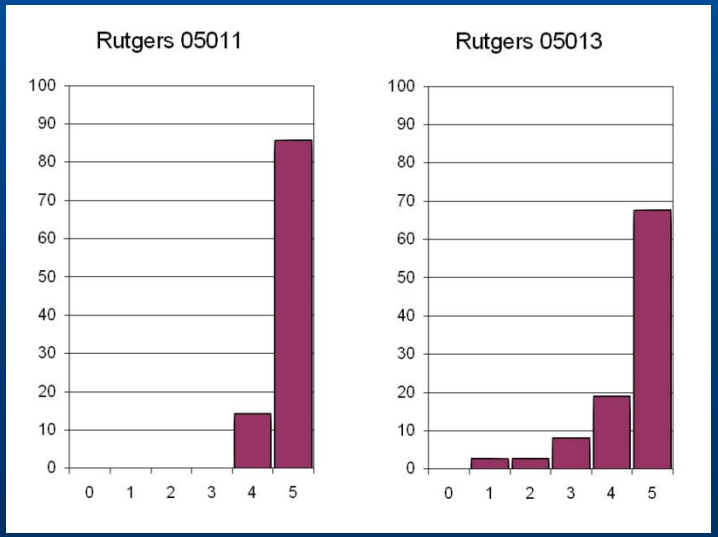
- Mother plants purchased from Badgersett in 1995
  - Fully EFB resistant in NJ since planting
- Crossed with susceptible *C. avellana* in 2001 and 2003 (each progeny 50+ trees)
- Rutgers 03010 and Rutgers 01-Adel-1 same female parent
- Found much fewer EFB-resistant offspring than was expected
- Further supports the idea that some *C. avellana* carry dominant allele(s) for susceptibility



Backcross to *C. avellana*…

- We selected two resistant plants from Rutgers 01-Adel-1 and crossed them with susceptible *C. avellana*
- Unfortunately, nearly all progeny were highly susceptible…
- While only based on a few genotypes, the overall results with *C. americana* and advanced-generation hybrids suggest the need to develop F2 generations to recover resistance
  - Increases breeding timeline significantly
  - Currently, we have over 70 additional progeny now in the field to further investigate *C. americana* hybrids
  - Used wide diversity of C. americana parents from USDA and OSU collections





Conclusions on inheritance of resistance in progeny

- We can use the field-assessed Disease Phenotype of progeny to better understand and predict inheritance of resistance
- Most cultivars and selections that showed complete resistance in Oregon transmitted a high level of resistance to a useful proportion of their progeny in NJ
  - Several new sources of EFB resistance appear to be transmitted in a dominant fashion
- However, with many progeny it appears that other genes are also modifying the disease phenotype
  - These modifying genes have yet to be studied
- More work had to be done to understand inheritance in new hybrid crosses
- Studies are underway to more closely examine modifying genes as well as the effects of pyramiding multiple genes for resistance

Rutgers Breeding program:

- Started in 1996, we have around 35,000 trees in the field from controlled crosses and new germplasm introdcutons
- The breeding programs continues: 10 years ago we had very few EFB resistant selections with decent kernel quality
  - Today we have many thousands of seedlings that meet these criteria. The challenge is now identifying the best plants for clonal propagation
- From our earliest efforts, we selected 14 plants showing excellent qualities:
  - Highly EFB resistant; medium to large size nuts, with over 50% kernel by weight; round kernels; high crop loads, few kernel defects

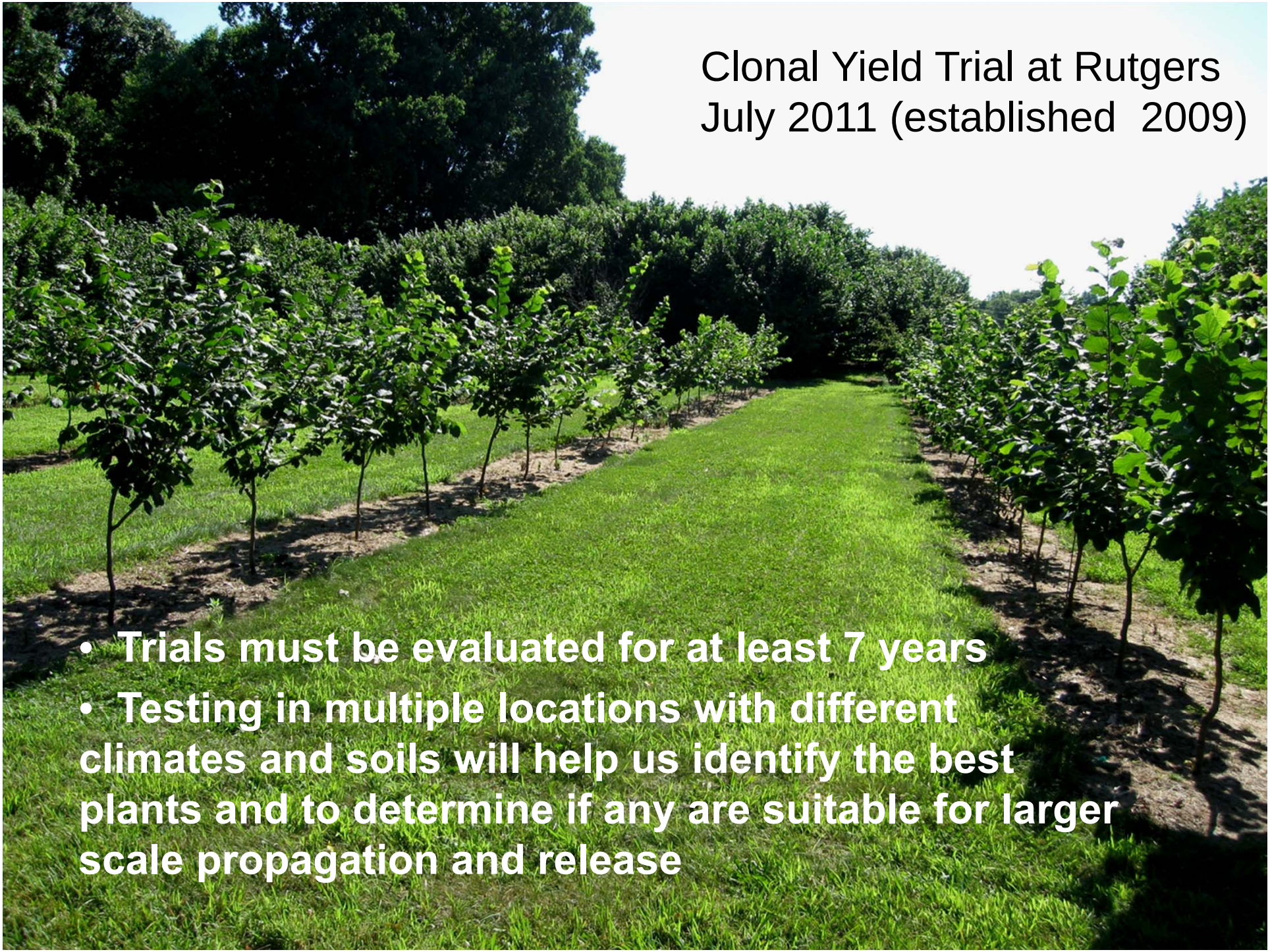
14 EFB-Resistant selections being propagated for testing:

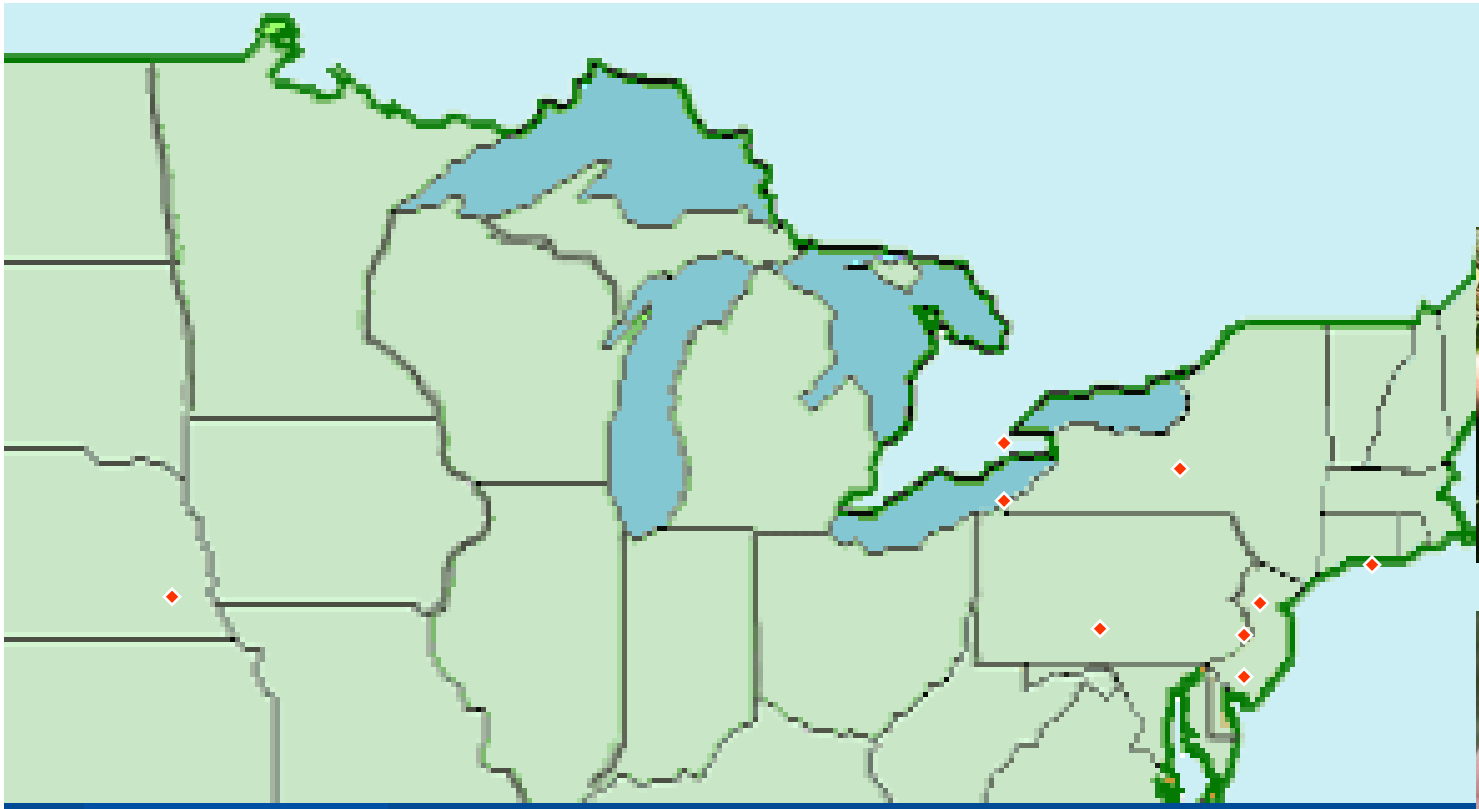
ID Number	Resistance source	Kernel Characteristics (mm) 10 kernel ave. Height	Length	Width	*ave. kernel weight (g)	*ave. kernel %
CRXR09P32	Grand Traverse	15	13	14	1.3	53.5
CRXR10P69	Grand Traverse	15	12	14	1.4	57.7
CRXR11P07	Grand Traverse	16	13	14	1.3	50.2
CRXR11P10	Grand Traverse	15	12	13	1.3	52.3
CRXR12P35	Grand Traverse	14	13	14	1.2	51.5
CRXR04P43	Ratoli	14	12	13	1.0	57.8
CRXR06P56	Ratoli	16	11	13	1.0	47.7
CRXR03P26	Yoder #5 (‘Rush’)	17	12	13	1.2	45.0
CRXR03P70	Yoder #5 (‘Rush’)	17	12	13	1.4	52.4
CRXR07P58	Yoder #5 (‘Rush’)	14	14	15	1.4	45.5
CRXR08P24	Yoder #5 (‘Rush’)	15	13	14	1.3	44.8
CRXR11P47	Yoder #5 (‘Rush’)	15	12	12	1.0	55.3
CRXR11P48	Yoder #5 (‘Rush’)	14	12	13	1.1	57.3
CRXR11P43	Zimmerman (Gas.)	20	13	14	1.1	53.6

Barcelona: kernel is 1.6 g, kernel % is 44.2

Lewis: kernel is 1.1 g, kernel % 47.4

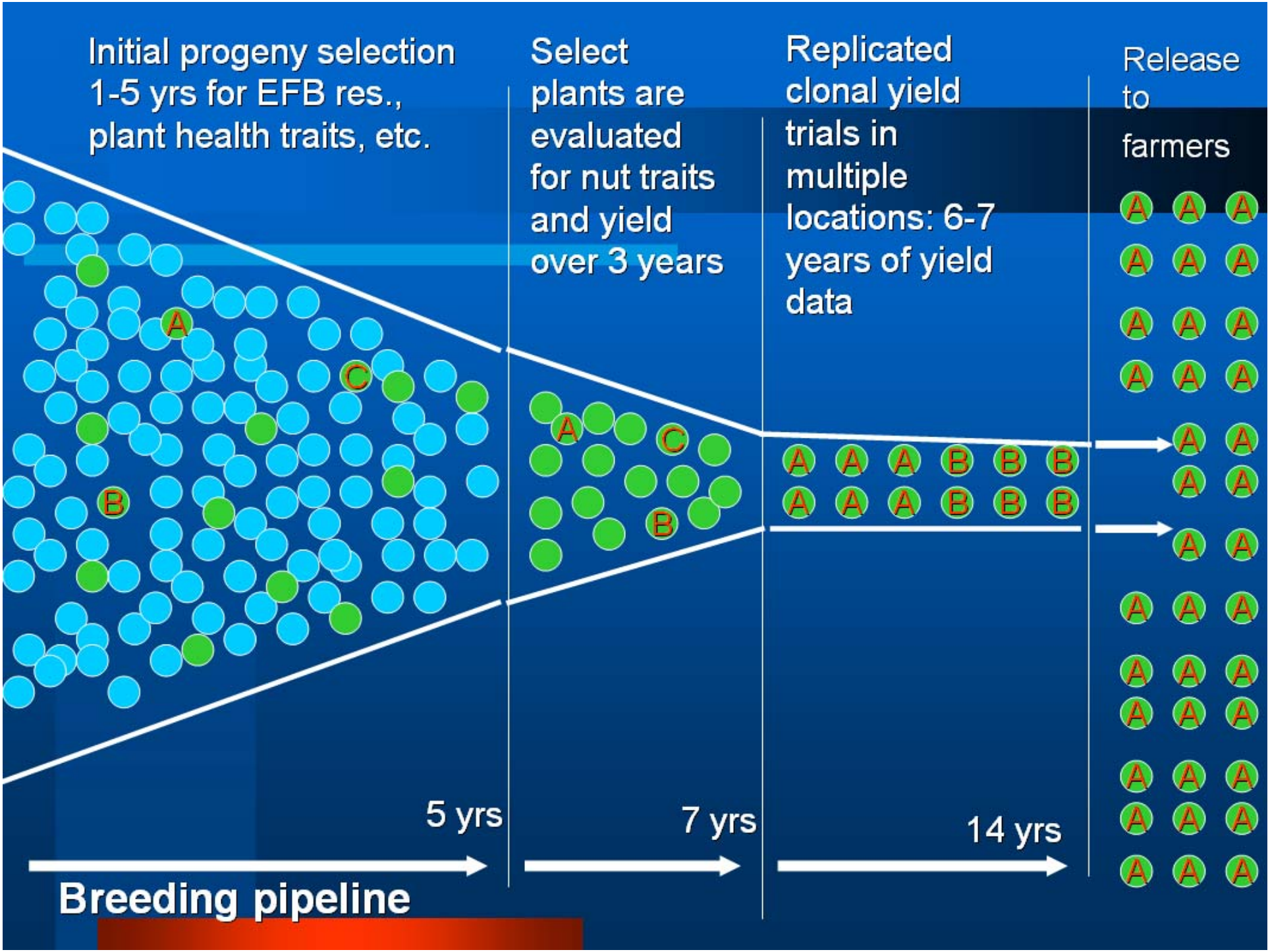
* 20 nut average yearly, over 2 or 3 years data

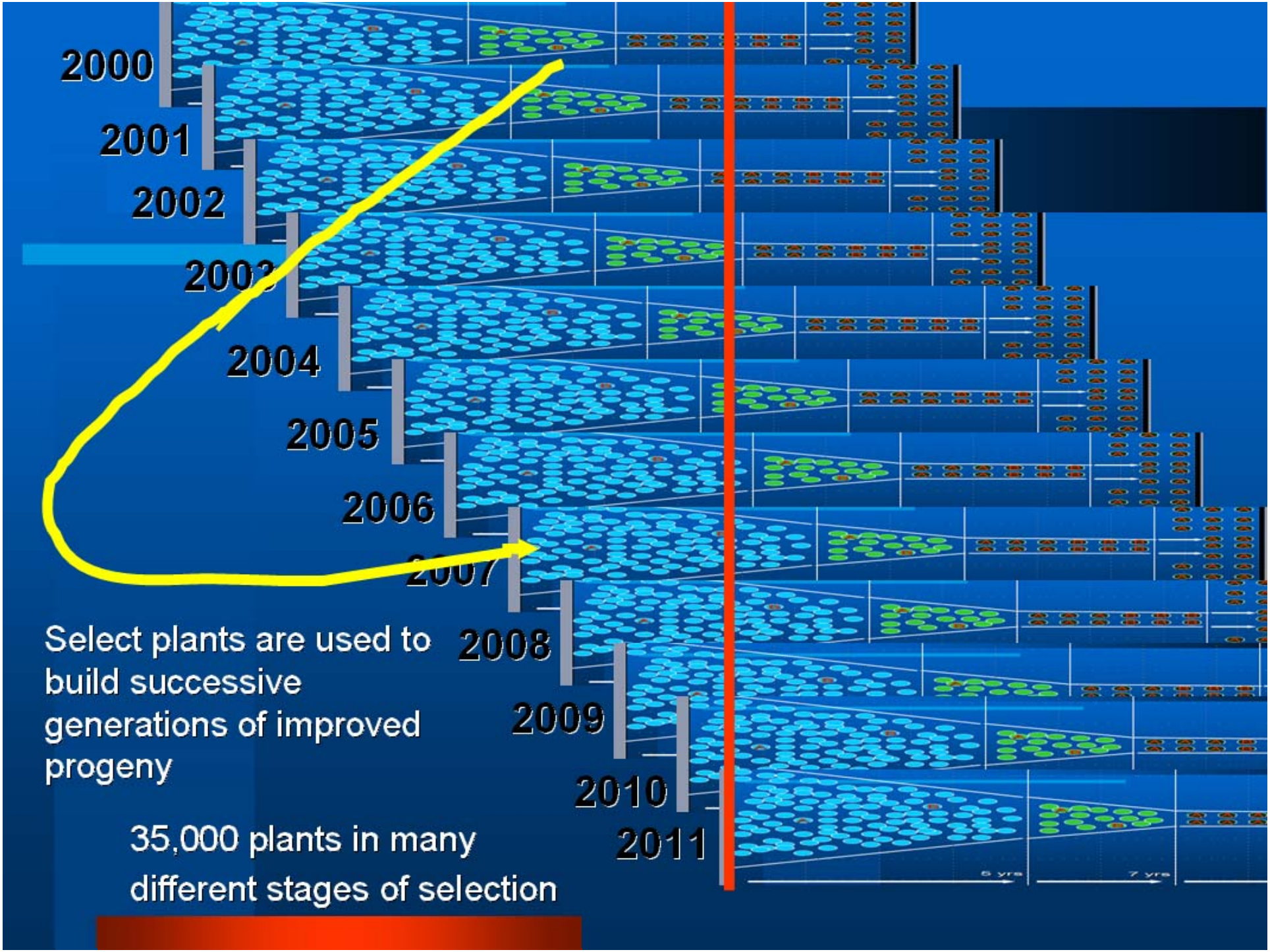

Clonal Yield Trial at Rutgers
July 2011 (established 2009)
• Trials must be evaluated for at least 7 years
• Testing in multiple locations with different climates and soils will help us identify the best plants and to determine if any are suitable for larger scale propagation and release



Trials located at:

- Rutgers (2009 and 2010; New Brunswick, NJ)
- University of Nebraska, Lincoln (2009)
- University of Guelph, Ontario, Canada (2011)
- Malcolm Olsen (2010; Findley Lake, NY—western NY)
- Jeff Zarnowski (2010; Cortland, NY—central NY)
- Peter Haarmann (2010; Aquebogue, NY—eastern Long Island)
- Tucker Hill (2009/2010; Etters, PA)
- Shuster Farms (2011; Stockton, NJ—western NJ)
- Ruscke Farms (2011; Millville, NJ—southern, NJ)


Initial progeny selection
1-5 yrs for EFB res.,
plant health traits, etc.
Select
plants are
evaluated
for nut traits
and yield
over 3 years
Replicated
clonal yield
trials in
multiple
locations: 6-7
years of yield
data
Release
to
farmers
A
B
C
5 yrs
7 yrs
14 yrs
Breeding pipeline


2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Select plants are used to build successive generations of improved progeny
35,000 plants in many different stages of selection
6 yrs
7 yrs

Final conclusions

- We've been striving to build and amass a very wide pool of genetic resources of *Corylus* to support long-term breeding efforts
  - Diversity will be key to adapting to our uncertain future climate and new/introduced pests (i.e. brown marmorated stink bug)
- Determining genetic diversity of sources of EFB-resistance and inheritance of resistance in progeny will help us streamline breeding efforts while maintaining diversity in breeding lines
- The use of molecular tools to supplement traditional breeding provides an increase in efficiency and effectiveness
- Evaluating clonal plants across multiple locations will still be the ultimate test


Questions?

Acknowledgments and thanks!

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- Contributors:

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Hybrid Hazelnut Consortium partners:

OSU
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