

# **Combining Phenotype, Genetics, and Genomics to Develop Common Bean varieties with Resistance to Highly Variable Pathogens**

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Agricultural  
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# Common Bean (*Phaseolus vulgaris*)

- **Diploid species**
- **11 pairs of chromosomes**
- **Self-fertilized – not always**
- **“fixes nitrogen” from the air”: internal fertilization**
- **The most important legume for direct human consumption**
- **Legumes – and common bean - are richer in proteins than all other plants**



## Dry Beans



## Green, snap beans

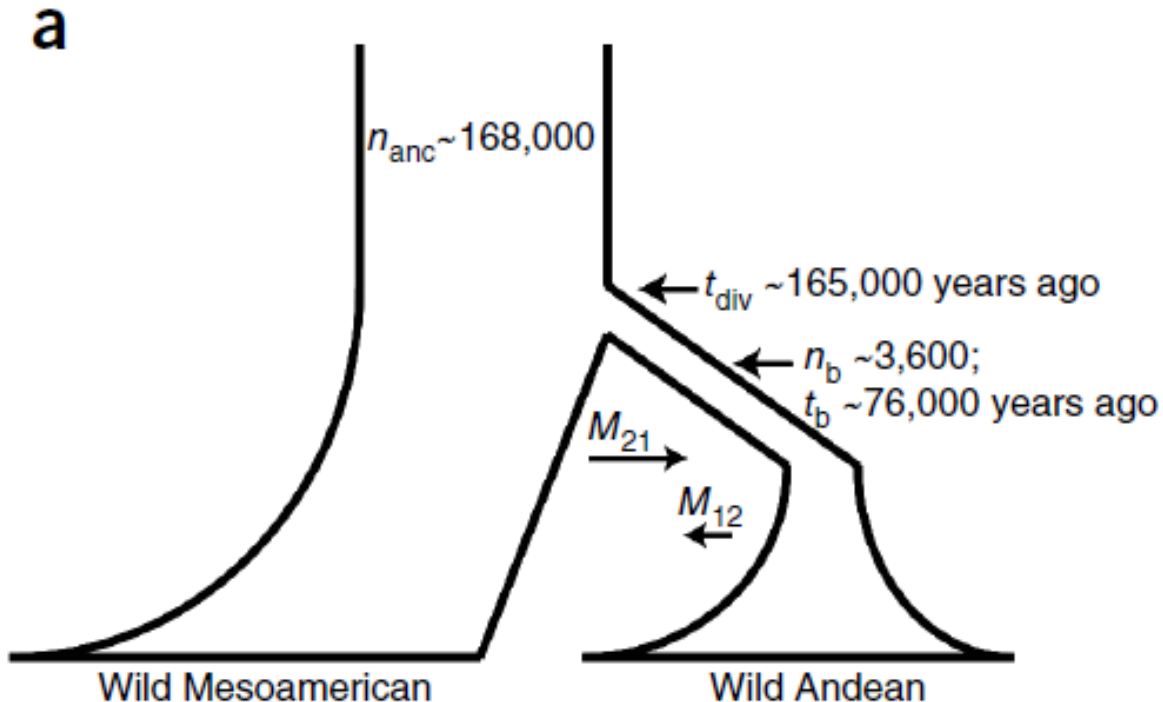




# The common Originated in Mexico

Wild beans originated in Mexico

~ 165,000 years ago a wild ancestral Mesoamerican population expanded to South America





## Parallel Domestication Two events in two locations

**Beans domesticated in two places:**

- **the Andes mountains of Peru**
- **The Lerma-Santiago basin of Mexico.**

Gaut, Nature Genetics, Vol. 46, No. 7, 2014.

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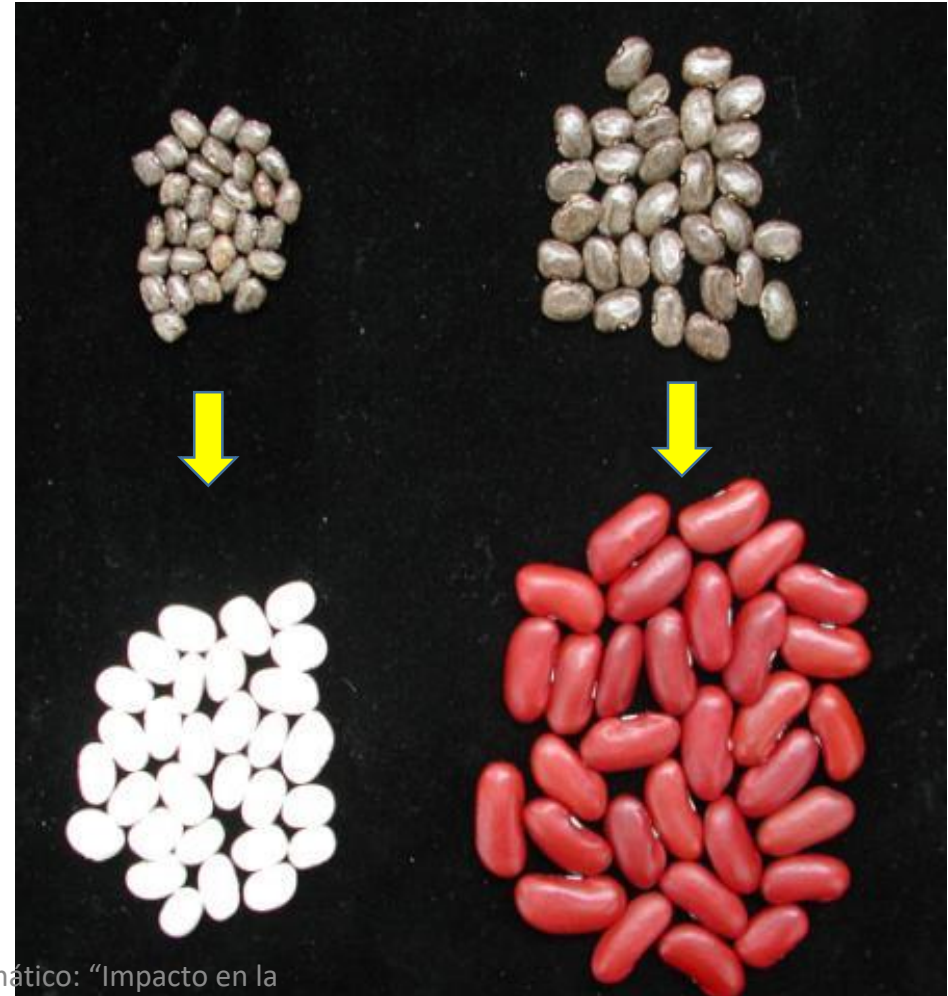
# Domesticated Common Beans Originated from Wild beans

**Wild**

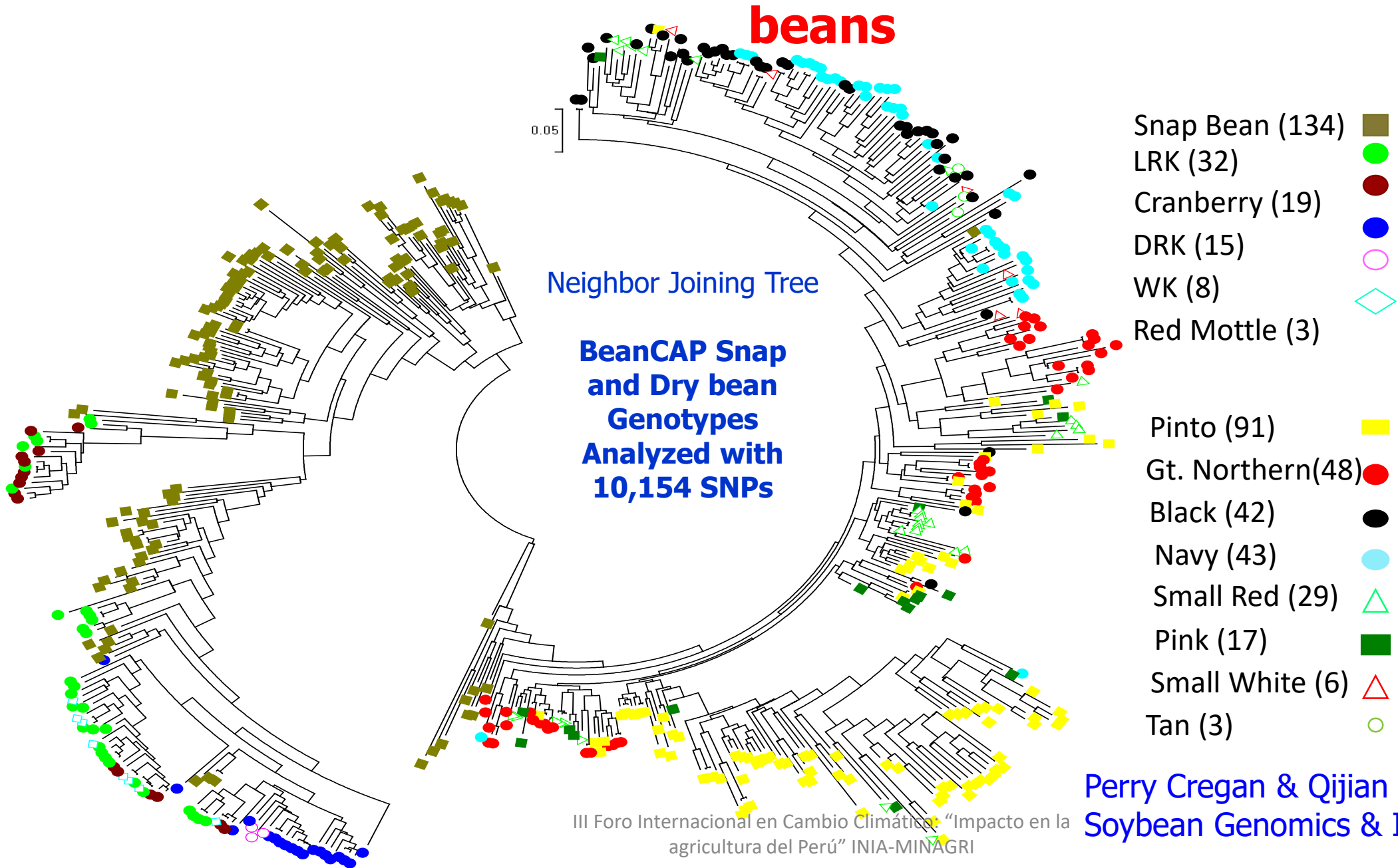
**Mesoamerican  
& Andean beans**



**Domesticated**  
**Mesoamerican &**  
**Andean beans**  
**(Predominate in Peru)**



# Multiple Characteristics separate Andean from Mesoamerican beans





# Common Bean is susceptible to many diseases

| Causal organisms - Plant part affected | Number of diseases |
|----------------------------------------|--------------------|
| Fungal – Subterranean                  | 10                 |
| Fungal – Aerial                        | 25                 |
| Viruses                                | 26                 |
| Bacteria                               | 5                  |
| Phytoplasmas                           | 4                  |
| Nematodes                              | 6                  |

**As reported in APS Compendium of Bean Diseases, 2<sup>nd</sup> Edition, 2005**

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# Many Diseases Cause Severe Yield and Quality Losses on Common Bean







**Anthracnose**  
caused by  
*Colletotrichum lindemuthianun*



**Common Bean Rust**  
Caused by  
(*Uromyces appendiculatus*)



**Angular If Spot**  
caused by  
*Pseudocercospora griseola*



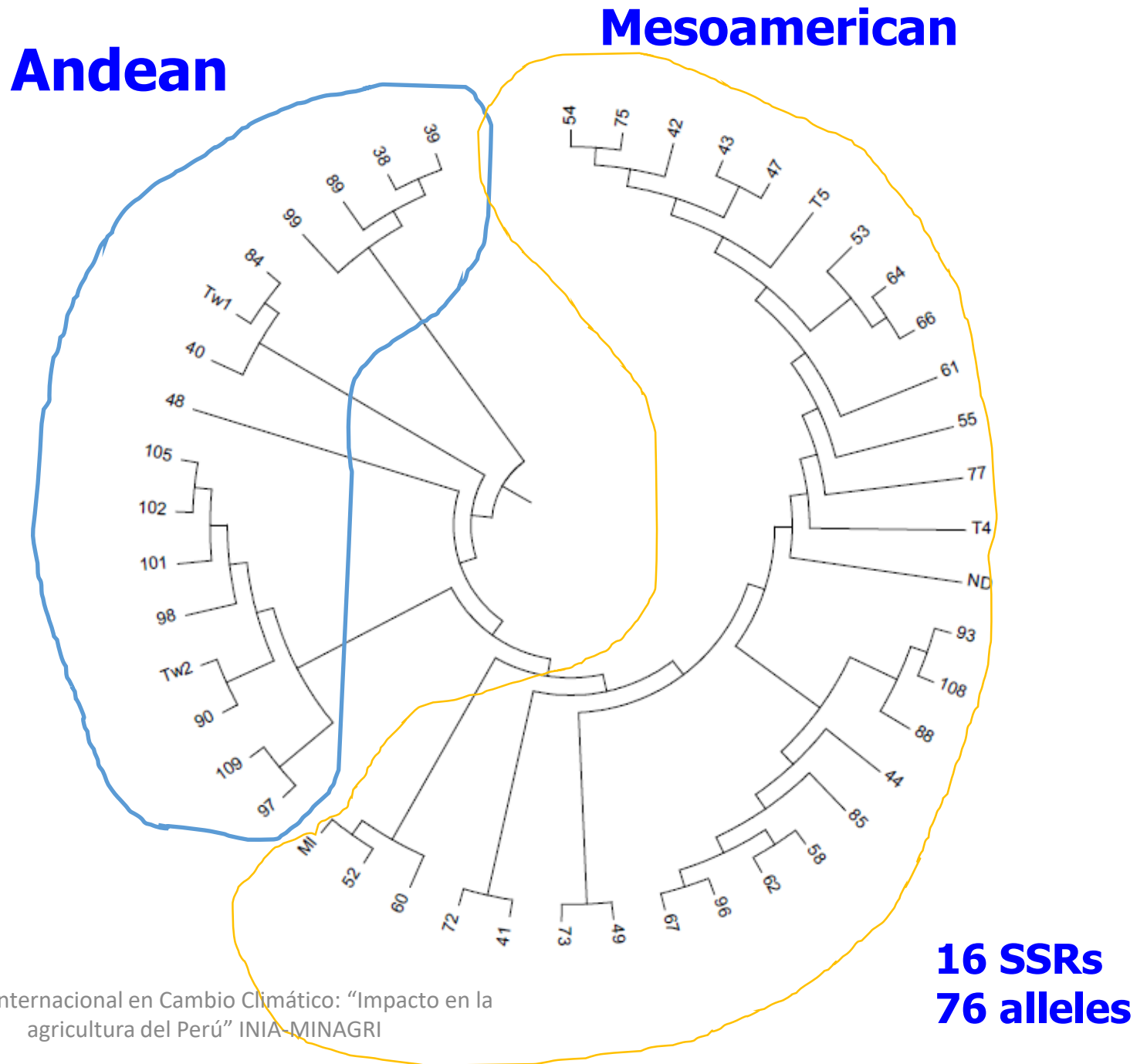
# **These three pathogens are very similar to each other**

- **The rust pathogen is biotroph and the ANT and ALS pathogens are hemi-biotrophs**
- **They survive on common bean**
- **Their populations contain many virulent strains (races)**
- **New virulent races occur often and they infect varieties that previously were resistant.**
- **Races may change from one year or location to another**

# **These three pathogens are very similar**

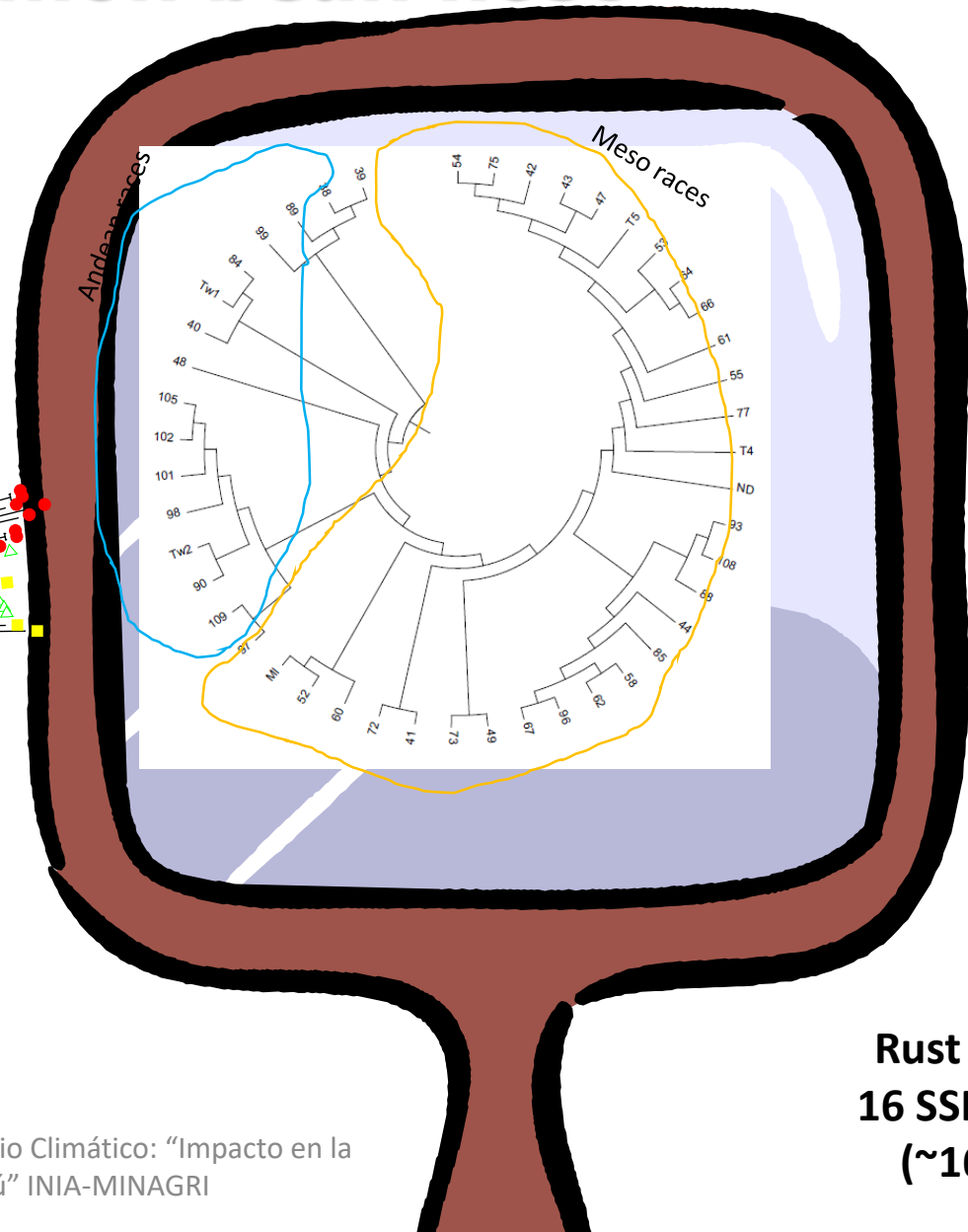
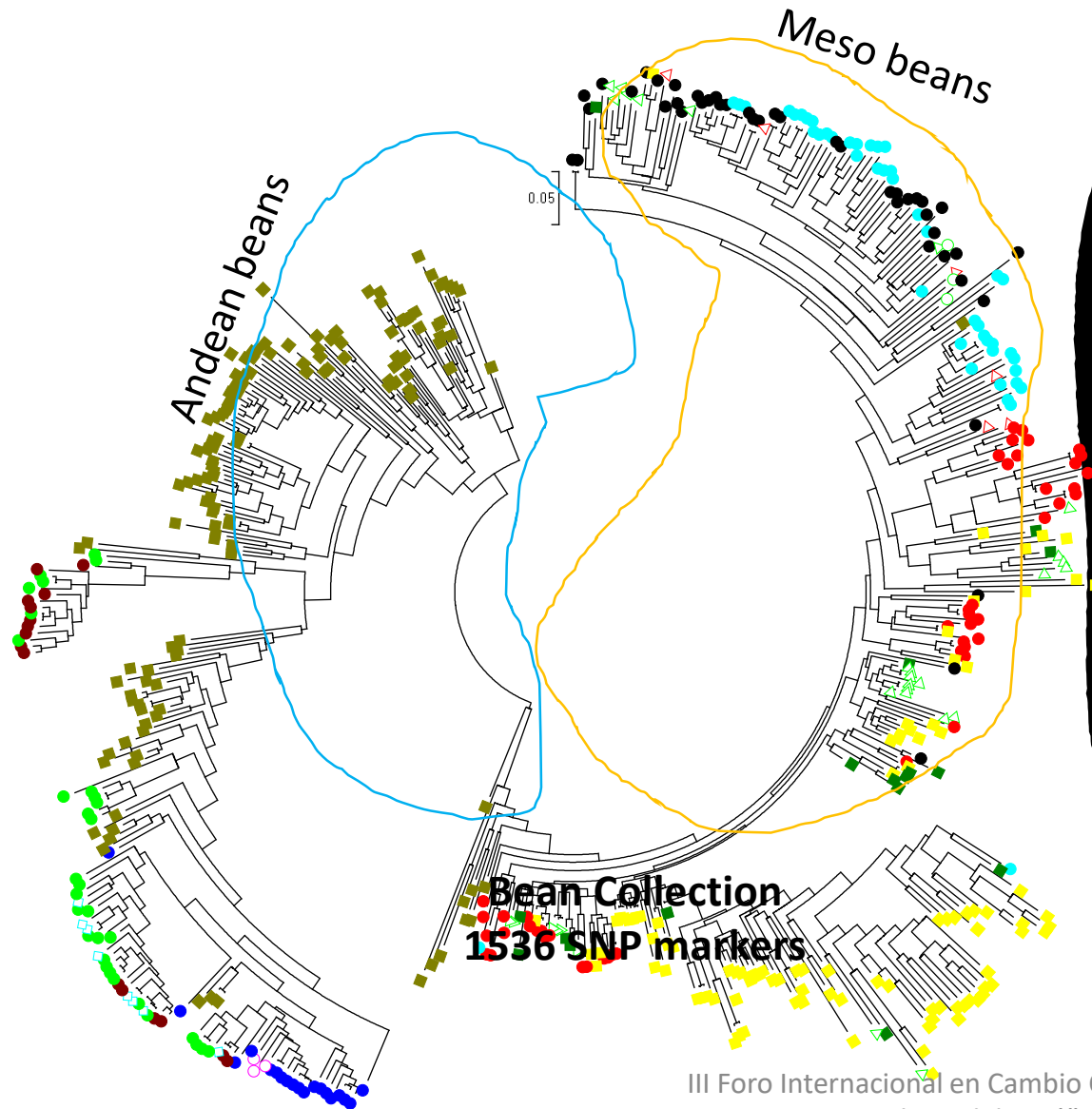
- **The virulence diversity (races) separate into two distinct groups:**
  - **Andean races**
  - **Mesoamerican races**
- **Andean races isolated only from Andean beans and correspond to the Andean gene pool**
- **Mesoamerican races isolated mostly from Mesoamerican beans and correspond to Mesoamericans gene pool**

**Using virulence  
and single  
sequence repeat  
(SSR) markers,  
46 races  
separated into  
two distinct  
groups:  
Andean and  
Mesoamerican**





# Diversity of the three pathogens mirrors diversity of their common bean host



# **Host Resistance in Common Bean**

- **Most cost-effective strategy**
- **Easily adopted in developed and developing nations**
- **Most useful when appropriate genetic variation exists**
- **Often only strategy available**
- **Clean seed production – not an option in developing nations**

# Andean Anthracnose Resistance Genes

| Gene                    | Cultivar            | Linkage Group |
|-------------------------|---------------------|---------------|
| <i>Co-1</i>             | MDRK                | <b>Pv01</b>   |
| <i>Co-1<sup>2</sup></i> | Kaboon              | <b>Pv01</b>   |
| <i>Co-1<sup>3</sup></i> | Perry Marrow        | <b>Pv01</b>   |
| <i>Co-1<sup>4</sup></i> | AND 277             | <b>Pv01</b>   |
| <i>Co-1<sup>5</sup></i> | Widusa              | <b>Pv01</b>   |
| <i>Co-12</i>            | Jalo Vermelho       | -             |
| <i>Co-13</i>            | Jalo Listras Pretas | Pv03          |
| <i>Co-14</i>            | Pitanga             | <b>Pv01</b>   |
| <i>Co-15</i>            | Corinthiano         | Pv04          |
| <i>Co-w</i>             | Jalo EEP 558        | <b>Pv01</b>   |
| <i>Co-x</i>             | Jalo EEP 558        | <b>Pv01</b>   |
| <i>Co-y</i>             | Jalo EEP 558        | Pv04          |
| <i>Co-z</i>             | Jalo EEP 558        | Pv04          |
| <i>Co-AC</i>            | Amendoim Cavalho    | <b>Pv01</b>   |
| <i>Co-PA</i>            | Paloma              | <b>Pv01</b>   |



# Mesoamerican anthracnose resistance genes

| Gene                           | Cultivar                         | Linkage group |
|--------------------------------|----------------------------------|---------------|
| <i>Co-2</i>                    | Cornell 49-242                   | Pv11          |
| <b><i>Co-3</i></b>             | Mexico 222                       | Pv04          |
| <b><i>Co-3</i><sup>2</sup></b> | Mexico 227                       | Pv04          |
| <b><i>Co-3</i><sup>3</sup></b> | BAT 93; PI 207262                | Pv04          |
| <b><i>Co-3</i><sup>4</sup></b> | Ouro Negro                       | Pv04          |
| <b><i>Co-3</i><sup>5</sup></b> | <b>G 2333</b> ; MSU 7-1; H1 line | Pv04          |
| <b><i>Co-4</i></b>             | TO                               | Pv08          |
| <b><i>Co-4</i><sup>2</sup></b> | Sel 1308; <b>G 2333</b>          | Pv08          |
| <b><i>Co-4</i><sup>3</sup></b> | PI 207262                        | Pv08          |
| <b><i>Co-5</i></b>             | TU                               | Pv07          |
| <b><i>Co-5</i><sup>2</sup></b> | Sel 1360; <b>G 2333</b>          | Pv07          |
| <i>Co-6</i>                    | AB 136                           | Pv07          |
| <i>co-8</i>                    | AB 136                           |               |
| <i>Co-11</i>                   | Michelite                        | -             |
| <i>Co-16</i>                   | Crioulo 159                      | Pv04          |
| <i>Co-17</i>                   | Sel 1308                         | Pv03          |

# Andean and Mesoamerican Angular leaf spot resistance gens

| Gene symbol              | Resistance Source | Gene Pool | Linkage Group |
|--------------------------|-------------------|-----------|---------------|
| <i>Phg-1</i>             | AND 277           | A         | Pv01          |
| <i>Phg-2</i>             | Mexico 54         | MA        | Pv08          |
| <i>Phg-2<sup>2</sup></i> | BAT 332           | MA        | Pv08          |
| <i>Phg-3</i>             | Ouro Negro        | MA        | Pv04          |
| <i>Phg-4</i>             | G5686             | A         | Pv04          |
| <i>Phg-5</i>             | CAL 143           | A         | Pv10          |
|                          | G5686             | A         | Pv10          |

# Mesoamerican and Andean Rust resistance genes in common bean

| Gene         | Cultivar            | Gene Pool | Linkage group |
|--------------|---------------------|-----------|---------------|
| <i>Ur-3</i>  | Aurora              | MA        | Pv11          |
| <i>Ur-4</i>  | Early Gallatin      | A         | Pv06          |
| <i>Ur-5</i>  | Mexico 309          | MA        | Pv04          |
| <i>Ur-6</i>  | Golden Gate Wax     | A         | Pv11          |
| <i>Ur-7</i>  | Great Northern 1140 | MA        | Pv11          |
| <i>Ur-9</i>  | Pompadour Checa 50  | A         | Pv01          |
| <i>Ur-11</i> | PI 181996           | MA        | Pv11          |
| <i>Ur-12</i> | Pompadour Checa 50  | A         | Pv07          |
| <i>Ur-13</i> | Redlands Pioneer    | A/MA      | Pv08          |
| <i>Ur-14</i> | Ouro Negro          | MA        | Pv04          |

Gilio, T.A.S., Hurtado-Gonzales, O.P., Gonçalves-Vidigal, M.C., Valentini, G., de Lima Castro, S.A., Julio Cesar Ferreira Elias, J.C., Song, Q., **Pastor-Corrales, M.A.** 2019. Genetics and fine mapping of an anthracnose resistance locus in Andean common bean landrace Amendoim Cavalo. Corresponding Author. Submitted to BMC Genomics

De Lima Castro, S.A., Gonçalves-Vidigal, M.C., *Gilio, T.A.S.*, Lacanallo, G. F., Valentini, G., Ramos Martins, V., Song, Q, Galván, M.Z, *Hurtado-Gonzales, O.P.*, **Pastor-Corrales, M.A.** 2017. Genetics and mapping of a new anthracnose resistance locus in Andean common bean Paloma. BMC Genomics 18:1-12

Valentini, G., Gonçalves-Vidigal M.C., *Hurtado-Gonzales, O.P.*, *de Lima Castro, S.A.*, Cregan, P.B., Song, Q., **Pastor-Corrales, M.A.** 2017. High Resolution mapping reveals Linkage between genes in common bean cultivar Ouro Negro conferring resistance to the rust, anthracnose, and angular leaf spot diseases. Theor. Appl. Genet. 130: 1705-1722

Hurtado-Gonzales, O.P., Valentini, G., Gilio, T.A.S., Martins, A.M., Song, Q., and **Pastor-Corrales, M. A.** 2017. Fine mapping of *Ur-3*, a historically important rust resistance locus in common bean. G3 7 (2): 557-569

Gonçalves-Vidigal, M.C., *Cruz, A.S.*, Lacanallo, G.F, Vidigal Filho, P.S., *Sousa, L.L.*, Pacheco, C.M.N.A., McClean, P., Gepts, P., **Pastor-Corrales, M.A.** 2013. Co-segregation analysis and mapping of the anthracnose *Co-10* and angular leaf spot *Phg-ON* disease resistance genes in common bean cultivar Ouro Negro. Theor. Appl. Genet. 126: 2245-2255

Gonçalves-Vidigal, M.C., Cruz, A.S., Garcia, A., Kami, J., Vidigal Filho, P.S., *Sousa, L.L.*, McClean, P., Gepts, P., **Pastor-Corrales, M.A.** 2011. Linkage mapping of the *Phg-1* and *Co-1<sup>4</sup>* genes for resistance to angular leaf spot and anthracnose in the common bean cultivar AND 277. Theor. Appl. Genet 122: 893-903



# **A Genetic Solution: Pyramiding various Genes for Resistance to Rust**

- **10 resistance genes**
- **Mesoamerican beans :**
  - **Ur-3, Ur-5, Ur-7, Ur-11, Ur-13, Ur-14**
- **Other genes in Andean beans:**
  - **Ur-4, Ur-6, Ur-9, Ur-12**
- **New R genes are being discovered**
- **Combination of Mesoamerican and Andean confer resistance to all known races of rust pathogen**

# Gene Pyramiding

Combining six resistance genes into a single cultivar

**Great northern**

BelMiNeb-RMR-8, -9, -10, -11, -12, -13

**Pinto**

BelDakMi-RMR-18, -19, -20, -21, -22, -23

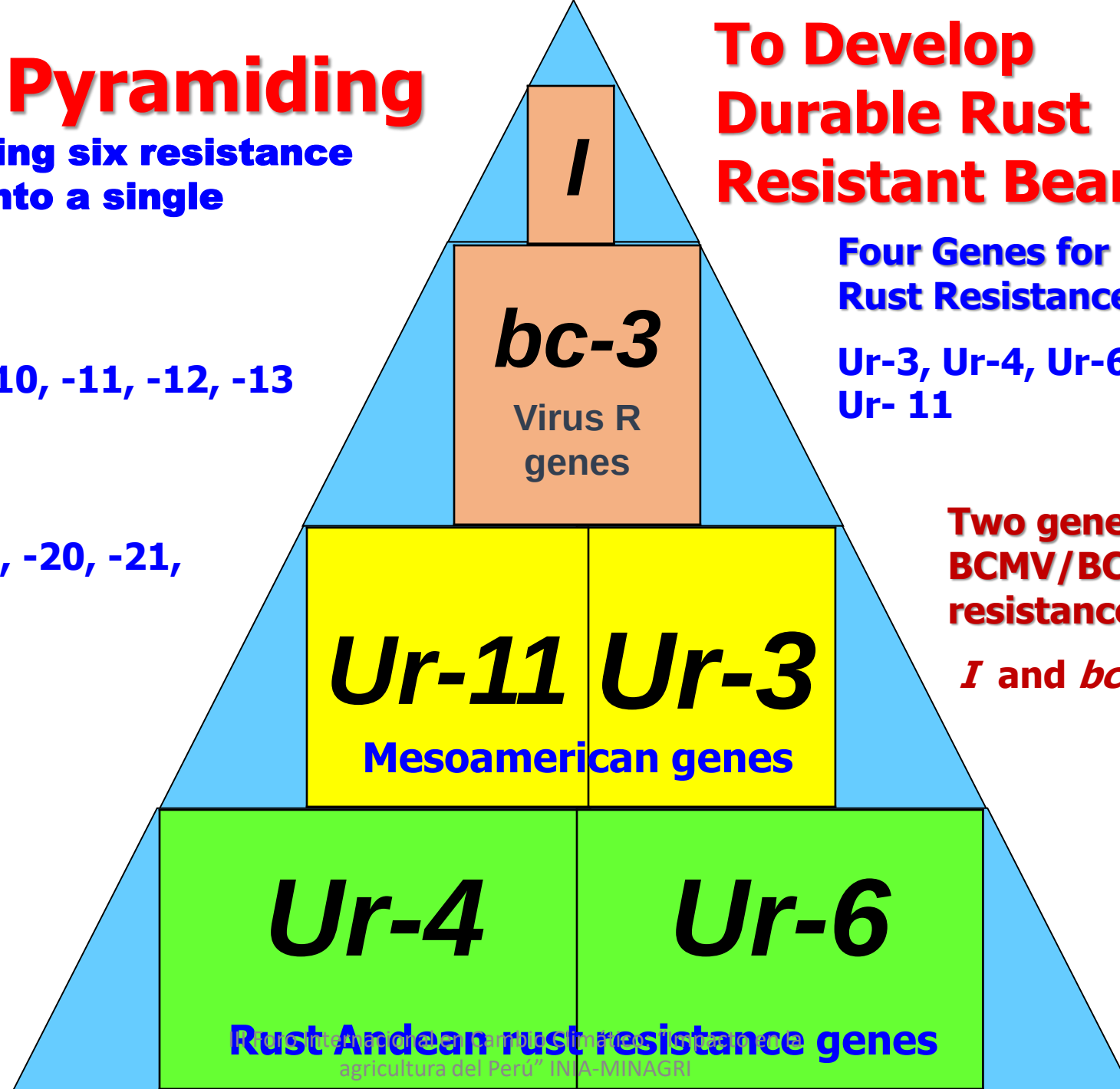
**To Develop Durable Rust Resistant Beans**

Four Genes for Rust Resistance

Ur-3, Ur-4, Ur-6 & Ur-11

Two genes for BCMV/BCMNV resistance

*I* and *bc-3*



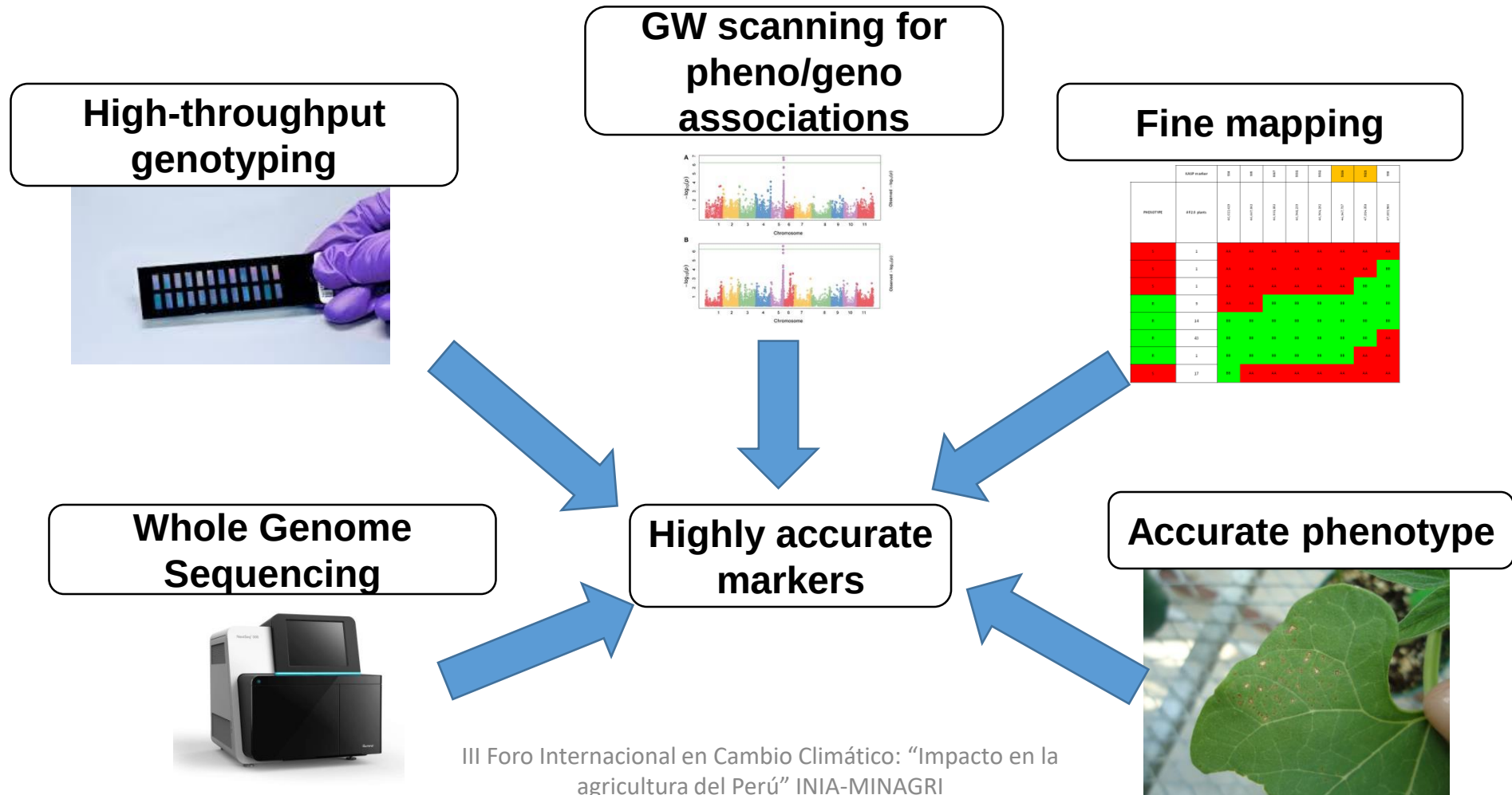
# **Fine mapping of genes conferring resistance to Rust and Anthracnose of Common Bean**

Oscar P. Hurtado-Gonzales<sup>1</sup>, Giseli Valentini<sup>2</sup>, Thiago S. A. Gilio<sup>2</sup>, Quigley, Chuck<sup>1</sup>,  
Maria C. Goncalvez-Vidigal<sup>2</sup>, Marcio Ferreira<sup>1</sup>, Qijian Song<sup>1</sup>, M.A. Pastor-Corrales<sup>1</sup>

<sup>1</sup>Bean Pathology, Soybean Genomics and Improvement Lab, USDA-ARS, Beltsville  
Maryland, USA

<sup>2</sup>Universidade Estadual de Maringá, Maringá, PR, Brazil

# Combining Genomics, Genetics, and Phenotyping to accelerate and increase accuracy of markers



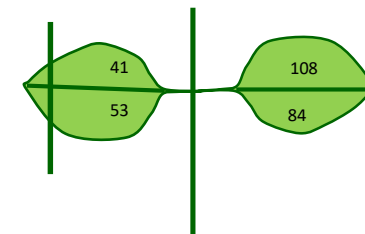


# Mapping the *Ur-3* rust resistance gene

## STEP 1: Population development

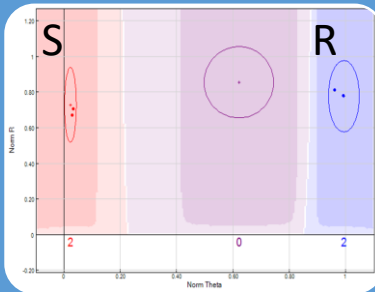
- Cross Pinto 114 (S) x Aurora (R-*Ur-3*)
- Inoculation of parent, controls, and segregating population with four races of rust pathogen.

- Inoculation 7 dap
- Evaluation 14 dai



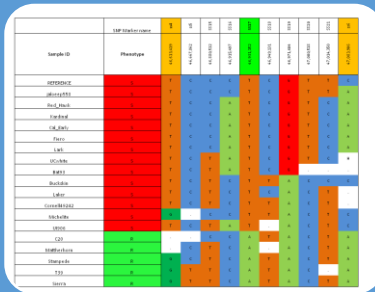
**Inoculation diagram**

# Fine Mapping *Ur-3* rust resistance gene



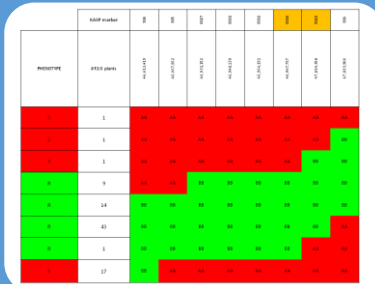
## Chromosomal location of *Ur-3* locus: Bulk Segregant Approach

- F2 plants **phenotyped** with Races 41 and 53 (cross Pinto114 (S)x Aurora (R,*Ur-3* alone).
- Susceptible pool (S) and parents (S and R) are **genotyped** with 6 K illumina SNP chip.
- Positive SNPs are converted into KASP markers and mapped in F2 plants.



## Linking phenotype to sequence: Local Association

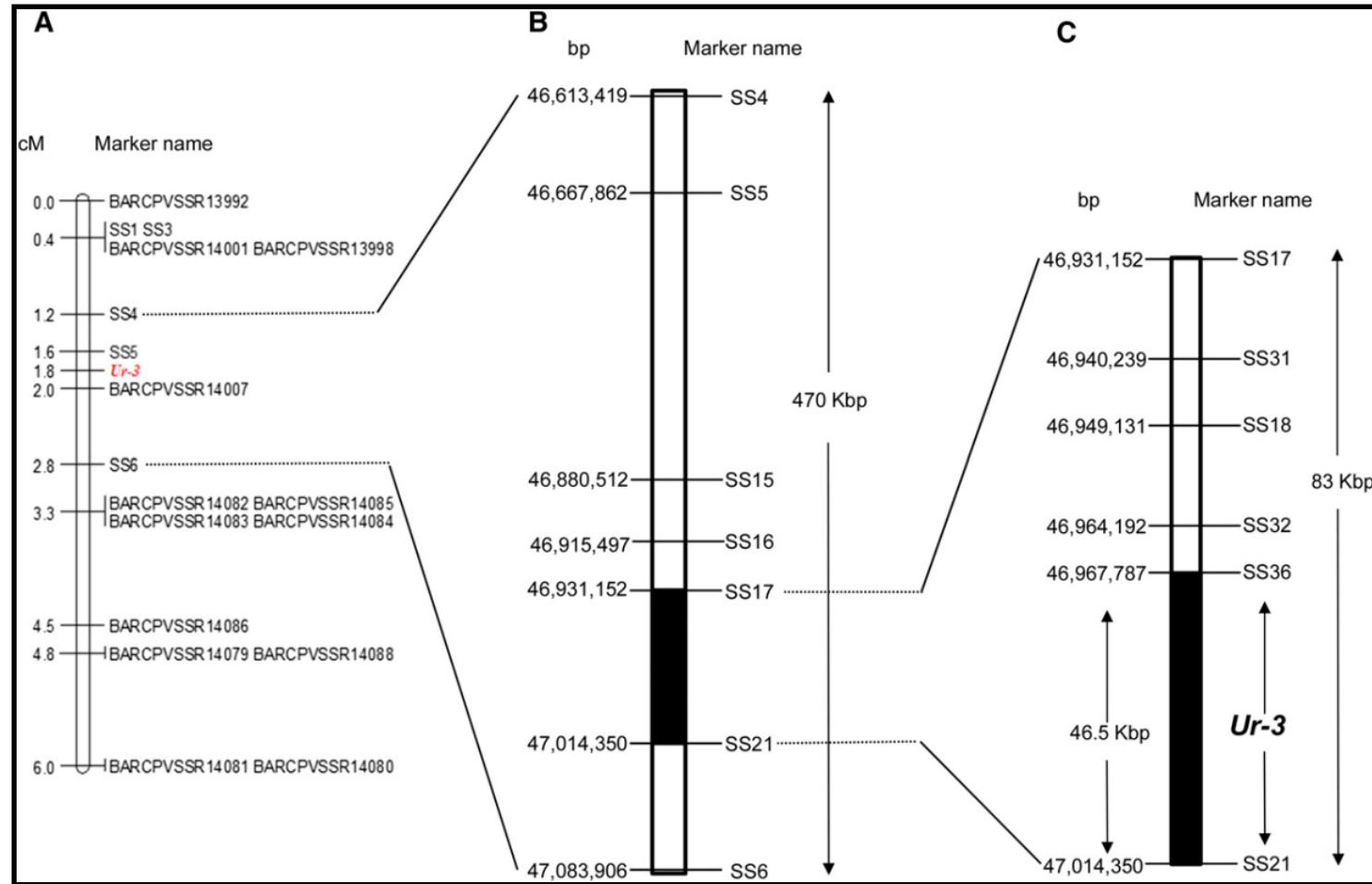
- 18 sequenced lines are phenotyped with Races 41 and 53
- Haplotypes are built around flanking SNPs (ss4 and ss6).
- Informative haplotypes are converted into markers



## Fine mapping and marker validation: F2:3 plants and diverse panel are phenotyped/genotyped

- Flanking region (~46Kb) is determined by genotyping with additional markers across the interval and correlating with phenotype
- Marker(s) are validated on a wide diverse phenotyped panel of bean varieties

# Highly accurate markers are now developed in short period of time



From 470 kb to 46 kb

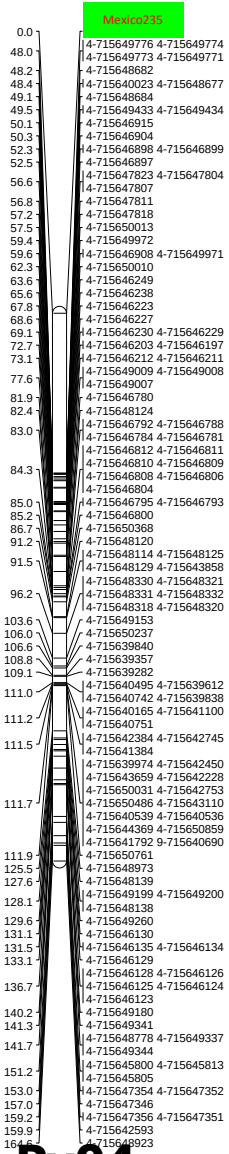
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Hurtado-Gonzales et al. 2017

# Mapping unknown rust resistance genes: Mexico 235

| Bean Genotype | Ur-Genes                | Number of races of <i>U. appendiculatus</i> |             |
|---------------|-------------------------|---------------------------------------------|-------------|
|               |                         | Resistant                                   | Susceptible |
| Aurora        | <i>Ur-3</i>             | 55                                          | 39          |
| Mexico 235    | <i>Ur-3</i> + <b>UK</b> | 83                                          | 11          |

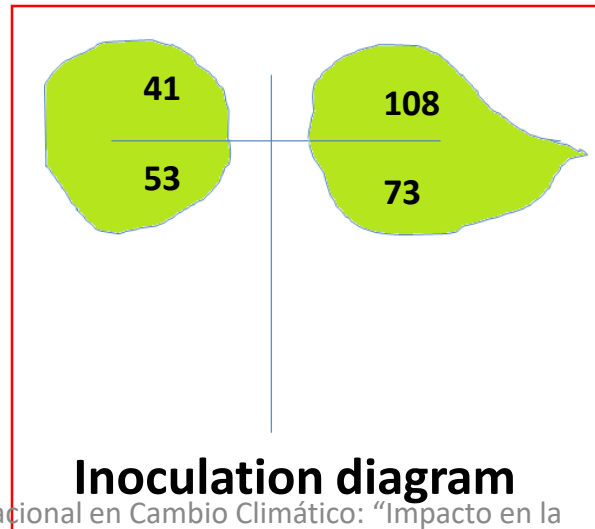
| Bean Genotypes      | Ur-genes                   | Races of <i>U. appendiculatus</i> |    |    |    |
|---------------------|----------------------------|-----------------------------------|----|----|----|
|                     |                            | 41                                | 53 | 49 | 67 |
| Aurora              | <i>Ur-3</i>                | R                                 | R  | S  | S  |
| Mexico 235          | <i>Ur-3</i> + <b>UK</b>    | R                                 | R  | R  | R  |
| Early Gallatin      | <i>Ur-4</i>                | S                                 | S  | R  | S  |
| Mexico 309          | <i>Ur-5</i>                | R                                 | R  | S  | S  |
| Golden Gate Wax     | <i>Ur-6</i>                | S                                 | S  | S  | S  |
| Great Northern 1140 | <i>Ur-7</i>                | S                                 | S  | R  | R  |
| Pompadour Checa 50  | <i>Ur-9</i> + <i>Ur-12</i> | S                                 | S  | R  | S  |
| PI 181996           | <i>Ur-11</i>               | R                                 | R  | R  | R  |
| Redland Pioneer     | <i>Ur-13</i>               | S                                 | S  | S  | S  |



# Simultaneous fine mapping of *Ur-4* and *Ur-5* to obtain tightly-linked and accurate markers

- Cross Early Gallatin x Mexico 309
- F<sub>2</sub> population ~400 plants
- Phenotyped with 4 races of *Uromyces appendiculatus*

| <i>Ur</i> -Gene | Reaction to 4 Races of <i>U. appendiculatus</i> |     |    |    |
|-----------------|-------------------------------------------------|-----|----|----|
|                 | 73                                              | 108 | 41 | 53 |
| <i>Ur-4</i>     | HR                                              | HR  | S  | S  |
| <i>Ur-5</i>     | S                                               | S   | TP | TP |



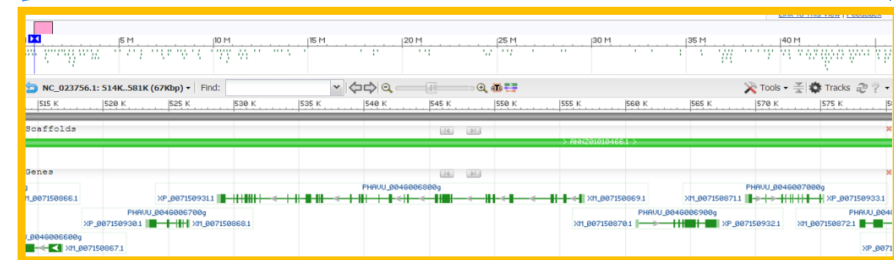


# Targeted SSR and KASP markers developed to accurately map *Ur-4* and *Ur-5*

|                                                  | <i>Ur-4</i>      | <i>Ur-5</i>     |
|--------------------------------------------------|------------------|-----------------|
| Number of F <sub>2:3</sub> plants                | ~570             | ~100            |
| Rust race used during F <sub>2:3</sub> screening | 108              | 53              |
| Type of reaction                                 | HR               | TP              |
| Type of markers developed                        | KASP/SSR         |                 |
| Fine mapped genomic region                       | 1.68 Mb -> 20 Kb | 0.7 Mb -> 67 Kb |
| Number of candidate genes                        | 3                | 6               |



***Ur-4* candidate genes on chromosome Pv06**



***Ur-5* candidate genes on chromosome Pv04**

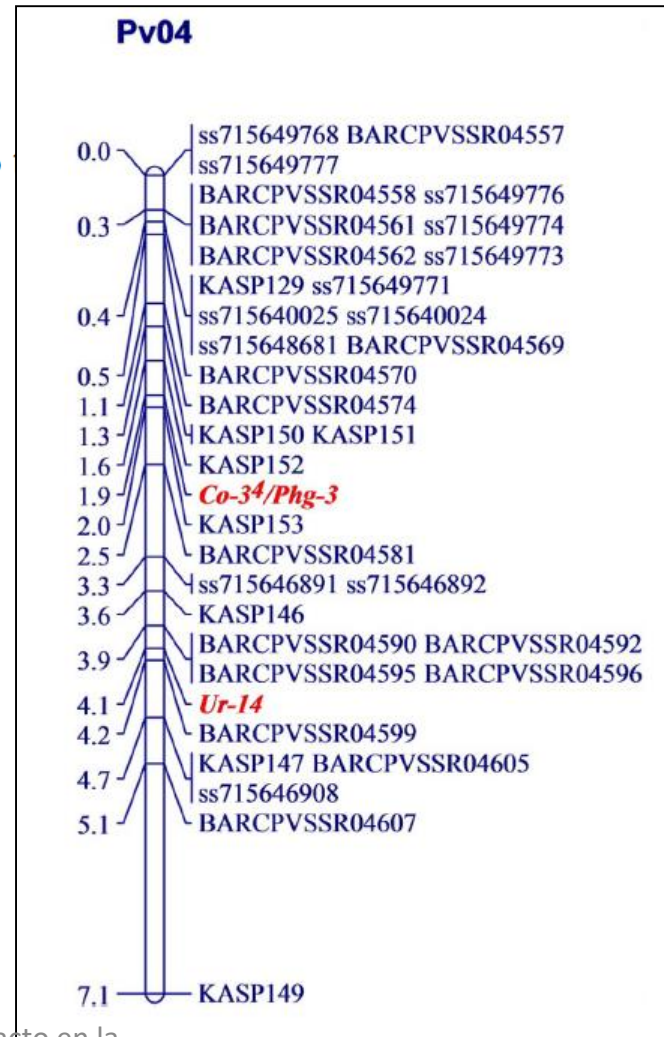
# Flanking markers can be developed for clusters of genes

## High-resolution mapping reveals linkage between genes in common bean cultivar Ouro Negro conferring resistance to rust, anthracnose, and angular leaf spot diseases

Giseli Valentini<sup>1</sup> · Maria Celeste Gonçalves-Vidigal<sup>1</sup> · Oscar P. Hurtado-Gonzales<sup>2</sup> · Sandra Aparecida de Lima Castro<sup>1</sup> · Perry B. Cregan<sup>2</sup> · Qijian Song<sup>2</sup> · Marcial A. Pastor-Corrales<sup>2</sup>

| Parental cross.                                                                                                        | Generation       | Observed ratio (RR:RS:SS) | Expected ratio (1RR:2RS:1SS) | $\chi^2$ | P value (2 df) |
|------------------------------------------------------------------------------------------------------------------------|------------------|---------------------------|------------------------------|----------|----------------|
| Race 73 of <i>C. lindemuthianum</i> , the anthracnose pathogen of the common bean                                      |                  |                           |                              |          |                |
| Rudá                                                                                                                   | SP               | 0:0:20                    |                              |          |                |
| Ouro Negro                                                                                                             | RP               | 20:0:0                    |                              |          |                |
| Rudá × Ouro Negro                                                                                                      | F <sub>2:3</sub> | 43:88:48                  | 44.75:89.5:44.75             | 0.32     | 0.85           |
| Races 15-1 (41), 15-3 (47), 31-1 (53) and 31-7 (58) of <i>U. appendiculatus</i> , the rust pathogen of the common bean |                  |                           |                              |          |                |
| Rudá                                                                                                                   | SP               | 0:0:20                    |                              |          |                |
| Ouro Negro                                                                                                             | RP               | 20:0:0                    |                              |          |                |
| Rudá × Ouro Negro                                                                                                      | F <sub>2:3</sub> | 45:87:47                  | 44.75:89.5:44.75             | 0.18     | 0.91           |

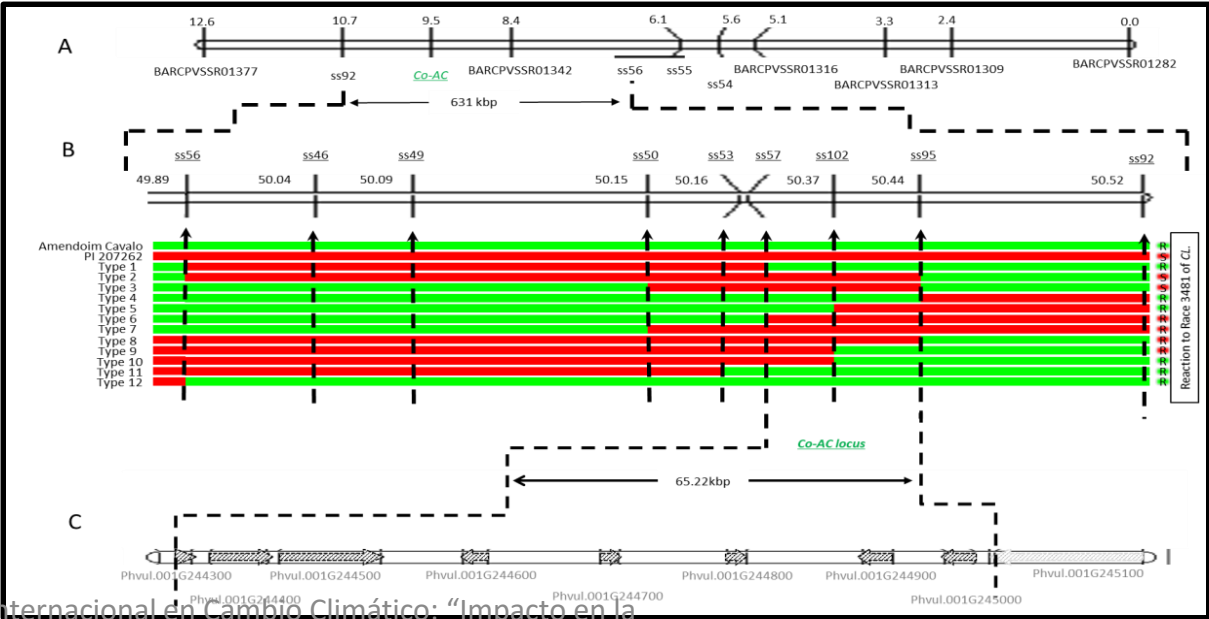
SP susceptible parent, RP resistant parent



# New broad-spectrum anthracnose resistance genes can be identified

| Differentials<br>Cultivars | Gene<br>pool | Resistance Gene(s)                                        | Races of <i>Colletotrichum lindemuthianum</i> |   |   |    |    |    |    |    |    |    |     |     |      |      |      |
|----------------------------|--------------|-----------------------------------------------------------|-----------------------------------------------|---|---|----|----|----|----|----|----|----|-----|-----|------|------|------|
|                            |              |                                                           | 2                                             | 7 | 9 | 19 | 23 | 39 | 55 | 65 | 73 | 89 | 449 | 453 | 1545 | 2047 | 3481 |
| Amendoim Cavalo            | A            |                                                           | R                                             | R | R | R  | R  | R  | R  | R  | R  | R  | S   | S   | R    | R    | R    |
| Michelite                  | M            | <i>Co-11</i>                                              | R                                             | S | S | S  | S  | S  | S  | S  | S  | S  | S   | S   | S    | S    | S    |
| MDRK                       | A            | <i>Co-1</i>                                               | S                                             | S | R | S  | S  | S  | S  | R  | R  | R  | R   | R   | R    | S    | R    |
| Perry Marrow               | A            | <i>Co-1<sup>3</sup></i>                                   | R                                             | S | R | R  | S  | S  | S  | R  | R  | R  | R   | S   | R    | S    | R    |
| Cornell 49-242             | M            | <i>Co-2</i>                                               | R                                             | R | S | S  | R  | R  | R  | R  | S  | S  | R   | R   | S    | S    | S    |
| Widusa                     | A            | <i>Co-1<sup>5</sup></i>                                   | R                                             | R | R | R  | S  | R  | S  | R  | R  | S  | R   | R   | R    | S    | S    |
| Kaboon                     | A            | <i>Co-1<sup>2</sup></i>                                   | R                                             | R | R | R  | R  | S  | S  | R  | R  | R  | R   | R   | R    | S    | R    |
| Mexico 222                 | M            | <i>Co-3</i>                                               | R                                             | R | R | R  | R  | R  | R  | S  | S  | S  | S   | S   | R    | S    | R    |
| PI 207262                  | M            | <i>Co-4<sup>3</sup>/Co-3<sup>3</sup></i>                  | R                                             | R | R | R  | R  | R  | R  | R  | R  | R  | S   | S   | R    | S    | S    |
| TO                         | M            | <i>Co-4</i>                                               | R                                             | R | R | R  | R  | R  | R  | R  | R  | R  | S   | S   | R    | S    | S    |
| TU                         | M            | <i>Co-5</i>                                               | R                                             | R | R | R  | R  | R  | R  | R  | R  | R  | R   | R   | S    | S    | R    |
| AB 136                     | M            | <i>Co-6/co-8</i>                                          | R                                             | R | R | R  | R  | R  | R  | R  | R  | R  | R   | R   | S    | S    | S    |
| G 2333                     | M            | <i>Co-4<sup>2</sup>/Co-5<sup>2</sup>/Co-3<sup>5</sup></i> | R                                             | R | R | R  | R  | R  | R  | R  | R  | R  | R   | R   | R    | R    | S    |

Locus definition  
at high  
resolution



# Consensus to build a Marker-Trait Association panel (MTA)

## GOAL: MARKER VALIDATION PRIOR TO DEPLOYMENT -UNIQUE HAPLOTYPE ASSOCIATED WITH THE TRAIT

- Bean collection:
  - Elite material
  - Diverse Germplasm
- Phenotyped with multiple races
- Marker validated on different types of crosses (F<sub>2</sub>, BCs, etc)
- Under different genotyping platforms

■ Table 7 Validation of the KASP marker SS68 tightly linked with the *Ur-3* rust resistance locus on 130 common bean cultivars

| Genotype         | Ur Gene <sup>a</sup>            | Dry/Snap Bean | SS68 <sup>b</sup> |
|------------------|---------------------------------|---------------|-------------------|
| Pinto 114        | <i>ur-3</i>                     | Dry bean      | AA                |
| Aurora           | <i>Ur-3</i>                     | Dry bean      | BB                |
| Mexico 235       | <i>Ur-3+</i>                    | Dry bean      | BB                |
| Ecuador 299      | <i>Ur-3+</i>                    | Dry bean      | BB                |
| NEP 2            | <i>Ur-3+</i>                    | Dry bean      | BB                |
| 51051            | <i>Ur-3+</i>                    | Dry bean      | BB                |
| Early Gallatin   | <i>Ur-4</i>                     | Snap bean     | AA                |
| Mexico 309       | <i>Ur-5</i>                     | Dry bean      | AA                |
| Golden Gate Wax  | <i>Ur-6</i>                     | Snap bean     | AA                |
| GN 1140          | <i>Ur-7</i>                     | Dry bean      | AA                |
| PI 181996        | <i>Ur-11</i>                    | Dry bean      | AA                |
| PC 50            | <i>Ur-9; Ur-12</i>              | Dry bean      | AA                |
| Redlands Pioneer | <i>Ur-13</i>                    | Dry bean      | AA                |
| Ouro Negro       | <i>Ur-14</i>                    | Dry bean      | AA                |
| Condor           | Susc; reported with <i>Ur-3</i> | Dry bean      | AA                |
| Vista            | Susc; reported with <i>Ur-3</i> | Dry bean      | AA                |
| Raven            | Susc; reported with <i>Ur-3</i> | Dry bean      | AA                |
| Jaguar           | Susc; reported with <i>Ur-3</i> | Dry bean      | AA                |
| Santa Fe         | <i>Ur-3</i>                     | Dry bean      | BB                |
| Merlot           | <i>Ur-3</i>                     | Dry bean      | BB                |
| Stampede         | <i>Ur-3</i>                     | Dry bean      | BB                |
| Alpine           | <i>Ur-3</i>                     | Dry bean      | BB                |
| Starlight        | <i>Ur-3</i>                     | Dry bean      | BB                |
| CO-54150         | <i>Ur-3</i>                     | Dry bean      | BB                |
| C 20             | <i>Ur-3</i>                     | Dry bean      | BB                |
| Matterhorn       | <i>Ur-3</i>                     | Dry bean      | BB                |
| Chase            | <i>Ur-3</i>                     | Dry bean      | BB                |
| Apache           | <i>Ur-3</i>                     | Dry bean      | BB                |
| Burke            | <i>Ur-3</i>                     | Dry bean      | BB                |
| La Paz           | <i>Ur-3</i>                     | Dry bean      | BB                |
| Aztec            | <i>Ur-3</i>                     | Dry bean      | BB                |
| T-39             | <i>Ur-3; Ur-?</i>               | Dry bean      | BB                |
| BelJersay-RR-1   | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelJersay-RR-4   | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelJersay-RR-5   | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelJersay-RR-6   | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelDade-RR-1     | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelDade-RR-2     | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelDade-RR-3     | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelDade-RGMR-4   | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| BelDade-RGMR-5   | <i>Ur-3; Ur-4</i>               | Snap bean     | BB                |
| Centennial       | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| Croissant        | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| CO-33875         | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| CO-34142         | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| CO-55119         | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| Kodiak           | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| Coyne            | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| ABC Weihing      | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| ABCP 8           | <i>Ur-3; Ur-6</i>               | Dry bean      | BB                |
| Stampede-R       | <i>Ur-3; Ur-11</i>              | Dry bean      | BB                |
| BelDak-RR-1      | <i>Ur-3; Ur-6, CNC</i>          | Dry bean      | BB                |
| BelDak-RR-2      | <i>Ur-3; Ur-6, CNC</i>          | Dry bean      | BB                |
| BelMiNeb-RMR-7   | <i>Ur-3; Ur-4, Ur-11</i>        | Dry bean      | BB                |
| BelDakMi-RMR-14  | <i>Ur-3; Ur-6, Ur-11</i>        | Dry bean      | BB                |
| BelDakMi-RMR-16  | <i>Ur-3; Ur-6, Ur-11</i>        | Dry bean      | BB                |
| BelDakMi-RMR-17  | <i>Ur-3; Ur-6, Ur-11</i>        | Dry bean      | BB                |

■ Table 7, continued

| Genotype        | Ur Gene <sup>a</sup>           | Dry/Snap Bean | SS68 <sup>b</sup> |
|-----------------|--------------------------------|---------------|-------------------|
| BelDakMi-RMR-18 | <i>Ur-3, Ur-4, Ur-6, Ur-11</i> | Dry bean      | BB                |
| BelMiNeb-RMR-8  | <i>Ur-3, Ur-4, Ur-6, Ur-11</i> | Dry bean      | BB                |
| BelMiNeb-RMR-10 | <i>Ur-3, Ur-4, Ur-6, Ur-11</i> | Dry bean      | BB                |
| BelMiNeb-RMR-11 | <i>Ur-3, Ur-4, Ur-6, Ur-11</i> | Dry bean      | BB                |
| BelMiNeb-RMR-12 | <i>Ur-3, Ur-4, Ur-6, Ur-11</i> | Dry bean      | BB                |
| Slenderette     | <i>Ur-4</i>                    | Snap bean     | AA                |
| Caprice         | <i>Ur-4</i>                    | Snap bean     | AA                |
| Gold Rush       | <i>Ur-4</i>                    | Snap bean     | AA                |
| Acclaim         | <i>Ur-5</i>                    | Snap bean     | AA                |
| B-190           | <i>Ur-6+</i>                   | Dry bean      | AA                |
| Olathe          | <i>Ur-6+</i>                   | Dry bean      | AA                |
| BelDakMi-RR-4   | <i>Ur-11</i>                   | Dry bean      | AA                |
| BelMiNeb-RR-2   | <i>Ur-11</i>                   | Dry bean      | AA                |
| BelMidak-RR-3   | <i>Ur-11</i>                   | Dry bean      | AA                |
| BelMidak-RR-4   | <i>Ur-11</i>                   | Dry bean      | AA                |
| BARC-RR-3       | <i>Ur-4; Ur-5</i>              | Snap bean     | AA                |
| BARC-RR-17      | <i>Ur-4; Ur-5</i>              | Snap bean     | AA                |
| BARC-RR-18      | <i>Ur-4; Ur-5</i>              | Snap bean     | AA                |
| BARC-RR-24      | <i>Ur-4; Ur-5</i>              | Snap bean     | AA                |
| BARC-RR-25      | <i>Ur-4; Ur-5</i>              | Snap bean     | AA                |
| BARC-RR-26      | <i>Ur-4; Ur-5</i>              | Snap bean     | AA                |
| BARC-RR-27      | <i>Ur-4; Ur-5</i>              | Snap bean     | AA                |
| BelMiNeb-RR-1   | <i>Ur-4, Ur-11</i>             | Dry bean      | AA                |
| BelMiNeb-RMR-3  | <i>Ur-4, Ur-11</i>             | Dry bean      | AA                |
| BelMidak-RR-1   | <i>Ur-4, Ur-11</i>             | Dry bean      | AA                |
| BelMidak-RR-2   | <i>Ur-4, Ur-11</i>             | Dry bean      | AA                |
| BelJersey-RR-10 | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BelJersey-RR-11 | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BelJersey-RR-12 | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BelJersey-RR-18 | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BelFla-RR-3     | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BelFla-RR-4     | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BelTenn-RR-1    | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BelTenn-RR-2    | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BeltGlade-RR-2  | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| BeltGlade-RR-3  | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| Cabot           | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| Clarke          | <i>Ur-4, Ur-11</i>             | Snap bean     | AA                |
| Montrose        | <i>Ur-5, Ur-7</i>              | Dry bean      | AA                |
| Kimberly        | <i>Ur-5, Ur-?</i>              | Dry bean      | AA                |
| BelDakMi-RR-1   | <i>Ur-6, Ur-11</i>             | Dry bean      | AA                |
| BelDakMi-RR-2   | <i>Ur-6, Ur-11</i>             | Dry bean      | AA                |
| BelDakMi-RR-3   | <i>Ur-6, Ur-11</i>             | Dry bean      | AA                |
| BelDakMi-RR-5   | <i>Ur-6, Ur-11</i>             | Dry bean      | AA                |
| BelDakMi-RMR-13 | <i>Ur-6, Ur-11</i>             | Dry bean      | AA                |
| Buster          | <i>Ur-3, Ur-5, Ur-7</i>        | Dry bean      | BB                |
| BelMiNeb-RMR-4  | <i>Ur-4, Ur-6, Ur-11</i>       | Dry bean      | AA                |
| BelMiNeb-RMR-5  | <i>Ur-4, Ur-6, Ur-11</i>       | Dry bean      | AA                |
| BelMiNeb-RMR-6  | <i>Ur-4, Ur-6, Ur-11</i>       | Dry bean      | AA                |
| BelNeb-RR-1     | <i>Ur-5, Ur-6, Ur-7</i>        | Dry bean      | AA                |
| BelNeb-RR-2     | <i>Ur-5, Ur-6, Ur-7</i>        | Dry bean      | AA                |
| PI 151385       | <i>Ur-11</i>                   | Dry bean      | AA                |
| PI 151388       | <i>Ur-11</i>                   | Dry bean      | AA                |
| PI 151395       | <i>Ur-11</i>                   | Dry bean      | AA                |
| PI 190078       | <i>Ur-11</i>                   | Dry bean      | AA                |
| Zenith          | <i>ur-3</i>                    | Dry bean      | AA                |
| Zorro           | <i>ur-3</i>                    | Dry bean      | AA                |

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# Summary

- **Rapid, low-cost development, highly accurate tightly-linked markers for common bean is achievable:**
  - **Update of major rust, anthracnose and angular leaf spot disease resistance genes**
  - **Map new disease resistance genes (or alleles of previously reported genes)**
  - **Identification of candidate genes**
- **Need for a marker-trait association panel to be used across institutions**
  - **Secure robust and highly accurate markers across common bean breeding material**

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# Thank you!



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## ARS-USDA Beltsville



**Robert Davis**  
**Descubrió espiroplasmas**

**Ted Diener**  
**Descubrió los Viroides**

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