Tomorrow's Rice

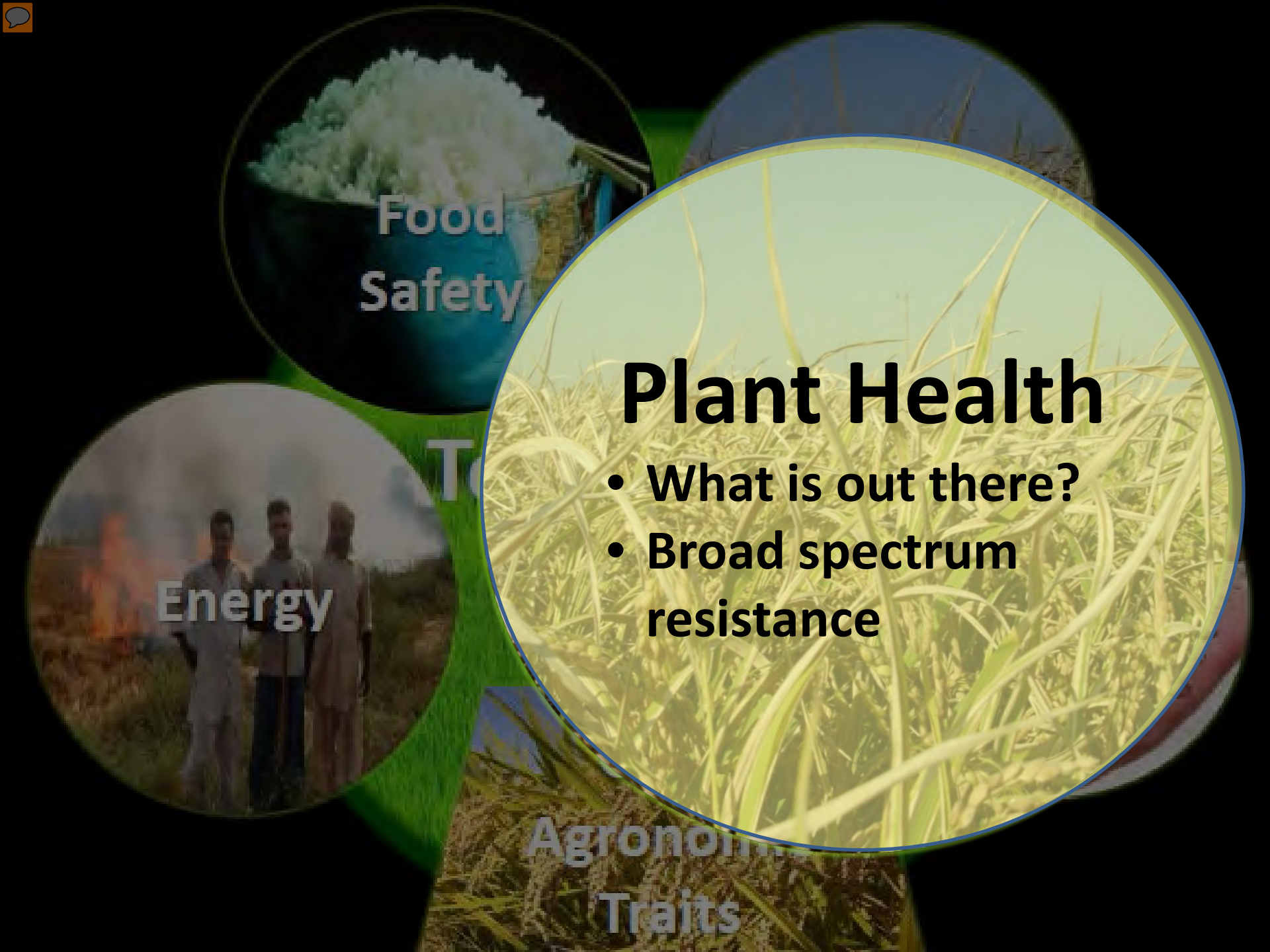
Jan E. Leach

Colorado State University

USAID

July, 2013


Food Safety
Plant Health
Tomorrow's Rice
Energy
Human Health
Good Agronomic Traits



Plant Health

- What is out there?
- Broad spectrum resistance

"….up to 40% of plant productivity in Africa and Asia, and about 20% in the developed world, is lost to pests and pathogens."

Somerville & Briscoe,
Science 2001 292:2217

"In rice production, estimates for loss potentials (for pathogens)…. averaged 15% ….worldwide."

E. C. Oerke, 2006.
Crop Losses to Animal Pests, Plant Pathogens, and Weeds

What is out there?

Need: Reliable, simple assays to detect rice pathogens in <u>field surveys</u> and <u>seed testing</u>

J. Lang, L. Triplett, V. Verdier, C. Vera Cruz, G. Ash, A. Djikeng, J. E. Leach

Colorado State University

Charles Sturt University

IRD Institut de recherche pour le développement

biosciences eastern and central africa

IRRI International Rice Research Institute

Step 1: Develop a one-step computational tool that will design specific diagnostic primers from draft genome sequence **UniPrimer*

Input: Target sequences

+

Input: Non-target sequences

~ 15-30 min. on laptop

Output:

- **Primers specific to all target sequences**
- **Primer information (optimal conditions, etc)**

Triplett et al., in prep

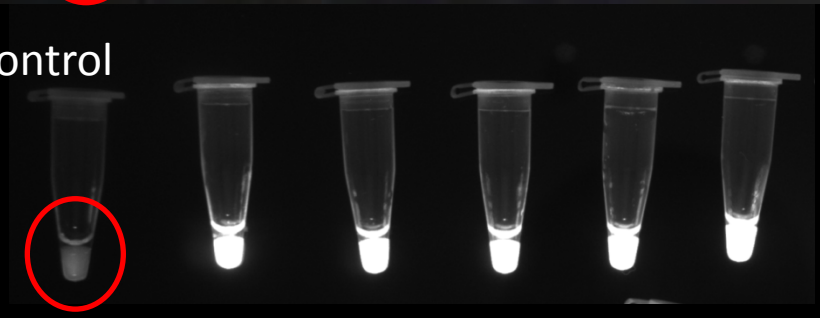
Diagnostic primers adapted to LAMP* assay for field surveys

Sequence genomes

Run Uniprimer

Adapt primers for LAMP

Test primer specificity & sensitivity



UV Light

Lang et al., 2010
Triplett et al., 2011
Lang et al., in prep
Triplett et al., in prep
Ash et al., in prep

Diagnostic Primers ready for field use

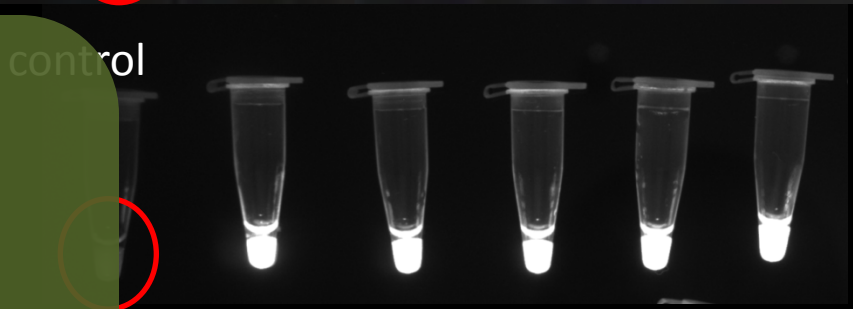
*Loop Mediated Isothermal Amplification

Diagnostic primers adapted to LAMP* assay for field surveys

Sequence genomes

Run Uniprimer*

Adapt primers for LAMP



Once draft genome available, primers designed and tested within 6 weeks

*Loop Mediated Isothermal Amplification

Primers/LAMP ready or in development* for:

- *Xanthomonas oryzae* pv. *oryzae* (bacterial blight)
- *X. oryzae* pv. *oryzicola* (bacterial leaf streak)
- *Pseudomonas fuscovaginae* (sheath brown rot)
- **Burkholderia glumae* (*bacterial* panicle blight)
- **Burkholderia gladiolae* (bacterial panicle blight)
- *Xanthomonas translucens* (black chaff & leaf streak wheat)

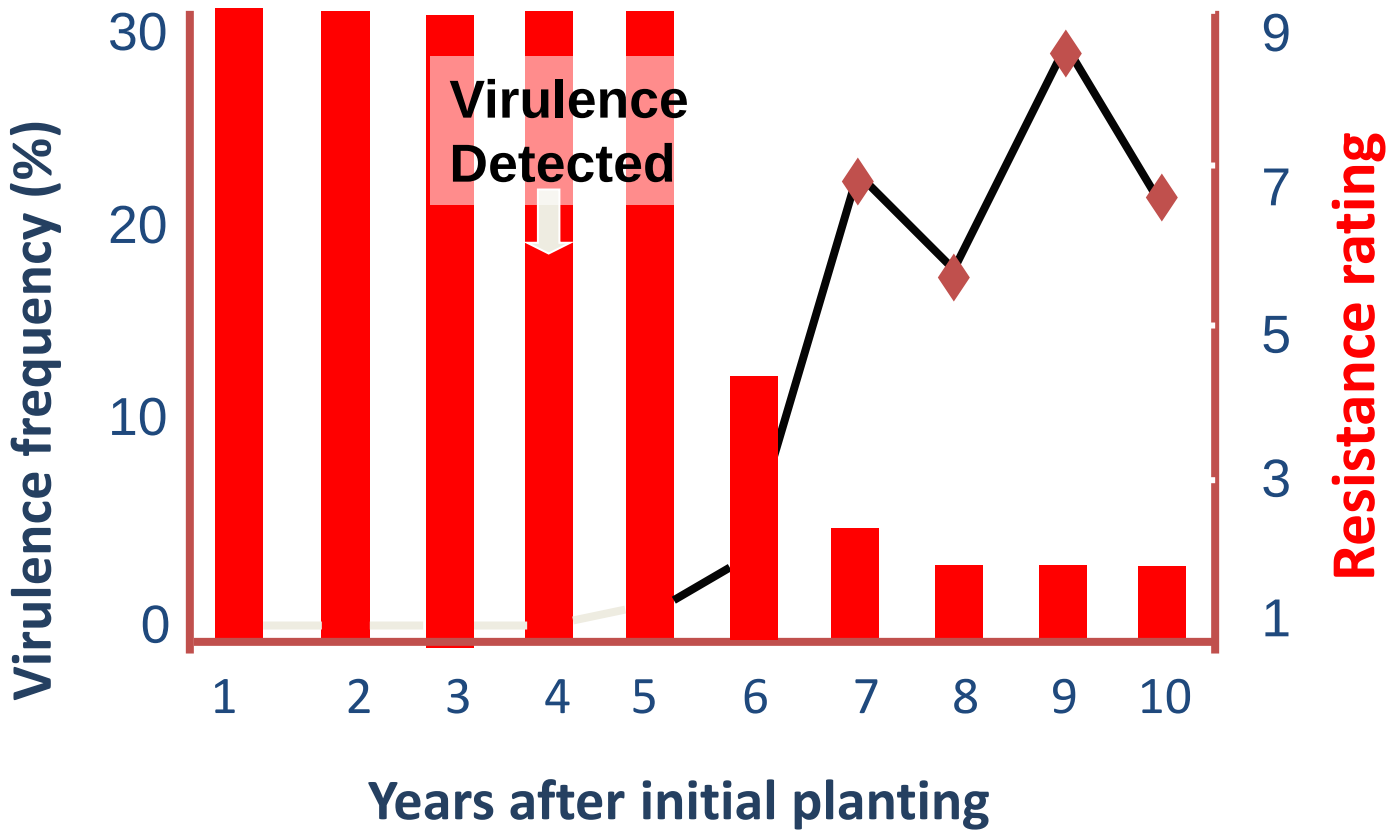
Plant Health

- What is out there?
- Broad spectrum resistance

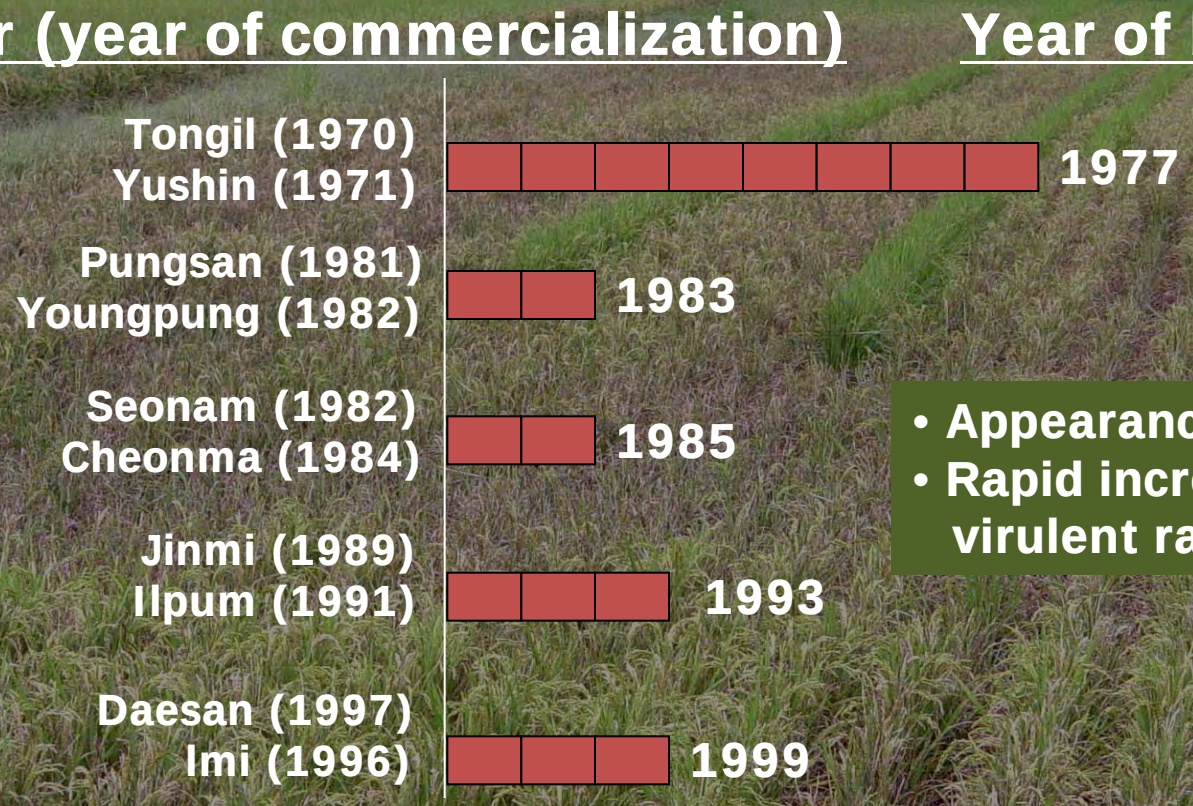
Current disease control practices largely exploit single R gene resistance

Bacterial blight control by single resistance (R) genes

Problem with use of single gene resistance: *Pathogen changes and overcomes resistance*



Single Gene Resistance Frequently Not Durable: Rice Blast



- Appearance of new races
- Rapid increase of virulent races

Need to increase durability of resistance of rice cultivars

S.S. Han et al., NIAST, Korea

Approaches to broad-spectrum, durable resistance

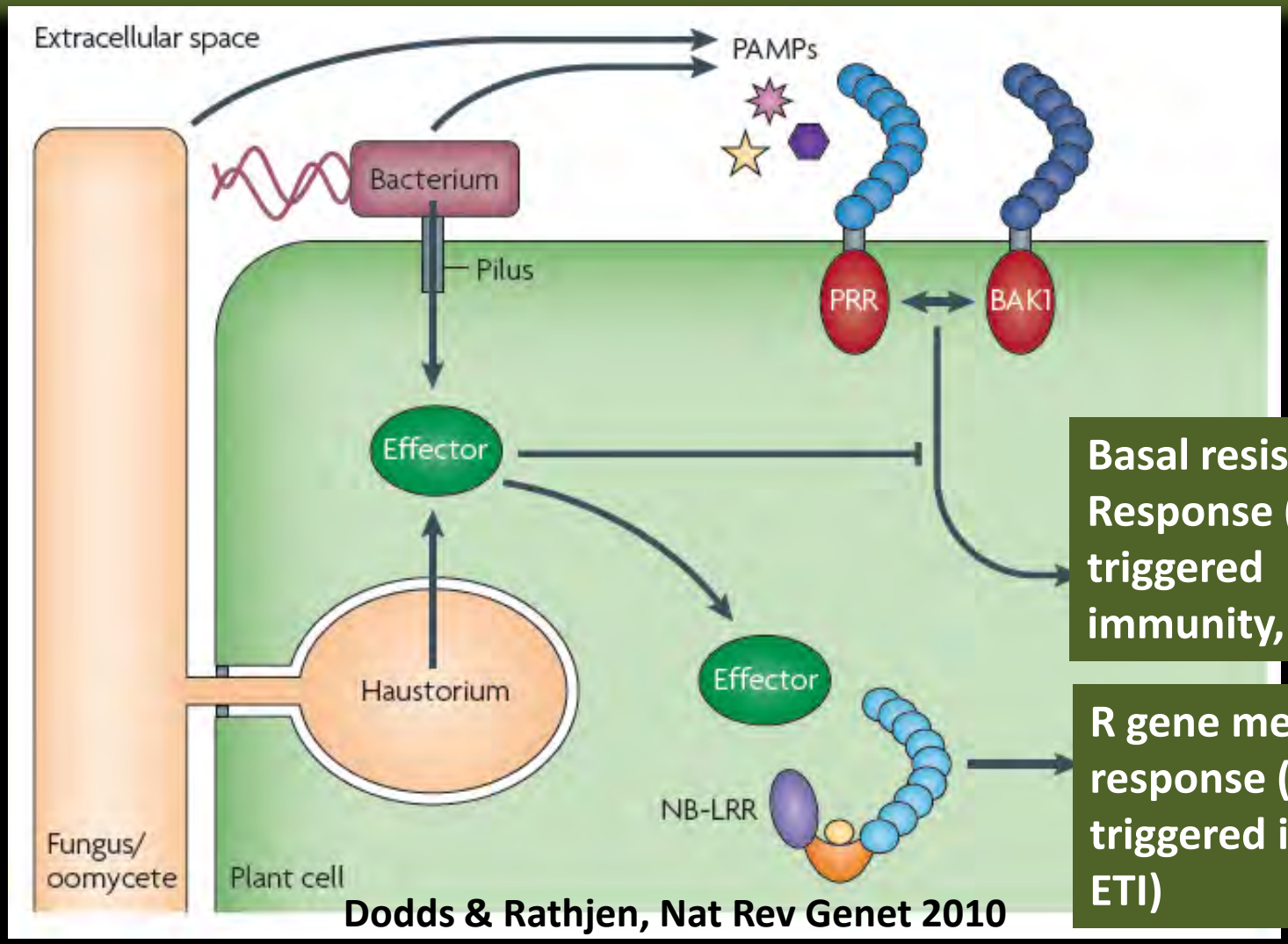
- Identify resistance governed by multiple genes (quantitative resistance)
  - Do defense response (DR) genes contribute to resistance QTL?
  - Does accumulation of those genes result in durable resistance?
  - Can accumulation of QTL be facilitated?

USAID-IRRI Linkage Program

Rice CAP

USDA

Basal resistance and R gene mediated resistance in plants

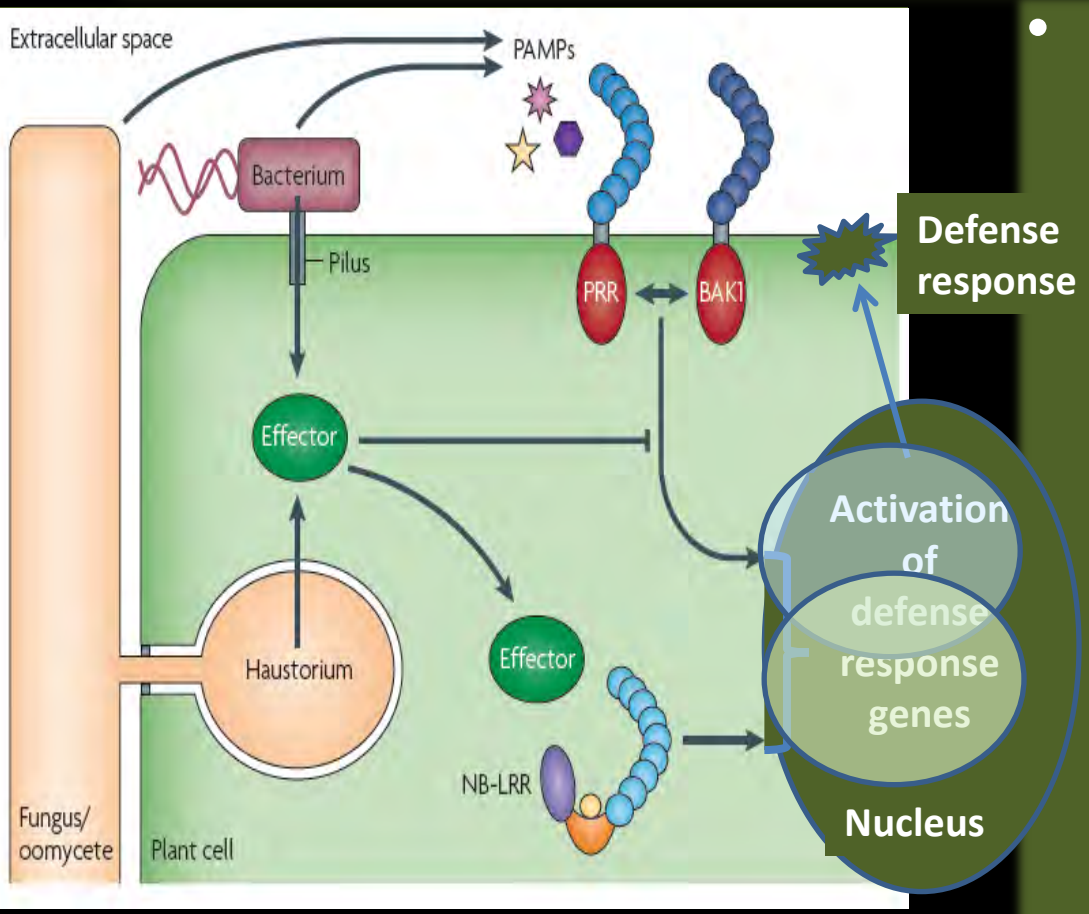


Dodds & Rathjen, Nat Rev Genet 2010

Basal resistance Response (PAMP triggered immunity, PTI)

R gene mediated response (Effector triggered immunity, ETI)

Transcript profiles of PTI and ETI pathways overlap



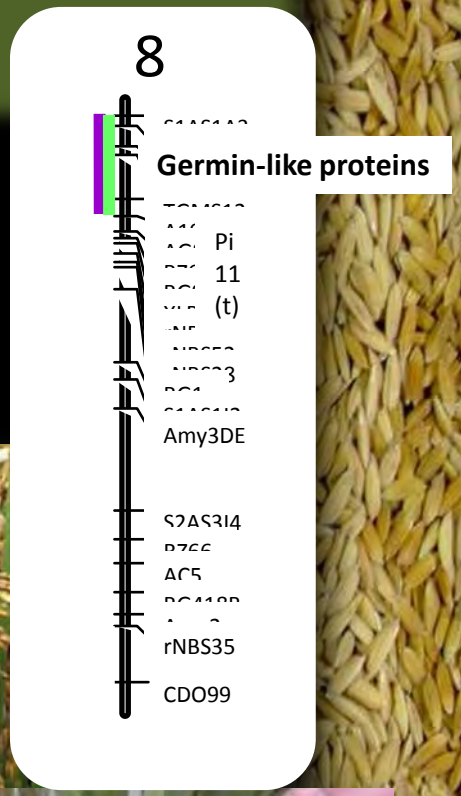
- **Induced Defense Response (DR) genes encode:**
  - **enzymes or proteins that collectively inhibit pathogen multiplication and/or spread, and are broadly functional in combating diverse pathogens**
  - **e.g.**
    - **Structural proteins**
    - **Enzymes of secondary metabolism**
    - **Enzymes directly involved in defense**
    - **Regulatory functions**

Dodds & Rathjen, Nat Rev Genet 2010

Basal responses governed by QTL: predicted to be long-lasting and broad spectrum

- ***QTL are controlled by many genes (multigenic):***
  - **Broad spectrum = effective against diverse types of pathogens**
  - **Durable = long lasting**

- ***Difficulty:***
  - **Because the genes responsible are not known, difficult to target for breeding**
  - **Because multiple genes with partial effects, difficult to score phenotypes**

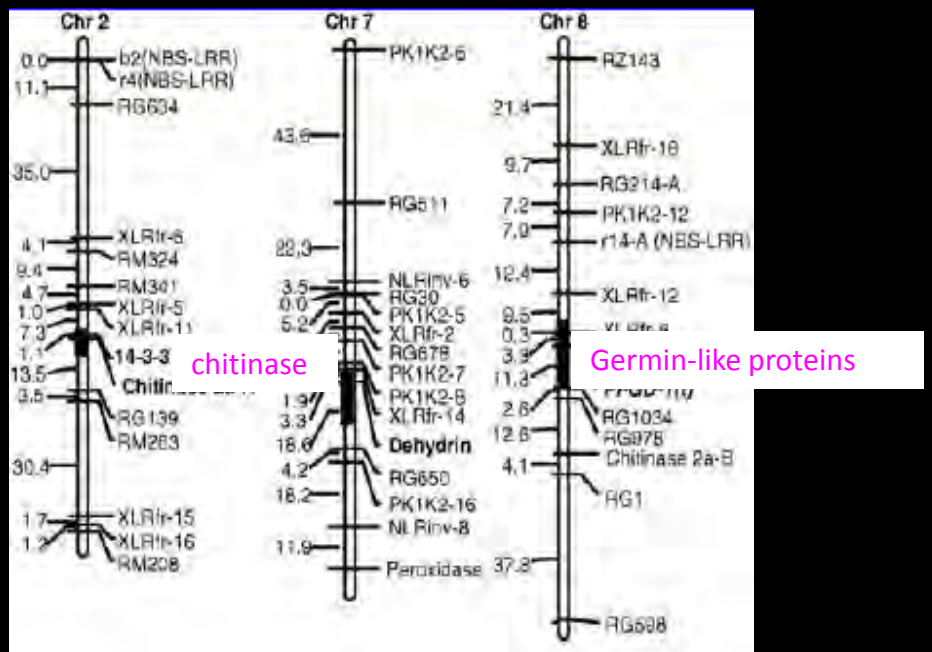


Rationale: Exploit natural diversity to identify genetic variation in defense response genes activated in basal resistance

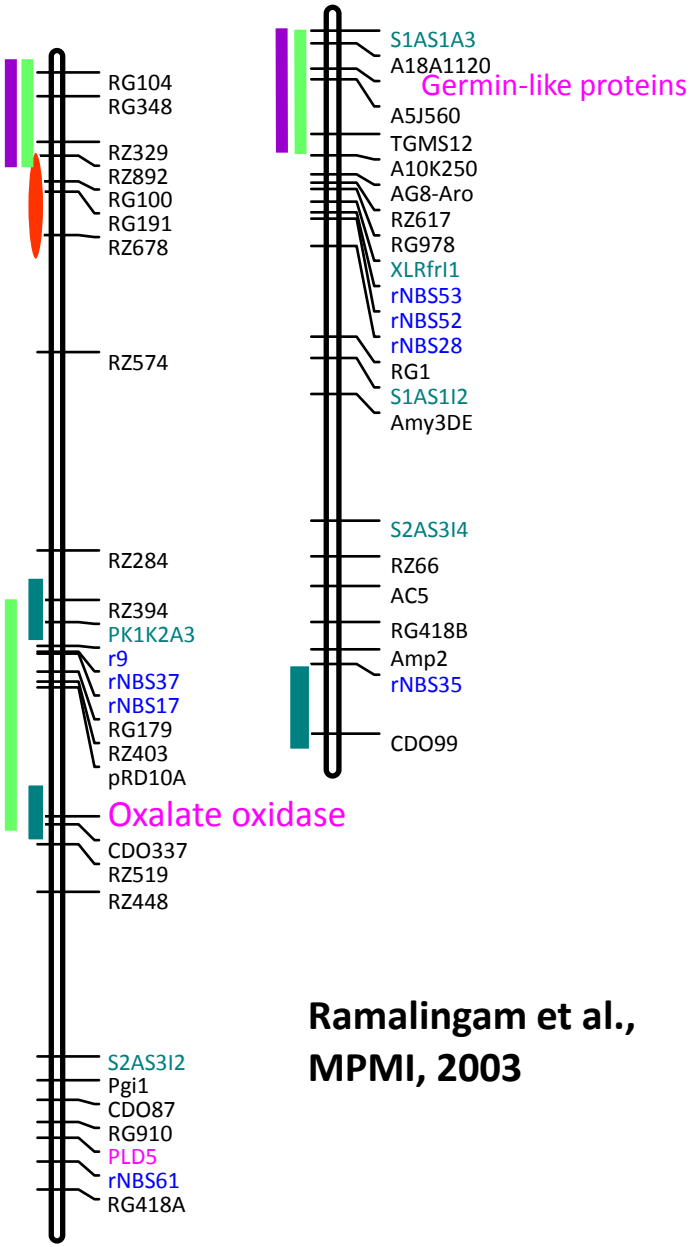
- **Plants exhibit diversity in the levels of basal resistance**
- **Predict diversity for resistance is associated with variation in DR gene content and/or their expression**
- **If true, then identifying genetic variation associated with phenotypic diversity could:**
  - **Reveal genetic mechanisms of basal resistance**
  - **Provide molecular markers to build more durable, broad spectrum resistance**
  - **Expose novel strategies to engineer resistance**

Do candidate DR genes co-localize with QTL?

- **YES: co-localize with resistance QTL for rice blast, bacterial blight, sheath blight, and brown planthopper in multiple mapping populations**



Liu et al., MPMI, 2004



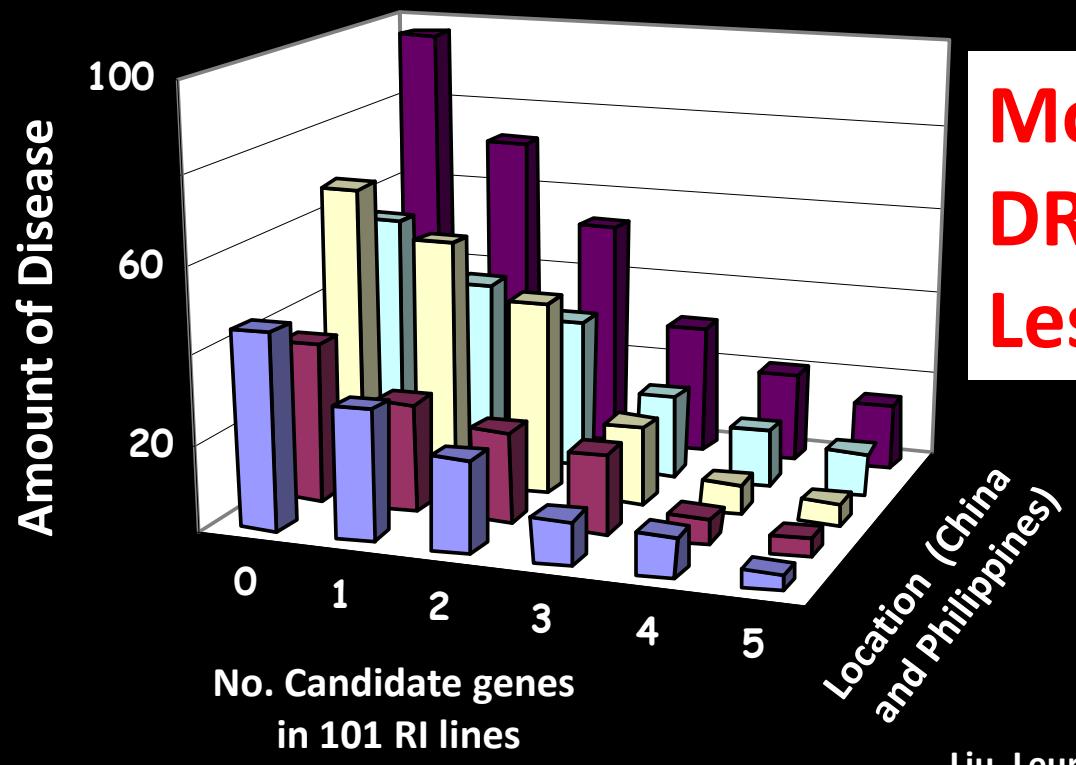
Ramalingam et al., MPMI, 2003

Do DR genes contribute to disease resistance QTL function? YES!

DR Gene(s) (silenced/mutated)	Location	Effect of Silencing/Mutation
Germin-like Proteins (*OsGLP8-1* through *OsGLP8-12*)	Chr 8	Enhanced susceptibility to blast and sheath blight diseases (Manosalva et al., 2009; Davidson et al., 2010)
Phenylalanine ammonia lyase (*OsPAL4-1* through *OsPAL4-4*)	Chr 2	Enhanced susceptibility to bacterial blight and sheath blight disease (Manosalva, Tonnesen, Lang *et al*., in prep)
Oxalate Oxidase (*OsOXO3-1* through *OsOXO4*)	Chr 3	Enhanced susceptibility to blast and *Sclerotinia* diseases (Carillo *et al*., 2009; Davidson *et al*., in prep)
Chitinase (*OsCHI2-1*)	Chr 2 Minor effect QTL	Enhanced susceptibility to sheath blight and bacterial blight (Snelling, Lee *et al*., in prep)
****14-3-3 protein (*OsGF14e*)**	Chr 2	**Enhanced resistance (GF14e is a negative regulator of resistance) (Manosalva *et al.* 2011)

Can accumulation of QTL enhance disease resistance?

(accumulate candidate defense response genes = markers for QTL)



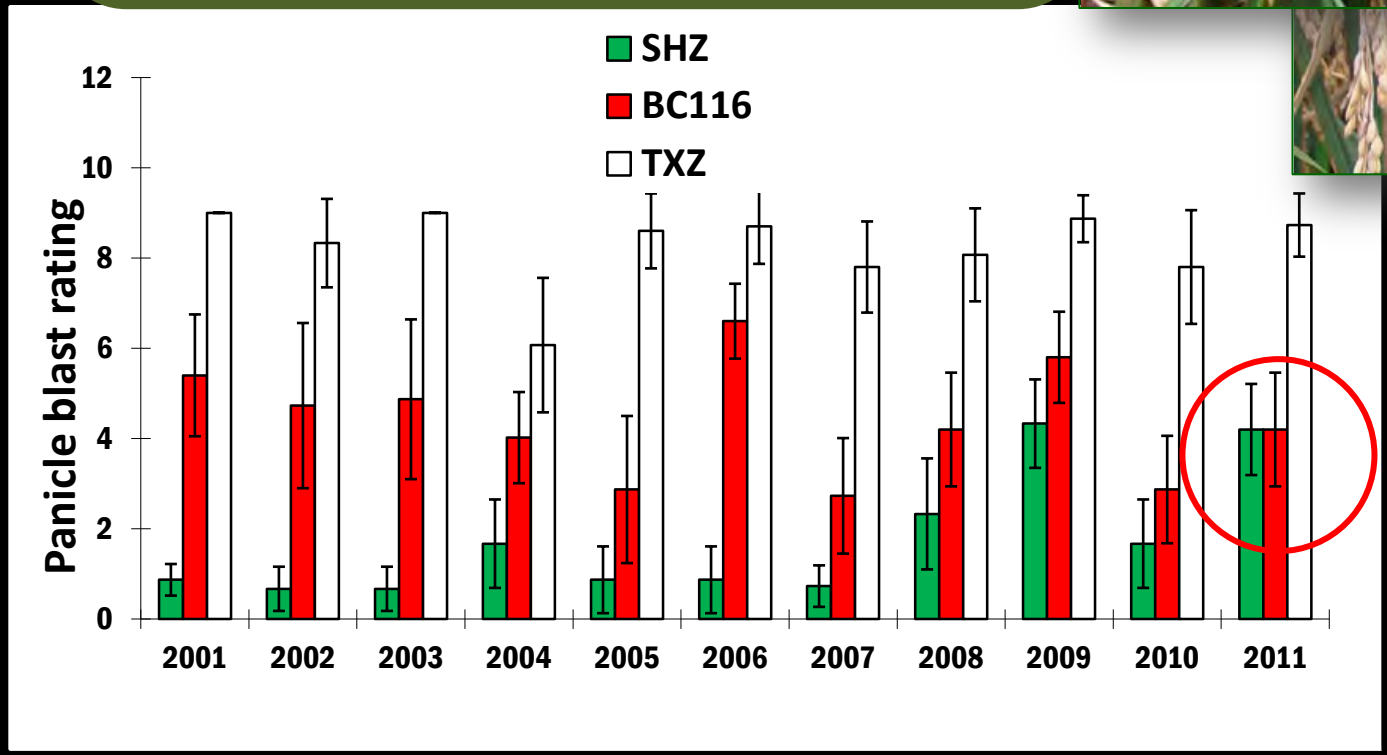
More regions with DR genes (QTL)→ Less blast disease

Liu, Leung et al., 2004, MPMI

Rice Research Institute, Guangdong, China

Is the resistance durable (long-lasting)?

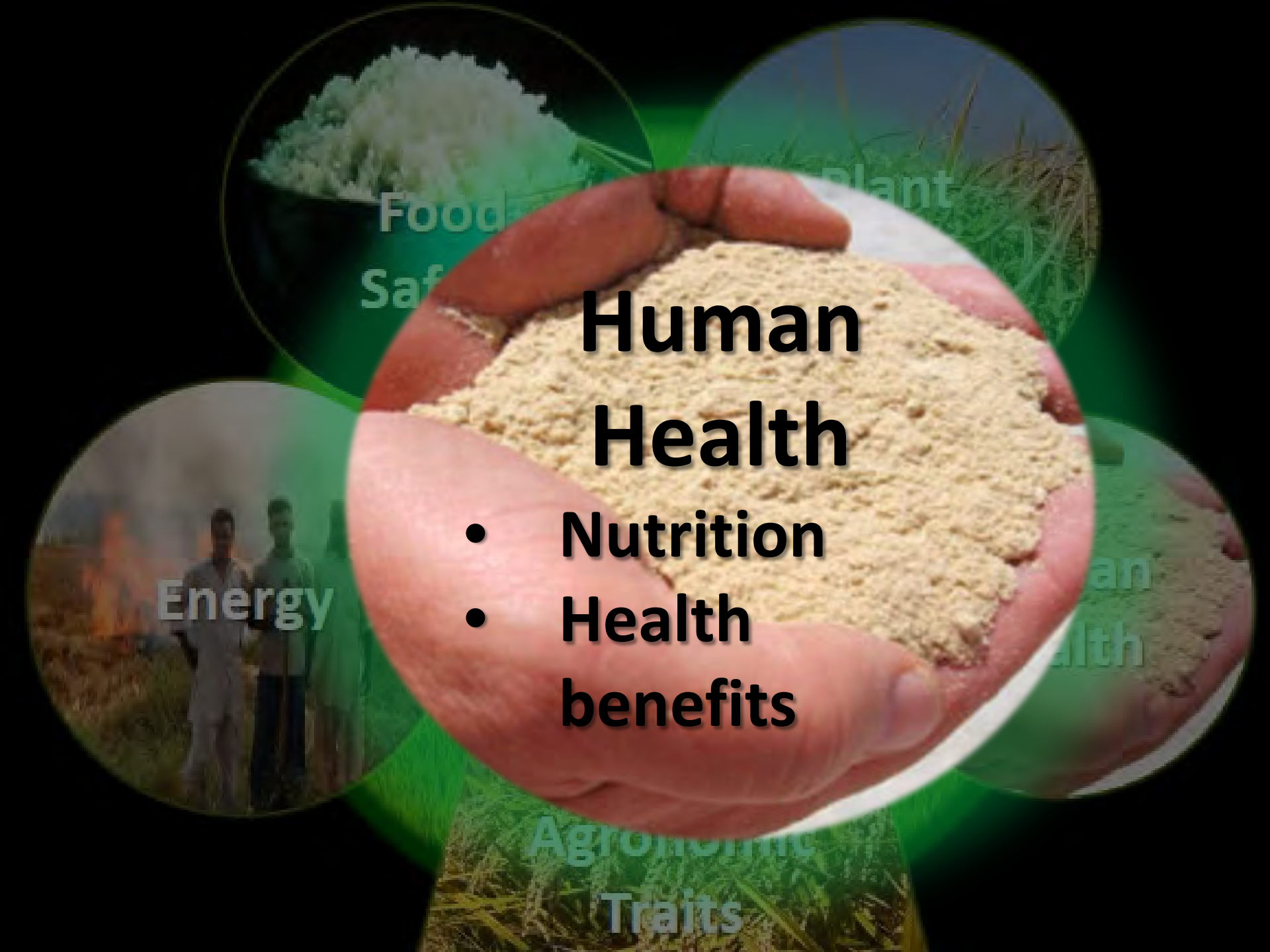
11 years (22 seasons) consecutive tests on leaf and panicle blast resistance in two locations…..so, looking good!



Bin Liu and Xiaoyuan Zhu

Rice Research Institute, Guangdong Academy of Sciences

Manosalva et al., 2009. Plant Physiol.



Human Health

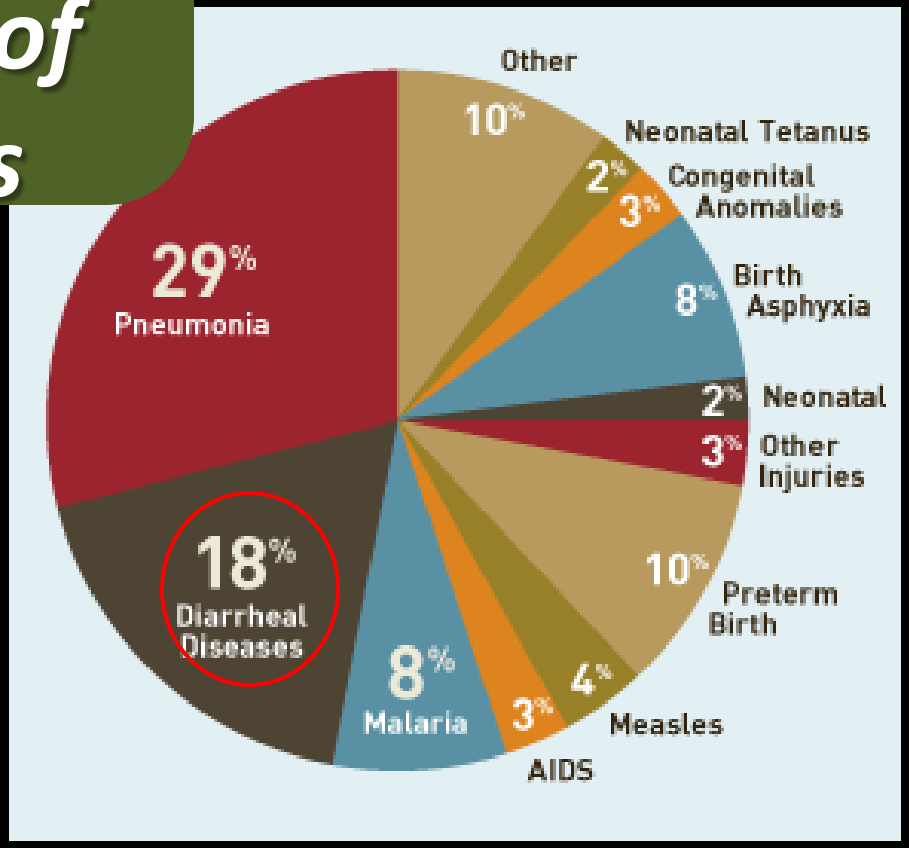
- Nutrition
- Health benefits

A Healthy Bowl of Rice: Improving Rice Bran to Reduce the Impact of Diarrheal Diseases

"Dietary rice bran supplementation for gut mucosal immunity & healthy rice crop improvement"

- E. Ryan, S. Dow, J. Leach

Funding: Bill & Melinda Gates Foundation

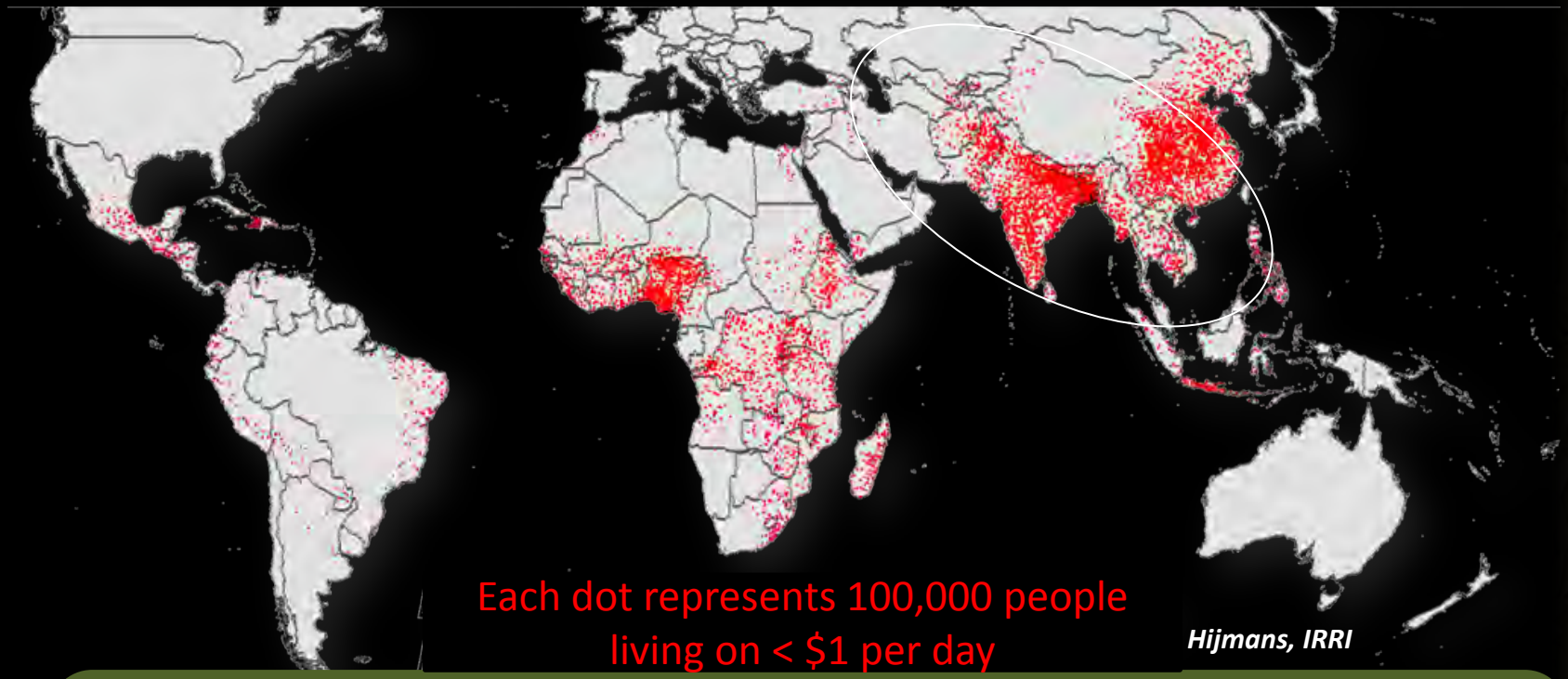


Diarrhea kills ~1.5 million children annually.

http://www.gatesfoundation.org/annual-letter/Pages/2009-preventing-childhood-deaths.aspx

Why rice?

Rice supplies more than half the calories for the world's population, and is the staple food for most of the world's poor



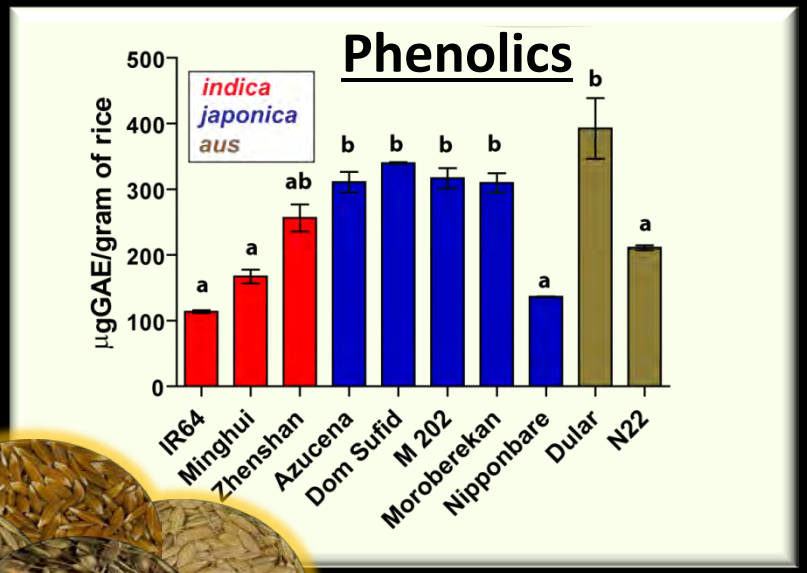
- **~ 560 million people in extreme poverty live in rice-producing areas, including areas where diarrheal diseases are prevalent**

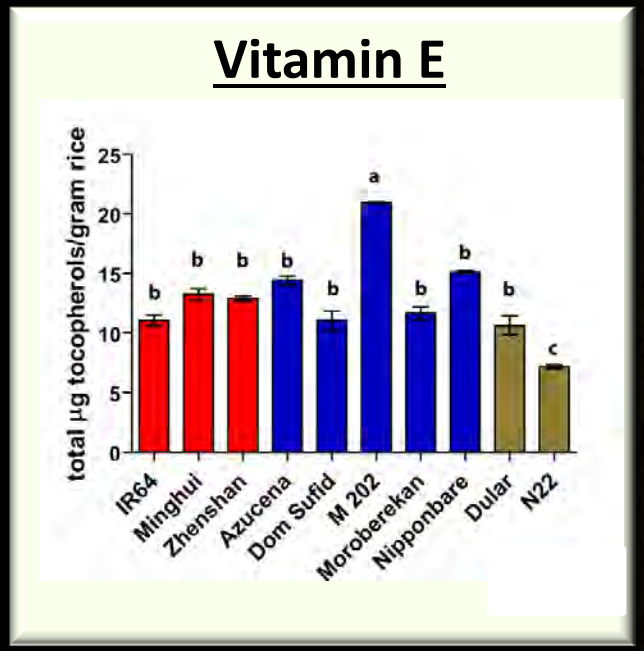
What rice components to use?
Rice Processing

Mali
Photos: V. Verdier

Why rice? Rice contains bioactive compounds

- **Cooked brown rice contains bioactive compounds**
- **Content differs among varieties**

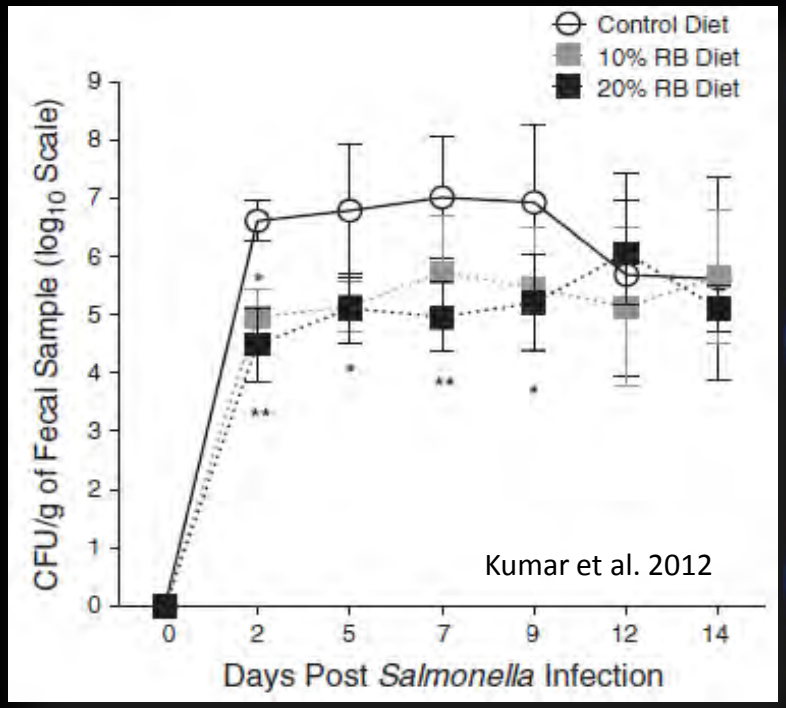


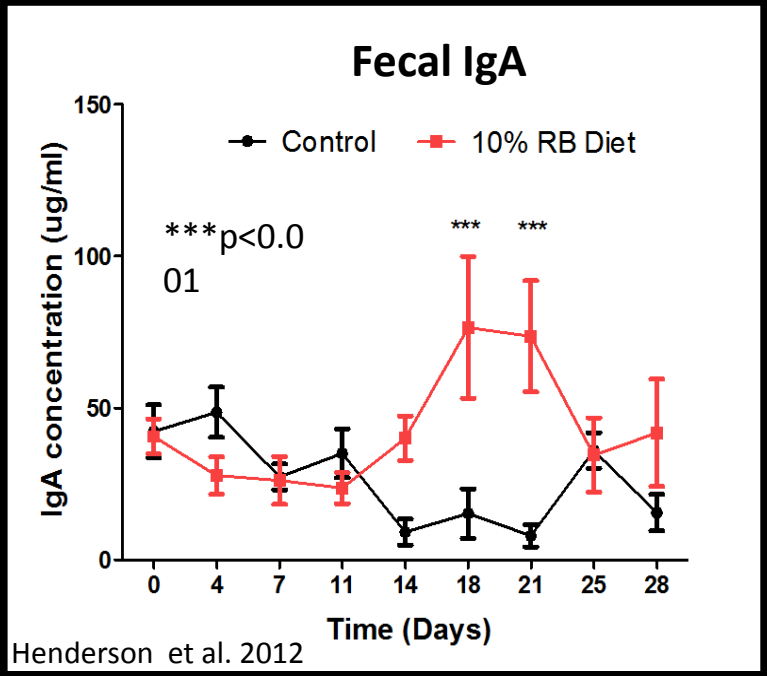


(Heuberger *et al*, PLoS ONE, 2010)

Why Rice Bran?

- In mice, dietary rice bran:
  - Reduces susceptibility to *Salmonella*
  - Induces fecal and serum non-specific IgA content, etc.
  - Increases fecal *Lactobacillus* spp.





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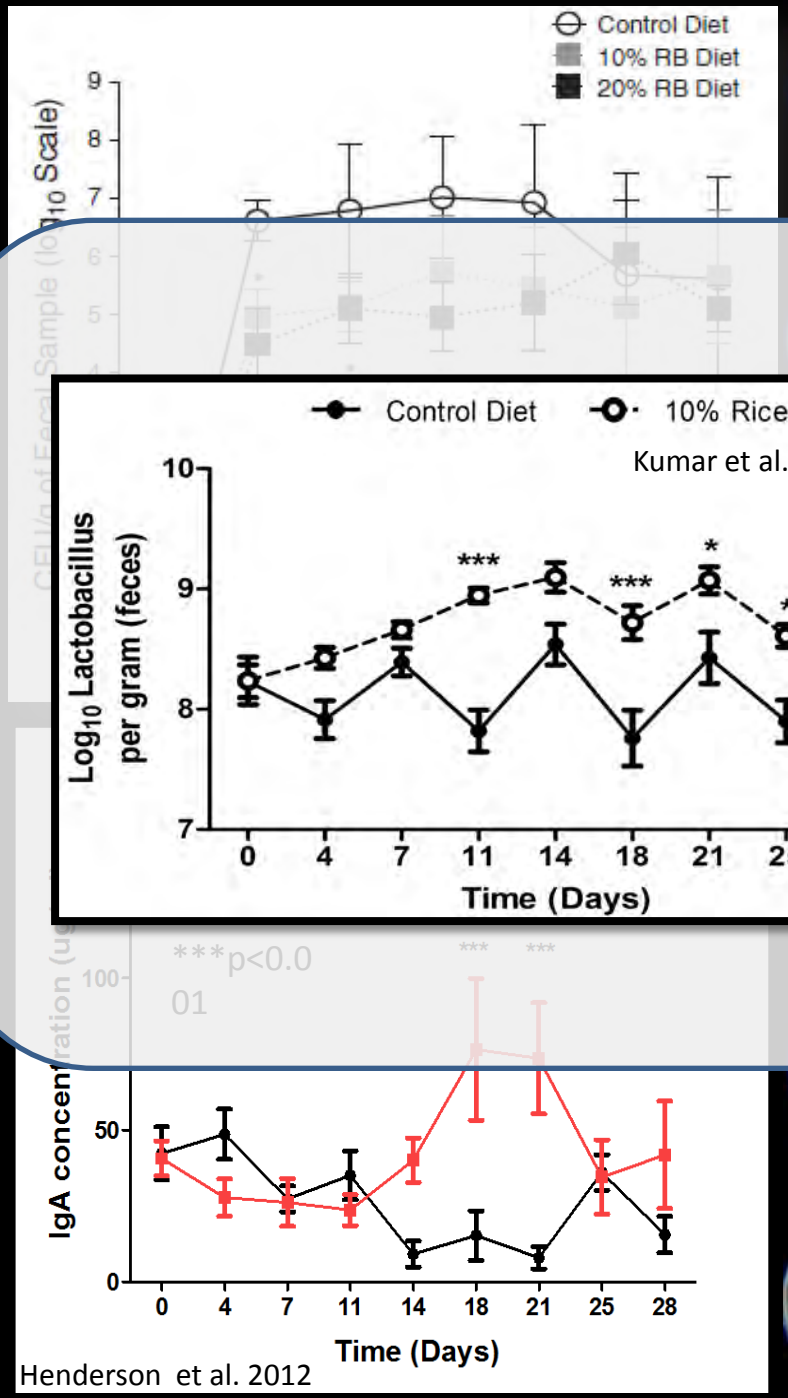
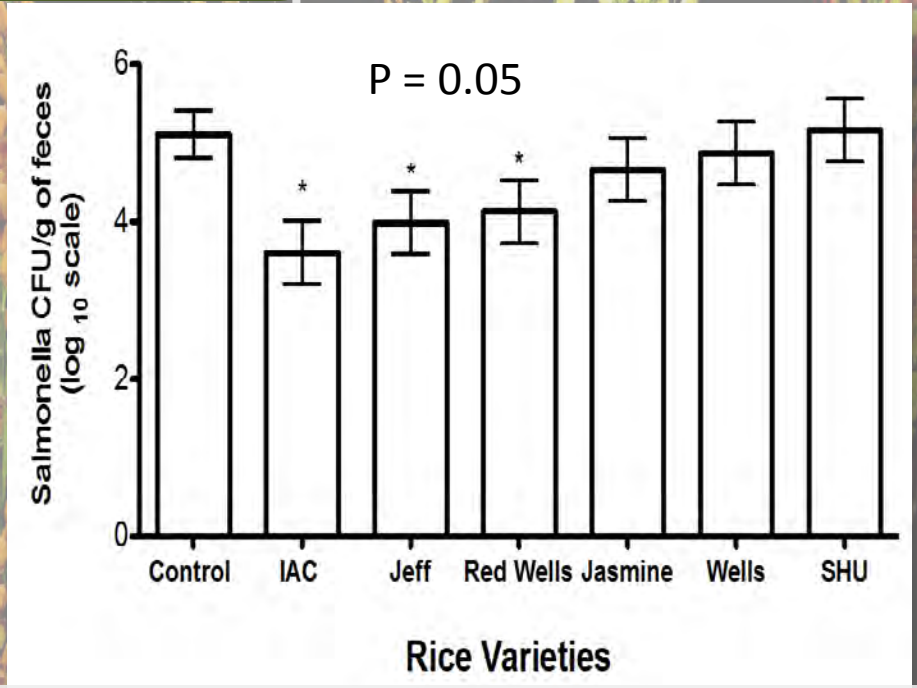


Why Rice Bran?

- **Variation in rice germplasm for rice bran bioactivity**



Improvement of rice bran for health traits:

- ***Identify genetic basis for variation in loci for synthesis of metabolites important for nutrition/health***

Energy

- Value added trait
- Optimize wall composition for energy process

Rice residue (straw and hulls), now burned as waste, are a valuable resource

Punia et al., CURRENT SCIENCE, 94: 1185
http://news.mongabay.com/bioenergy/2008/07/burning-issue-satellite-data-show-very.html

Rice residue (straw and hulls), now burned as waste, are a valuable resource

- In Asia, >700 million tons of rice straw & husks are produced annually
- Punjab yield roughly 100 million tons of rice straw per year, of which ¾ is burned
- Equivalent of 35 to 40 million tons of coal. (US consumes 2.74 million tons coal/day)
- This is only one state in one rice producing country….

Rice burning in Punjab
May 15, 2005

Punia et al., CURRENT SCIENCE, 94: 1185
http://news.mongabay.com/bioenergy/2008/07/burning-issue-satellite-data-show-very.html

Rice husk (hull) is the most prolific agricultural residue in rice producing countries

- 1 ton of rice paddy produces 220 kg rice husk
- 1 ton rice husk is equivalent to 410- 570 kWh electricity

Cambodia has over 30 syngas plants to convert rice hulls

SME RENEWABLE ENERGY

Rice husks converted to cash make rice sector more competitive

By operating a biomass gasifier with only 120 kg of rice husk, or 96 kg of wood, you can save up to 24 liters of diesel fuel per hour!

Biomass gasification is a

Using a gasifier, biomass can be converted to a gaseous fuel with high efficiency. This gas can drive a modified engine to run on 100% producer gas, or can replace up to 75% of fuel

husk is equal to $0.119 and 1 kg of wood to $0.148, when compared with the current price of diesel (October 2005).

A biomass gasifier system generally consists of a:

and water cooling system. The ANKUR gasifiers we use and supply are simple to operate, have excellent variable load capacity (with 3.1 turndown), have a short start-up time,

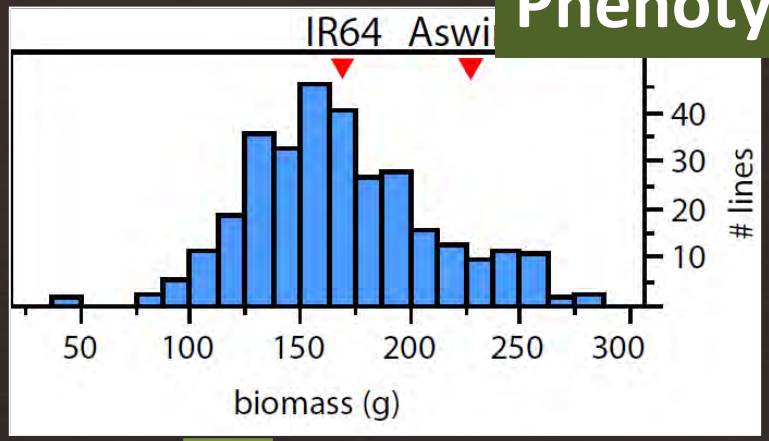
Stephen Haefele et al.
International Rice Research Inst

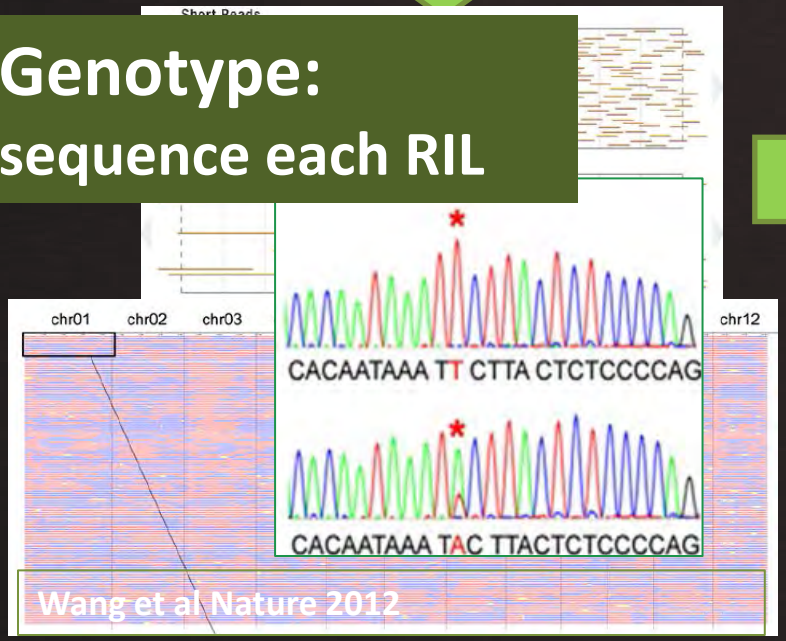
Tapping Genetic Variation to Improve Biomass Traits

Jan E. Leach
Colorado State University

CoPIs: H Leung, D Bush, A Kern, J McKay, BY Zhao

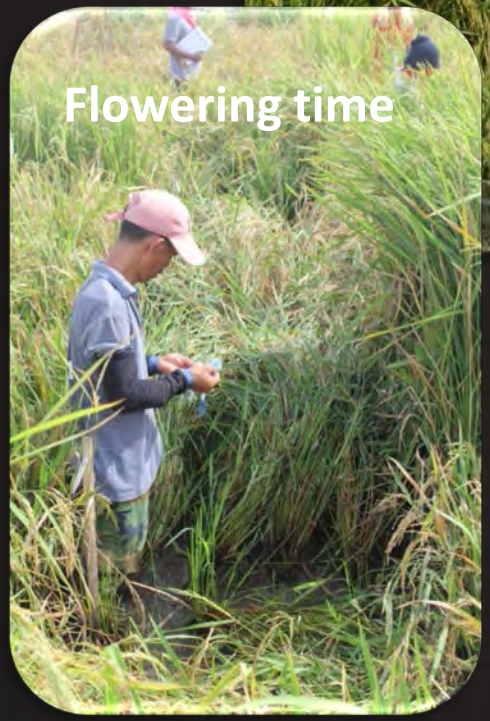
Discovery of genes controlling biomass

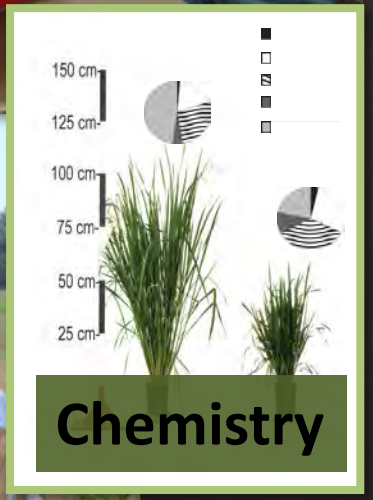




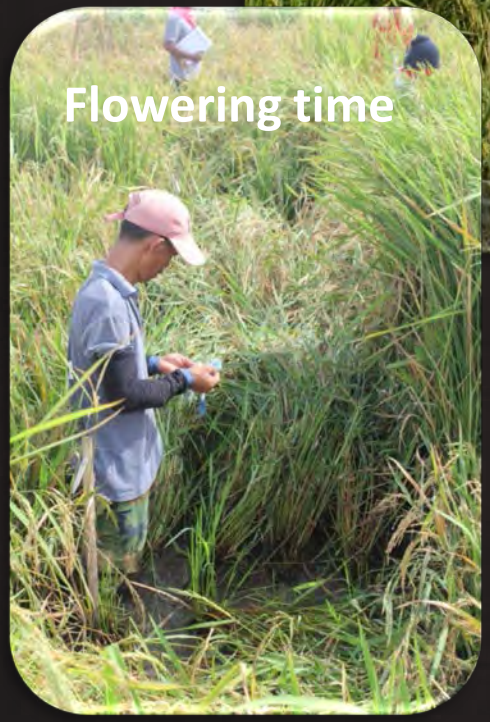
QTL/genes controlling optimal biomass

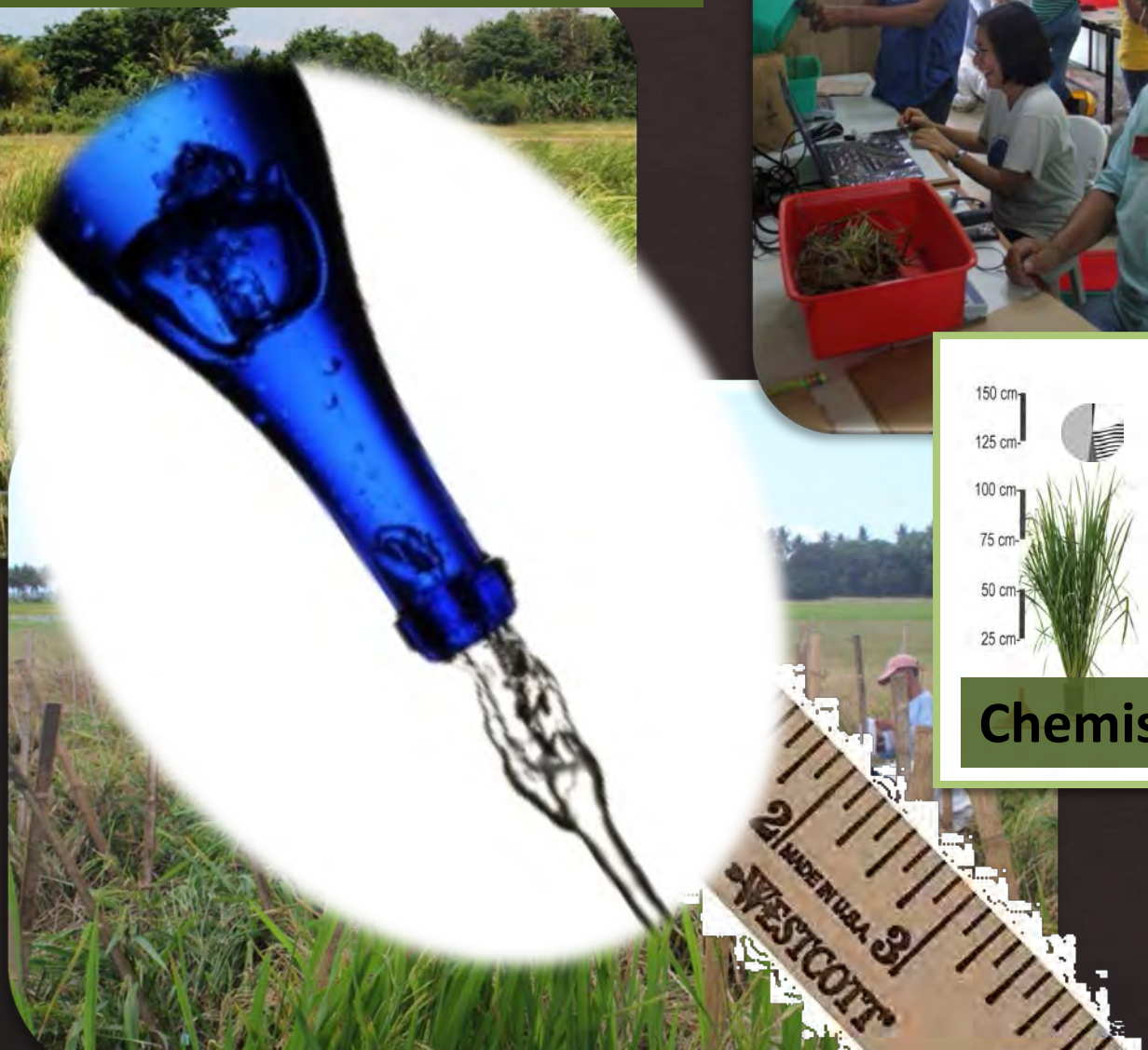
Field level phenotyping to identify biomass QTL

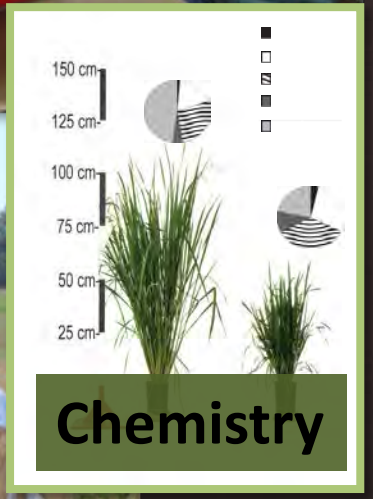




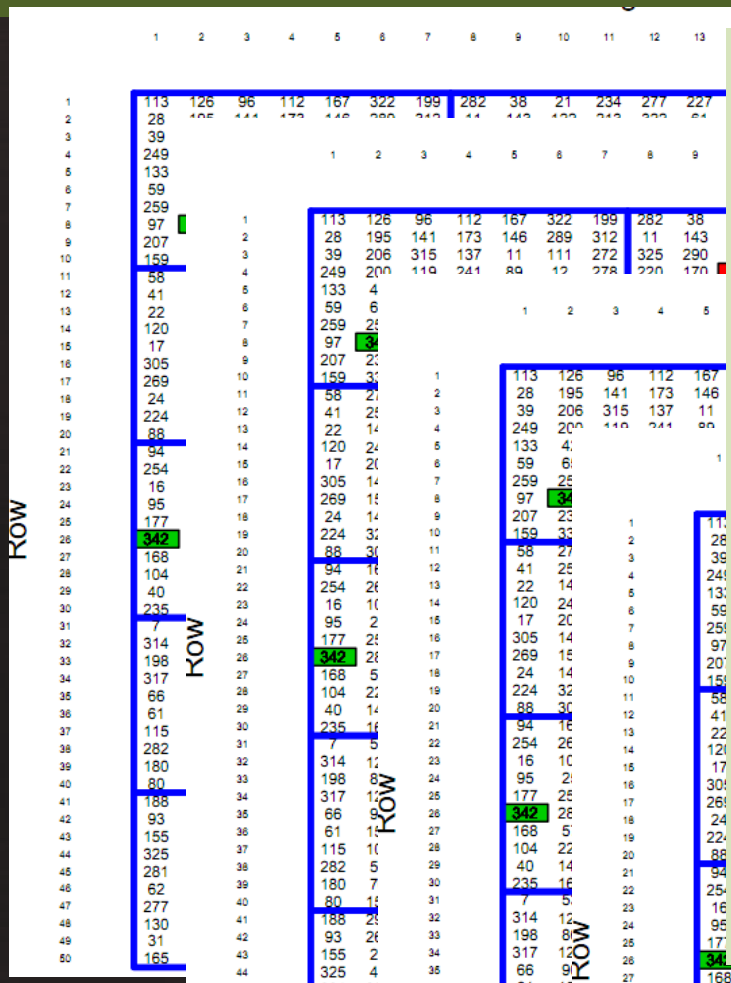
Field level phenotyping to identify biomass QTL



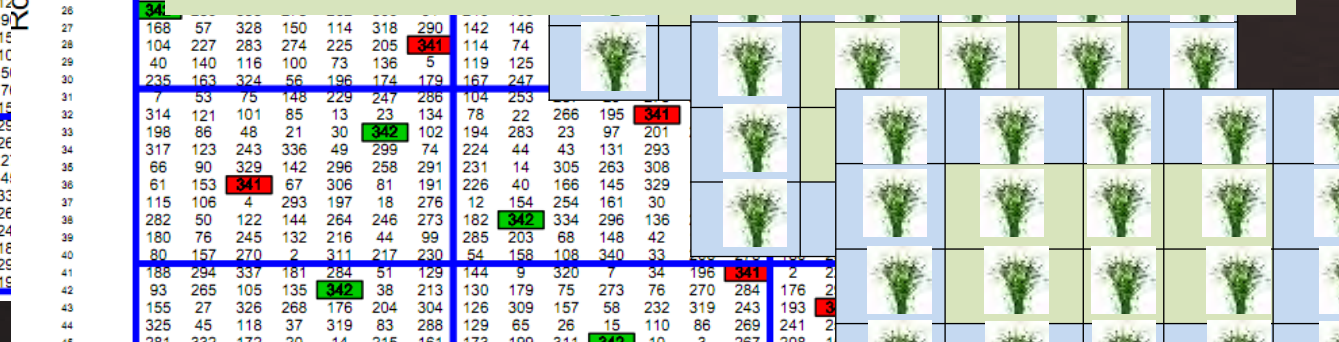




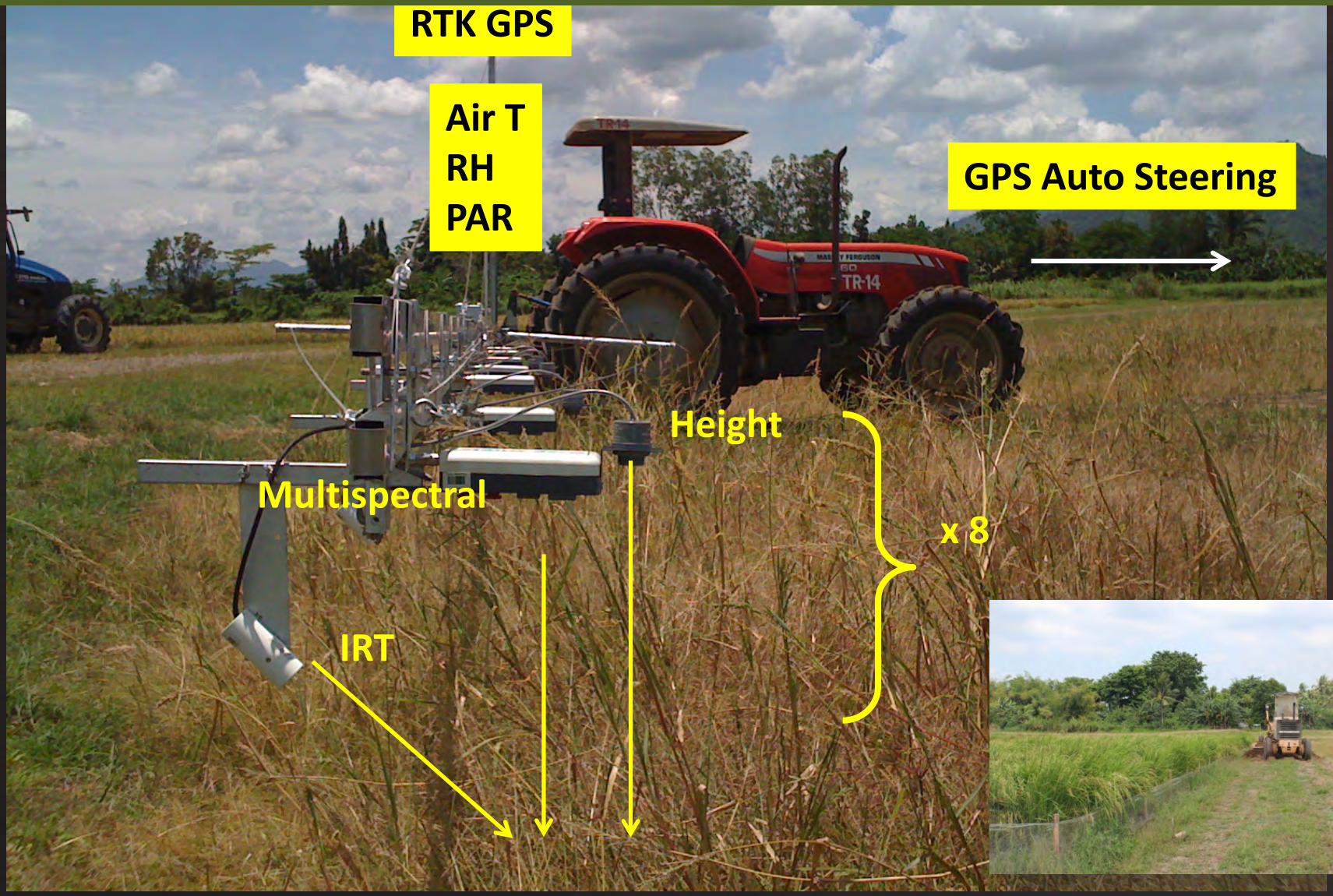
OryzaPhenome1: 2013



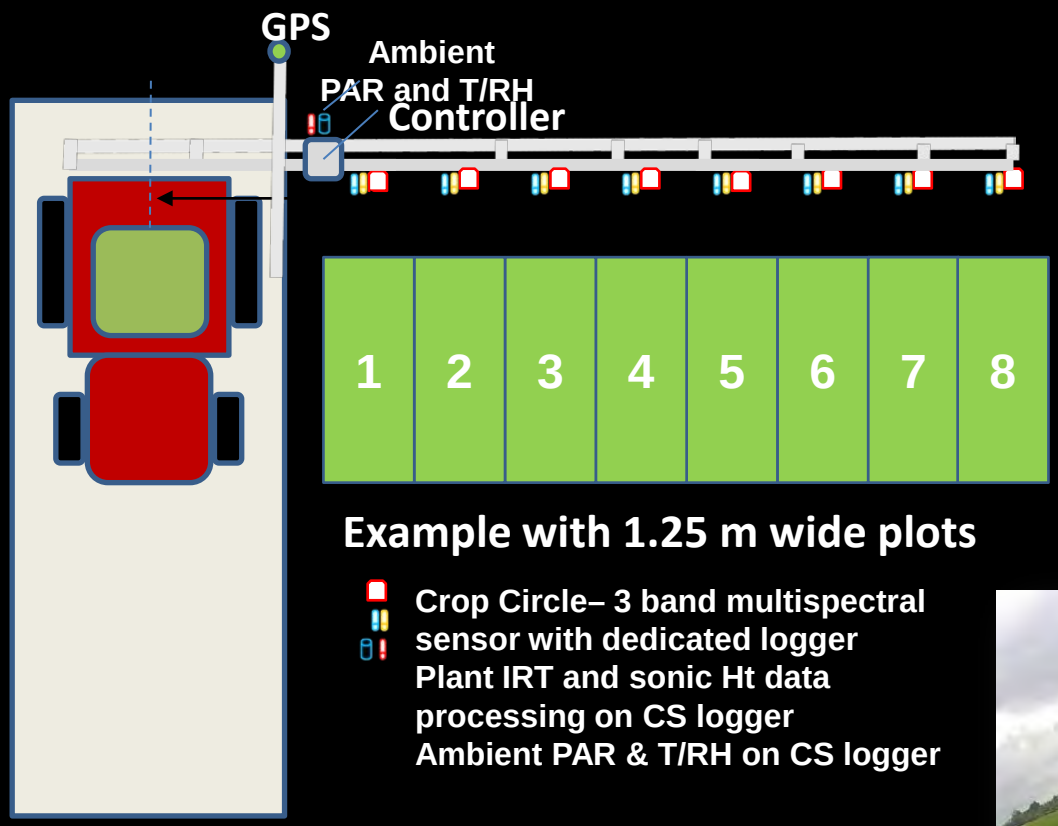
- ~1,500 Rice recombinant inbred lines
- 3 replications
- Semi-automated phenotyping + traditional
- Genotype all 1,500 RIL by sequencing

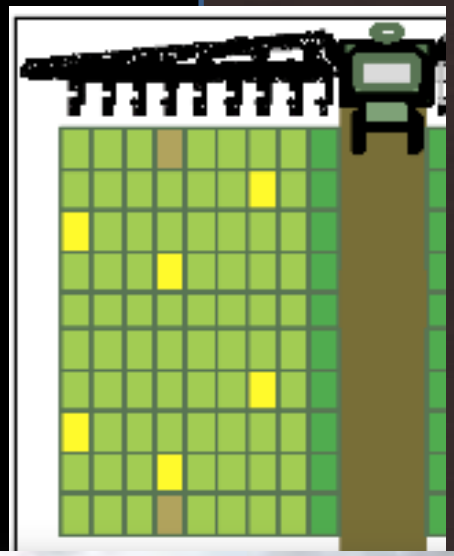


Semi-Automated Data Capture: (spectral, temp, RH, ….)



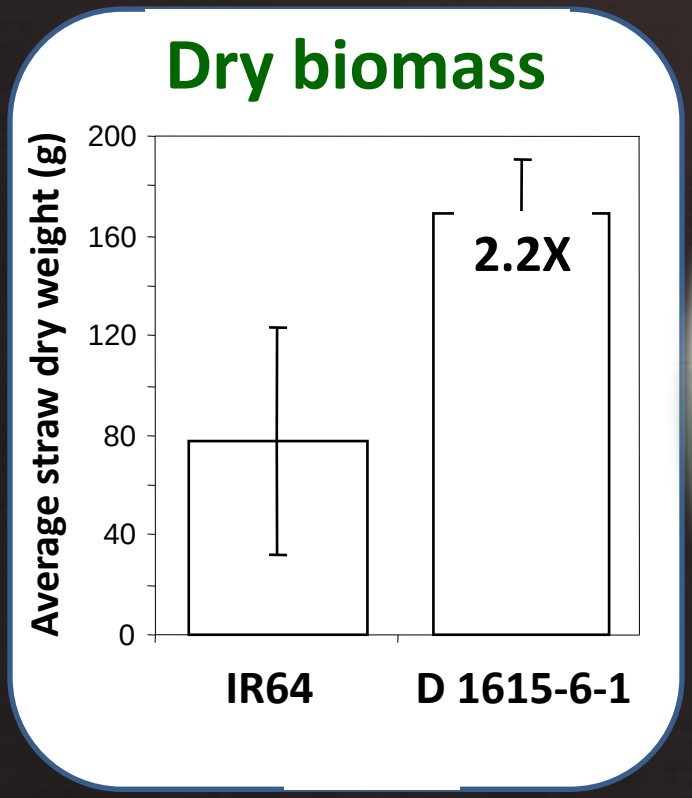
OryzaPhenomel: Automated data collection

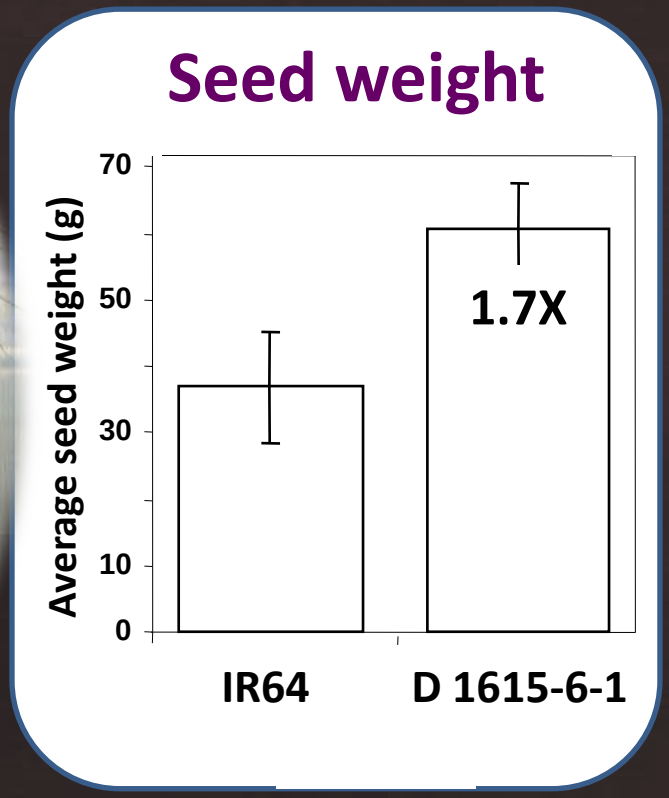




S. Klassen et al.

Mutant shows increased biomass and seed weight



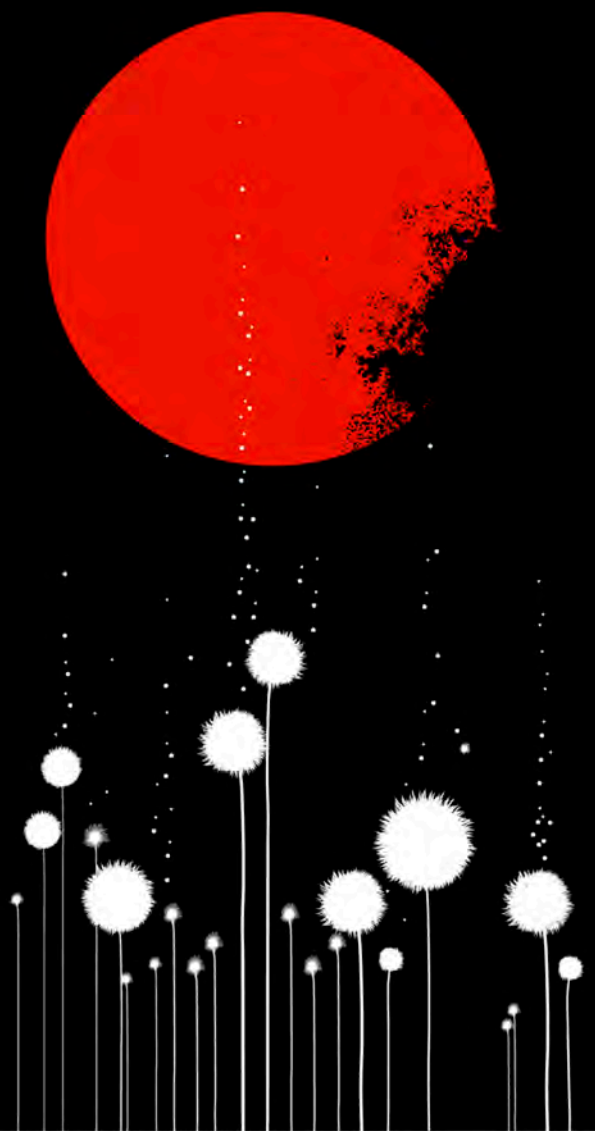


Broeckling et al. unpubl

Tomorrow's Rice will:

- Be durably resistant to a broad spectrum of diseases and pests
- Promote human health
- Provide energy (value added trait)
- And……

Be delicious!



"Without rice, even the cleverest housewife cannot cook."

Ancient Proverb