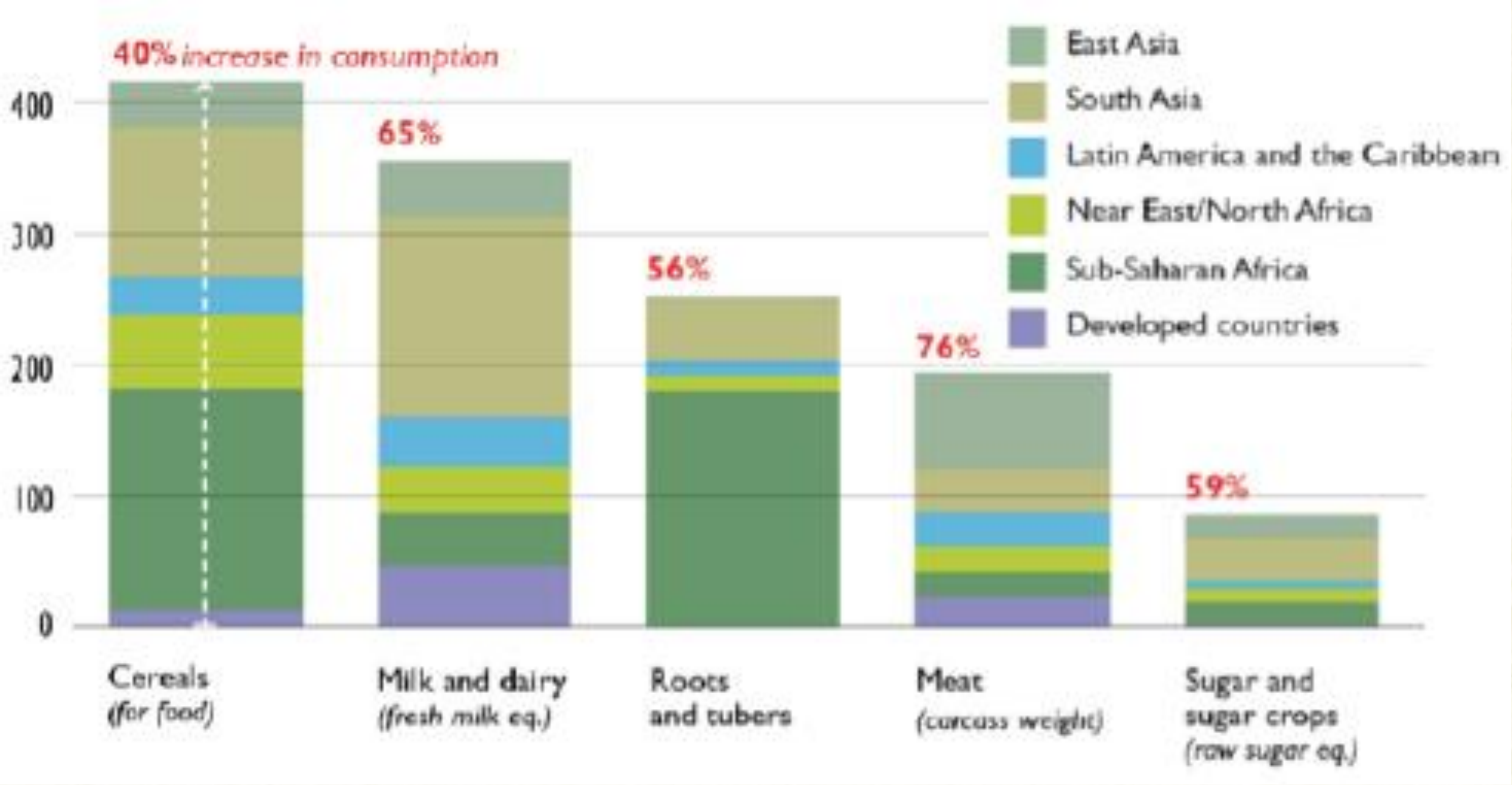
# Mitigating Abiotic Stresses through Breeding for Yield Stability

**Arvind Kumar**
**IRRI, Philippines**

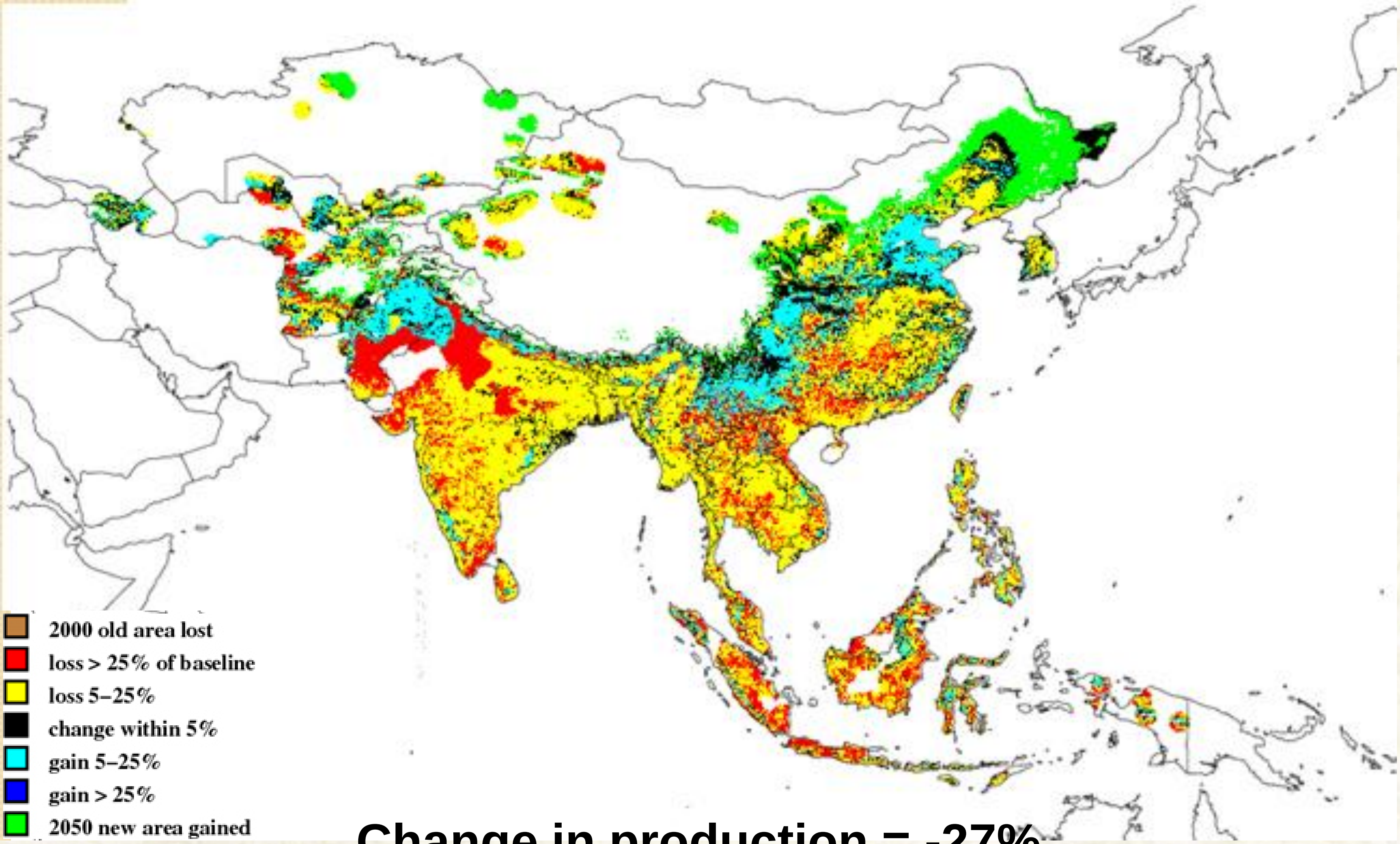
**2016 HRDC Annual Meeting**
**March 31, 2016**

# Need for increasing food demand by 2050 (MT)




Source: Sadler 2015

# Climate induced percentage change in production in 2050: Irrigated Rice in Asia




**Change in production = -27%**

Source: ADB-IFPRI 2009, Srinivasan, A, ADB

# Hybrid Rice Research

| Period | Research achievement |
|---|---|
| 1981-91 | Development of CMS lines:IR58025A,IR62829A reached NARS in 1991 |
| 1991-95 | Identification of restorer lines, tolerance to biotic stresses- identification of CMS line, restorer lines, hybrids |
| 1995-2000 | Improvement of CMS lines for biotic stress tolerance, increased fertility, increased heterosis |
| 2000-2010 | Quality improvement, addition of biotic stress tolerance |
| 2010- continue | Large scale movement of hybrids to rainfed areas |

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# Biotic stress tolerance

**Research at IRRI: 1970-2000**
**Application in Hybrids: 1995-2010**

| Stress | Genes | Prominent genes/ donors |
|---|---|---|
| Bacterial blight | 27- *Xa 1--------Xa27* | IRBB60, IET8585, PR111, PR113, PR115 |
| Blast | > 60 genes, *Pi 9* | *Pi 9, Pi 40* |
| Brown spot | $qBL_{12.1}$ | IR 86126-45-B-B Dinarado/IR64 |
| BPH | 26 | BPH 3, BPH 17, BPH 18, BPH 20, BPH 21 |
| Gall midge | 10 | *Gm 4*- Abhaya<br>*Gm 8*- Aganni |

**Improved lines with resistant genes largely used in the hybrid programs**

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# Tolerance to abiotic stresses- Need

- Hybrid movement/adaptation to rainfed areas
- Yield decrease due to climate change related activities
- Drought, high temp, low temperature problems likely to increase
- More short spells of floods
- Soil fertility deterioration/expansion in problem soils
- Water, Labor shortages

**General perception:**

- **Tolerance to abiotic stress is too complex to be used in breeding programs**
- **Tolerance to abiotic stresses is linked to low yield potential**

## Traits development for abiotic stresses at IRRI

1. Submergence tolerance
2. Stagnant flooding
3. Anaerobic germination
4. Salinity tolerance
5. Drought tolerance
6. High temperature
7. Low temperature
8. Direct seeded rice

- **Donors for different stresses identified after screening 000's of accessions,**
- **Mapping populations, QTLs identified, RILs/NILs**
- **Improved lines with QTLs/genes developed**
- **Improved lines with combinations of QTLs/genes developed**

# *Submergence tolerance: Swarna Sub1*

- **1970s: tolerant types identified**
- **1990: Breeding lines, mapping**
- **2006: *SUB1* cloned, MABC**
- **2009 – varieties released**

***SUB1*: Major QTL on Chr. 9, provides protection for 3 -18 d of complete flooding**

**FR13A "Donor"** **Sensitive Variety**

**-Sub1** **+Sub1**

**Swarna**

**Ismail and Team, IRRI**

# Sub1 varieties released in Asia

| Breeding line | Year | designation | Country |
|---|---|---|---|
| IR05F102 (Swarna) | 2009 | Improved Swarna | India |
| | 2009 | INPARA-5 | Indonesia |
| | 2010 | BRRI dhan-51 | Bangladesh |
| | 2011 | Swarna-Sub1 | Nepal |
| | 2011 | Yemyoke Khan | Myanmar |
| IR07F102 (IR64) | 2009 | NSIC Rc194 | Philippines |
| | 2009 | INPARA-4 | Indonesia |
| IR07F290 (BR11) | 2010 | BRRI dhan-52 | Bangladesh |
| IR09F436 (Ciherang) | 2011 | INPARA-5 | Indonesia |
| | 2014 | BINA dhan11 | Bangladesh |
| IR07F101 (S. Mahsuri) | 2012 | S. Mahsuri-Sub1 | India |
| | 2011 | S. Mahsuri-Sub1 | Nepal |
| | 2014 | BINA dhan12 | Bangladesh |
| CR1009-Sub1 | 2014 | CR1009-Sub1 | India |

Ismail and Team, IRRI

# QTLs for tolerance to stagnant flooding

| Traits | QTL | Chr. | LOD | $R^2$ |
|---|---|---|---|---|
| DTF | q $SFDTF_{3.1}$ | 3 | 12.51 | 26.00 |
| DTF | q $SFDTF_{5.1}$ | 5 | 4.11 | 7.00 |
| GRAIN YIELD IN KG PER HECTARE | q $SFGY_{3.1}$ | 3 | 6.20 | 14.30 |
| GRAIN YIELD IN KG PER HECTARE | q $SFGY_{5.1}$ | 5 | 3.66 | 12.20 |
| GRAIN YIELD IN KG PER HECTARE | q $SFGY_{6.1}$ | 6 | 3.46 | 7.40 |
| LEAF SHEATH 3rd INTERNODE LENGTH | q $SFLSI_{3-2.1}$ | 2 | 4.16 | 10.00 |
| LEAF SHEATH 3rd INTERNODE LENGTH | q $SFLSI_{3-5.1}$ | 5 | 3.49 | 8.00 |
| LEAF SHEATH 2ND INTERNODE LENGTH | q $SFLSI_{2-5.1}$ | 5 | 4.73 | 10.20 |
| LEAF SHEATH 2ND INTERNODE LENGTH | q $SFLSI_{2-6.1}$ | 6 | 4.10 | 9.00 |
| LEAF SHEATH 1st INTERNODE LENGTH | q $SFLSI_{1-5.1}$ | 5 | 4.40 | 11.00 |
| PLANT ELONGATION RATE | q $SFPER_{5.1}$ | 5 | 12.46 | 32.00 |
| PLANT HEIGHT | q $SFPH_{3.1}$ | 3 | 4.04 | 8.30 |
| PLANT HEIGHT | q $SFPH_{5.1}$ | 5 | 5.59 | 12.10 |
| SURVIVAL RATE | q $SFSR_{1.1}$ | 1 | 2.89 | 10.00 |
| SURVIVAL RATE | q $SFSR_{6.1}$ | 6 | 2.97 | 7.30 |

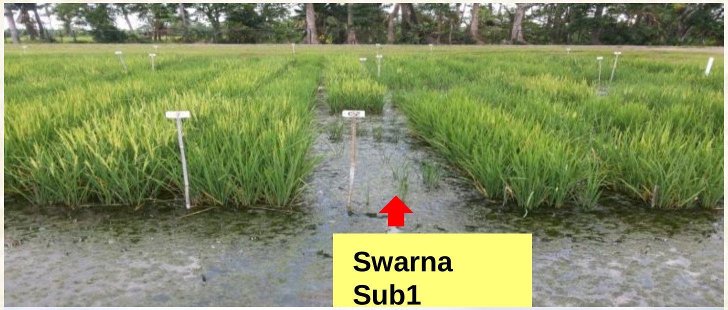
- **Fine mapping being initiated for $qSFGY_{3.1}$ and $qSFGY_{5.1}$**

E. Septiningsih, S. Dixit, IRRI

# Sub + SF tolerant breeding lines



| Designation | Yield SF | Yield normal | SF | Sub |
|---|---|---|---|---|
| IR13F441 | 2807 | 5145 | 3 | 4 |
| IR13F484 | 1924 | 4721 | 3 | 4 |
| IR13F556 | 1578 | 4645 | 2 | 4 |
| IR13F662 | 1504 | 4273 | 3 | 4 |
| IR13F475 | 2366 | 4118 | 2 | 4 |
| IR13F474 | 2590 | 4019 | 1 | 4 |

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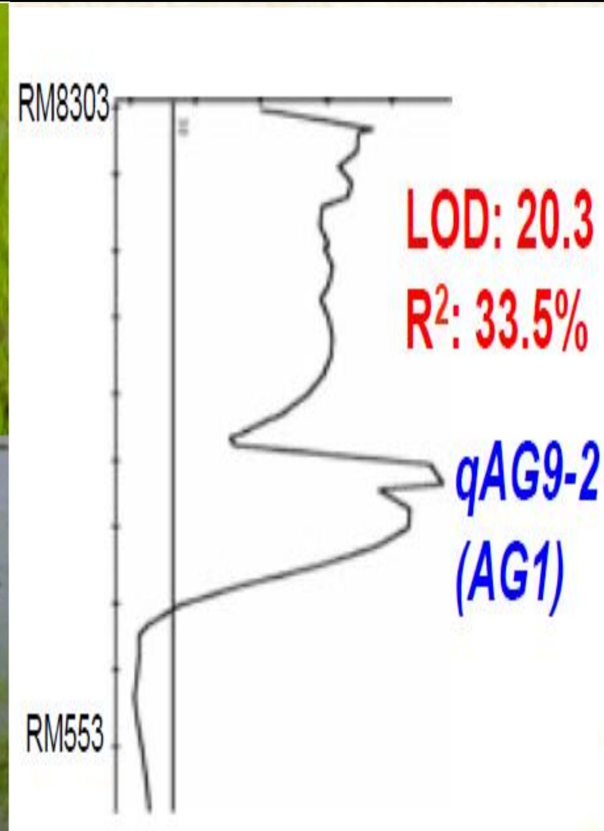
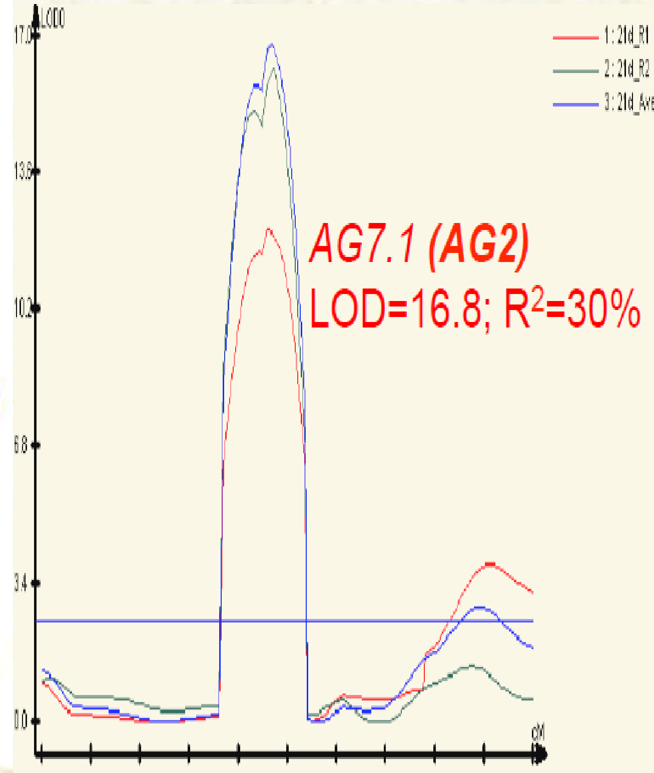
# Anaerobic germination QTLs and MAS

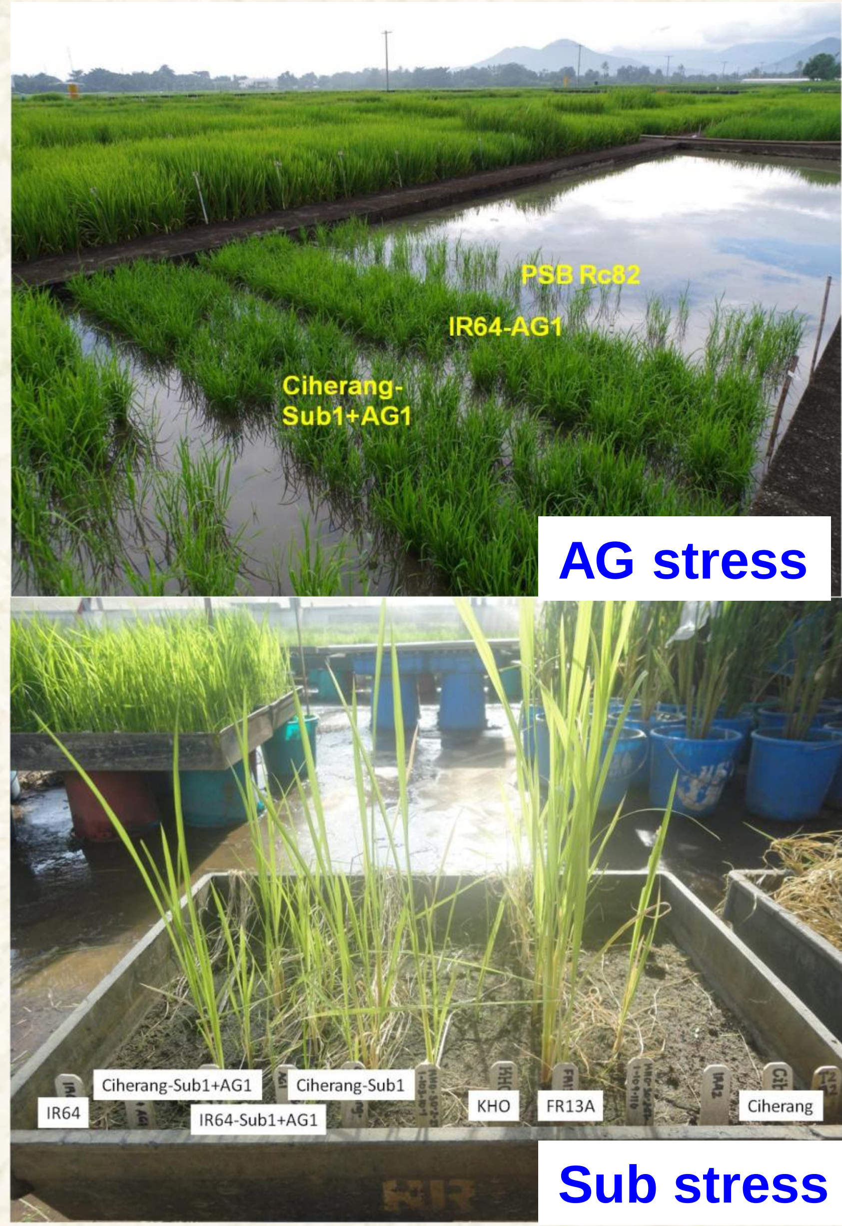

- **QTL discovered in a KHO/ IR64 $BC_2F_{2:3}$ population**
- **QTL fine mapped and candidate gene Identified (Kretzschmar et al. 2015)**

- **QTL discovered in a Ma Zhan Red/ IR42 $BC_2F_3$population**
- **QTL fine mapping and candidate gene analysis ongoing (H. Tnani et al.)**

**Ismail, Septiningsih, Tobias, IRRI**

# MAB for Anaerobic germination

- **Rc82-AG1 and Rc82-AG2 developed—seeds ready for multiplication**
- **BG300-Sub1+AG1 and BG300-Sub1+AG2 development is underway**
- **BG366-Sub1+AG1 and RC22-Sub1+AG1 development is underway**
- **Ciherang-Sub1+AG1+AG2 developed; seed multiplication is underway**

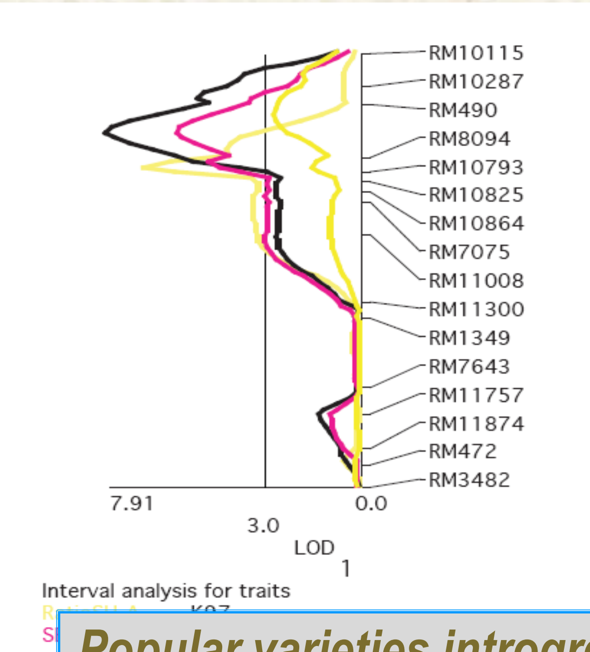


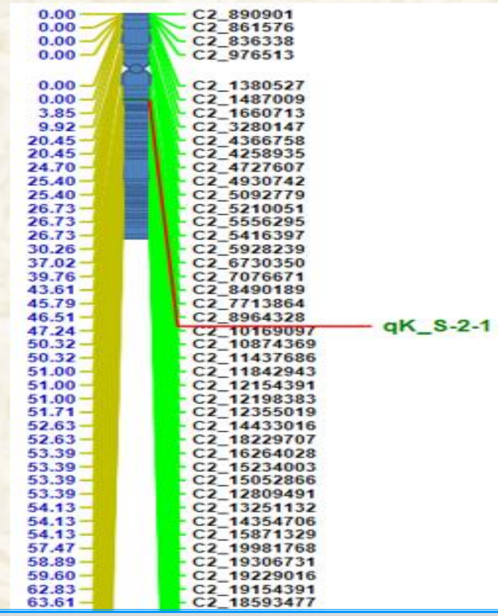

E. Septiningsih

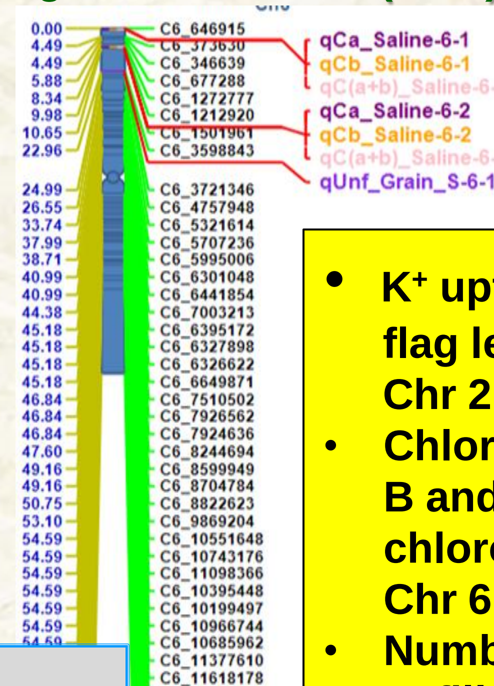
# Tolerance to salinity stress

**Vegetative stage- *Saltol***

**Reproductive stage CSR28/Sadri (RILs)**




**Chr 6**

- **K+ uptake in flag leaf on Chr 2**
- **Chlorophyll A, B and total chlorophyll on Chr 6**
- **Number of unfilled grains on Chr 6**

***Popular varieties introgressed with Saltol:***

- **BRRI dhan28**
- **BRRI dhan29**
- **BR11**
- **IR64**
- **AS966**
- **Swarna**

Ismail, Singh, IRRI

# Major QTLs for grain yield under drought

| QTLs | Chr | Donors | Recipients | Ecosystems |
|---|---|---|---|---|
| $qDTY_{1.1}$ | 1 | N22, Apo, Vandna, Dagad deshi, Dular, Kali Aus | Swarna, IR64, MTU1010, Sabitri | Upland, lowland |
| $qDTY_{2.2}$ | 2 | Aday sel | IR64 | Upland, lowland |
| $qDTY_{2.3}$ | 2 | Vandana, Kali Aus | Way Rarem, IR64 | Upland, lowland |
| $qDTY_{3.1}$ | 3 | Apo, IR55149-04 | Swarna, TDK1 | Upland, lowland |
| $qDTY_{3.2}$ | 3 | Vandana, N22, Moroberekan IR77298-5-6-18 | Way Rarem, Swarana, Sabitri | Upland, lowland |
| $qDTY_{4.1}$ | 4 | Aday sel | IR64 | Upland, lowland |
| $qDTY_{6.1}$ | 6 | Apo, IR55419-04 | Swarna, TDK1 | Upland, lowland |
| $qDTY_{6.2}$ | 6 | IR55419-04, Moroberekan | Swarna, TDK1 | Upland, lowland |
| $qDTY_{12.1}$ | 12 | Way Rarem, IR74371-46-1-1, Dular | Vandana, Sabitri, Sabitri | Upland, lowland |

**IRRI improved the yield by 0.8-1.5 t/ha under moderate to severe drought of ten popular rice varieties following MAB- Vandana, Swarna, IR64, TDK, Sabitri, Kalinga 3, Sambha Mahsuri, MR219, MRQ74, Anjali**

# Drought tolerant lines free from linkage drag

| | Designation | Stress | | | Non stress | | |
|---|---|---|---|---|---|---|---|
| | | DTF | PHT | GY | DTF | PHT | GY |
| A | IR 91659:41-95-5-B | 90 | 72 | 3079 | 94 | 84 | 4530 |
| | IR 91659:54-36-9-B | 92 | 68 | 3299 | 96 | 82 | 5027 |
| | IR 91659:41-95-6-B | 86 | 69 | 3123 | 96 | 81 | 4487 |
| | Swarna | 102 | 63 | 561 | 96 | 84 | 4312 |
| $qDTY_{1.1}$ | LSD$^{0.05}$ | 3 | 6 | 771 | 3 | 5 | 1246 |
| B | IR 90266-B-491-1 | 83 | 92 | 1750 | 74 | 109 | 5750 |
| | IR 90266-B-155-1 | 86 | 96 | 1637 | 73 | 113 | 5740 |
| | IR 90266-B-53-1 | 84 | 102 | 1947 | 70 | 116 | 5672 |
| | TDK1 | 99 | 73 | 173 | 74 | 111 | 5985 |
| $qDTY_{6.2}$ | LSD$^{0.05}$ | 4 | 10 | 714 | 8 | 14 | 1578 |
| C | IR81896-B-B-309 | 98 | 82 | 1928 | 92 | 138 | 5174 |
| | IR81896-B-B-481 | 98 | 76 | 929 | 95 | 127 | 5592 |
| | IR81896-B-B-305 | 102 | 85 | 808 | 94 | 130 | 6717 |
| | Swarna | | 54 | 0 | 101 | 126 | 4965 |
| $qDTY_{3.1}$ | LSD$^{0.05}$ | 7 | 24 | 664 | 6 | 11 | 2200 |
| | IR 79971-B-102-B | 79 | 84 | 920 | 83 | 110 | 3547 |
| | IR 79971-B-421-B | 84 | 79 | 756 | 84 | 110 | 3156 |
| | IR 79971-B-86-B | 68 | 76 | 847 | 73 | 101 | 3311 |
| *D* | Vandana | 64 | 73 | 617 | 63 | 94 | 2180 |
| $qDTY_{2.3}$ | LSD$^{0.05}$ | 5 | 10 | 241 | 3 | 12 | 782 |

**Vikram et al. 2015, Sci. Reports**

# MAB for abiotic stress: *IR64 + qDTYs*


Parent 2007

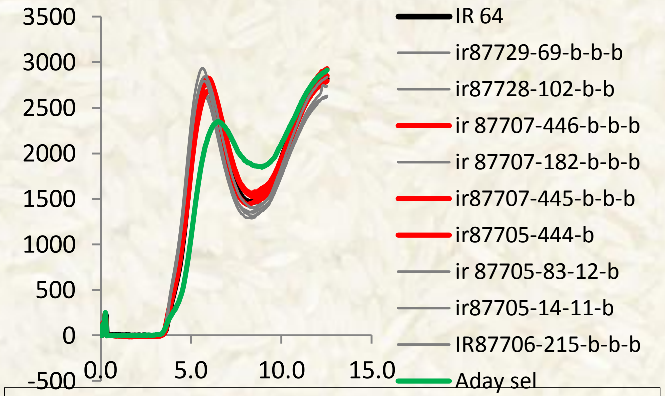
QTL, introgression 2010

Product released in 2014 as IR 64 drt 1 in India, Sukha dhan 4 in Nepal, Yeanelo 4 in Myanmar

IR64 drought IR64

IR64 drought IR64

IR64 IR64 drought




RVA test: similar cooking quality

- ***IR64 drought: first molecular product for drought***
- **0.6- 1.2 t/ha yield advantage under drought with similar high yield under irrigated situation**

**High quality as that of IR64**

| ENTRY | Rajshahi | Nepalganj | RPR | HYD SS | HYD MS | Hazaribag | Rewa |
|---|---|---|---|---|---|---|---|
| IR64 -DR | 1525 | 3472 | 3956 | 1684 | 3800 | 1604 | 3731 |
| IR 64 | 980 | 1597 | 2662 | 660 | 3085 | 958 | 2503 |
| SED | 156 | 170 | 285 | 939 | 600 | 422 | 909 |

Kumar et al., IRRI

# Flood + drought tolerant varieties

| Designation | DTFNS | DTFS | PH | PHS | GYNS | GYS | SUB 4DAD | SUB 7DAD |
|---|---|---|---|---|---|---|---|---|
| IR 96321-1447-651-B-1-1-2 | 94 | 93 | 90 | 71 | **5396** | 1629 | 3 | 3 |
| IR 96321-315-323-B-3-1-1 | 93 | 102 | 100 | 69 | **7000** | 1712 | 3 | 2 |
| IR 96321-558-257-B-4-1-2 | 94 | 89 | 87 | 63 | **5624** | 1465 | 3 | 3 |
| IR 96321-1447-521-B-2-1-2 | 93 | 92 | 91 | 73 | **5897** | 1539 | 3 | 3 |
| IR 96321-558-257-B-5-1-2 | 97 | 97 | 87 | 60 | **5696** | 1367 | 2 | 2 |
| IR 96321-558-563-B-2-1-1 | 96 | 93 | 88 | 63 | **6069** | 1219 | 3 | 3 |
| IR 94391-131-358-19-B-1-1-1 | 79 | 76 | 79 | 51 | **7969** | 1728 | 3 | 3 |
| **Swarna** | 106 | 117 | 95 | 67 | **5243** | 742 | **8** | **8** |
| **Swarna sub 1** | 105 | 119 | 96 | 65 | **5656** | 488 | **3** | **4** |

**IRRI**

**Hyderabad, India**

**Bihar, India**

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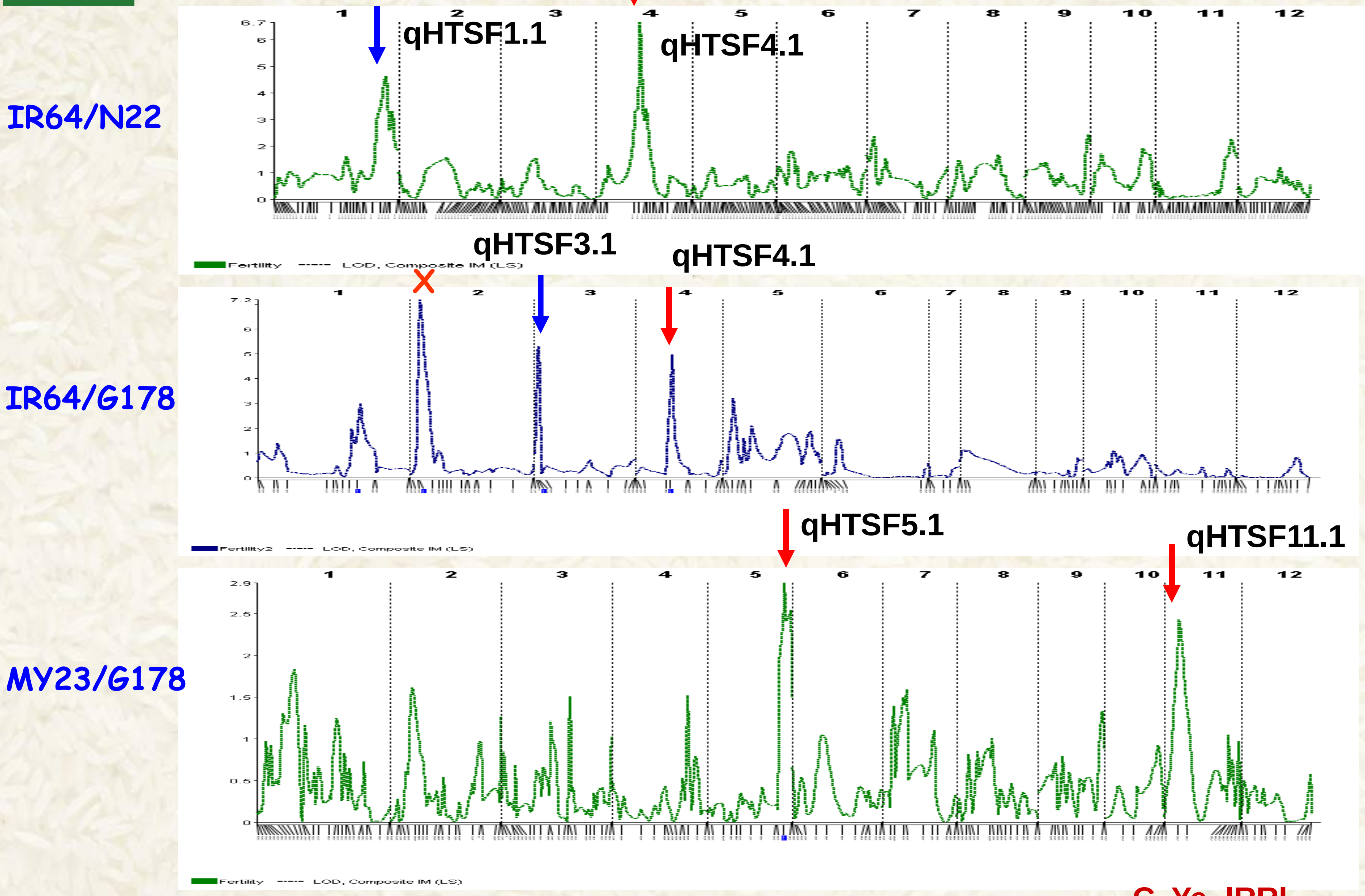
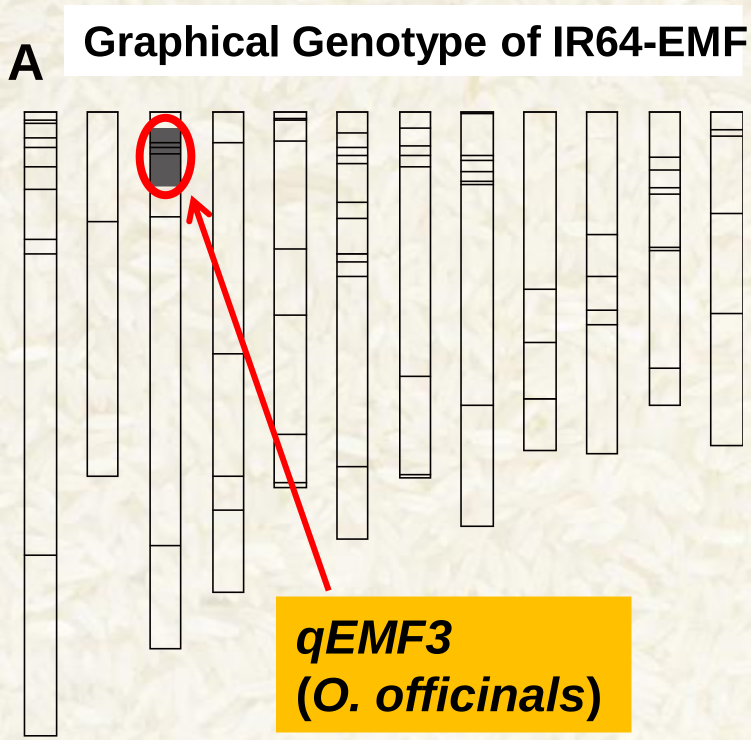
# High Temperature: QTLs identified, introgressed

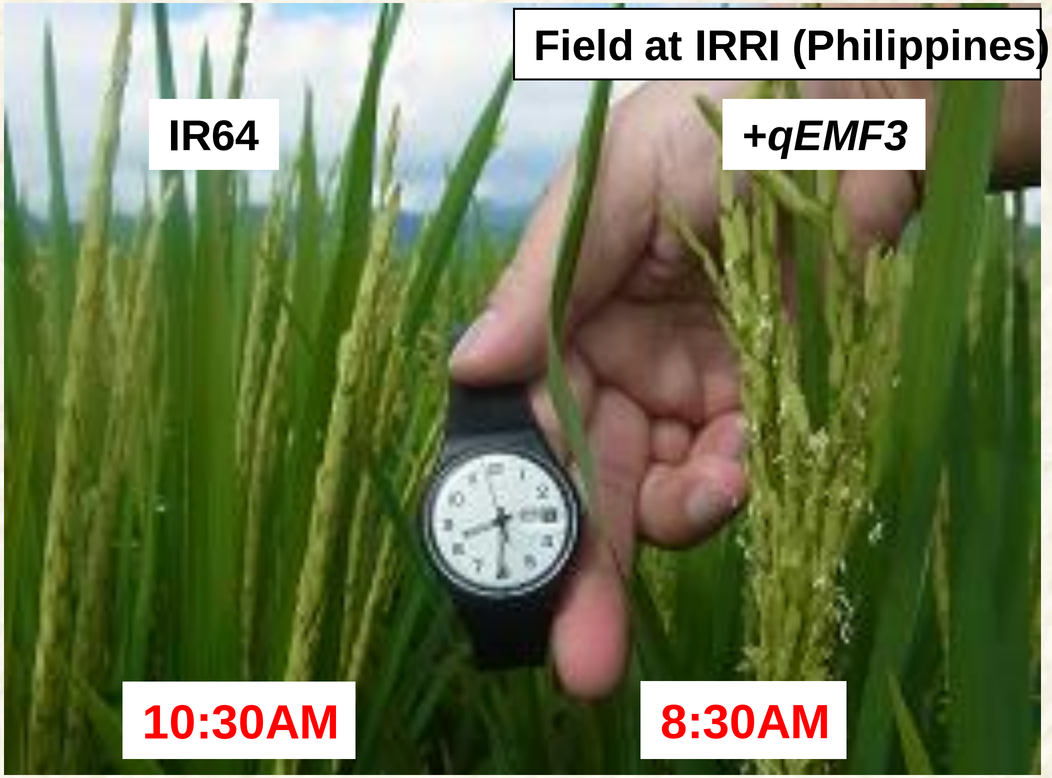



C. Ye, IRRI

# Development of IR64-NIL for Early-Morning Flowering

Hirabayashi et al. (2015) J. Exp. Bot.




**90-120 min earlier FOT in NIL than IR64 (recurrent parent)**

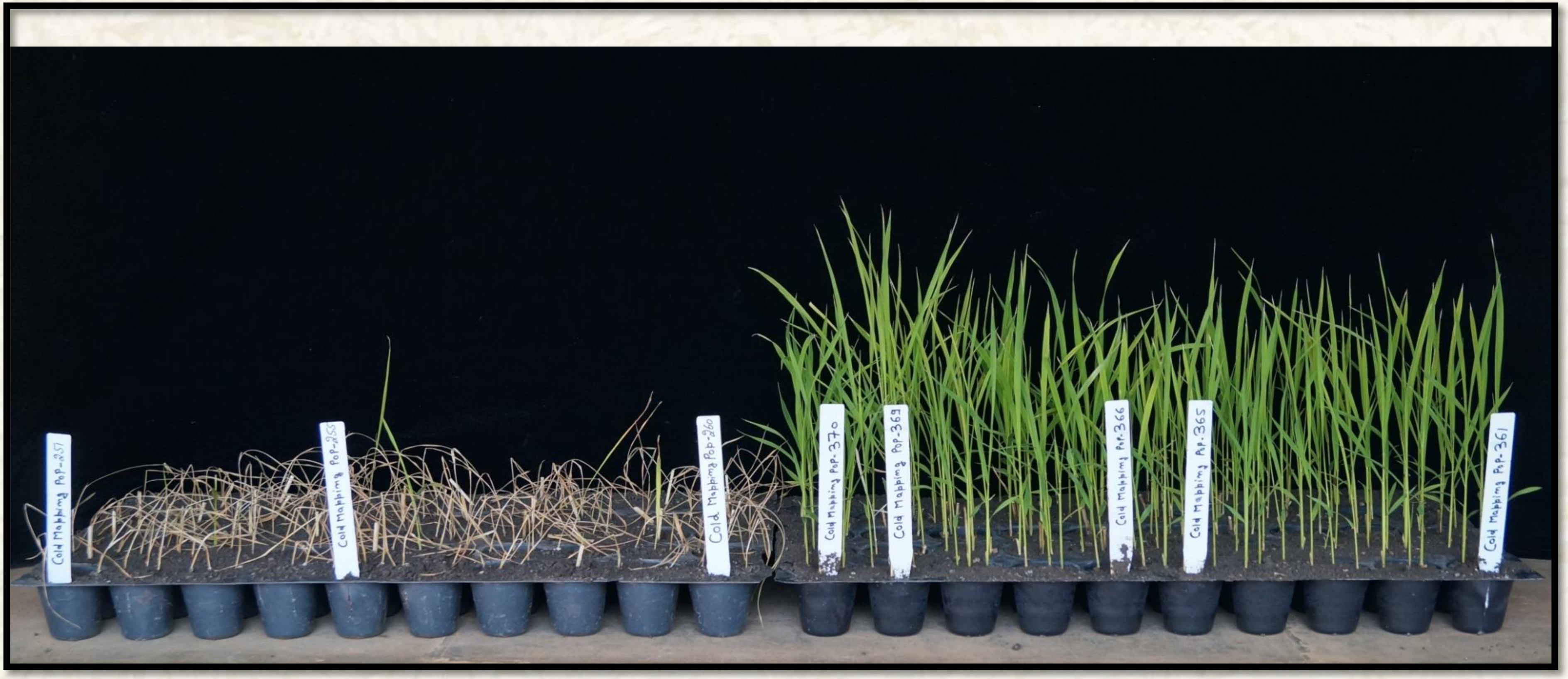
## IR64EMF, and IR64HT+EMF lines developed

Ishimaro et al., IRRI

IRRI

# Low temperature

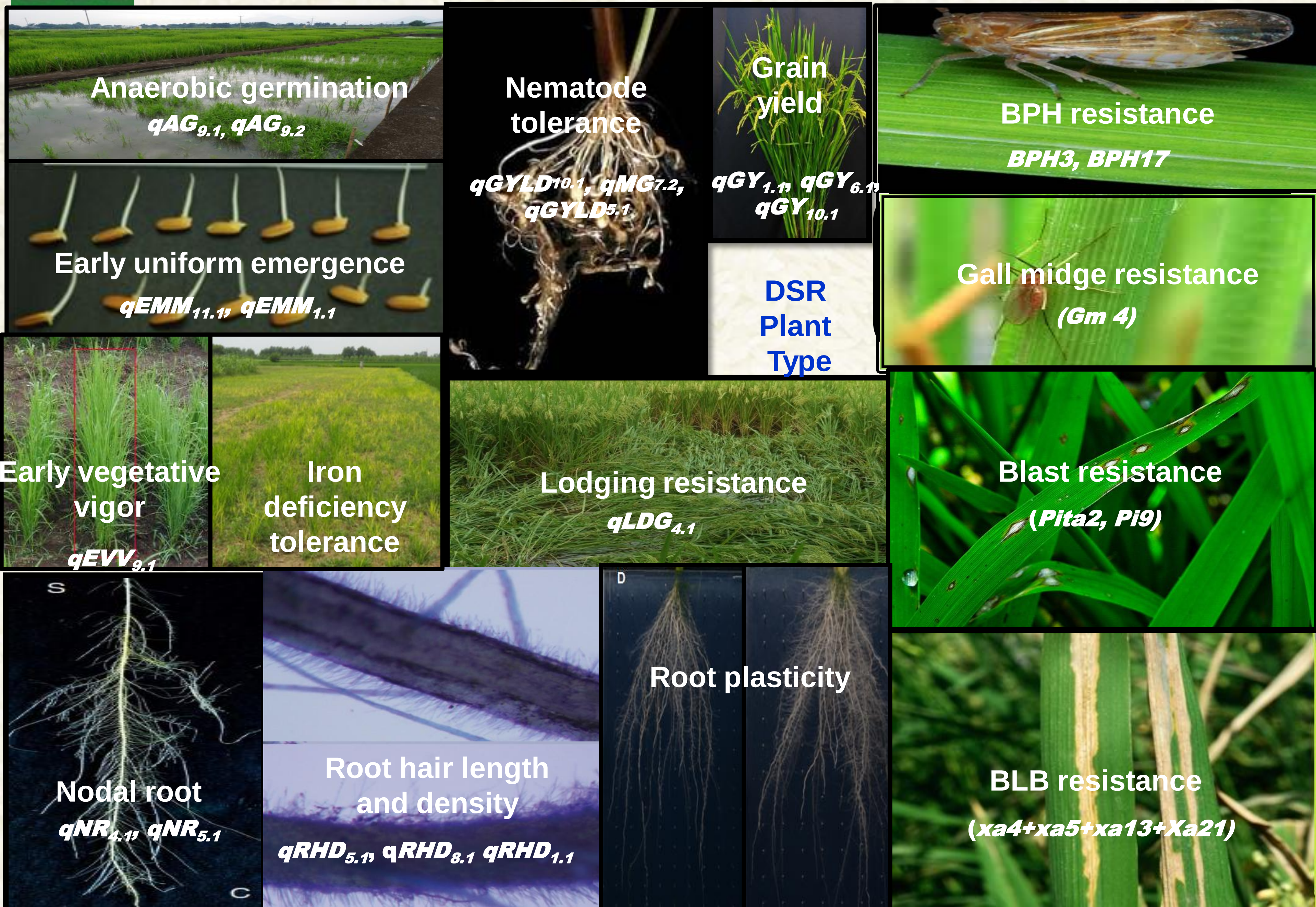
- **Not many Indica accessions known for tolerance to low temperature, new donors identified**
- **Tolerance from Japonica transferred to Indica**



**Cold reaction of mapping population derived from the cross MTU-1010/ donor at 10 °C /15 days in the indoor growth chamber (Conviron®)**

**Jena, Kumar, IRRI**

# Direct seeding- labor, water shortage



# MAB for Multi-stress tolerance: across stresses

1. Drought + Submergence+ High temp + low temp
2. Salinity + Submergence
3. Drought+ submergence
4. Salinity + Zn deficiency + Fe toxicity
5. Submergence + Stagnant Flooding/AG
6. Submergence + BLB

## What comes from trait development

1. Donors for different traits

2. Improved lines with QTLs/genes free from undesirable linkages

3. Pre-breeding lines with combinations of traits

4. Improved varieties for single traits/combination of traits

5. Linked markers for QTLs/genes for tolerance to abiotic stresses

## How much use for Hybrid Rice

1. Most of the QTLs /genes identified are effective, most of the abiotic stress tolerance trait lines show yield advantage of 0.8-1.2 t/ha under single/combinations of stresses
2. Tolerance to abiotic stresses will become necessity in few years from now
3. Improve restorer/CMS lines introgressing QTLs/genes- similar to done earlier for biotic stress tolerance
4. Use of improved lines/mapping populations lines with improved plant type as restorer lines-

    - Better adaptation to abiotic stresses
    - Increased heterosis- carry more variability
    - Increased seed setting

**Thank you very much**

**for your**

**kind attention**