Climate change and food production in Asia

Home of the Green Revolution
Established 1960

Jagadish SVK, E Septiningsih, A Kumar, Singh RK
International Rice Research Institute
DAPO Box 7777, Metro Manila, Philippines
RICE and food security of Asia

Million people on <$1.25 per day

Latin America and the Caribbean
Sub-Saharan Africa
East Asia
SouthEast Asia
South Asia

Rice Wheat Pulses Maize Millet Sorghum Cassava Soybeans Potatoes
Global rice demand until 2035

Additional rice needed: 116 million tons by 2035

2010 global rice production

Asia • Africa • Americas • Rest of World
Potential effects of elevated CO$_2$ and high temperatures on rice

Increased [CO$_2$]  
- Higher air T  
- Higher canopy Temp/VPD  
  - More droughts
  - More salinity
  - More flooding

Increased [non CO$_2$]  
- Precipitation changes
- Sea level rise/ extreme events

Stomata:  
- *partial closure  
- *lower density
  - Lower sat uptake
  - Higher Photosynthesis  
  - Higher WUE
  - More biomass production
  - Higher nutrient demand
  - Higher respiratory losses
  - Shorter growing season
  - Spikell Sterility

Wassmann et al., 2009, Adv. Agron.102, 91-133
Outline

Progress in adapting rice to
  ▪ High temperature stress
  ▪ Drought stress
  ▪ Submergence
  ▪ Salinity

➢ Companion stresses

➢ Global partnership (GRiSP)
High temperature stress
Jagadish SVK
k.jagadish@irri.org

Drought stress
Arvind Kumar
a.kumar@irri.org

Submergence tolerance
Endang Septiningsih
e.septiningsih@irri.org

Salinity tolerance
Singh RK
r.k.singh@irri.org
High temperature stress

Progress in adapting rice to
- High temperature stress
- Drought stress
- Submergence
- Salinity

- Companion stresses
- Global partnership (GRiSP)
Anthesis and Microsporogenesis – most sensitive stages

Redrawn from Satake & Yoshida, 1978
Is EMF trait useful?

Shading and staggered sowing

Materials – Local varieties

Concept – early hours have low radiation and temperature

Comparison – with (EMF) and without (on EMF) shading

Locations – TNAU, IARI-India
**N22 a true high temperature tolerant donor**

<table>
<thead>
<tr>
<th>Accession</th>
<th>Type</th>
<th>30°C</th>
<th>35°C</th>
<th>38°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azucena</td>
<td>S</td>
<td>66.1</td>
<td>23.4</td>
<td>02.9</td>
</tr>
<tr>
<td>Bala</td>
<td>T</td>
<td>89.8</td>
<td>81.4</td>
<td>40.6</td>
</tr>
<tr>
<td>CG 14</td>
<td>MT</td>
<td>89.6</td>
<td>71.7</td>
<td>19.1</td>
</tr>
<tr>
<td>Co 39</td>
<td>T</td>
<td>86.1</td>
<td>83.5</td>
<td>40.5</td>
</tr>
<tr>
<td>IR 64</td>
<td>MT</td>
<td>93.2</td>
<td>68.3</td>
<td>18.7</td>
</tr>
<tr>
<td>Moroberekan</td>
<td>S</td>
<td>83.3</td>
<td>39.9</td>
<td>06.4</td>
</tr>
<tr>
<td><strong>N22</strong></td>
<td>HT</td>
<td>95.6</td>
<td>91.3</td>
<td>63.7</td>
</tr>
<tr>
<td>WAB 56-104</td>
<td>S</td>
<td>94.6</td>
<td>76.0</td>
<td>19.2</td>
</tr>
</tbody>
</table>

Jagadish et al., 2008, Crop Sci., 48:1140–1146

- **N22** two most tolerant accessions identified
- **N22** tolerant at microsporogenesis stage
- **N22** most tolerant to high night temperature under field (Peng et al., UnPub) and under controlled environments (Coast et al., UnPub)
Physiological processes determining spikelet fertility

Moroberekan stress

N22 stress

Moroberekan control

N22 control

Moroberekan stress

N22 stress

Jagadish et al., 2010, J Ex Bot, 61, 143–156
QTLs/proteins for heat tolerance at anthesis

Jagadish et al 2010 – Bala x Azucena

Xiao et al 2010 – 996 × 4628
Boro rice at Jessore, Bangladesh

Wassmann et al., 2009, Adv. Agron.102, 91-133
Jakobabad, Pakistan

Wassmann et al., 2009, Adv. Agron.102, 91-133
High temperature and humidity interaction (VPD)

- **85% RH**
- **60% RH**

**Genotypes**
- IR36
- IR24
- Hinohikari
- Yumehikari

**Fertile spikelet (%)**

- **Hot and Dry** (VPD=3.5)
- **Hot and Humid** (VPD=1.75)

Weerakoon et al., 2008 J. Agron. & Crop Sci., 135-140
....collaborating with NARES network

India (Hot and Dry)  Bangladesh (Hot and humid)
Courtesy – S. Sheryl, IRRI  Courtesy – Dr Masuduzzaman, BRRI
When will we have a heat tolerant line?

IR64 x N22

F1 x IR64

F2

BC1F1 x IR64

QTL mapping

BC2F1

Background selection (SNP)

BC2F2

IR64

BC3F1

Background selection

BC3F2

NIL

BC3Fn

QTL pyramiding

Field trial

Ye et al.

RIL Fn

F2

BC1F1

QTL for HNT
QTL for different growth stages

Current

By 2015

Recipients – NSICRe222

Now F5

Fine mapping 1st

Marker development

Fine mapping 2nd

Marker development

Map based cloning

Gene specific marker for MAB
Night temperature and rice

\[ y = -423.6 + 39.2x - 0.89x^2 \ (r^2 = 0.77) \]

Peng et al., 2004

\[ Y = 0.040X^2 + 2.418X - 29.22 \quad R^2 = 0.87 \]

Nagarajan et al., 2010

Impact of unit change on yield (kg/ha)

Welch et al., 2010
High night temperature and maintenance respiration

Recent findings
- 43 entries screened
- Contrasting entries identified
- In susceptible entry
  - Spikelet fertility not reduced
  - Biomass, N, NSC reduced
  - Rate of grain filling reduced
  - Grain width reduced
  - Quality deteriorated
- Flag leaf and panicles proteomics at 100% flowering and 12 DAF flowering and 43 proteins sequenced

Shi et al., 2013. New Phytologist. 197, 825–837
Rice growing regions vulnerability

Improvements
- Day and night
- Daily temperature
- Global planting dates
- Incorporating RH?

Laborte, Nelson et al.
Drought stress

Progress in adapting rice to

- High temperature stress
- **Drought stress**
- Submergence
- Salinity

- Companion stresses
- Global partnership (GRiSP)
Drought Research at IRRI: Strategy

**Conventional approaches**

- Use improved pre-breeding lines as donors
- Direct selection for grain yield
- Combine high yield with good yield under drought
- Confirm performance in multi location testing in target environment-Drought breeding network

**Molecular approaches**

- Use traditional/wild donors in mapping populations
- Identify major drought yield QTLs
- Introgress QTLs in improved drought susceptible varieties
- Physiological and molecular mechanism of QTLs drought tolerance
Submergence and Salinity stress

Progress in adapting rice to
- High temperature stress
- Drought stress
- Submergence
- Salinity

- Companion stresses
- Global partnership (GRiSP)
QTL mapping for submergence tolerance

- **SUB1 QTL**: $R^2 = \sim 70\%$, Chr. 9, from FR13A (Xu and Mackill, 1996)
- Cloned as a cluster of 3 ERF genes: **SUB1A**, **SUB1B**, and **SUB1C** (Xu et al., 2006)
First six *Sub1* mega-varieties developed

<table>
<thead>
<tr>
<th>Sub1 variety</th>
<th>Gen.</th>
<th>Fixed line names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swarna-Sub1</td>
<td>BC2</td>
<td>IR 05F101</td>
</tr>
<tr>
<td></td>
<td>BC3</td>
<td>IR 05F102</td>
</tr>
<tr>
<td>Samba Mahsuri-Sub1</td>
<td>BC2</td>
<td>IR 07F101</td>
</tr>
<tr>
<td></td>
<td>BC3</td>
<td>IR 07F287</td>
</tr>
<tr>
<td>IR64-Sub1</td>
<td>BC2</td>
<td>IR 07F102</td>
</tr>
<tr>
<td></td>
<td>BC3</td>
<td>IR 07F292</td>
</tr>
<tr>
<td>TDK1-Sub1</td>
<td>BC3</td>
<td>IR 07F289</td>
</tr>
<tr>
<td>CR1009-Sub1</td>
<td>BC2</td>
<td>IR 07F291</td>
</tr>
<tr>
<td>BR11-Sub1</td>
<td>BC2</td>
<td>IR 07F290</td>
</tr>
</tbody>
</table>

- Swarna-Sub1, IR64-Sub1, BR11-Sub1, Samba Mahsuri-Sub1, and TDK1-Sub1 have been released in several countries.
- More Sub1 varieties developed, such as Ciherang-Sub1 and PSBRc18-Sub1

*Neeraja et al. TAG (2007)  
Iftekharuddaula et al. Euphytica (2011)*
Tolerance to anaerobic germination (AG) for direct seeding ecosystem

- Capability of seeds to germinate and elongate under hypoxia (low oxygen) or anoxia (no oxygen).
- Direct seeding is becoming more popular among farmers in both rainfed and irrigated ecosystems.
- An effective means of weed control in irrigated areas.
- Improving crop establishment due to unleveled fields or flash floods after direct seeding.
- Tolerance to AG is independent of \textit{SUB1}.
Major QTL for seedling stage salinity tolerance

Fine-map and MAB

Saltol QTL

10.4 Mb
RM1287
10.9
RM1287
10.3
RM8094
11.5
RM3412
12.1
RM493
12.2
RM140
12.7
RM8115

IR29 X Pokkali
R² > 0.40

Chromosome 1

RM8115
RM562
RM7075
RM8115
RM562

Gregorio 1997; Bonilla et al. 2002

SKC1
RM8094
RM3412
RM493
RM140
RM8115

Niones 2004
Thomson et al. 2007
Gregorio 1997; Bonilla et al. 2002

Na K
Na/K

RM10655
RM10694
RM10696
RM10701
RM10711
RM10713
AP3206
RM10748
RM10772
RM10773
RM10793
RM10800
RM10835
Multiple abiotic stress tolerance

Progress in adapting rice to
- High temperature stress
- Drought stress
- Submergence
- Salinity

- Companion stresses
- Global partnership (GRiSP)
Abiotic and biotic stress interactions

Mittler, 2006
Mapping heat and drought tolerant regions of South and SE Asia

Bangladesh, eastern India, southern Myanmar, and northern Thailand

Jagadish et al., FPB, 2011, 38, 261–269
“2-in-1” rice, combined tolerance of salinity and submergence is now being evaluated in target sites in Asia.

10 days submerged in saline water

Sub1 only  SalTol+ Sub1
Major rice deltas and sea level rise
Different RH regimes and seedling growth under salt stress

55 % RH

0 mM NaCl

60 mM NaCl

100 mM NaCl

CGIAR Thematic Area 3: Sustainable crop productivity increase for global food security

A Global Rice Science Partnership (GRiSP)

An evolving alliance of IRRI, AfricaRice & CIAT with Cirad, IRD, JIRCAS and hundreds of research and development partners worldwide

Each dot represents 5,000 ha of rice

Irrigated
Rainfed lowland
Rainfed upland
Financial support

Bill & Melinda Gates Foundation

USAID

BMZ

The Lee Foundation Rice Scholarship Program

http://www.grisp.net

http://grisp.irri.org/Global RiceScience-Scholarships