SEARCA PROFESSORIAL CHAIR PUBLIC LECTURE

PLANT ADAPTATION TO ENVIRONMENTAL STRESSES:
A KEY CHALLENGE TO RICE FOOD SECURITY

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Food security

WHY MATTERS TO **RICE FOOD SECURITY**

When all people, at all times, have physical, social and nutritious food that meets their dietary needs and healthy life — FAO 2010

At present – Malaysian are food secured

National food security defined by some to mean self-sufficiency — Andersen, 2009

National food sovereignty – measure extent to which the country had the means to make available to its people the food needed or demanded
Rice food security - Malaysia

Total Rice Production & Import

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (Million MT)</th>
<th>Import (Million MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1.22</td>
<td>0.33</td>
</tr>
<tr>
<td>2000</td>
<td>1.38</td>
<td>0.59</td>
</tr>
<tr>
<td>2006</td>
<td>1.53</td>
<td>0.84</td>
</tr>
<tr>
<td>2007</td>
<td>1.54</td>
<td>0.8</td>
</tr>
<tr>
<td>2008</td>
<td>1.62</td>
<td>0.93</td>
</tr>
<tr>
<td>2009</td>
<td>1.64</td>
<td>1</td>
</tr>
<tr>
<td>2010</td>
<td>1.65</td>
<td>1.1</td>
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<tr>
<td>2011</td>
<td>1.65</td>
<td>1.1</td>
</tr>
<tr>
<td>2012</td>
<td>1.53</td>
<td>1.1</td>
</tr>
<tr>
<td>2013</td>
<td>2.7</td>
<td>1.1</td>
</tr>
</tbody>
</table>

- Production (Million MT) 73.5%
- Import (Million MT) 26.5%

73.5% Production
26.5% IMPORT
Sustained reliance on rice import?

Scenario on importing countries, Vietnam and Thailand

Future of Vietnam’s rice production threatened by climate change. **New IFAD project to aid Mekong Delta small farmers as rice crops are devastated by rising temperatures, sea levels,**  
*Source: International Fund For Agricultural Development Report 22 May 2014*

The International Panel of Climate Change (IPCC) list Vietnam as one of the most affected countries by climate change.

A decrease in agriculture land production area, averagely there is a loss between **50,000 to 70,000** hectare of agriculture land for industrial purposes, equivalent to **400,000 to 500,000 tons** loss of rice per year.  
*Source: Revisiting Vietnam Rice Farming: Moving Towards Industrialization (2012)*
Sustained reliance on rice import?

Concern of increase population and rice availability

- In 2015: 68 Million, 12 Million less than predicted

1. Internal policy – satisfying export market – safety and quality organic rice (quality rice)
2. Labor shortages
3. Climate change: yield of Thai rice expected to decline about 18% in the 2020s

Mekong Wetlands Biodiversity Conservation and Sustainable Use Programme (MWBP) (2005) the risk of losing paddy fields acreages.
National Level:
Boosting rice production is the main target - reducing yield gap.

National average rice yield, yield to reach 100% SSL and potential yield.

2013: 73.5% Self sufficient (Rosnani, 2015)
Maximizing farmer’s income (monthly take home pay) from NKEA ETP PROGRAM

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
<th>Quantity</th>
<th>Cost (RM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8am</td>
<td>Super Ppl</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>8am</td>
<td>Grannt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9am</td>
<td>6 clwr 2 hr (6am + 7am)</td>
<td>6</td>
<td>540.00</td>
</tr>
<tr>
<td>9am</td>
<td>6 clwr x 50.00</td>
<td>6</td>
<td>300.00</td>
</tr>
<tr>
<td>10am</td>
<td>Upah Orange Kacau</td>
<td>1 bag</td>
<td>118.00</td>
</tr>
<tr>
<td>10am</td>
<td>Kacau Progres</td>
<td>4 Ltr</td>
<td>35.00</td>
</tr>
<tr>
<td>11am</td>
<td>13 bag + 118.00</td>
<td></td>
<td>1534.00</td>
</tr>
<tr>
<td>11am</td>
<td>14 plt + 3.50 + 1 + 24.00</td>
<td></td>
<td>73.00</td>
</tr>
<tr>
<td>12pm</td>
<td>21 pmn + 5.00</td>
<td>21</td>
<td>105.00</td>
</tr>
<tr>
<td>12pm</td>
<td>19 plt x 3.50</td>
<td>19</td>
<td>69.50</td>
</tr>
<tr>
<td>12pm</td>
<td>23 bag x 2.00</td>
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<td>46.00</td>
</tr>
<tr>
<td>12pm</td>
<td>15 pmn x 5.00</td>
<td>15</td>
<td>75.00</td>
</tr>
<tr>
<td>1pm</td>
<td>15 pmn + 5.00</td>
<td>15</td>
<td>75.00</td>
</tr>
<tr>
<td>1pm</td>
<td>18 bag x 1 bag</td>
<td>18</td>
<td>90.00</td>
</tr>
<tr>
<td>1pm</td>
<td>15 pmn x 5.00</td>
<td>15</td>
<td>75.00</td>
</tr>
</tbody>
</table>

Net Income: 8266 for 6 acres @ RM 1366 per acre

Take home monthly: RM 227 per acre (6 man-month)
Input management

Luxury consumption of inputs especially fertilizer – associated with pest and disease infestation – 20 days to harvest: neck blast (30%) - 19th April 2015

Pest and disease early warning system.
Managing rice plants under environmental stresses

**Short – term**
Agronomic manipulation – immediate action plan for plant survival and farmers livelihood

**Intermediate**

**Long – term**
Crop improvement program - crop breeding. Molecular research - C3 to C4, Transgenic rice etc.

Feb 24, 2014 - Minister’s visit to drought affected area in MADA
Bill Gates Pledges $20 Million For Rice Research

By news desk on January 28, 2008

Microsoft founder Bill Gates has pledged to donate nearly $20 million to the International Rice Research Institute for research into helping rice farmers deal with global warming.

The Philippines-based institute said it would use the donation from the Microsoft founder to harness scientific advances and address major unsolved problems in agriculture. The Bill and Melinda Gates Foundation will release the $19.9-million grant over three years.

Rice is a staple food for 2.4 billion people. Annual rice output must increase by nearly 70% to nearly 880 million MT in 2025 to meet projected global demand.
Photosynthesis Boost
The world's highest-production crops use a super-efficient form of photosynthesis. It's known as C4 photosynthesis because the first step is the formation of a four-carbon molecule. C3 photosynthesis, found in most plant species, starts with a three-carbon molecule.

Major C4 and C3 crops (annual production in metric tons)

Carbon Concentrators
In C4 plants, a wreath-like arrangement of cells (lower image) helps concentrate carbon dioxide. A ring of mesophyll cells (green) captures the carbon dioxide, which is conveyed to an inner ring of bundle-sheath cells (orange). The arrangement is known as the Kranz anatomy, after the German word for wreath.
Rice Matters

Farmers are struggling to meet growing demand for rice, the staple for half of the world's population.

Projected shortfall in rice production (in millions of tons)

- 2050 expected demand: 1,309
- Shortfall: 394
- 2050 expected production: 915

Rice provides 19% of global dietary energy

Plateauing yields

1990

- Last year that average rice yields increased in California

33%

- Percentage of rice-producing regions where yields have plateaued

Efficient Farming

A unit of water goes further with C4 crops, producing far more food. In China, planting C4 rice could feed 50 percent more people per hectare.

Rice and corn grown with a given amount of water (the unit is a hectare covered to a depth of one millimeter with water)

- C4 Corn
  - 30–37 kg
- C3 Rice
  - 15–22 kg

People fed yearly in China by one harvest from one hectare of C3 vs. C4 rice

- C3 Rice
  - 26 people
- C4 Rice
  - 39 people
C$_3$ Rice: Productivity low – Why (?)

RUBISCO is a dual natured enzyme: Functions as both Carboxylase & Oxygenase

Calvin Cycle

Oxygenase activity of RUBISCO: +PG

Photorespiration

RUBP → PGA → PG → Glycolate → Glyoxylate

CO$_2$ → Serine → 2 Glycine

NH$_3$
Photorespiration: The major challenge for yield loss in rice

Calvin Cycle

- CO₂
- O₂
- RUBISCO
- PG
- RUBP
- PGA
- CH₂O

Chloroplast

- Glycolate
- Glyoxylate

Peroxisome

- Actually, ~30% at 25 °C (Zhu et al. 2010)

- **25% assimilatory C is lost**

Mitochondria

- Serine
- CO₂
- 3C
- NH₃
- 2 Glycine
- 2 x 2C
**C₄ Photosynthesis**: Highly productive

Mesophyll & Bundle sheath
So-called “Kranz Anatomy”.

- Photorespiration low
- WUE high
- NUE high (Brown 1999)
- LUE high
- CO₂ compensation low

CO₂ pumping mechanism; C supply remains unchanged

**Oxygenase activity of** RUBISCO is suppressed in C₄ plant
Calvin Cycle

Atmospheric

CO₂ → O₂ → PG → *Glycolate → Glyoxylate

RUBISCO

RUBP → PGA

CH₂O

***Target: Chl. G forms Glycerate -- Photorespiratory bypass (Zhu et al. 2010)

**25% assimilatory C is lost

***Target: Photorespiratory CO₂ re-assimilation (Sage & Sage 2009)

Serine → CO₂

2 Glycine

2 x 2C

3C

NH₃

2 Glycine
Metabolic engineering is one of the important tools to engineer C₄ rice

*Photorespiratory bypass

**Photorespiratory CO₂ reassimilation

***Single-cell CO₂ pumping mecha. via PEPCase engineering
$C_4$ rice will be more efficient in CO$_2$ concentration

Increased efficiency in water and nitrogen use (Eco-efficient)

Improved adaptation to hotter and dryer environments (Climate change)
Updates

The December 2014 results, achieved by the C4 consortium and led by Paul Quick (IRRI) in the Philippines, introduced key C4 photosynthesis genes into a rice plant and showed that it carried out a rudimentary version of the supercharged photosynthesis process.

(The MIT Technology Review, Jan 2015)
DEVELOPMENT OF SUBMERGENCE TOLERANT RICE
PRODUCTION OF SUBMERGENCE TOLERANT RICE

Crossed new panicle

Selected lines in the plot

Crop in the field
SALINITY TOLERANT LINES MR 219-4

SALINITY TOLERANT RICE LINES PLANTED IN GLASSHOUSE

6 INDEPENDENT SALINITY TOLERANT RICE LINES PRODUCED
Chinese scientist and crop physiologist Ping Shengduo is inspecting rice samples at the International Rice Research Institute in Los Banos, Laguna. — AFP picture

Scientists fight threat to rice

LOS BANOS (Philippines) An agricultural research station south of Manila, a group of scientists are battling against time to breed new varieties of rice as global warming threatens one of the world's major sources of food. According to the International Rice Research Institute (IRRI), more than half the world's 6.5 billion people depend on rice for nutrition. "Parts of the world will become drier and apparently the area is already happening," said Morcovan crop physiologist Eslado Soriano. "But most importantly, it's going to shift the rainfall distribution. It's going to become unpredictable, and that is the problem for rice cultivation," he said. Chinese scientist Ping Shengduo warns that global warming will increase the frequency of high temperatures, which could reduce rice yields. He says the global at risk is the rice crop. The Intergovernmental Panel on Climate Change predicts that the globe will warm by 2°C globally every 10 years. Higher night-time temperatures mean less energy is left for grain growth, reducing yields. "We need to develop varieties that can grow under high temperatures. We are working on that," Soriano said. IRRI is a key part of the "Green Revolution" that dramatically raised cereal yields in the 1960s, but has had trouble keeping up with global demand. Increasingly, rice research focuses on "new frontier projects" to meet the threat. This is part of a more conventional research in rice plants. "The plants are not the only factors that affect rice yield. The soil quality, water availability, and other factors also play a role," Soriano said. Drought- and salinity-tolerant rice varieties are essential to addressing the problem, he said. Some 3.6% of the world's cultivated land is affected by salinity, and 20% is infested by weeds. "We need to develop rice varieties that can grow under these conditions," Soriano said. A dry spell in hot spots such as northern India can push up to 10 million people onto rice. "Future rice yields are key to reducing the threat," he said.
Identified few tolerant lines

High temperature tolerance
Drought /water limited rice cultivar

the development of cultivar that can tolerate water limited water condition.

UPM-MINT-MARDI-UMT - stress tolerant rice cultivar through induced mutation breeding.

Mutant MR219-4

unique because it performed very well under saturated conditions in irrigated areas and aerobic conditions (sprinkler assisted irrigation) under dryland regime (Abdullah et. al., 2010).

Plant physiological attributes: higher stomatal conductance
<table>
<thead>
<tr>
<th>Rice varieties</th>
<th>Normal flooding conditions</th>
<th>Water limited conditions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>173</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>219</td>
<td>170</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>211</td>
<td>224</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>219Ai</td>
<td>390</td>
<td>151</td>
<td></td>
</tr>
<tr>
<td>219Aii</td>
<td>230</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>219Bi</td>
<td>309</td>
<td>327</td>
<td></td>
</tr>
<tr>
<td>219Bii</td>
<td>403</td>
<td>311</td>
<td></td>
</tr>
<tr>
<td>211Ci</td>
<td>335</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>211Cii</td>
<td>405</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>211Di</td>
<td>276</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>211Dii</td>
<td>251</td>
<td>185</td>
<td></td>
</tr>
</tbody>
</table>

MR219-4 Mutant developed
Prioritised Research IRPA RMK8

Challenged with full submerged and salinity stresses

Physiological and biochemical attributes indicated promising traits for environmental stress tolerant (Maziah, Damanik, New Hew, Mohd Razi (UPM) Abdullah M Z (UMT))

Further exploration: LRGS program
Plants under aerobic condition in MARDI S..Perai (MR219-4) at ripening stage). Mutant MR219-4 was unique because it performed very well under saturated conditions in irrigated areas and aerobic conditions (sprinkler assisted irrigation) under dryland regime. In addition, the mutant can also tolerate submergence and therefore can be planted in flood-prone rainfed areas. The superior adaptation and yield performance of mutant MR219-4 under aerobic condition was obviously a very interesting finding because its parent, MR219 has never been recommended for aerobic soil (Abdullah et al, 2010)
Again – what are immediate measures for rice farmers to cope with drought or water limited

**How and what to address**

1. Drought prevails – problem with grain filling, at what phenological stages?
2. What fertilization regimes to be applied
3. Intrusion of weeds, how to manage
4. If there are water resources available – how to make full use of water availability, e.g. how much water/when to irrigate

**Yield losses (drought stress) from 2008-2011**

- 2010: 51%
- 2009: 22%
- 2008: 14%
- 2007: 16%
- 2011: 12%

Management under drought to lessen devastating damage to farmer’s income and rice availability
Main target: Carbon gain at low water potential (internal water deficit) creating plant adaptation under external stresses

The Challenge: maximize harvest index as a strategy for crop adaptation regulated at several sites. High net photosynthetic rates do not necessarily contribute to high HI because a large part of the fixed CO2 may be diverted into starch or non-harvestable biomass.

Understanding of plant metabolism at different phenological stages / adjustment

Rice and other cereals; Grainfilling: sensitive to climate changes.
Theoretical background of grain filling:

Monocarpic plants such as rice need to initiate whole plant senescence to remobilize the pre-stored reserves.

Pre-stored reserves contribute $1/4 - 1/3$ to the final weight of a grain, a big potential to exploit.

Delayed senescence delays such remobilization and leads to unused food in straws.
Grainfilling = efficient assimilate partitioning

- C reserve in stem and sheath
- 20-40%

Grain filling

Empty grains

Full grains
Type of treatments that had been imposed to rice plant experiment. T1 = well watered / control, T2 = WS at 60 - 70 DAS, T3 = WS at 70 - 80 DAS, T4 = WS at 80 - 90 DAS T5 = WS at 60 - 69 and 70 - 80 DAS T6 = WS at 70 - 79 and 80 - 90 DAS. *DAS = Day after Sowing. *WS = Water Stress

Drought prevails at reproductive stage resulted to 75-80% yield reduction
Filled grain under different water availability at different phenological stages. (1: Flooded, 2: Field capacity at first flowering, 3: Field capacity at panicle initiation, 4: Field capacity at active tillering, 5: Field capacity)  
Source: Zulkarnain et al, 2008
The problems:

Senescence is unfavorably delayed by heavy-use of N-fertilizers, introduction of lodging-resistant cultivars, (stay ‘green’ for too long at maturity) and utilization of heterosis (e.g. hybrid rice).

In all the cases, slow grain filling and unused food are the two problems.
In the field under water-saving culture:

Comparison between wheat plots that were well-watered or un-watered during grain-filling stage. Fate of fed $^{14}$C was measured on day 18 from anthesis.

<table>
<thead>
<tr>
<th>Duration from anthesis to maturation (days)</th>
<th>Fate of fed $^{14}$C ($^{14}$CO$_2$ applied 10 days early)</th>
<th>Total sugars left in stem (on day 26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-watered</td>
<td>41 days</td>
<td>41.3 % in kernels</td>
</tr>
<tr>
<td>Unwatered</td>
<td>31 days</td>
<td>81.3 % in kernels</td>
</tr>
</tbody>
</table>

Soil drying can greatly promote senescence and C remobilization.

Yang et al. 2001
Rationale for controlled soil drying:

1. A mild soil drying may not seriously disrupt the phloem function.

2. A faster filling will have some advantages in “stay green” cultivars because the phloem link to grains may lose its function earlier than chlorophyll disappears.

3. The gain from an accelerated grain filling from pre-anthesis food reserve may outweigh any loss of photosynthesis as a result of imposed soil drying.

(Source: Davies, Bacon and Mohd Razi, 2004)
Effect of different water management and alternate irrigation practice on rice yield (kg/ha) at Ladang Merdeka Mulong, in KADA
Physiological adaptation – regulating water regimes based on phenological adjustment

Continuous flooding

Mild water deficit imposed
imposing intentional stress by regulating water regimes benefits grain filling in rice and enable water saving
Grain filling = efficient assimilate partitioning

1. Endogenous enrichment of growth stimulants

Under drought conditions, endogenous application of growth bio stimulants can improve grain filling attributed to high HI (assimilate partitioning).
1. Growth enhancers for drought alleviation

1. 66% yield increased over untreated control.

2. Grain filling increased by 20%

2. Foliar fertilizer and growth stimulants

Foliar fertilizer and growth stimulants application-LRGS -UPM intervention
Polyamines for drought alleviation improve the assimilate partitioning in favor of spikelet on the secondary branches raise the number of high-density grains in the panicle increases the remobilization

Synthesis of sucrose synthase enzyme activities
2. Potassium fertilization and drought stress in rice

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant Height, cm</th>
<th>Leaves No./hill</th>
<th>Tillers No./hill</th>
<th>Days to flowering</th>
<th>Grain yield (g/pot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>102.89±0.44a</td>
<td>22±0.33c</td>
<td>5±0.17a</td>
<td>80±1.25a</td>
<td>91.403±1.99a</td>
</tr>
<tr>
<td>WS</td>
<td>95.22±0.45c</td>
<td>25±0.44b</td>
<td>4±0.29b</td>
<td>74±1.20b</td>
<td>45.907±3.19c</td>
</tr>
<tr>
<td>WSK</td>
<td>98.78±0.89b</td>
<td>29±0.22a</td>
<td>5±0.22a</td>
<td>77±0.67b</td>
<td>75.163±2.94b</td>
</tr>
</tbody>
</table>
Conclusion

Plants adjust to a changing environment by various means of adaptation mechanism.

A great challenge for plant biologists in the 21st century is to enhance crop development under challenges of environmental stresses to sustain and improve rice food security.

The key challenge is to find adaptation to environmental threats imposed by climate changes. The ultimate aim is to improve livelihood of farmers as they are the active players whom, through them with Allah swt permission, we and our future generation will be able to continue feeding on rice.
Terima Kasih | Thank You