Maize for Asian tropics: *Chasing the moving target*

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Thank you!

Partners:
- ICAR-IIMR, Ludhiana, Punjab, India
- NMRI, Ha Noi, Vietnam
- NSFCRC, Tak Fa, Thailand
- BARI, Gazipur, Bangladesh
- MMRI, Sahiwal, Pakistan
- NMRP, Rampur, Chitwan, Nepal
- IAS, BHU, Varanasi, U.P., India
- AAU, Anand, Gujarat, India
- UAS, Raichur, Karnataka, India
- BAU, Sabor, India
- Corteva Agrisciences, Hyderabad, India
- Kaveri Seeds Pvt. Ltd., Hyderabad, India
- Ajeet Seeds, Aurangabad, India
- BRAC Center, Dhaka, Bangladesh

Donors:
- ICAR/DARE, Govt. of India
- USAID F-t-F Initiative of the US Govt.
- BMZ/GIZ, Germany
- Syngenta Foundation for Sustainable Agriculture
- CGIAR-CRP Maize Agrifood system
- RKVY, Govt. of Odisha
- Govt. of A.P. & Karnataka, India
Maize trends in Asia: Production, Demand, Consumption & Net trade

(Source: FAOSTAT, 2018)
Maize mega-environment in Asian tropics

A challenging environment!

<table>
<thead>
<tr>
<th>~20% Irrigated</th>
<th>~80% Rainfed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

- **Irrigated**:
  - ~20%
  - Spring: 7%
  - Winter: 13%
  - Optimal moisture: 11%

- **Rainfed**:~80%
  - High-input environment but Heat stress-prone:
  - Spring: 7%
  - Winter: 13%
  - Optimal moisture: 11%

- **Drought/Excess moisture**:
  - Erratic distribution pattern of monsoon, prone to drought (+/-heat) and waterlogging within same crop cycle.

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- **High-input environment**:
  - >1500mm rainfall, excess-moisture/waterlogging

- **Excess moisture**:
  - >1500mm rainfall, excess-moisture/waterlogging

~76% of the total maize in Asian tropics is grown in stress-prone/marginal conditions!
Drought: Frequency increased as 8 severe drought years in last 14 years

~70% land drought prone; 22% flood prone and 18% to cyclones

Heat: frequent episodes of heat waves; e.g. in 2016 soaring $T_{max}$ past 45°C in Thailand, 42°C in Cambodia, and 50°C in parts of South Asia.

Frost: common in northern regions, e.g. severe yield loses in winter maize in South Asia during 2017-18

(Source: Erickson et al., 2011)
<table>
<thead>
<tr>
<th>S.No.</th>
<th>CML No.</th>
<th>Downy Mildew Score 1</th>
<th>Downy Mildew Score 2</th>
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<td>1.0</td>
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<tr>
<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>CML-466</td>
<td>1.0</td>
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<tr>
<td>4</td>
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<td>5</td>
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<td>8</td>
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<td>19</td>
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</table>

(Rashid et al., 2013)

Climate change effects in Asian tropics
More virulent strains of diseases/pests

We must stop the relentless march of pests that attack crops

The fall armyworm can travel up to 100 km in one night. (Image: ACIM)

MORE STORIES
1. How the Scottish Labour could still keep Jeremy Corbyn
2. Free speech is crumbling under the weight of the young’s easy virtue
3. The Kavanaugh affair is urgent and exposes our ignorance of judges’ political biases
4. One day, parents will regret we've done to modern childhood
5. ‘Just one more inch’: I’ve eaten the real pressure which made me lose weight

Image: FAW
Climate varies at different temporal scales

Observed **Annual Rainfall in Asian tropics** in the Last 100 Years

How important is each scale?
Which one to follow for crop production?

*Source: Walter E. Baethgen, 2016*
Inter-annual variation in rainfall during Monsoon months (Aug & Sep) during past 10 years (2007-17)

Stress type & occurrence varies with space & time, and therefore targeted breeding for a specific trait is challenged!
Prolonged \(\text{Tmax (≥1 week)}\) \(≥35.0 – 37.5°C = \text{Heat stress}; >37.5°C = \text{Severe heat stress}\)

<table>
<thead>
<tr>
<th>Year</th>
<th>Week Range</th>
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<tbody>
<tr>
<td>2010</td>
<td>09-23 Week</td>
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<td>2011</td>
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<td>2012</td>
<td>09-24 Week</td>
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<td>2013</td>
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<td>2014</td>
<td>12-26 Week</td>
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<td>2015</td>
<td>12-23 Week</td>
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<tr>
<td>2016</td>
<td>10-22 Week</td>
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<tr>
<td>2017</td>
<td>12-23 Week</td>
</tr>
<tr>
<td>2018</td>
<td>10-22 Week</td>
</tr>
<tr>
<td>2019</td>
<td>12-23 Week</td>
</tr>
</tbody>
</table>

Heat stress

\(40°C\)

\(35°C\)

* Prolonged \(\text{Tmax (≥1 week)}\) on the 2010-2018 period during spring season in different years.
Stress-resilient technology, that gives high yields under OPTIMAL & resilience under:

- Drought/Heat/Waterlogging/anaerobiosis
- Agronomic package(s) for enhancing system resilience
- Resistance to major biotic stresses
Protect (attainable) yields

- Some major break-through!
- More efficient/ideal plant type,
- Innovative crop agronomy to support new plant type

Grain yield (t ha\(^{-1}\))

- Stress resilient cultivars
- Agronomic package(s) enhancing resilience
- Scale & gender neutral tools/technologies
- Reduce other losses (post-harvest)

(Source: updated from Edmeades et al., 2007)
Protect (attainable) yields  
(e.g. rainfed maize in India)

**Kharif yields of 514 districts***

<table>
<thead>
<tr>
<th>Average</th>
<th>2.26 t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0.31 t ha⁻¹</td>
</tr>
<tr>
<td>Max</td>
<td>6.53 t ha⁻¹</td>
</tr>
</tbody>
</table>

OUT of TOTAL = 514 districts

- <1.0 t/ha = 19
- 1.0 - <2.0 t/ha = 200
- 2.0 - <3.0 t/ha = 196
- 3.0 - <4.0 t/ha = 82
- >4.0 – 6.5 = 17

The ≥5.0t Challenge  
Where to pay more attention?

*Kharif yields of 514 districts*  
*District-wise mean yields for last three years (2013-14, 2014-15 & 2015-16)*
Target downside risk reduction, with upside potential

High-yielding locations
(Mean of 11 locations)

Moderate locations
(Mean of 19 locations)

Low-yielding locations
(mean of 27 sites)

Grain yield (t/ha)

“Guaranty of Minimum” under stress, along with
“Claim of Maximum” under optimal conditions!
Breeding stress-resilient maize...

- Causes yield-drag under optimal conditions (? !?)
- It’s a myth, no truth!
- It is grain yield across...

Stress-resilient maize = Normal maize

Equipped to cope-up with odds, whenever it comes!

be equally competent, depends upon -

1. Constitution of base germplasm (Stress donor + Elite lines)
2. Selection criteria (across stressed and un-stressed environment)

Yield gains with stress-resilient hybrids over checks evaluated at 52 sites in S & SE Asia

(Das et al., 2018; TS6-90, 13th AMC)
Breeding stress-resilient maize...

using integration of novel tools and methods with proven rules of abiotic stress breeding

- Base germplasm with key ingredients
- Field-based high precision phenotyping
- Root traits phenotyping & integration
- Genomic-based breeding - GWAS for MTA, RC-GS etc.
- Double haploid (DH) technology
Constitution of base population: foundation-stone for a stress resilient breeding program

**Identify inbred lines (8-10)**

**Intermate to form F1’s (P1 × P2, P1 × P3, ...)**

**Intermate F1’s (F1 × F1)**

**Self to derive families**

**S₂:₃ families test crossed to opposite heterotic group testers**

**Geneotype S₂:₃ families**

**TC evaluated under managed DT and WL trials**

**Intermate top 5-10% S₂:₃ based on progeny test cross to constitute C₁**

**Recurrent selection for 2-3 cycles (RC-GS); derive lines (DH) from advanced cycle**

---

**Constitution of base population:**

**Foundation-stone for a stress resilient breeding program**

- Identify inbred lines (8-10)
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- Intermate F1’s (F1 × F1)
- Self to derive families
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**Table: MPS-A**

<table>
<thead>
<tr>
<th>Lines</th>
<th>Reactions</th>
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<tbody>
<tr>
<td>CAL146</td>
<td>DT+Elite*</td>
</tr>
<tr>
<td>VL108871</td>
<td>DT*</td>
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<tr>
<td>VL108851</td>
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<td>ZL11884</td>
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<tr>
<td>VL1010090</td>
<td>Elite*</td>
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<td>CAL14101</td>
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<td>ZL11959</td>
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**Table: MPS-B**

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<td>CIL12180</td>
<td>Elite</td>
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</tbody>
</table>

* Stalk rot score ≤5.0; All lines with good resistance to common foliar diseases (TLB & rust)
Desirable root phenotype for stress-resilience

Rooting volume (cm$^3$ plant$^{-1}$)

- Mean: 74.76
- Range: 5.74 - 326.6
- $h = 0.44$

Stress period water-use (litres)

- Mean: 8.77
- Range: 4.8 - 15.6
- SE = 1.77, $H = 0.54$

Rooting length-density (cm cm$^{-3}$)

- Mean: 0.49
- Range: 0.09 - 2.67 plant$^{-1}$
- $h = 0.85$

Transpiration efficiency (g litre$^{-1}$)

- Mean: 10.72
- Range: 4.6 - 18.5
- SE = 0.52, $H = 0.46$

AAA project (SFSA)
Genomics evolves rapidly...!

(Courtesy: Raman Babu, CIMMYT/Corteva)
Subjective!

Phenotyping

Manual/time consuming

2. Precision phenotyping: (Precision + Accuracy)
   - In conducting the trials/experiments (location, crop management, stress management)
   - In observations/data capture

Accurate

Not Accurate

Precise

Not precise

Courtesy: Vincent Vadez, ICRISAT
• Several traits within an hour!
• High throughout, cheaper, accurate!
• But NOT precise, as it’s a BAD trial!
• Several traits within an hour!
• High throughout, cheaper, accurate!

• And precise, as it’s a well-managed, good trial!

All three aspects are important, but the order of priority may be:

1. High precision in field trial
2. Accuracy in data capture
3. High throughput
Precise phenotyping for key abiotic stresses...
High-throughput phenotyping
Digital data capture using proximal/remote sensing

Focus on cost-effective, affordable tools, deployable across sites

(M. Zaman-Allah CIMMYT)
Harmonized phenotyping protocols

A must for across-site trials
Selection across moisture regimes (DT, WL and Optimal)

\[ y = -0.0686x + 3.8792 \]

\[ R^2 = 0.0163 \]

Grain yield under waterlogging (t/ha)

Grain yield under drought (t/ha)

GY of selected fraction under Optimal condition (7.4 – 11.6 t/ha)

CRMA project, (funded by GIZ, Germany)
Stress Resilient Hybrids

CRMA project, (funded by GIZ, Germany)
Heat stress projection in South Asia and advantage of HT hybrids

Heat Tolerant Maize for Asia (HTMA), Funded by USAID F-t-F
Temperature regime in South Asia during flowering/grain-filling stage of maize

**Spring season maize**

**Rainy season maize**

Temperature regime in South Asia during flowering/grain-filling stage of maize.
Natural heat stress by managing planting time & tracking GDD

Severe stress

Mild-stress

HTMA – USAID project
All heats are not same!

Different types of heat stress:

- **High VPD sites** (Tmax: 35 - >40°C; VPD: >5.0 kPa)
- **Moderate VPD sites** (Tmax: 35 - >40°C; VPD: 3.0-5.0kPa)
- **Low VPD sites** (Tmax: 35 - 40°C; VPD: <3.0 kPa)

(Vinayan et al., 2018; TS06-125, 13th AMC)
Advanced stage HT hybrids under heat stress

**Low VPD sites** (Tmax: 35 - >40°C; VPD: <3.0 kPa)

- # Location: 8
- 61 ENT
- 64 ENT

**Moderate VPD sites** (Tmax: 35 - >40°C; VPD: 3.0-5.0 kPa)

- # Locations: 9
- 14 ENT
- 10 ENT
- 4 ENT
- 17 ENT

**High VPD sites** (Tmax: 35 - >40°C; VPD>5.0 kPa)

- # Locations: 8
- 107 ENT
New generation of heat stress resilient hybrids

Performance across VPD regimes, # Locations: 31

Low VPD sites = Tmax: 35 - 40°C; VPD: <3.0 kPa
Mod. VPD sites = Tmax: 35 - >40°C; VPD: 3.0-5.0 kPa
High VPD sites = Tmax: 35 - >40°C; VPD: >5.0 kPa
Sharing germplasm & products...

- International Maize Improvement Consortium (IMIC)-Asia
  
  Deployment & scale-out of new hybrids, including CIMMYT x CIMMYT or CIMMYT (donors) x partner lines

- Partnerships through bi-lateral projects, e.g.-CRMA, HTMA, IMTA etc. Research, development, deployment & scale-out

- Partnerships with other developmental projects in region (e.g.NSAF, AIP etc.: Deployment & scale-out
Selection of high-yielding stress-resilient hybrids....

A multi-funnel approach

After stage-3 testing....

Focus on specific adaptability/niche markets, along with wider-adaptation
Farmers (women & men) participatory selection
One-size doesn't fit to all!

Combination of traits for various stress-prone ecologies

Grain yields (t ha\(^{-1}\))

Opt+HT+WL+DT  Opt+HT+DT  Opt+WL+DT  OPT+HT+WL  OPT+DT

At least two OPT/HT/WL/DT

Opt- Wet season optimal, HT-Heat, WL-managed water logging, DT-Managed Drought

(Das et al., 2018, TS6-90, 13th AMC)
To conclude..

► Demand for maize in Asia and climate change effects – *surpassing most of the projections*

► Maize in Asian tropics is largely rain-fed exposed to weather extremes; often face compound effects of multiple stresses

► Asian tropics are highly vulnerable to climate change effects, *with high inter-annual variability, which adds further challenges to an already challenging environment*

► Native variation exist in tropical maize, *though at low frequency, that could be systematically pyramided in stress-resilient varieties.*

► The way forward: targeted improvement for *High-yielding stress-resilient* (rather than high-yielding risky) maize with plasticity to cope with climate variability
Thanks for your Attention!