CIMMYT Wheat Breeding: Continuing genetic gains through the development of high yielding and nutritious varieties

Suchismita Mondal
Bread Wheat Improvement Team
Wheat breeding priorities

High and Stable Yield Potential

- Disease & Pest Resistance
- Drought Tolerance/Improved WUE
- Heat Tolerance
- End-use Quality
- Enhanced Zn & Fe for Nutrition
- Enhanced Zn & Fe for Nutrition

Enhanced Zn & Fe for Nutrition

Heat Tolerance

End-use Quality

Drought Tolerance/Improved WUE

Enhanced Zn & Fe for Nutrition

Heat Tolerance

End-use Quality

Drought Tolerance/Improved WUE
Up-scaled breeding and testing to deliver genetic gain (5 years breeding cycle)

- Parental diversity
- ~1500 Simple, 600 top and 600 BC1
- Targeted utilization of new genes, traits and germplasm
- Large population sizes
- Selected-bulk selection scheme

Each selection in field adds to genetic gain for more than one trait
Grain yield evaluations advanced lines
Cd. Obregon, Mexico

1st year Yield Trial, 9044 lines, 323 trials, 2 reps

Bed sowing normal irrigation

Late heat sowing in beds
Possibilities with high throughput phenotyping in wheat breeding

- Aerial and UAV based HTP implemented
- CT and NDVI highly correlates with grain yield ($r = 0.5-0.7$)
- However, CT has strong $G \times Y$ and $G \times E$ effect

Looking forward:
- Complementing early generation selections with HTP
- Algorithms to estimate other agronomic traits, e.g. heading (days) and plant height
- Evaluating feasibility of assessing certain foliar disease
Genomic predictions are very promising for some diseases & quality traits. Challenges: G x E and G x Y interactions need extensive research to improve predictions for grain yields.
Grain yield enhancement:

The genetic gains in grain yield continues 2016, 2017 & 2018: new lines showing superior yields are often Borlaug100 derivatives

- 2015, n=9100 mean 83%
- 2016, n=9506 mean 89%
- 2017, n=9940 mean 88%

2014: 1.6% lines
2015: 2.8% lines
2016: 7.1% lines
2017: 9.5% lines
2018: 7.3% lines
81 Countries receiving CIMMYT Spring Wheat nurseries 2016/17
Genetic gains in grain yield for CIMMYT derived bread wheat varieties created between 1964-2009 (CENEB, Cd. Obregon, Sonora, Mexico)

- Trials conducted (2009-10 to 2014-15)
- Conservation agriculture on permanent beds & conventional tillage on beds
- Full and reduced irrigation management
- Semidwarf varieties, adapted for full irrigation, oldest “Siete Cerros”

**Annual genetic yield gain-Full Irrigation:**
- Permanent Beds: 0.69% (36.8 ± 5.8 kg ha⁻¹, R² = 0.77, P < 0.01)
- Conventional Beds: 0.59% (35.9 ± 7.2 kg ha⁻¹, R² = 0.66, P < 0.01)

**Annual genetic yield gain-Reduced Irrigation:**
- Permanent Beds: 0.36% (22.3 ± 6.7 kg ha⁻¹, R² = 0.46, P < 0.01)
- Conventional Beds: 0.35% (12.6 ± 4.1 kg ha⁻¹, R² = 0.42, P = 0.01)

Genetic gains in Elite Spring Wheat Yield Trial (ESWYT, 2006-07 to 2014-15)

Geographical distribution of 426 sites

1.6 % increase/year in grain yield compared to long-term CIMMYT checks
0.5 % increase/year in grain yield compared to local check/new varieties
Genetic gains in Semi-Arid Wheat Yield Trial (SAWYT, 2003-04 to 2013-14)

1.6 % increase/year in grain yield compared to long term CIMMYT checks
Variety registration trials in Northwestern Mexico under optimum irrigation

*CENEB, INIFAP, Cd. Obregon, 2017-18*

<table>
<thead>
<tr>
<th>Variety/ breeding line</th>
<th>Year of release</th>
<th>Mean grain yield (t/ha)</th>
<th>Grain yield (%) Roelfs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROELFS F2007</td>
<td>2007</td>
<td>5.947</td>
<td>100</td>
</tr>
<tr>
<td>ONAVAS F2009</td>
<td>2009</td>
<td>5.833</td>
<td>98</td>
</tr>
<tr>
<td>BORLAUG 100</td>
<td>2014</td>
<td>6.583</td>
<td>111</td>
</tr>
<tr>
<td>STLN/MUNAL #1//2*BORL14</td>
<td>2019?</td>
<td>7.057**</td>
<td>119</td>
</tr>
</tbody>
</table>

**P<0.001

Performance similar to CIMMYT breeding trials (3 years) & yield potential trial (1 year)

~ 1.5% annual genetic gain during 2007-2019 compared to 0.7% during 1966-2007

Data source: Miguel Camacho, CENEB, INIFAP, Cd. Obregon, Sonora, Mexico
Keeping pace: Grain yield & Zinc enhancement (Y16-17 & Y17-18)

Average grain yield: 6.2 t/ha (Y16-17) vs 6.8 t/ha (Y17-18)

Frequency of lines with + 10 ppm Zn 15% (Y16-17) vs 23.5% (Y17-18)
From genetic resources to High zinc wheat in farmers’ fields of South Asia in less than 10 years

Progenitors:

Zn-Shakti’ PVS variety: Extra-early with +14 ppm Zn (40% increase) adopted by >40000 farmers in NEPZ

CROC1_/AE.SQUARRSO(210)\]/
INQALAB 91*2/KUKUNA/3/
PBW343*2/KUKUNA

Zincol 2016: 1st high zinc wheat in Pakistan with +6 ppm Zn = 2000 tons of seed to be sown in 2016-17

OASIS/SKAUZ//4*BCN/3/2*PASTOR
/4/T.SPELTA PI348449/5/BACEU
#1/6/WBLL1*2/CHAPIO

WB02/HPPW-01 =
T.DICOCCONCI9309/AE.SQUARR
OSA (409)\]/MUTUS/3/2*MUTUS
Two sister lines (+6 ppm Zn) released for NWPZ of India
<table>
<thead>
<tr>
<th>Country</th>
<th>Name of variety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afghanistan</td>
<td>Daima-17, Lalmi-17, Shamal-17</td>
</tr>
<tr>
<td>Argentina</td>
<td>BIOCERES 1008, MS INTA 815</td>
</tr>
<tr>
<td>Australia</td>
<td>Borlaug100, SEA Condamine</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>BARI Gom 31, BARI Gom 33</td>
</tr>
<tr>
<td>Bhutan</td>
<td>Bumthang kaa Drukchu</td>
</tr>
<tr>
<td>Bolivia</td>
<td>Cupesi CIAT, INIAF Tropical</td>
</tr>
<tr>
<td>Egypt</td>
<td>Misr 3</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Amibara 2, Kingbird, Lemu, Wane</td>
</tr>
<tr>
<td></td>
<td><strong>Outcome:</strong> 95 direct CIMMYT-derived varieties released by 20 partner countries (2015-2018)</td>
</tr>
<tr>
<td>Nepal</td>
<td>Chyakhura, Danphe, Munal, Tilottama</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Lacriwhit 9, Lacriwhit 10</td>
</tr>
<tr>
<td>Rwanda</td>
<td>Cyumba, Gihundo, Keza, Kibatsi, Majyambere, Mizero, Nyangufi, Nyaruka, Reberaho, Rengerabana</td>
</tr>
<tr>
<td>Spain</td>
<td>Tujena</td>
</tr>
<tr>
<td>Sudan</td>
<td>Ageeb, Akasha</td>
</tr>
<tr>
<td>Tajikistan</td>
<td>Haydari, Roghun</td>
</tr>
<tr>
<td>Turkey</td>
<td>Altinoz, Ekinoks, Kayra, Koc 2015, Nisrat</td>
</tr>
</tbody>
</table>
Pre-breeding in GWP: Developing proof of concept for trait(s) that add value and broadening the genepool

Gemma Molero
Wheat Physiology
Global Wheat Program Pre-breeding activities

Genetic resources

Multiple Teams in GWP & Partners

Use of Wild relatives

Quality traits

Heat and Drought

Yield Potential

**Use of Wild relatives**
- Crossing with wild relatives:
  - Example Leymus for biological nitrification inhibition (BNI)

**Quality traits**
- Improving quality traits
  - Bread Wheat
  - Durum Wheat

**Heat and Drought**
- Exploiting diversity based on:
  - genomics (SeeD)
  - phenomics (Trigo)

**Yield Potential**
- IWYP and Trigo:
  - MAS for HI using major genes
  - HTP
  - GS
  - Balancing S:S
Wide Crosses with Wild Relatives: Biological nitrification inhibition from *Leymus racemosus*

Has the potential to radically increase NUE by preventing losses of available soil N

Wheat parents CS (-BNI)  
N short arm translocation (+BNI)

<table>
<thead>
<tr>
<th></th>
<th>Yield</th>
<th>Biomass</th>
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</thead>
<tbody>
<tr>
<td>CS (-BNI)</td>
<td>972 Kg/ha</td>
<td>3,606 Kg/ha</td>
</tr>
<tr>
<td>(+BNI)</td>
<td>831 Kg/ha</td>
<td>5,536 Kg/ha</td>
</tr>
</tbody>
</table>

50% higher biomass
Introgression of genes associated to high content of endosperm soluble fiber (arabinoxylan)

**Objective**: increase soluble fiber content in white refined flours

**Progress**: starting crosses in this cycle
Pre-Breeding in Durum Wheat Improvement

Quality enhancing/diversifying genes transferred to elite durum backgrounds

- **Grain Protein Content (GPC-B1)**
  - *T. dicocoides*
  - Source: durum stock from UC Davis

- **Glutenin Sub-units**
  - *Glu-D1* (bread wheat)
  - Source: durum stocks from UC Riverside + CIMMYT

- **Starch Modification**
  - *SBElI* (Mutations)
  - Source: durum stocks from UC Davis

- **Soft Texture**
  - *Pin A+B* (bread wheat)
  - Source: durum stocks from USDA-WA

**Marker-Assisted Selection or Marker-Assisted Backcrossing + Phenotypic/Quality Selection**

Several elite lines with novel industrial quality attributes:
- Phenotypically confirmed
- Evaluation of industrial potential started
- Evaluation of agronomic value ongoing

Durum Program
GWP Marker Lab
GWP Quality Lab
# Exploiting diversity based on genomics (SeeD)

## Grain yield under heat

<table>
<thead>
<tr>
<th>GID</th>
<th>Exotic parent type</th>
<th>2015-16</th>
<th>2016-17</th>
</tr>
</thead>
<tbody>
<tr>
<td>7641495</td>
<td>Synthetic</td>
<td>2261</td>
<td>2346</td>
</tr>
<tr>
<td>7644075</td>
<td>Synthetic</td>
<td>2325*</td>
<td>2418**</td>
</tr>
<tr>
<td>7645422</td>
<td>Synthetic</td>
<td>2338*</td>
<td>2488**</td>
</tr>
<tr>
<td>7645970</td>
<td>Synthetic</td>
<td>2214</td>
<td>2407*</td>
</tr>
<tr>
<td>7689940</td>
<td>Landrace</td>
<td>2415*</td>
<td>2362</td>
</tr>
<tr>
<td>BAJ #1</td>
<td>Check</td>
<td>2144</td>
<td>2216</td>
</tr>
<tr>
<td>VOROBEY</td>
<td>Check</td>
<td>1769</td>
<td>1985</td>
</tr>
<tr>
<td>SOKOLL</td>
<td>Check</td>
<td>NA</td>
<td>2023</td>
</tr>
</tbody>
</table>

## Grain yield under drought

<table>
<thead>
<tr>
<th>GID</th>
<th>Exotic parent type</th>
<th>2015-16</th>
<th>2016-17</th>
</tr>
</thead>
<tbody>
<tr>
<td>7643084</td>
<td>Synthetic</td>
<td>3587</td>
<td>4510*</td>
</tr>
<tr>
<td>7642492</td>
<td>Synthetic</td>
<td>3480</td>
<td>4574*</td>
</tr>
<tr>
<td>7688508</td>
<td>Landrace</td>
<td>3360</td>
<td>4787*</td>
</tr>
<tr>
<td>7687479</td>
<td>Synthetic</td>
<td>3167</td>
<td>5198**</td>
</tr>
<tr>
<td>7642491</td>
<td>Synthetic</td>
<td>2766</td>
<td>5151**</td>
</tr>
<tr>
<td>VOROBEY</td>
<td>Check</td>
<td>3346</td>
<td>4613</td>
</tr>
<tr>
<td>BAJ #1</td>
<td>Check</td>
<td>3111</td>
<td>4858</td>
</tr>
<tr>
<td>SOKOLL</td>
<td>Check</td>
<td>NA</td>
<td>3968</td>
</tr>
</tbody>
</table>

**Up to 11% yield increase under heat & 5% under drought**
Exploiting diversity based on phenomics (Trigo)

Lines derived from strategic crosses for Heat Tolerance
NW Mexico, Combined analysis 2015-2016 & 2016-2017

<table>
<thead>
<tr>
<th>PT Line</th>
<th>Type</th>
<th>Yield (g m⁻²)</th>
<th>%vs. Best check</th>
</tr>
</thead>
<tbody>
<tr>
<td>C80.1/3<em>QT4118//KAUZ/RAYON/3/2</em>TRCH/4/BERKUT/KRICAUFF</td>
<td>Elite-Introgression</td>
<td>496</td>
<td>27.6*</td>
</tr>
<tr>
<td>WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA (205)//…</td>
<td>Synthetic+Landrace derivative</td>
<td>494</td>
<td>26.9*</td>
</tr>
<tr>
<td>BCN/WBLL1//PUB94.15.1.12/WBLL1</td>
<td>Landrace derivative</td>
<td>472</td>
<td>21.2*</td>
</tr>
<tr>
<td>SOKOLL//PUB94.15.1.12/WBLL1</td>
<td>Synthetic+Landrace derivative</td>
<td>471</td>
<td>20.9*</td>
</tr>
<tr>
<td>SOKOLL/WBLL1</td>
<td>Synthetic derivative</td>
<td>462</td>
<td>18.8*</td>
</tr>
<tr>
<td>PUB94.15.1.12/FRTL/5/CROC_1/AE.SQUARROSA (205)//…</td>
<td>Synthetic+Landrace derivative</td>
<td>459</td>
<td>18.0*</td>
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<tr>
<td>SOKOLL//PUB94.15.1.12/WBLL1</td>
<td>Synthetic+Landrace derivative</td>
<td>455</td>
<td>17.0*</td>
</tr>
<tr>
<td>MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1</td>
<td>Synthetic+Landrace derivative</td>
<td>451</td>
<td>16.0*</td>
</tr>
<tr>
<td>VOROBEY</td>
<td>Check</td>
<td>389</td>
<td></td>
</tr>
<tr>
<td>SOKOLL</td>
<td>Check</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>BORLAUG100 F2014</td>
<td>Check</td>
<td>357</td>
<td></td>
</tr>
</tbody>
</table>

**Up to 28% yield increase under heat**

New Pre-breeding lines with improved adaptation to heat stress (introgression, synthetics and landrace background)
IWYP and Trigo pre-breeding pipeline

- Landraces
- Elite lines
- FIGs (ICARDA)
- Gene bank
- Synthetics

Crossing

- Conceptual models
- Source-sink traits (Grain yield, Biomass, CT, NDVI, adaptation to density, spikes)
- Genetic diversity/Pedigree

Generation advancement

International nurseries

- Yield based selection
- Genomic selection
- Physiological traits (NDVI and CT)

WYCYTs and SATYNs
Major genes associated with HI & Grain Yield

Gene positively effecting HI
TARGET of EAT (TaToe1-B1)
FLOWERING LOCUS T3 (TaFT3-B1- 1 copy)
Eps-D1
Ppd-B1 (6 to 11 copies)

Gene positively effecting GY
TARGET of EAT (TaToe1-B1)
FLOWERING LOCUS T3 (TaFT3-B1- 1 copy)
Vrn-D1a
Complex traits: Aerial remote sensing for HTP

Genomic and pedigree based prediction models durum wheat

Correlation between predicted and observed values

YLD  NDV1Vg  GNO  NDVIIIg  TGW  DTM  DTA  PH

Traits
Sukumaran et al., 2018. The Plant Genome
Genomic selection also a valuable tool for pre-breeding with genetic resources

Basis for ‘source’ x ‘sink’ strategic crossing

Trait hierarchy (in relation to their degree of integration) depicting the main drivers of yield (biomass and harvest index), and sub-components
## International yield trials data
### 4th WYCYT (2016/17)

<table>
<thead>
<tr>
<th>Clusters based on G x E for yield</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster of sites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td>5.44*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best PT line (t/ha)</td>
<td>4.96 ns</td>
<td>5.45*</td>
<td>7.41*</td>
<td>5.89 ns</td>
<td>8.05*</td>
<td>5.44*</td>
</tr>
<tr>
<td>Borlaug (t/ha)</td>
<td>5.29</td>
<td>4.46</td>
<td>5.45</td>
<td>5.65</td>
<td>7.28</td>
<td>5.09</td>
</tr>
<tr>
<td>% over Borlaug</td>
<td>-6.2%</td>
<td>22.3%</td>
<td>36.0%</td>
<td>4.2%</td>
<td>10.6%</td>
<td>6.9%*</td>
</tr>
</tbody>
</table>
Global Wheat Program
“Regional Offices”
14 CIMMYT wheat varieties released in last 5 years

Production up by 60% after 2010

Ethiopia

- Excellent emergency support and scaling up in 2017
- 1082 tons of maize and wheat distributed to 72,371 households (434,226 individuals) in 55 districts
Kazakhstan: Kazakhstan-Siberia Network on Wheat Improvement (KASIB) & Shuttle Breeding “Mexico-KASIB” Program:

- 21 Breeding programs of Kazakhstan and Russia united in year 2000
- By 2018:
  - >25,000 advanced lines developed and evaluated
  - >70 varieties released

KASIB is one of the best examples of regional and Int. cooperation

In 2016-17:
- Russia: 1st in the world for wheat grain export;
- Kazakhstan: 1st in the world for wheat flour export
CIMMYT wheat in China

- 20,000 accessions stored in Chinese gene bank
- Over 300 cultivars developed from CIMMYT wheat, covering 10% area, worth US $ 3.4 billion
- Received eight awards from State Council since 1998

CAAS-CIMMYT wheat team
Ten scientists, 10 support staff, and 20 postgraduates
Quality and molecular labs, three breeding stations
IRAN
5.4 million ha wheat

24 of 69 wheat/ triticale varieties released during 2001-18 were from CIMMYT

Iran-CIMMYT Joint Project (20 m USD)
“Increasing the Productivity of Wheat and Wheat-based Systems in Iran”
Turkey: Int. Winter Wheat Improvement Program

Objectives:
• Develop winter wheat germplasm for Central and West Asia
• Winter wheat germplasm exchange
• Maintain wheat landraces
• Research on priority topics

Country | Varieties released
---|---
Afghanistan | 5
Armenia | 4
Azerbaijan | 4
Georgia | 6
Iran | 7
Kazakhstan | 2
Kyrgyzstan | 9
Tajikistan | 6
Turkey | 32
Turkmenistan | 3
Uzbekistan | 2

Total 80

7 varieties in 2017:
• Turkey (2)
• Iran (1)
• Kyrgyzstan (2)
• Turkmenistan (2)

www.iwwip.org
Improved seed is the major limitation. Hence, 8 Mobile Seed cleaners were introduced to empower farmers to multiply new varieties on their own and share among themselves.

Afghanistan
Wheat yields sustained despite serious issues.
17 CIMMYT varieties released in last 5 years (2013-17)

441 farmers cleaned 200 MT seed at their door step in 2017

Wheat production & yield in Afghanistan, 2005-2016

Yield (t/ha) - Production (million tonnes)

Wheat yields sustained despite serious issues.

17 CIMMYT varieties released in last 5 years (2013-17)

441 farmers cleaned 200 MT seed at their door step in 2017
Pakistan

• 10 varieties, 9 direct CIMMYT, released in a single year 2017
• 54 CIMMYT varieties released in last 10 years
• One biofortified - Zincol 2016

DNA-based 2-D digital barcodes for Wheat Varietal Identification and digital repository use – 130 Pakistan wheat cultivars
India, Nepal & Bangladesh

35 CIMMYT varieties released since 2010

1st biofortified wheat released in India and Bangladesh

1st durum wheat variety released in Nepal

For the first time in South Asia, 10 t/ha grain yield achieved (location: BISA, India)
Kenya

The Ug99 threat mitigated through Kenya phenotyping: identification, release and cultivation of resistant varieties during the last decade
Capacity building

- 287 scientists of 30 countries trained during 2011-18 at Mexico
- Around 350 participated in meetings, symposiums

Trainees at Mexico 2011-18

<table>
<thead>
<tr>
<th>Year</th>
<th>M</th>
<th>F</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>2011</td>
<td>43</td>
<td>5</td>
<td>48</td>
</tr>
<tr>
<td>2012</td>
<td>30</td>
<td>5</td>
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<td>2013</td>
<td>38</td>
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<td>2014</td>
<td>37</td>
<td>10</td>
<td>47</td>
</tr>
<tr>
<td>2015</td>
<td>31</td>
<td>8</td>
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</tr>
<tr>
<td>2016</td>
<td>23</td>
<td>6</td>
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</tr>
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<td>2017</td>
<td>32</td>
<td>9</td>
<td>41</td>
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<tr>
<td>Total</td>
<td>234</td>
<td>52</td>
<td>286</td>
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There was a significant progress in wheat research
Acknowledgements

Bill and Melinda Gates Foundation & DFID: DGGW Project HarvestPlus Project, (CRP A4NH)

Governments: ACIAR, Australia BMZ, Germany ICAR, India SAGARPA, Mexico USAID, USA

Farmers’ organizations: Agrovegetal, Spain GRDC, Australia (ACRCP & CAIGE Projects) Patronato-Sonora, Mexico

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Thank you for your interest!

#CIMMYTsw18
Pre-Breeding Outputs

• Crossing with wild relatives: recent outputs
  – *Example: Leymus* for biological nitrification inhibition

• Improving quality traits
  – Bread Wheat
  – Durum Wheat

• Pre-breeding outputs for heat and drought
  – Exploiting diversity based on genomics (SeeD)
  – Exploiting diversity based on phenomics (Trigo)

• The international Wheat Yield Partnership
  – MAS for harvest index using major genes
  – High throughput phenotyping
  – Genomic selection
  – Balancing source and sink