Proceedings

of the 2nd International Workshop of the Wheat Yield Consortium

CENEB, CIMMYT, Cd. Obregón, Sonora, Mexico
12-15 March 2012

Matthew Reynolds, Hans Braun, and Emma Quilligan
(Editors)

USAID FROM THE AMERICAN PEOPLE
BBSRC bioscience for the future
GRDC Grains Research & Development Corporation
MasAgro Modernización Sustentable de la Agricultura Tradicional
CIMMYT International Maize and Wheat Improvement Center
SAGARPA Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación

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Sponsored by

SAGARPA through MasAgro, Mexico; BBSRC, UK; USAID, USA; and GRDC, Australia

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Abstract: The abstracts herein are of presentations by crop experts for the "2nd International Workshop of the Wheat Yield Consortium". Sponsored by SAGARPA's international strategic component for increasing wheat performance, under the *Sustainable Modernization of Traditional Agriculture Program* (MasAgro); BBSRC, UK; USAID, USA; and GRDC, Australia.

The event covers innovative methods to significantly raise wheat yield potential, including making photosynthesis more efficient, improving adaptation of flowering to diverse environments, addressing the physical processes involved in lodging, and physiological and molecular breeding. The workshop represents the current research of the International Wheat Yield Consortium that involves scientists working on all continents to strategically integrate research components in a common breeding platform, thereby speeding the delivery to farmers of new wheat genotypes.

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2nd International Workshop of the Wheat Yield Consortium

Tuesday 13th March (Quality Inn)

8:00	**Registration**	
8:45 -9:15	**Welcome** **WYC and the WHEAT CRP**	Erasmo Valenzuela Hans Braun
9:15-10:30	**Business Plan** Science Overview Review of WYC Funding scenarios	 Matthew Reynolds Steve Visscher Hans Braun
10:30-11:00		Coffee Break
11:00-12:00		Consolidation of Business and WorkPlan (E. Warham)
12:00-13:00		Lunch in Quality Inn
13:00		Depart for CENEB
13:30-14:00		Launch of Blimp
14:00-17:00		Visit to MEXPLAT
17:30		Group Photo in front of Training Building
18:00-20:30		**Carne Asada and Mariachis at CENEB**

Wednesday 14th March (Quality Inn)
WYC Research Highlights, Priorities and Plans

8:00 am to 10:00 am

Theme 1: Increasing photosynthetic capacity and efficiency
Chairperson: Richard RICHARDS

- SP1.1 Phenotypic selection for photosynthetic capacity & efficiency (J. Evans)
- SP1.2 Capturing the photosynthetic potential of spikes (G Molero)
- SP1.3 Optimising canopy photosynthesis, photosynthetic duration (A Condon)
- SP1.4 Chloroplast CO_2 pumps (John Evans)
- SP1.5 Optimising RuBP Regeneration (M Parry)
- SP1.6 Improving the Thermal Stability of Rubisco Activase (M Parry)
- SP1.7 Replacement of LS Rubisco (M Parry)

10:00 - 10:30 Coffee

10:30 - 12:30

Theme 2: Optimizing partitioning to grain while maintaining lodging resistance
Chairperson: Helene LUCAS

- SP2.1 Optimizing harvest index (HI) by increasing partitioning to spike growth and maximizing grain number (J Foulkes)
- SP2.2 Optimizing developmental pattern to maximize HI (G Slafer, S Grifiths)
- SP2.3 Improving HI by modifying sensitivity to environmental cues (W Davies)
- SP2.4 Improving grain filling and potential grain size (D Calderini & J LeGouis)
- SP2.5 Identifying traits & genetic sources for lodging resistance (P Berry)
- SP2.6 Modeling optimal combinations of traits (R Sylvester Bradley)

12:30 - 13:30 Lunch

13:30 - 15:30pm

Theme 3: Breeding to accumulate yield potential traits
Chairperson: Stephen BAENZIGER

SP3.1 Trait, marker & hybrid breeding (M Reynolds, D Bonnet, H Braun)
SP3.2 Wide crossing to enhance Yield Potential (I King, D Bonnet)
SP3.3 Genomic selection to increase breeding efficiency (David Bonnett)
SP3.4 Germplasm evaluation and delivery (E Solis Moya, M Reynolds)

WYC update from China (Zhonghu He)

India proposed contribution to WYC (Vinod Tiwari)

15:30 - 16:00 Coffee

16:00 - 18:00 Consolidation of Business & Work Plan (E. Warham & S Vaughan)

19:30-21:00 Dinner at Los Arbolitos

Thursday 15th March (All Day parallel sessions at CENEB)

08:00- 16:00 **Consolidation of Business & Work Plan** (E. Warham & S. Vaughan)

Technical Advisory Committee meeting

Lunch at CENEB

16:30 - 17:30 **Wrap up in Auditorium**

17:30 – 19:00 **Cocktail and Folkloric Dance Group**

19:30 **Dinner at El Bronco (in Obregon)**

SP 2.5: Identifying traits and developing genetic sources for lodging resistance

Pete Berry[1], Francisco Pinera[2], Zoe Rutterford[3], Roger Sylvester-Bradley[3], Matthew Reynolds[2]
[1]ADAS High Mowthorpe, North Yorkshire, UK, [2]CIMMYT Mexico, [3]ADAS Boxworth, Cambridge, UK

Main Objectives

1. Identify sets of traits for different wheat growing environments to maximize lodging resistance with the least investment in structural dry matter (DM).
2. Test the effects of the optimum trait sets on lodging risk and structural DM in different wheat growing environments.
3. Understand the genetic basis of key lodging traits and develop genetic markers and phenotypic screens enabling breeders to rapidly select these traits.
4. Assess whether the target traits exist within breeders' germplasm and if necessary identify novel germplasm with the target traits that could be used in wide crosses.

State of the Art

Lodging is a persistent phenomenon in wheat which diminishes yield by up to 80%, as well as reducing grain quality. Therefore, any comprehensive strategy to improve wheat yield potential should include lodging resistance. A model of the lodging process has been used, with preliminary datasets describing the DM costs of improving lodging traits, to estimate the dimensions of a lodging-proof wheat plant with the least investment of biomass in the supporting stem and root system (Berry et al. 2007). Observations of a range of varieties grown in the UK showed that the root plate of the best variety was 7 mm less than the ideotype target and the widest stem was 0.5 mm below the ideotype target. Other stem character targets were achieved but not all in one variety, therefore wider germplasm must be screened to identify varieties with the target traits.

It is estimated that the UK lodging-proof ideotype will require 7.9 t ha^{-1} of stem biomass and 1.0 t ha^{-1} of root biomass within the top 10 cm soil, giving an above-ground harvest index (HI) of just 0.42. The DM requirements for increasing stem and root strength must be quantified in order to assess the extent to which structural requirements may compete with grain yield. Preliminary work has shown that DM density is positively related to the material strength of the stem wall, indicating a DM cost associated with increasing this strength parameter. The contribution made by the node and leaf sheath to stem strength is also unknown. Crop height has a large influence on the structural requirements, but the minimum height compatible with high yield has not been precisely quantified. Investigations are required to verify the DM cost of increasing material strength, understand height/yield relations, and identify germplasm with light/strong stems.

Previous projects have shown that lodging traits are under quantitative genetic control. Further work will be required to better understand genetic control of the traits and to investigate whether reliable genetic markers can be identified which function across a range of genotypes and environments. Phenotypic screens must also be investigated to assess whether they can offer an alternative method to genetic markers for selecting germplasm in case genetic markers with a large effect prove difficult to identify.

Results

Research in 2010-11 has focused on i) identifying spring wheat germplasm with strong anchorage and strong/light stems; ii) understanding the relationship between stem strength and stem weight; iii) developing methods enabling lodging traits to be rapidly assessed; and iv) quantifying the impact of lodging on yield.

Germplasm screening

Sixty elite spring wheat varieties from the CIMMYT Mexico Core Germplasm Panel (CIMCOG) population were grown at CENEB (Centro Experimental Norman E. Borlaug) in the Yaqui Valley, Sonora, Mexico, in a bed system (4 rows with 24 cm between each row). Each variety was replicated twice and 15 plants per plot were measured. The lodging associated traits were measured at GS69 + 20 days and all traits showed highly significant differences between the varieties. Comparisons with target traits for a lodging-proof ideotype in the UK environment showed that targets were achieved for height and stem material strength, and almost achieved for stem diameter and stem wall width (Table 1). Target traits for stem strength and root plate spread (main determinant of anchorage strength) were not achieved in any variety. In particular, the widest root plate observed was far below the ideotype target. It is known that root plate spread can be increased by establishing fewer plants/m^2 (Berry et al. 2000) and it is possible that crops must be sown at lower seed rates and a wider germplasm screen must be conducted to achieve the target root plate. The lodging-proof ideotype must be estimated for the wind speeds that occur in the Yaqui Valley; it is not known whether this will increase or decrease the UK ideotype targets.

Dry matter requirements of stem strength and anchorage strength

Stem strength of the bottom two internodes was positively and linearly related to the stem dry weight per unit length across the CIMCOG varieties (R^2 = 0.55; Figure 1). For the bottom internode 1, significant varietal differences were found between the varieties for stem dry weight per unit length expressed per unit of stem strength (P<0.05). A stem strength of 100 Newton millimetres (Nmm) could be achieved with a stem dry weight per unit length of 1.3-2.2 mg/mm. No significant differences were observed for internode 2, although stem dry weight per unit length per unit strength was strongly correlated between the two internodes (R^2 = 0.79). These results indicate that despite the general positive relationship between stem strength and stem dry weight per unit length, it should be possible to find varieties with strong and relatively light stems.

Regarding stem strength components, geometric principles infer that the width of the stem wall should be minimised and stem diameter maximised in order to minimise the DM required to achieve a particular strength (assuming stem wall density remains the same). Previous work on a small number of varieties had indicated a positive relationship between material strength and stem wall density, suggesting that a mid-range material strength should be targeted. Analysis of the CIMCOG material also revealed a positive relationship between material strength and stem wall density (R^2 = 0.37) but with

Table 1. A summary of ideotype targets, CIMCOG range, and best observed value.

Trait	*UK Ideotype target	CIMGOG range	Best observed value
Height (m)	*0.70*	0.61-0.99	0.72 (entry 20)
Stem strength (Nmm)	*250.00*	98-189	189 (entry 23)
Stem diameter (mm)	*4.94*	3.60-4.86	4.86 (entry 34)
Stem material strength (MPa)	*30.00*	14.1-34.3	29.7 (entry 46)
Stem wall width (mm)	*0.65 (Max)*	0.67-1.25	0.67 (entries 9, 26, 31, 37)
Root plate spread (mm)	*57.00*	28-37	37 (entries 8, 60)

*From: Berry et al. 2007

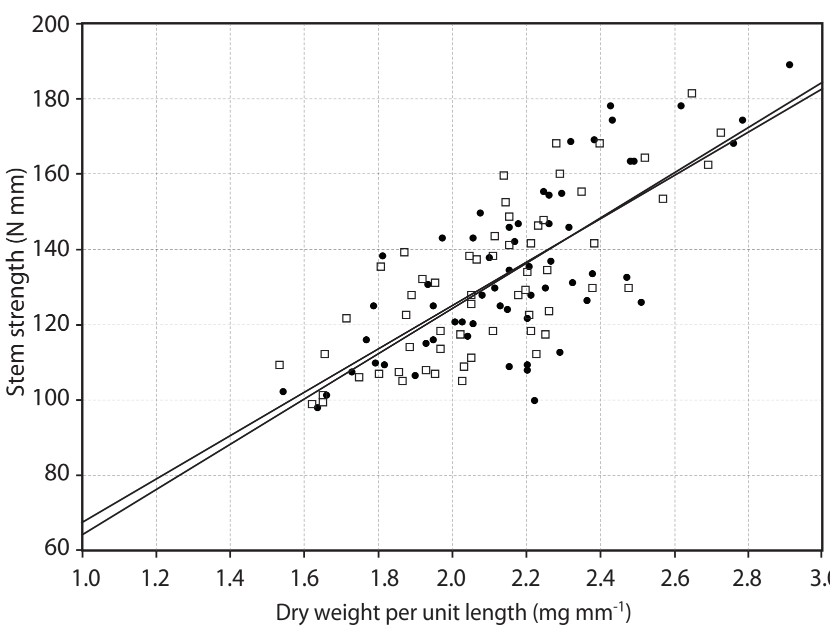

Figure 1. Relationship between stem strength and dry weight per unit length for internode one (solid circles; y = 4.15 + 60.1x; R^2 = 0.55; P<0.001); and internode two (open squares; y = 9.90 + 57.6x; R^2 = 0.57; P<0.001).

a shallower slope. Weak negative relationships were shown between diameter and stem wall density, and for grain yield with both stem wall density and stem material strength. These results must be analyzed to assess how they may affect the lodging trait targets for achieving a strong stem with the minimum investment in DM.

Detailed analysis at regular intervals between GS33 and GS87 of two varieties grown at two sites in the UK quantified how the density of the total stem wall DM and the density of the structural DM in the stem wall (total dry matter minus water soluble carbohydrates) varied between internodes and throughout the development of the crop. This analysis revealed that structural DM in the bottom two internodes (the ones most likely to buckle) did not increase after GS33, indicating that the structural DM requirement of these internodes would offer little competition with yield formation. Upper internodes will compete with yield for DM, but these must support a smaller leverage and therefore require less structural DM. On average, density of the structural DM in the stem wall decreased from 0.43 mg/mm for the bottom internode to 0.17 mg/mm for the peduncle. A comparison of the stem strength of the bottom two internodes with and without the leaf-sheath showed that the leaf-sheath had no significant effect on stem strength. Structural root DM in the top 10 cm of soil continued to increase until GS75, reaching 0.4 to 0.5 t/ha. Information on the DM requirements of stem and root strength is very important for SP2.6.

Rapid trait assessment

The CIMCOG dataset was analysed several times by taking trait averages from different subsets of the 15 plants that were measured in each plot. This showed that basing the analysis on either 10 or 5 plants enabled statistically significant differences to be detected for the same traits as were detected using a mean of 15 plants for all traits, apart from ear area (for which no significant difference was detected using a mean of 5 or 10 plants). R^2 values between the trait averages for 5 vs 15 plants ranged from 0.69 to 0.94, and for 10 vs 15 plants they ranged from 0.86 to 0.98. The coefficient of variation was only slightly smaller for 10 plants compared with 15, but there was a more noticeable increase for 5 plants. The optimum number of plants for measurement will depend upon the number of genotypes and replicates in the trial, but it is possible that the optimum for this trial would have been between 5 and 10 plants per plot which would have given significant time savings. A comparison of the stem strength traits for internodes 1 and 2, and the two stem wall width measurements taken for each internode, showed very high correlations and near identical statistical analyses, indicating opportunities for reducing the measurement protocol. Furthermore, height at centre of gravity was strongly correlated with height to the ear tip and could be omitted.

Several sets of digital photos have been taken on plots, with a wide range of plant populations, between ear emergence and harvest and of the stubble post-harvest, with associated measurements of stem diameter, shoots per m^2, and shoots per plant. Investigations are ongoing to see whether image analysis methods can be used to estimate stem diameter and shoot number, but early results do not look very promising. Analysis of UK datasets from LINK Project LK0958 showed that breeding lines with large canopies at GS31 tended to have weak stems during grain filling. Breeding lines with erect leaves at GS31 tended to have a weaker bottom internode and a wider root plate during grain filling. In general, the correlations between spring-time assessments and traits measured during grain filling were weak, but they were consistent across two seasons and both breeding populations.

Impact of lodging on yield

Datasets with detailed measurements of the amount and timing of natural lodging, together with grain yield, have been analyzed to develop a method of predicting the effect of lodging severity and timing on the proportion of yield lost due to lodging (Y_{LOSS}):

$$Y_{LOSS} = \frac{\sum_i^f \left(L_{90} \times 0.67 + L_{45} \times 0.20\right)}{n}$$

In the above equation, *i* and *f* are the first and last days of grain filling, L_{90} is the proportion of crop area lodged at 90° from the vertical; L_{45} is the proportion of crop area lodged between 1° and 89°; and *n* is the number of days of grain filling. The model predicted 75% of the variation in the proportion of yield lost due to lodging and the best-fit line was not significantly different from the 1:1 relationship. This information will be important for SP2.6 and a paper describing the development and testing of this method has been submitted to *Field Crops Research*.

References

Berry, P.M., et al. 2000. Field Crops Research 67:59-81.
Berry, PM., et al. 2007. Euphytica 154:165-179.