Understanding sorghum stem lodging: a biomechanical analysis and advanced imaging techniques using x-ray computed tomography (CT) to improve stem lodging resistance

Francisco E. Gomez [1] , Anastasia Muliana [2], Karl Niklas [3], William L . Rooney [1]

[1] Department of Soil and Crop Sciences [1], Texas A&M University, TX

[2]Department of Mechanical Engineering, Texas A&M University, TX

[3]School of Plant Biology, Cornell University, Ithaca, NY

Background and Objective

- The development of novel approaches to improve stem lodging such as biomechanical properties is highly important to assist crop breeders with plant-breeding research outcomes.
- Current breeding efforts to improve lodging resistance in sorghum have been typically relied on counting the number of lodged stalks at harvest. Unfortunately, this method is unreliable because it is severely confounded by abiotic and biotic factors.
- This study seeks to develop a new phenotyping method that does not rely on lodging-related abiotic and biotic factors and could potentially be used as a selective breeding tool to select for lodging resistance in bioenergy sorghum.

Methods & Results

Experiment # 1

- The mechanical properties of the stems of six mature sorghum cultivars were investigated using a three-point bending test protocol.

In Weslaco, Texas in a RCBD. Data was analyzed using a mixed model approach to estimate LSMeans. *Response= Geno +Stem Section;Traits* include: LG= Lodging, PSL=Plant Slenderness, EI=Flexural Rigidity, IVO=Int. Volume, IDM=Int. Diameter, NOI=Number of Internodes, PHT=Plant Height, Stiffness, ISL=Int Slenderness, STR= Strength, ILH= Int. Length.

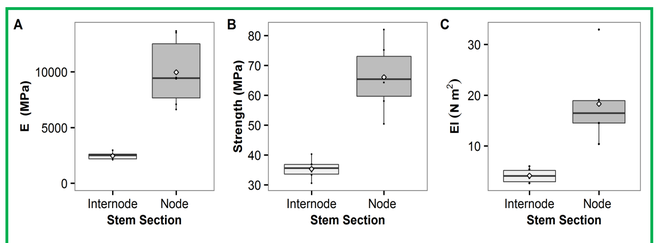

Figure 1. Boxplot for mechanical properties for internodes and nodes. A) Stiffness, B) Strength C) Rigidity

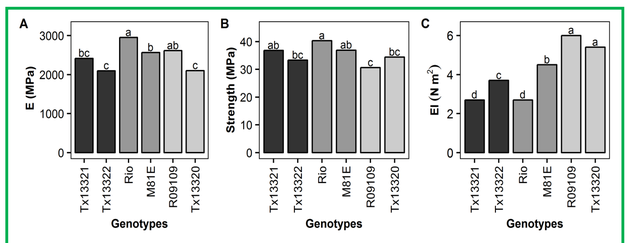

Figure 2. Bar plot for LSMeans for internode biomechanical properties averaged across internodes 1-8 for all six genotypes

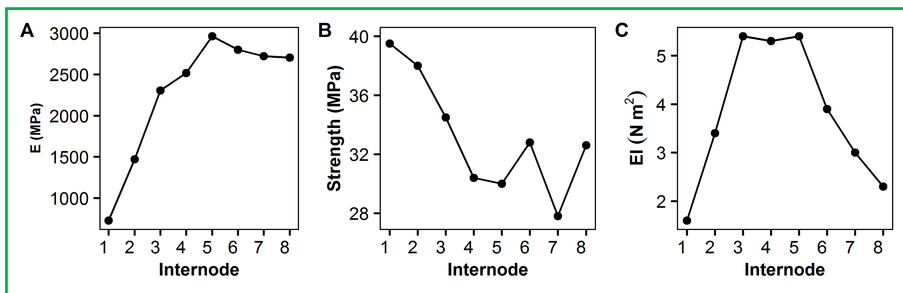

Figure 3. Line graph for biomechanical properties for internodes 1-8 (lowest = 1)

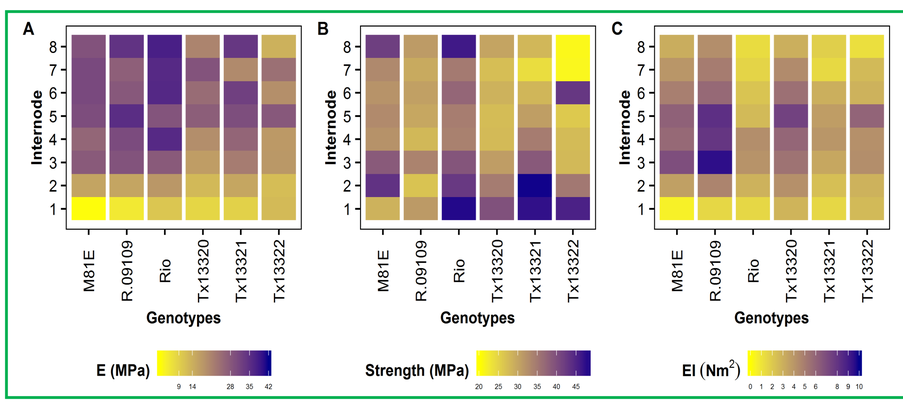

Figure 4. Heat bar plot for biomechanical properties for six sweet sorghum genotypes plotted against Internode No. (1-8) above the ground.

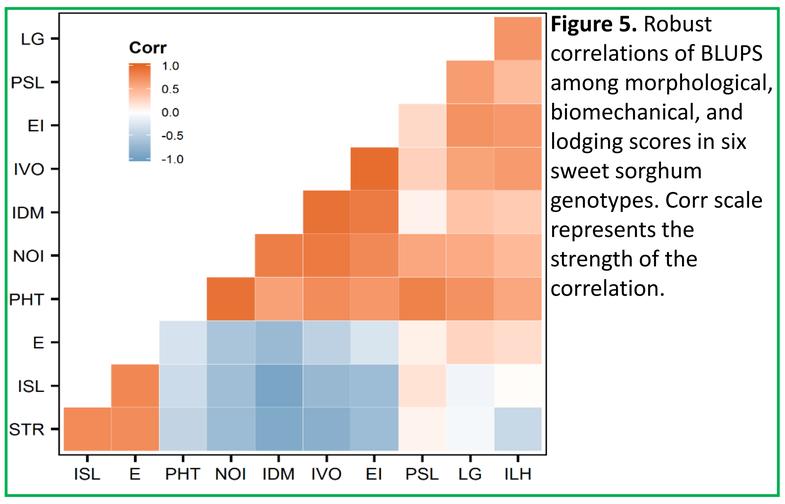

Figure 5. Robust correlations of BLUPS among morphological, biomechanical, and lodging scores in six sweet sorghum genotypes. Corr scale represents the strength of the correlation.

Figure 6. Representative images of three naturally occurring modes of failures observed in the culms of sorghum sweet types. (A) Brazier buckling or Brackling: failure of middle internodes (B) Snap (C) Buckling or Creasing

Experiment # 2

- The mechanical properties of the stems of 15 mature sorghum cultivars were investigated using a three-point bending test protocol in three locations in Texas in a RCBD.
- Data was analyzed using a mixed model approach to estimate LSMeans. Repeatabilities were estimated for morphological and mechanical traits with effects random.

$$y_{ijkl} = \mu + Loc_i + Blk(Loc)_{i(j)} + Geno + GenoLoc_{ik} + \varepsilon_{ijk}$$

where Loc: locations; Blk(Loc); block within locations; Geno: genotype; GenoLoc: genotype by environment interaction; ε: residual

Table1. Single environment and overall repeatability measurements across environments morphological and biomechanical traits of 15 sorghum genotypes grown in Texas.

		Significance of Fixed Effects			Repeatability Locations			
	Traits	E	G	GxE	CSE	CSL	WES	Overall
Plant Morphology	Height	**	**	**	0.98	0.97	0.97	0.74
	Slenderness Ratio	**	**	**	0.94	0.98	0.96	0.73
Internode Morphology	Length	**	*	**	0.86	0.77	0.50	0.66
	Diameter	*	**	**	0.94	0.94	0.97	0.70
	Slenderness Ratio	*	*	**	0.93	0.8	0.9	0.69
	Volume	*	*	*	0.91	0.87	0.89	0.63
Internode Biomechanics	Stiffness (E)	**	*	**	0.89	0.84	0.87	0.65
	Strength	**	**	**	0.81	0.87	0.86	0.72
	Rigidity (EI)	*	**	**	0.88	0.86	0.89	0.86

*Significant at the 0.05 probability level, ** Significant at the 0.01 probability level, ns=non-significant at 0.05 probability level

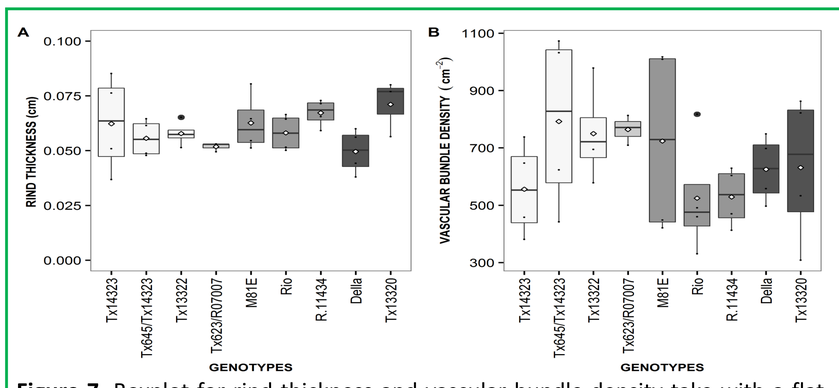

Figure 7. Boxplot for rind thickness and vascular bundle density take with a flat bed scanner with a semi-automated computer analyses.

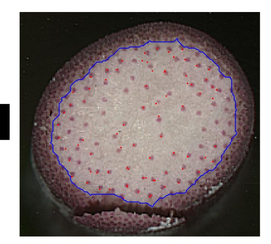

Figure 8. Cross section image processing of sorghum

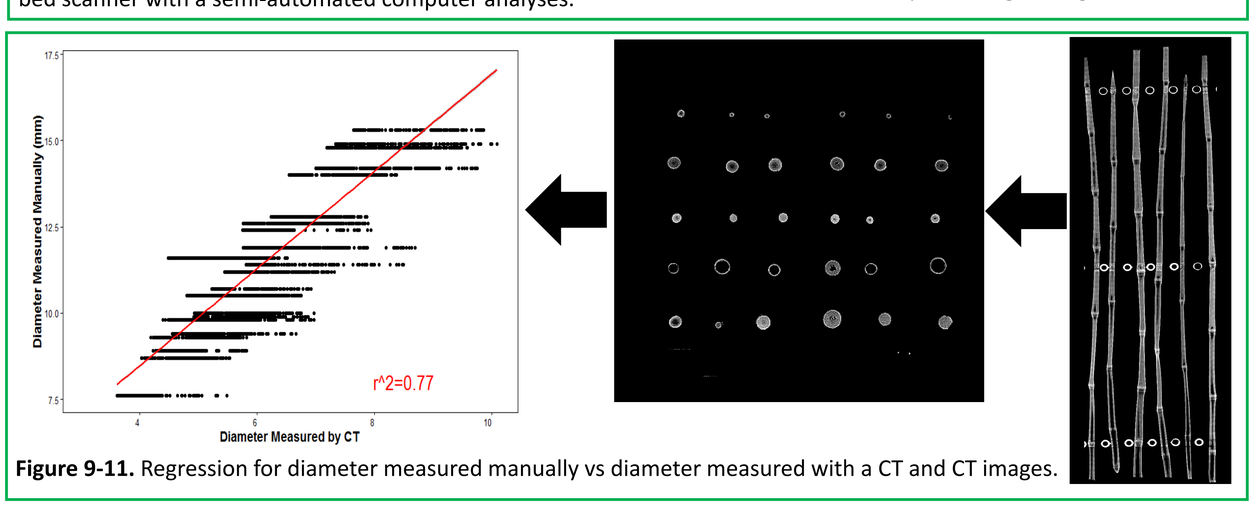

Figure 9-11. Regression for diameter measured manually vs diameter measured with a CT and CT images.

Conclusions

- Significant genetic variation was found for all mechanical properties.
- Biomechanical traits were moderately to highly repeatable within and across environments, indicating that phenotyping techniques were relatively consistent and not confounded by the environment.
- Mechanical properties were significantly associated with morphological traits as well as lodging tendency.
  - Nodes were two to three-fold stronger, stiffer, and more rigid than internodes.
  - In general, internodes were numerically weakest and more rigid between internodes 3 and 6, corresponding to the area where higher stem mechanical failure is observed.
- Image analysis using a flatbed scanner and x-ray computed tomography show promise for rapid phenotyping of stem anatomy, morphology, and mechanical properties.
- These results indicate the potential of these methods as a selective breeding tool for indirect selection or as a selective breeding index of stem lodging resistance in sorghum and future improvement.

References:

Heckwolf et al., (2015) Plant Methods.

E-mail: francisco.gomez@tamu.edu

TEXAS A&M UNIVERSITY