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Sorghum, the world's fifth most important cereal crop (area 46.9 million ha; production 63.3 million tons), is grown throughout the arid and semi-arid tropics. Drought stress is a major constraint, and post-flowering drought stress can result in significant yield losses due to reduced grain size, premature plant death, and increased disease susceptibility. The stay-green trait has been associated with post-flowering drought tolerance in many cereals including sorghum. Below is the progress realized in evaluating the sorghum reference set and stay-green QTL (*Stg3*, *Stg4* or *StgB*) introgression lines (QTL-IL) for post-flowering drought tolerance.

Allelic richness and diversity in sorghum reference set: A composite collection (3367 accessions) from the world collection (33,100 accessions) was developed, molecularly profiled, and a reference set (384 accessions) was proposed, which represents 78% (615 of the 789 alleles) of the SSR marker allelic diversity of the composite collection. All five races and ten intermediate races and geographic regions/countries were represented in this reference set (Figure 1). (<http://www.generationcp.org>)

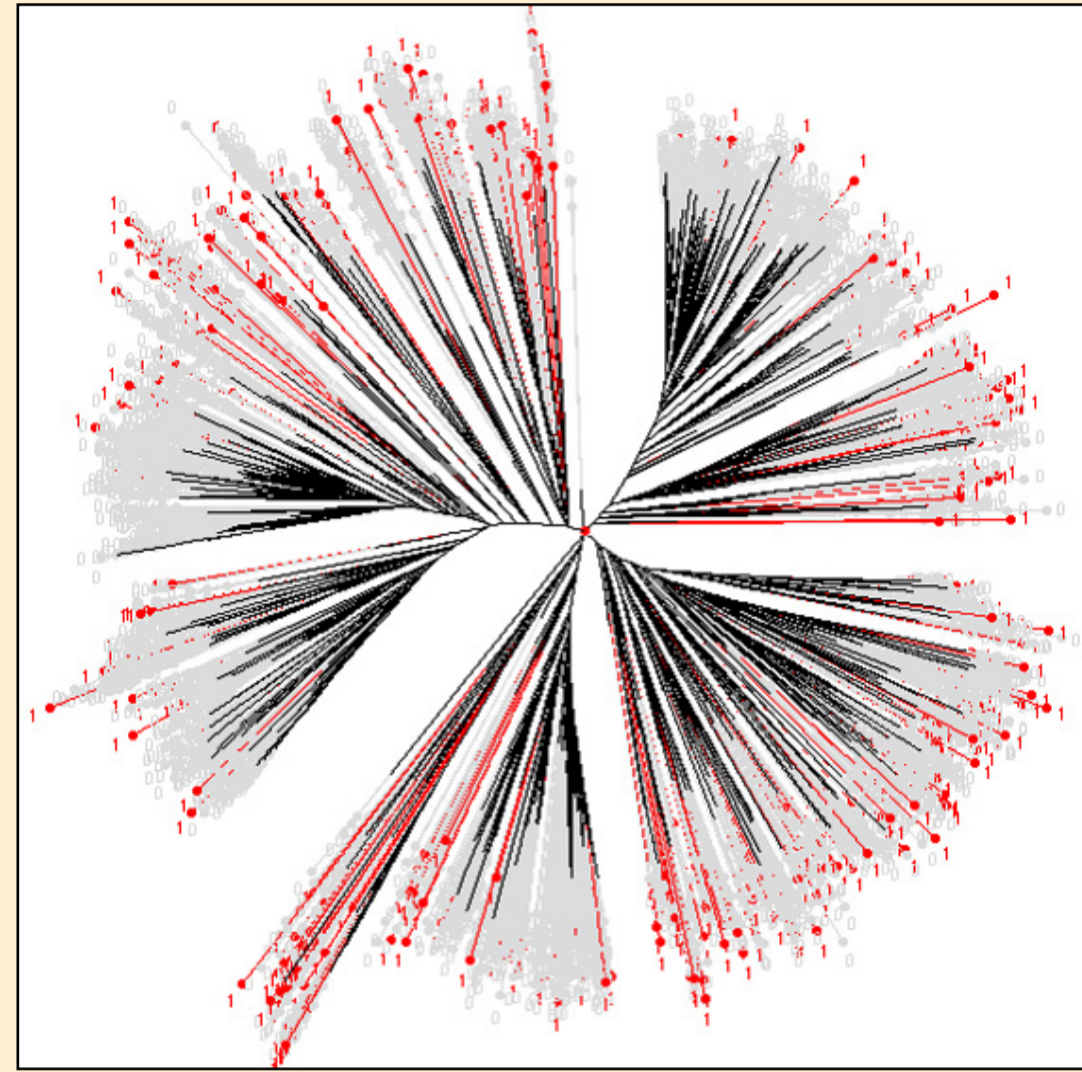


Fig. 1. Reference set accessions (red) representing diversity in composite collection (grey).

Assessing phenology and creating groups to evaluate adaptation to post-flowering drought stress

- Using 2007/08 postrainy season data on flowering from Patancheru, India, the reference set accessions were grouped into seven distinct phenological groups (G): G1 = earliest flowering; G7 = very late flowering type;
- Each group of accessions together with controls was grown separately in a split-plot design field trial with three replications during the 2008/09 postrainy season at Patancheru;
- Drought stressed and non-stressed (irrigated) moisture regimes were the main plots, while accessions within moisture regimes were the subplots;
- Imposed post-flowering drought stress by withholding irrigation from 31 days after sowing (DAS) in G1, 46 DAS in G2, 60 DAS in G3, 74 DAS in G4, 88 DAS in G5, 102 DAS in G6 and 115 DAS in G7;
- Once stress was imposed, drought-stressed main plots did not receive any further irrigation; non-stressed main plots continued to receive irrigation through crop maturity;
- The entire reference set was grown at Samanko, Mali, under terminal drought stress, sown on 3 October 2008. Irrigation was withheld once 50% of the plots reached 50% of flag leaf emergence.

Methodology to identify post-flowering drought tolerance

Difference in mean performance of grain yield between non-stressed and stressed plots was used to determine percentage change in response to the drought stress treatment. Accessions either with the least difference in response (reduction in grain yield) to the imposed stress or the higher grain yield performance under drought treatment were identified as drought tolerant. At Patancheru, India:

- Moisture (M) effects, genotype effects (G) and MxG interaction effects were significant for many traits including grain yield and chlorophyll content;
- 54 accessions yielded at par in the drought treatment, or were little affected (<10% yield reduction), compared to non-stressed conditions;
- 45 accessions produced >20% more grains in the drought treatment than in non-stressed treatment, with many retaining green leaf area for a longer period (Figure 2);



Fig. 2. IS 2367 retained green leaf area in the drought treatment while all leaves of IS 24009 dried up.

- 30 days after imposition of drought stress, 73 accessions had SPAD chlorophyll meter readings (SCMR) similar to those at flowering or a little reduced (<10%);
- SCMR I (at flowering) and SCMR II (at 30 days after flowering) were positively correlated under both non-stressed (0.626, $P < 0.01$) and drought-stressed (0.363, $P < 0.01$) conditions;
- Guinea-Kafir race accessions were least affected (27% reduction in grain yield) by the post-flowering drought stress treatment while Kafir-bicolor race accessions were most affected (79% reduction).

At Samanko, Mali:

- Stay-green trait, as measured by leaf senescence, differed significantly among entries, with lowest rate of -0.074 ± 0.010 leaf d^{-1} and highest $-0.225 \pm$ leaf d^{-1} , while data on chlorophyll content were not stable over time and not correlated with the rate of leaf senescence;
- Of 278 accessions, 22 were greener at grain maturity because they had been greener at flowering time, due to a lower rate of leaf senescence before flowering, and 34 because they had a lower rate of leaf senescence after flowering, being thus real 'stay green' (Table 1). Seven accessions have shared both qualities.

Table 1. Distribution of 278 accessions sorted by the number of green leaves lost after 5 weeks crossed with their number of green leaves at flowering.

Green leaves lost 5 weeks after flowering	Number of green leaves at flowering				
	4	5	6	7	8
-2	1	6	6	7	9
-3	7	13	8	7	
-4	13	20	28	13	2
-5		54	30	8	
-6			28	14	2
-7				8	1

Variation for water extraction (WE) and transpiration efficiency (TE) under post-flowering drought stress conditions

152 reference set accessions and 58 QTL introgression lines (QTL-IL) bred by marker-assisted backcrossing were evaluated for WE and TE under terminal drought stress (DS) and well-watered (WW) conditions in large and long PVC cylinders (2.0 m long and 25 cm diameter tubes), roughly mimicking the soil volume that sorghum plants would have at usual field planting densities (Figure 3). Preliminary analysis revealed:



Fig. 3. Lysimetric study of sorghum variation for water extraction (WE) and transpiration efficiency (TE) under post-flowering drought stress.

- A large range variation in WE (10.2 kg plant⁻¹ to 15.3 kg plant⁻¹) and TE (2.44 g kg⁻¹ to 6.09 g kg⁻¹ water transpired) among sorghum reference set accessions under DS, with a number of accessions showing higher WE and/or TE than stay-green QTL recurrent parent lines, R16 and S35 (Figure 4).

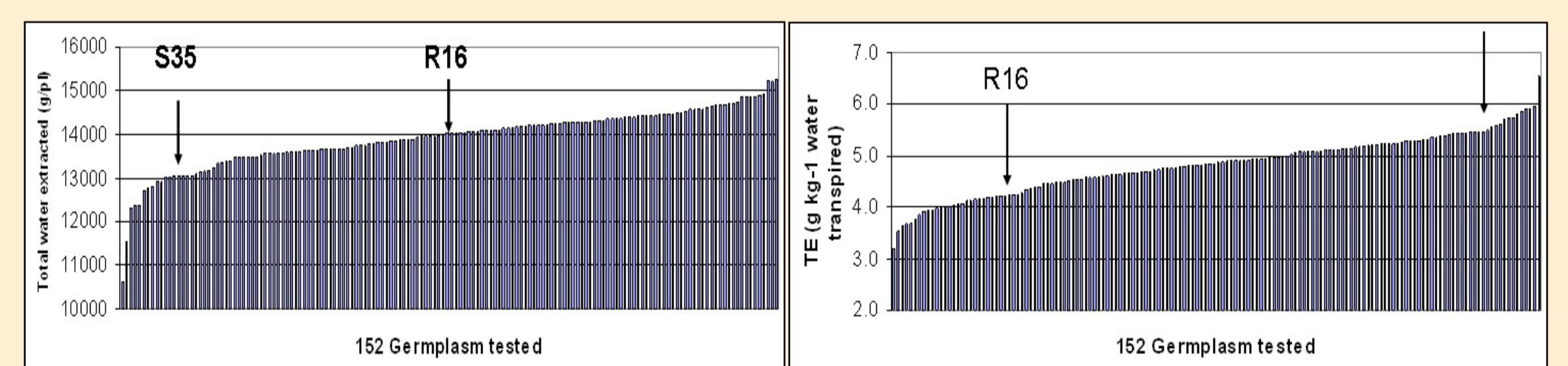


Fig. 4. Variation in water extraction (WE) and transpiration efficiency (TE) among sorghum reference set accessions.

- A number of stay-green QTL-IL in R16 background had higher TE under DS than under well-watered conditions (Figure 5).

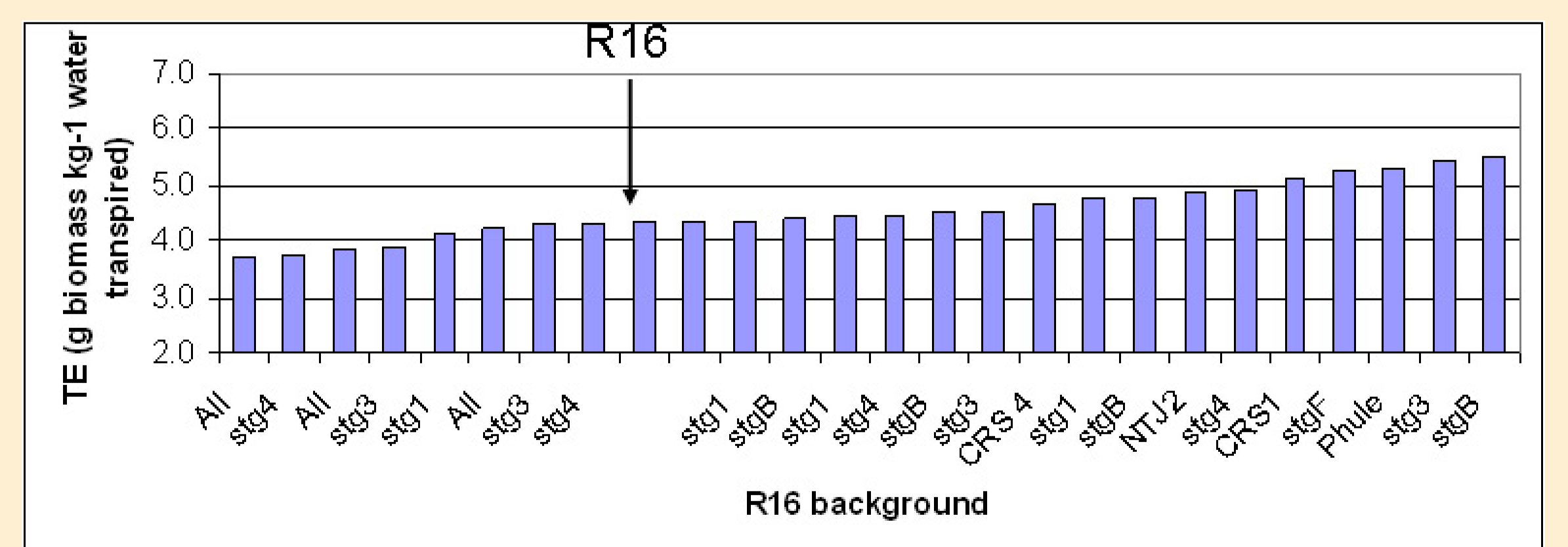


Fig. 5. Variation in transpiration efficiency among stay-green QTL-IL in R16 background.

Conclusions

- Many reference set accessions expressed stay-green trait
- Large range of variation in WE, TE and rate of senescence
- Many reference set accessions had higher WE and/or TE than R16 and S35
- Many QTL-IL in R16 background had high TE
- Races, as a group, responded differentially to drought stress

(Related GCP Project-SP1 Commissioned G4008.02: Phenotyping sorghum reference set for drought tolerance)