Evaluation of Post-Flowering Drought Resistance Property of Ethiopian Sorghum Accessions Collected From the Drought Prone Northern Part of Ethiopia.

ABSTRACT

Drought being the major factor limiting production of crops, developing crops that have the mechanism to cope with such a drought prone production environments has become vital. Sorghum is known for its post-flowering drought resistance property (stay-green). This study evaluated 165 sorghum landraces collected from draught prone areas of Ethiopia for this property. Based on visual rating, 56 accessions were selected and further data was recorded on them. Twelve accessions were identified that scored within the top 20 in at least three of the four traits which are positively correlated (relative water content, chlorophyll content, proportion of green leaves remaining 30 days after flowering, green leaf area at flowering). Nineteen accessions, in addition to showing these traits also had higher extent of tillering, indicating the potential for dual purpose sorghum. The cluster analysis grouped the accessions into four clusters. Based on the cluster mean, Cluster 4 and Cluster 2 showed superiority in most of the traits. Members of Cluster 1 had higher proportion of green leaves remaining 30 days after flowering and the least proportion of green leaves remaining 15 days after flowering; indicating that the accessions included in this cluster showed better performance through a mechanism of slower rate of senescence or type B stay-green rather than delayed on set of senescence. The cluster groups showed a clear pattern of association according to their collection area; however, there were two distinct clusters (Cluster 3 and Cluster 4). The present result proposed 56 candidate stay-green sorghum accessions. The result also showed that these candidate materials differ in the mechanism by which they attained the stay-green syndrome, indicating the possibility of generating stay-green materials that would be different genetically and in their physiological responses as well.

Key words: drought, drought resistance, post-flowering, sorghum, stay-green

1. INTRODUCTION

Drought occurs in all continents of the world. It occurred in the grain-producing regions of the United States and the former Soviet Union and affected greatly the international food supply and demand (Meshcherskay and Blazherich, 1997). However, in recent decades most droughts, which devastated human populations and the environment, occurred in Africa. To many African states, drought is a persistent and recurrent problem. Drought has been identified as the main cause of food insecurity, for example in the Amhara Region of Ethiopia (Ramakrishna and Assefa Demeke, 2002).

Drought is a major factor for crop loss especially in the semi-arid tropics. Due to human population growth increased production of crops is required more than ever. Sorghum is better adapted to water limiting environments compared to most other crops (Mullet *et al*., 2001; Sanchez *et al*., 2002). This attribute is of great importance as the demand for food and water supplies increases due to world population growth (Gleick, 2003). In the semi arid environments, sorghum is the most important crop well known for its drought resistance ability, especially of the stay-green property (post-flowering drought resistance property). This property of sorghum has been reported to have no yield penalty under optimal conditions, improving yield under post-flowering drought stress conditions. Hence many breeding programs are trying to incorporate this valuable trait. For stay-green property only three known sources of stay green are being used in breeding programs, these are B-35 and E-36 which have Ethiopian origin and KS-19 which has Nigerian origin. A major undertaking at present is to identify molecular markers associated with stay-green property, for which there is a need to identify more stay-green materials.

Ethiopia is home for diversity of sorghum landraces. From this diversity many economically valuable traits have been found for international usage. The post-flowering drought resistant trait named as stay-green has also been found in Ethiopian sorghum accessions. For example, B-35 has already been identified as a stay-green material derived from Ethiopian line and is now used in breeding programs (Borrell *et al*., 1999); this probably indicating that Ethiopia has production environments in which this trait is likely to develop.

The limited numbers of sources of stay-green sorghum materials currently in use in sorghum breeding programs contrasts with its importance in improving adaptation to post-flowering drought stress and with the effort being invested in identifying molecular markers to transfer it to new lines more effectively. A search for additional source of stay green, which may be different genetically or physiologically, would thus be worthwhile. The objective of this project is thus to evaluate Ethiopian sorghum accessions for stay-green property.

Landraces, also known as traditional varieties, are cultivated forms of a crop species, which have evolved over generations of selections by farmers (Harlan, 1992). Landraces are characterized by high genetic heterogeneity, good adaptation to local environmental conditions and low productivity. They are also noted as sources of useful genes required for further increment and maintenance of the productivity of modern varieties (Harlan, 1992).

In landraces, a series of beneficial selection has occurred as a result of environmental stresses. The screening of such landraces is an important part of the agricultural research and development process. Hence, these landraces are potential evaluation materials for positive out come in the search for more stay-green materials.

3. MATERIALS AND METHODS

3.1. Weather Condition during the Experimental Season.

The rainfall was highest in July which is after planting. Comparable rainfall but lower than that of July was observed in August and September; however, the lowest rain was observed in October followed by no rain in November (Table 1). Flowering for all the collection materials was observed at the last week of September. As a result the experimental season was promising for the evaluation of the sorghum accessions under post-anthesis drought stress conditions for selecting candidate materials.

Table 1. **Meteorological record of monthly rainfall and its distribution for the experimental season at the experimental site (Dera)**

Month	Rainfall (mm) (monthly)	Rain days
January	18.2	2
February	37.1	4
April	26.1	3
May	50.0	3
June	77.6	11
July	115.4	13
August	103.9	12
September	104.8	14
October	6.3	2
November	0	0

3.2. Seed Sample Collection

From 24 December 2006 to 4 January 2007 a field trip was organized to Northern part of Ethiopia for seed sample collection.

Prior to sample collection, identification of the most important drought prone production pockets that are likely to show greatest diversity of forms was done. For this, different stakeholders, particularly research centers and sub-centers and the bureau of agriculture and rural development at district (Wereda) level were approached. They not only assisted in the identification of the likely potential diversity targets in their respective mandate areas, but also they gave local guidance service in the course of the collection so that as many diverse types as possible hopefully with minimum number of duplication is acquired.

A total of 165 accessions were collected from Central Tigray (37), South Tigray (69), North Wello (42) and South Wello (17) (Appendix 1). Map showing areas from which the sorghum accessions were collected is presented in Figure 1.

Standard collection method followed by Ethiopian Institute of Biodiversity Conservation (IBC) was used. Efforts were also made to address both ecological and genetic diversity by making frequent sampling (every 5-10 km distance) particularly from predetermined likely hot spots of genetic diversity. The collection was done from farmer’s field, threshing ground, farm stores and from markets. Random sampling technique (for seed) supplemented with biased sampling (for panicle) was employed as deemed necessary. Passport data were completed for each sampling as per the IBC

format. This format also enables to make preliminary (informal) observation of the production constraints, usage of the crop and historical trends in seed delivery system.
Accordingly, 165 accessions collected from drought prone areas of Northern Ethiopia along with two adapted varieties (Seredo and Meko) and two known sources of stay-green (B-35 and E-36) as controls (standard checks) were used.

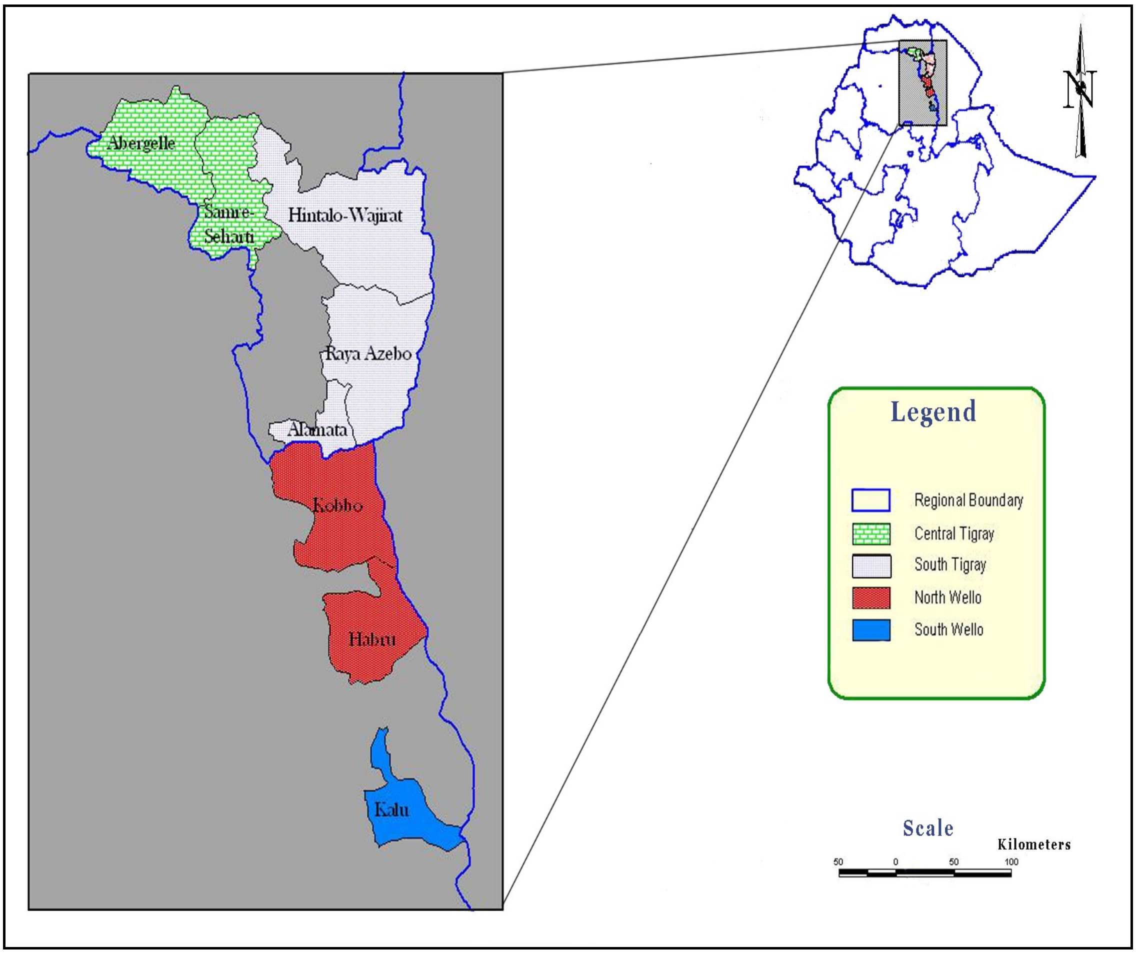

Figure 2. **Map showing areas from which the sorghum accessions were collected.**

3.3. Field Preparation and Experimental Design

The experiment was conducted under rainfed lowland conditions during 2007/2008 cropping season at Dera (Sub-center of Kulumsa Agricultural Research Center). The augmented experimental design introduced by Federer (1956, 1961, and 1991) was used for the experiment. An augmented experimental design (AED) is usually useful for testing a large number of genotypes in early generations when valid statistical analyses are needed particularly when seed supplies are too limited to permit replication. The basic concept of augmented design construction is to establish a standard replicated design using checks for which sufficient seeds are available. Each replicate forms a complete block, incomplete block, or cell, depending on the standard design. Additional unassigned plots are created within each replicate and unreplicated entries for which there are insufficient seeds. The entries are assigned to these plots in the form of an incomplete block design. In this experiment

there were five (5) blocks; the area of each block was 253.125m^2 (4.5m x 56.25m). The space between blocks was 2m. And the plot area of a single raw is 3.375m^2 (4.5m x 0.75m).
The checks were randomly allotted to each plot within the blocks. Each of the accessions was planted in a single row of 4.5m long using the recommended row to row and plant to plant spacing. Two seeds were planted per hill and finally thinned to one plant per hill after two weeks of emergence.

A common border of a variety with modest resource requirement separating each plot was alternatively planted every other row to make border effects constant across the genotypes (accessions and checks).

Planting was done on June 23 and DAP fertilizer was applied on the same day as side dressing and other agricultural practices were done as per recommended for sorghum cultivation

3.4. Data Collection

3.4.1. Green leaf area, number and visual rating of stay-green

In order to minimize effect due to intra accession competition, plants to be used for plant data collection were selected from spots with full stand (avoiding those that are immediately adjacent to a missing hill from any side). Anthesis was defined as the time when 50% of the anther had extruded from 50% of 10 tagged panicles in each plot. Physiological maturity was determined by assessing black layer in 10 tagged plants, beginning with the grain in the upper most quartile. Physiological maturity was defined as the time at which basal grains in 50% of the tagged panicles attained black layer (Borrell, *et al*., 2000a)

According to Van Oosterom *et al.* (1996) and Borrell *et al.* (2000a) green leaf area duration during grain filling appears to be a product of different combinations of three distinct factors: green leaf area at flowering, time and on set of senescence and subsequent rate of senescence. And hence, green leaf area was measured using CI, 202 Area Meter (CID, Inc. USA). At flowering the fourth leaf was cut from three stands for each accession and total leaf area was determined for each and the mean was taken as representative for comparison.

Number of green leaves only on the main stalk was counted starting from flowering. The numbers of fully expanded leaves were measured at 15 days interval. A leaf was considered senesced when more than 50% of its area had senesced. Then, at physiological maturity visual ratings of stay-green expression were recorded on a scale of 1-5 based on the degree of leaf and plant death at physiological maturity on a plot basis. Score 1 indicates very few or no senesced leaves where as 5 indicates complete leaf and plant death as used by Hirut Kebede *et al*. (2001).

3.4.2. Leaf relative water content and chlorophyll content

Relative water content of the leaves was determined at physiological maturity. Fixed size of leaf (1cm^2) was sampled from the leaves and fresh weight was measured on the field, then leaves were suspended in distilled water for 24 hours at 25^{0}C under fluorescent light. The sample was blotted dry and weighed prior to oven drying at 80^{o}C for at least 15 hours, and then relative water content was determined by the method of Barrs and Weatherley using the following formula

$$\left(FW - DW \middle/ TW - DW\right) \times 100\ \%$$

Where FW = Fresh weight, DW= dry weight, TW=turgid weight)

Relative water content at mid day was determined for the whole samples and on ten randomly selected accessions relative water content at dawn was determined.
At physiological maturity Chlorophyll index reading were taken with SPAD-502 Chlorophyll Meter (Spectrum Technology Inc.). These values provide an indication of the relative amount of total chlorophyll present in plant leaves. The values were calculated according to the amount of light transmitted by the leaf area (2 × 3 mm) in two wavelength regions in which the absorption of chlorophyll is different. Higher SPAD values represent higher total chlorophyll contents.

3.4.3. Leaf nitrogen analysis

Leaf nitrogen concentration was determined at flowering. The nitrogen analysis was done at the Laboratory of Water Works Design and Supervision Enterprise.

3.4.4. Tillering and plant height

Tillering (basal tillers) was scored at flowering and plant height was also determined at maturity.
After visual rating of senescence at physiological maturity only those accessions that performed well (i.e. those who scored 1 and 2) were considered for the subsequent data collection. The twelve characters scored and the abbreviations used are given in Table 2.

Table 2. List of characters studied in the experiment

Character	Abbreviations
Green leaf number at flowering	GLNAF
Proportion of green leaves remaining 15 days after flowering	R15DAF
Proportion of green leaves remaining 30 days after flowering	R30DAF
Maximum green leaf area at flowering	GLAAF
Chlorophyll content (SPAD reading value)	SPAD
Relative water content	RWC
Nitrogen content	Nc
Plant height	PH
Extent of tillering	TL
Thousand seed weight	TSW
Grain yield per panicle	GYPP
Visual rating of Senescence	VR
GYPP	Grain yield per panicle

4. DATA ANALYSIS

The analysis was done as per the procedure for standard augmented design. Since all new selections did not occur together in a block, it was impossible to compare them directly. However, it was possible to get a reasonable estimate of block effect as the checks occurred together in a block. This estimate was used to adjust the treatment means. The adjustment index is calculated as:

$$\boxed{Aj = 1(Bj - M)/C}$$

Where Bj= Block total

M= Sum of check means (C1=SCi/5)

C= Number of checks

(The adjustment index is calculated for each block)

Then, the adjusted mean of the new selections was obtained by subtracting the adjustment index of each block from the observed means of the new selections.

$$Yij = Oij - Aj$$

The analysis of variance was calculated just like random complete block design (RCBD) with C checks as treatments, B blocks and a total of CXB observations. Due to the imbalance created owing to the occurrence of new entries in a block, different standard errors were used in comparing different terms. The formulas used to compare new entries in the same and different block were,

- Between test treatments in the same block=

$$\sqrt{2\ MSE}$$

- Between two test treatments not in the same block=

$$\sqrt{2\ MSE\ (1 + 1/C\ )}$$

- Where MSE is the mean square error from analysis of variance of the checks and C is the number of checks

The analysis of variance for the checks was done using the SAS SOFTWARE VERSION 2001(The Proc ANOVA procedure was used). For the Multivariate analysis (cluster analysis and principal component) the SAS SOFTWARE VERSION 2001 was used. The Proc cluster and Prin Comp procedure were used respectively. The SAS procedure was first run and the appropriate number of clusters was determined from the Pseudo F and t^2 values. The appropriate number of clusters was determined by observing the point at which the Pseudo F value showed a sudden positive change and t^2 value is lower.

The data set contained 56 entries, and 9 quantitative traits for each entry. The traits included height, number of green leaves at flowering, proportion of green leaves remaining 15 and 30 days after flowering, extent of tillering, green leaf area at flowering, chlorophyll content, relative water content

and leaf nitrogen content. Three clustering methods were used- average linkage, centroid and Ward's minimum variance. In the first two clustering methods, the pseudo F reached its peak at cluster 4. The pseudo t^2 also reached its minimum at cluster 4. Therefore, it seems that the two methods agree on the number of clusters (while the Ward's minimum variance showed no clear pattern). Looking at the second candidate was a bit difficult because if we go to cluster 6 the pseudo F is smaller than that of cluster 4. Hence, we may decide that the entries could be classified in to 4 clusters based on 9 characteristics.
The SAS program was run using 7 numbers of clusters then it was adjusted to 4 numbers of clusters and re-run. The data were standardized before running the analysis by subtracting the mean and dividing by the standard deviation.

5. RESULT
5.1. The Stay-green Evaluation

At physiological maturity senescence and stay-green accessions could be easily differentiated by visual observation as captured in Figure 2 (see also slide 1), thus only those accessions that have performed well up to physiological maturity were selected based on the visual rating of senescence.

Sorcoll-008/07 Sorcoll-035/07

Figure 3. **Senescent (Left) and potential stay-green (Right) accessions (These photographs were taken on the same day at physiological maturity).**

Table 3 presents the error mean square, least significant difference, critical value at t error degrees of freedom and alpha from analysis of variance for augmented randomized complete block design for 9 traits. Based on the error mean square from the analysis of variance, Table 4 presents the estimated standard errors calculated for pair wise comparison of entries belonging to the same block and different block. Accordingly, the means of all traits and the block accessions are occurring in is attached in Appendix 3 and Appendix 2, respectively.

Table 3. **Error mean square, least significant difference, critical value at t error degrees of freedom and alpha from analysis of variance for augmented randomized complete block design for 9 traits**

Parameter	**Error Mean Square**	**Least Significant Difference (LSD)**
NGLAF	1.155996	1.4816
R15DAF	0.001281	0.0493
R30DAF	0.029643	0.2373
TL	0.282343	0.7322
GLAAF	1744.045	57.548
SPAD	1.568347	1.7257
PH	483.4213	30.298
RWC	189.274	18.958
NC	0.054437	0.3215
Alpha=**0.05**; Error degrees of freedom=**12**; Critical value at t= **2.17881**		

Table 4. **Estimated Standard error of differences calculated for pair wise multiple comparisons among accessions within and different blocks for 9 traits**

Parameter	**Within block**	**Between blocks**
NGLAF	1.52052359	1.699997
R15DAF	0.0506162	0.056591
R30DAF	0.24348717	0.272227
TL	0.75145592	0.840153
GLAAF	59.0600542	66.03115
SPAD	1.77107143	1.980118
PH	31.0940927	34.76425
RWC	19.45631	21.75282
NC	0.3299606	0.368907

Appendix 3 presents means of 9 traits as obtained from each of the experimental materials. Sorcoll-160/07 has the highest and third lowest green leaves number at flowering and nitrogen content respectively. Sorcoll-39/07 has the lowest green leaves number and relative water content. Sorcoll-

176/07 has the highest proportion of green leaves remaining 15DAF (R15DAF) while Sorcoll-56/07 has the lowest and the second lowest R15DAF and R30DAF.Sorcoll-159/07 has the highest and the lowest R30DAF and plant height respectively. Sorcoll-032/07 has the lowest R30DAF. Sorcoll-180/07 has the highest, second highest and third highest green leaves area at flowering, tillering and relative water content, respectively. Sorcoll-028/07 has the lowest and third highest green leaf area at flowering and tillering, respectively. Sorcoll-015 has the highest and second lowest plant height and extent of tillering, respectively. Sorcoll-035 and Sorcoll-009/07 have the highest and lowest SPAD reading respectively. Sorcoll-009/07 has the highest and second lowest nitrogen content and relative water content. Sorcoll-101/07 has the lowest nitrogen content. The relative water content at dawn of ten randomly selected accessions is presented in appendix 4.

Table 5 shows the correlation among the 9 measured traits. Green leaf area at flowering has shown positive significant correlation with SPAD chlorophyll index reading (SPAD) and relative water content at 0.01 confidence interval. SPAD reading and proportion of green leaves remaining 30 days after flowering (R30DAF) have shown significant positive correlation at 0.05 confidence interval. Similarly relative water content (RWC) showed significant positive correlation with proportion of green leaves remaining 30 days after flowering. Plant height showed significant negative correlation with proportion of green leaves remaining 15 days after flowering, extent of tillering, green leaf area at flowering, SPAD chlorophyll index reading and relative water content.

Table 6 shows the top 20 ranking accessions for each of the traits measured. For the traits that showed significant positive correlation (R30DAF, GLAAF, SPAD and RWC), 12 accessions have occurred overlapping in at least three of the above mentioned correlated traits (Table 7). Most of the accessions in this group have also shown higher proportion of green leaves remaining 15 days after flowering and nitrogen content at anthesis.

Accession Sorcoll-015/07, Sorcoll-028/07 and Sorcoll-035/07 have been observed to occur overlapping in proportion of green leaves remaining 15 days after flowering and leaf nitrogen content at anthesis. Accession Sorcoll-160/07 occurred in both proportion of green leaves remaining 15days after flowering and 30 days after flowering. While accession Sorcoll-027/07 observed to have higher proportion of green leaves remaining 15 days after flowering. Accession Sorcoll-062/07 and Sorcoll-155/07 had higher proportion of green leaves remaining 15 days after flowering, SPAD chlorophyll index reading and leaf nitrogen content at anthesis.

Table 5. **Correlation coefficients of 9 traits used**

	NGLAF	R15DAF	R30DAF	TL	GLAAF	SPAD	PH	RWC	NC
NGLAF	1.000								
R15DAF	-0.141	1.000							
R30DAF	0.103	0.196	1.000						
TL	-0.191	0.111	-0.068	1.000					
GLAAF	0.222	-0.059	0.239	0.034	1.000				
SPAD	0.208	0.081	0.288*	0.037	0.406**	1.000			
PH	0.142	-0.109	-0.060	-0.299*	-0.145	-0.138	1.000		
RWC	0.099	-0.037	0.295*	-0.020	0.386**	0.245	-0.281*	1.000	
NC	-0.206	0.178	-0.268*	0.202	-0.259	-0.129	-0.055	0.004	1.000

* 0.05, ** 0.01

Table 6. **Summary of the top 20 selected accessions in their descending ranking order**

GLNAF	R15DAF	R30DAF	GLAAF	PH	TL	SPAD	RWC	NC
Sorcoll-160/07	Sorcoll-176/07	Sorcoll-159/07	Sorcoll-180/07	Sorcoll-015/07	Sorcoll-179/07	Sorcoll-035/07	Sorcoll-068/07	Sorcoll-009/07
Sorcoll-047/07	Sorcoll-027/07	Sorcoll-089/07	Sorcoll-080/07	Sorcoll-101/07	Sorcoll-180/07	Sorcoll-141/07	Sorcoll-086/07	Sorcoll-178/07
Sorcoll-056/07	Sorcoll-015/07	Sorcoll-026/07	Sorcoll-087/07	Sorcoll-080/07	Sorcoll-028/07	Sorcoll-146/07	Sorcoll-180/07	Sorcoll-053/07
Sorcoll-168/07	Sorcoll-011/07	Sorcoll-087/07	Sorcoll-179/07	Sorcoll-012/07	Sorcoll-027/07	Sorcoll-040/07	Sorcoll-090/07	Sorcoll-029/07
Sorcoll-119/07	Sorcoll-026/07	Sorcoll-163/07	Sorcoll-176/07	Sorcoll-013/07	Sorcoll-032/07	Sorcoll-124/07	Sorcoll-070/07	Sorcoll-012/07
Sorcoll-054/07	Sorcoll-028/07	Sorcoll-146/07	Sorcoll-060/07	Sorcoll-124/07	Sorcoll-076/07	Sorcoll-026/07	Sorcoll-159/07	Sorcoll-155/07
Sorcoll-062/07	Sorcoll-012/07	Sorcoll-180/07	Sorcoll-085/07	Sorcoll-029/07	Sorcoll-009/07	Sorcoll-062/07	Sorcoll-176/07	Sorcoll-062/07
Sorcoll-026/07	Sorcoll-160/07	Sorcoll-081/07	Sorcoll-091/07	Sorcoll-091/07	Sorcoll-011/07	Sorcoll-180/07	Sorcoll-146/07	Sorcoll-011/07
Sorcoll-159/07	Sorcoll-159/07	Sorcoll-179/07	Sorcoll-168/07	Sorcoll-056/07	Sorcoll-029/07	Sorcoll-081/07	Sorcoll-032/07	Sorcoll-026/07
Sorcoll-124/07	Sorcoll-089/07	Sorcoll-141/07	Sorcoll-101/07	Sorcoll-089/07	Sorcoll-035/07	Sorcoll-060/07	Sorcoll-085/07	Sorcoll-085/07
Sorcoll-141/07	Sorcoll-101/07	Sorcoll-090/07	Sorcoll-146/07	Sorcoll-141/07	Sorcoll-053/07	Sorcoll-179/07	Sorcoll-163/07	Sorcoll-124/07
Sorcoll-089/07	Sorcoll-180/07	Sorcoll-091/07	Sorcoll-054/07	Sorcoll-045/07	Sorcoll-124/07	Sorcoll-070/07	Sorcoll-081/07	Sorcoll-040/07
Sorcoll-090/07	Sorcoll-163/07	Sorcoll-139/07	Sorcoll-139/07	Sorcoll-127/07	Sorcoll-142/07	Sorcoll-032/07	Sorcoll-178/07	Sorcoll-060/07
Sorcoll-091/07	Sorcoll-155/07	Sorcoll-142/07	Sorcoll-063/07	Sorcoll-081/07	Sorcoll-012/07	Sorcoll-159/07	Sorcoll-124/07	Sorcoll-156/07
Sorcoll-101/07	Sorcoll-162/07	Sorcoll-178/07	Sorcoll-062/07	Sorcoll-138/07	Sorcoll-156/07	Sorcoll-138/07	Sorcoll-060/07	Sorcoll-028/07
Sorcoll-081/07	Sorcoll-062/07	Sorcoll-160/07	Sorcoll-141/07	Sorcoll-046/07	Sorcoll-159/07	Sorcoll-127/07	Sorcoll-076/07	Sorcoll-015/07
Sorcoll-011/07	Sorcoll-141/07	Sorcoll-086/07	Sorcoll-142/07	Sorcoll-139/07	Sorcoll-162/07	Sorcoll-164/07	Sorcoll-089/07	Sorcoll-035/07
Sorcoll-180/07	Sorcoll-035/07	Sorcoll-035/07	Sorcoll-163/07	Sorcoll-146/07	Sorcoll-178/07	Sorcoll-090/07	Sorcoll-127/07	Sorcoll-076/07
Sorcoll-127/07	Sorcoll-127/07	Sorcoll-101/07	Sorcoll-090/07	Sorcoll-076/07	Sorcoll-119/07	Sorcoll-155/07	Sorcoll-087/07	Sorcoll-013/07
Sorcoll-139/07	Sorcoll-142/07	Sorcoll-085/07	Sorcoll-127/07	Sorcoll-027/07	Sorcoll-085/07	Sorcoll-178/07	Sorcoll-179/07	Sorcoll-032/07

Table 7. Accessions that ranked within the top 20 in at least three of the correlated traits (R30DAF, GLAAF, SPAD and RWC)

In at least three
Accessions
Sorcoll-060/07
Sorcoll-085/07
Sorcoll-087/07
Sorcoll-090/07
Sorcoll-127/07
Sorcoll-141/07
Sorcoll-146/07
Sorcoll-159/07
Sorcoll-163/07
Sorcoll-178/07
Sorcoll-179/07
Sorcoll-180/07

5.2. Principal Component and Cluster Analysis

The principal component analysis showing the factor scores of each character among the 56 sorghum accessions, eigen values and percentage total variance accounted for by three principal components is presented in Table 8. The three principal components accounted for about 55.13% of total variance with the first principal component only taking 27.07%. The relative discriminating power of principal axes as indicated by the eigen values was high (2.71) for axis 1 and low (1.11) for axis 3. The first principal component that accounted for the highest proportion (27.07%) of total variation was mostly correlated with green leaf area at flowering, proportion of green leaves remaining 30 days after flowering, SPAD chlorophyll index reading and relative water content. Characters that were mostly correlated with the second principal component were proportion of green leaves remaining 15 days after flowering, extent of tillering, and leaf nitrogen content at anthesis. The third principal component was dominated by traits such as proportion of green leaves remaining 15 days and 30 days after flowering and plant height.

The average linkage cluster (Table 9) analysis grouped those accessions which are in a near geographical proximity of their collection area. Out of the 28 accessions in cluster 1 most accessions were collections from Central and Southern Tigray while only four accessions were from North Wello. Central Tigray and South Tigray are in a near geographic proximity and with greater possibility of seed exchange than North Wello as a result they have contributed many accessions to this cluster showing the similarity among the collection materials from these areas.

Out of the 23 accessions in cluster 2, South Tigray and North Wello contributed 21 accessions, whereas Central Tigray and South Wello contributed one accession each. This shows that North Wello collections share much similarity with those collections from South Tigray. The only accession from South Wello grouped itself with this cluster, showing its similarity with collections from North Wello.

Distinct clusters which only contain collections from Central Tigray and South Tigray have been grouped in Cluster 3. This shows that there are accessions which are distinct from the accessions of their collection area. Cluster 4 also contained only collections from south Tigray, showing their distinctiveness from accessions of their collection area and also their proximities.

If we also try to see the contribution of each collection area to the selected candidate materials; South Tigray has contributed 26 accessions, Central Tigray 13 accessions, North Wello 16 accessions and South Wello 1 accession. Dendrogram showing the genetic similarity among the 56 sorghum accessions based on nine traits is presented in Figure 3.

Table 8. **Principal component analysis showing the contribution (factor score) of each character among the 56 sorghum accessions, eigen values and percentage total variance accounted for by the first four principal components**

Characters	**PC1**	**PC2**	**PC3**
NGLAF	0.18	-0.43	-0.11
R15DAF	0.05	0.36	0.71
R30DAF	0.37	-0.05	0.50
TL	0.02	0.51	-0.24
GLAAF	0.45	-0.08	-0.23
SPAD	0.37	-0.02	0.05
PH	-0.24	-0.48	0.27
RWC	0.37	0.09	-0.22
NC	-0.24	0.40	-0.06
Eigen values	2.71	1.70	1.11
% Variance	27.07	16.99	11.07
% Cumulative	27.07	44.06	55.13

Table 9. Average linkage cluster analysis, origin of accessions and accessions belonging to each of the four clusters based on 9 traits.

Clusters	No. of Accessions		Origin	Accessions
C1	**23**	**8**	Central Tigray	Sorcoll-011/07, Sorcoll-012/07, Sorcoll-015/07, Sorcoll-026/07, Sorcoll-027/07, Sorcoll-035/07, Sorcoll-038/07, Sorcoll-039/07
		10	South Tigray	Sorcoll-045/07, Sorcoll-047/07, Sorcoll-053/07, Sorcoll-056/07, Sorcoll-068/07 , Sorcoll-070/07, Sorcoll-076/07, Sorcoll-081/07, Sorcoll-089/07, Sorcoll-119/07
		5	North Wello	Sorcoll-124/07, Sorcoll-137/07, Sorcoll-138/07, Sorcoll-160/07, Sorcoll-164/07
C2	**23**	**1**	Central Tigray	Sorcoll-032/07
		10	South Tigray	Sorcoll-040/07, Sorcoll-054/07, Sorcoll-060/07, Sorcoll-062/07, Sorcoll-063/07, Sorcoll-085/07, Sorcoll-086/07, Sorcoll-090/07, Sorcoll-091/07, Sorcoll-101/07,
		11	North Wello	Sorcoll-127/07, Sorcoll-139/07, Sorcoll-141/07, Sorcoll-142/07, Sorcoll-146/07, Sorcoll-155/07, Sorcoll-156/07, Sorcoll-159/07, Sorcoll-162/07, Sorcoll-163/07, Sorcoll-168/07
			South Wello	Sorcoll-178/07
C3	**5**	**4**	Central Tigray	Sorcoll-009/07, Sorcoll-013/07, Sorcoll-028/07, Sorcoll-029/07
		1	South Tigray	Sorcoll-046/07
C4	**5**	**5**	South Tigray	Sorcoll-080/07, Sorcoll-087/07, Sorcoll-176/07, Sorcoll-179, Sorcoll-180

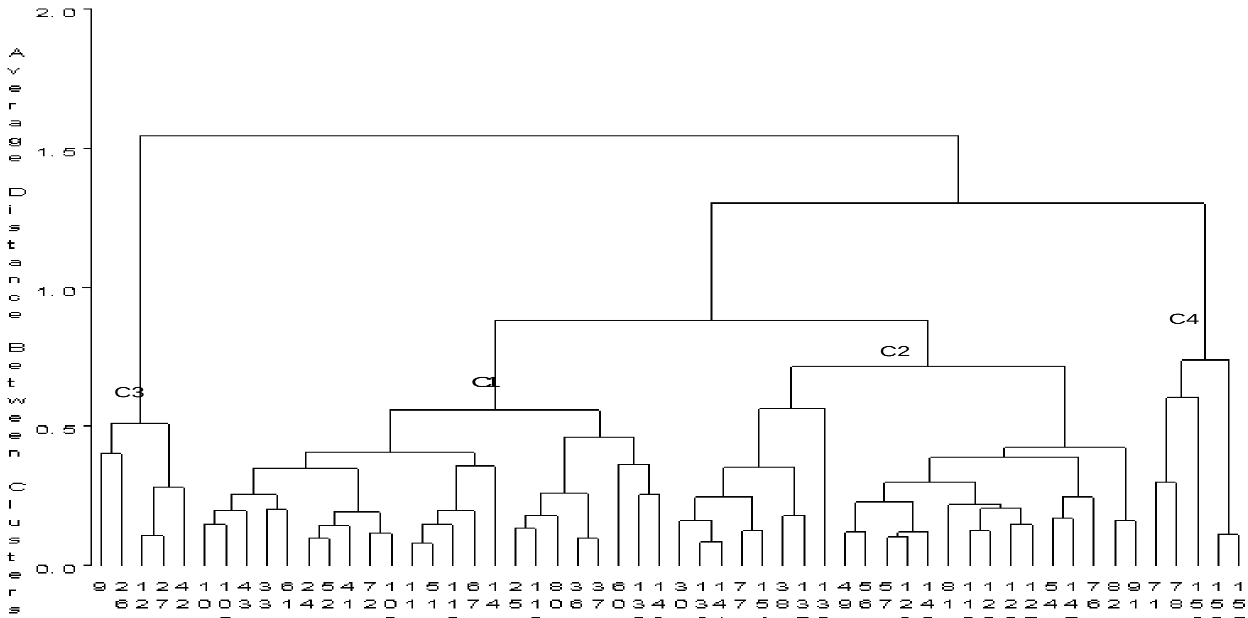

Figure 4. **Dendrogram showing the genetic similarity among the 56 sorghum accessions based on nine traits.**

5.3. Grouping of Candidate Accessions on the Basis of Stay- green Traits

The 56 candidate stay green sorghum accessions have been grouped in to 4 clusters. On the basis of combined mean of the accessions in their respective cluster, Cluster 1 accessions had a higher proportion of green leaves remaining 30 days after flowering (slower rate of senescence) followed by accessions from Cluster 4. The four Clusters have a relatively comparable proportion of green leaves remaining 15 days after flowering (delayed onset of senescence), with Cluster 4 having the highest value and Cluster 1 the least. Cluster 3 had the higher leaf nitrogen content at flowering, second higher value for number of green leaves remaining 15 days after flowering and extent of tillering (Table 10).

Cluster 4 accessions had a higher green leaf area at flowering, mid day relative water content followed by Cluster 2 accessions for the respectively mentioned traits. Whereas Cluster 2 accessions had higher SPAD Chlorophyll index reading values which in turn Cluster 4 accessions had the second place. Cluster 4 accessions had also the higher extent of tillering.

Cluster 1 accessions with higher proportion of green leaves remaining 30 days after flowering had also second higher value for nitrogen content at flowering.

Table 10. **Cluster mean for each traits.**

Cluster	NGLAF	R15DAF	R30DAF	TL	GLAAF	SPAD	PH	RWC	NGLAF
1	11.05	0.957	1.615	1.615	482.8	38.25	249.9	36.64	3.011
2	11.09	0.961	0.625	1.527	590.5	40.55	222.8	41.87	2.972
3	10.2	0.982	0.518	2.435	340.4	26.3	209.4	28.59	3.253
4	10.47	0.983	0.66	3.081	708.9	39.62	217.5	48.8	2.92

5.4. Further Descriptive Results

Thousand seed weigh and grain yield per panicle have also been recorded. Accordingly, Sorcoll-026/07(32,75.88), Sorcoll-029/07 (38,98.36), Sorcoll-045/07 (36,72.74), Sorcoll-046/07 (31,66.56), Sorcoll-178/07 (36,65.5) are accessions which have occurred on top ten for both thousand seed weight and grain yield per panicle (values indicated in the bracket are thousand seed weight (in grams) and grain yield per panicle (in grams) respectively). Whereas Sorcoll-09/07(31), Sorcoll-015/07 (38), Sorcoll-035/07 (35), Sorcoll-080/07 (30), Sorcoll-081/07 (30) were the top five for thousand seed weight. Sorcoll-013/07 (55.6), Sorcoll-038/07 (56.6), Sorcoll-162/07 (71.92), Sorcoll-163/07 (87.6), Sorcoll-176/07 (82.2) were the top five for grain yield per panicle.

6. DISCUSSION

6.1. Stay-green Ratings of the Accessions

The long term goal of this project is to identify more stay-green materials, understand the physiological basis of the sorghum stay-green property and to identify the genes that contribute to this trait in different sorghum genotypes. This preliminary evaluation of the Ethiopian sorghum cultivars collected from drought prone areas of the Northern part was intended to identify candidate stay-green materials for future study.

Xu *et al.* (2000) indicated that visual stay-green ratings were a reliable indicator of leaf senescence and should be useful to sorghum breeders in evaluating progeny when breeding for drought tolerance. Likewise, in this experiment visual ratings was done at physiological maturity in a 1-5 scale and those scored 1 and 2 have been promoted for further data recordings (Appendix 5). Visual rating was used in evaluating the germplasm for post-flowering drought tolerance and in transferring the stay green trait to elite lines, for example, conversion lines such as B35 (Rosenow, 1994).

Drought stress during the post-flowering period accelerates senescence in many plant species by driving many physiological processes in the same direction as normal senescence (Nooden, 1988). Senescence is normally characterized by chlorophyll loss and a progressive decline in photosynthetic capacity. Early onset of senescence affects assimilation and grain filling in crop plants. The rate of senescence determines the maintenance of quality flowers, fruits, and vegetables. Therefore, any defense mechanism that postpones the onset of senescence and keeps leaves green will benefit the crop.

In the present study accessions such as Sorcoll-011/07, Sorcoll-015/07, Sorcoll-026/07, Sorcoll-027/07, Sorcoll-028/07, Sorcoll-176/07 displayed higher proportion of green leaves remaining 15 days after flowering. According to the classification of stay-green by Thomas and Smart (1993), they may have probably shown Type A behavior. Genes associated with Type A stay-green are likely to be involved in the timing of the initiation of senescence. Accessions such as Sorcoll-087/07, Sorcoll-089/07, Sorcoll-146/07, Sorcoll-159/07, Sorcoll-163/07, Sorcoll-180 have displayed higher proportion of green leaves remaining 30 days after flowering. According to Thomas and Smart (1993), they may have probably shown Type B behavior. Genes involved in Type B stay-green are more likely to encode for senescent related activities such as catabolic enzymes. Thomas and Smart (1993) emphasized that the stay-green character in one genetic line may have a superficial resemblance to the character in another, yet the common phenotype may arise from very different underlying physiological and biochemical mechanisms. Accessions such as Sorcoll-026-07, Sorcoll-035-07, Sorcoll-101/07, Sorcoll-141/07, Sorcoll-159/07, Sorcoll-160/07, Sorcoll-163/07, and Sorcoll-180/07, displayed higher proportion of green leaves remaining 15 days and 30 days after flowering; and hence according to Thomas and Smart (1993), they may have probably shown both Type A and Type B behavior. This shows that even if the common end in this sorghum accessions is phenotypically similar, they have followed different physiological mechanisms. This is in line with the works of Thomas and Smart (1993) and Borrell *et al*. (2000a). Borrell *et al*. (2000a) found that KS 19 hybrids displayed delayed onset and reduced rate of senescence, yet B35 hybrids displayed delayed onset. This showed that a common stay-green phenotype may arise from very different underlying physiological mechanisms indicating that there is more than one way for a plant to stay-green.

Borrell and Hammer (2000) indicated that stay-green hybrids exceeded senescent hybrids in leaf nitrogen concentration at anthesis (3.11 vs. 2.83). In our study, only ten out of the 56 accessions showed leaf nitrogen concentration less than or equal to 2.83. Whereas, the rest had values greater than 2.83. Out of the accessions that had higher leaf nitrogen concentration 28 accessions have values more than 3.00. Borrell and Hammer (2000) indicated that leaf nitrogen concentration at anthesis was correlated with onset (r=0.751**, N=27) and rate (r=-0.783**, N=27) of leaf senescence under terminal water deficit. In our experiment similar trend was recorded for rate (r=-0.268***)** of leaf senescence, but not with proportion of green leaves remaining 15 days after flowering (r=.0.178).

During grain filling period, there are two sources of nitrogen for grain growth: concurrently absorbed nitrogen from the soil and remobilized nitrogen from vegetative tissue (Ta and Weiland, 1992). Rajcan and Tollenaar (1999) reported that the proportion of nitrogen derived from the soil during grain filling in maize (*Zea mays* L.) was 60% for Pioneer 3902 (stay-green hybrid) and 40% for Pride 5 (senescent hybrid). Under conditions of abiotic stress such as drought or nitrogen deficiency, remobilization of nitrogen from vegetative tissues becomes particularly important for grain growth (Ta and Weiland, 1992). Delayed remobilization of nitrogen from leaves maintains photosynthesis capacity for long, possibly resulting in higher grain yield. According to Borrell *et al*. (2001) leaf nitrogen concentration of stay-green hybrids is higher than senescent hybrids in both higher and lower soil nitrogen conditions; and hence, delayed senescence resulting from this should, in turn, allow more carbon and nitrogen to be allocated to the roots of stay-green hybrids during grain filling, thereby maintaining a greater capacity to extract nitrogen from the soil compared with senescent hybrids. The selected candidate materials may probably reward materials which drive most proportion of nitrogen from the soil during grain filling.

According to Xu *et al*. (2000) under severe post-flowering drought conditions, the stay-green lines, such as B35 have a SPAD values above 40 and extremely susceptible lines, such as Tx700 have a SPAD value of about 14 and essentially be without chlorophyll in leaves. The candidate materials selected in this study showed a SPAD reading value up to 60 (Sorcoll-068/07); 23 accessions had a SPAD values greater than 40, 26 accessions greater than 30, 6 accessions greater than 25, and 1 accession less than 20. The results show these materials have potential stay-green property.

Relative water content at dawn of the 10 randomly selected accessions of the candidate materials was higher ranging from 58.32%-99.11% (Appendix 6) indicating that their stalk transporting system continued to function under severe drought condition. In a study conducted by Xu *et al*. (2000) non stay-green lines had 38% relative water content. In this evaluation relative water content at mid day of 31 accessions was less than or equal to 38%, the rest had more than 38%. This indicated that the candidate accessions do have higher relative water content at dawn.

6.2. Grouping of Candidate Accessions on the Basis of Stay- green Traits

If selection is to be made between cluster groups for future breeding exercise on various traits the combined mean table of the four similarity clusters would be of use.

Cluster 1 which has the highest proportion of green leaves remaining 30 days after flowering and the lowest proportion of green leaves remaining 15 days after flowering. According to Thomas and Smart (1993) this cluster constitutes accessions that prevail Type B. Our findings suggest the fact that if further evaluation for this specific trait is needed, this cluster (cluster 1) would be of better preference.

Cluster 4 probably constitutes accessions with more stay-green property since it has higher values for most of the traits. It had the higher proportion of green leaves remaining 15 days after flowering, green leaf area at flowering, mid day relative water content and extent of tillering. It also had second higher value for proportion of green leaves remaining 30 days after flowering, SPAD chlorophyll index reading. Cluster 2 may also take the second position in this respect following Cluster 4.

Van Oosterom *et al*. (1996) stated stay-green as a valuable trait for both grain and fodder production in dual sorghums. This is because greater functional leaf area during grain filling in stay-green types is associated with increased accumulation of soluble sugars, thereby reducing their dependence on stored assimilates from the stem to fill grain (McBee *et al*., 1983). Hence, the higher concentration of stem sugar in turn improves the digestible energy content of the straw, making stay-green a valuable trait for both grain and fodder production. Therefore, accessions in Cluster 3 and 4 which have a higher extent of tillering, could potentially contribute to dual purpose sorghum.

6.3. Relative Contribution of Each Collection Area for Candidate Materials

Since the sample sizes from each collection area are different it will be difficult to with certainty about the relative favorability of the collection areas to develop the stay-green property, but in this particular experiment South Tigray and North Wello take the first and second place, respectively, in contributing more candidate materials. Here, these two zones had also similar position in the original number of sample. Therefore, to see the clear variation in relative favorability of the collection areas to develop the stay-green trait comparable and extensive sampling from each collection areas is needed.

For those interested to carry on this study back up seed of these accessions is available at Holeta Agricultural Research Center. The collection data book of the accessions is compiled and available at Addis Ababa University, Ecophysiology Laboratory.

7. CONCLUSIONS AND RECOMMENDATIONS

Variation was observed among sorghum accessions for post-flowering drought resistance property (stay-green). A total of fifty-six potential candidate materials were selected that attained the stay-green syndrome in various ways. Hence, the present result suggests that these selected candidate materials have the potential to give out stay-green materials which may be different physiologically.

Candidate materials collected from the same area which grouped themselves in one cluster may be showing their genetic similarity. Some candidate materials grouped themselves in a different cluster showing their distinctiveness from those accessions in their collection area.

For future it is recommended that, these sorghum accessions need to go through extensive study to come up with best materials. In the present study the selected materials had showed higher SPAD Chlorophyll reading at physiological maturity but there is a need to see their performance across their developmental stages. Further measurements on total green leaf area both at flowering and maturity and observing the rate of loss of leaf area between flowering and maturity is also essential. Measurements on above ground biomass both at flowering and maturity should be done by first dividing them in to main stem and tillers, then dividing each of those components into green leaf, dead leaf, stem and panicle. Investigating the yield potential of candidate materials under fully irrigated condition and comparing it with their yield under post-flowering drought stress condition is essential.

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LIST OF APPENDICES

Appendix 1. List of the collection materials and their origin

No.	***Acc. No.***	**Origin**		**No.**	**Acc. No.**	**Origin**		**No.**	**Acc. No.**	**Origin**
1	*Sorcoll-001/07*	Central Tigray		56	Sorcoll-062/07	South Tigray		111	Sorcoll-128/07	North Wello
2	*Sorcoll-002/07*	Central Tigray		57	Sorcoll-063/07	South Tigray		112	Sorcoll-130/07	North Wello
3	*Sorcoll-003/07*	Central Tigray		58	Sorcoll-065/07	South Tigray		113	Sorcoll-131/07	North Wello
4	*Sorcoll-004/07*	Central Tigray		59	Sorcoll-066/07	South Tigray		114	Sorcoll-132/07	North Wello
5	*Sorcoll-005/07*	Central Tigray		60	Sorcoll-068/07	South Tigray		115	Sorcoll-134/07	North Wello
6	*Sorcoll-006/07*	Central Tigray		61	Sorcoll-070/07	South Tigray		116	Sorcoll-135/07	North Wello
7	*Sorcoll-007/07*	Central Tigray		62	Sorcoll-071/07	South Tigray		117	Sorcoll-136/07	North Wello
8	*Sorcoll-008/07*	Central Tigray		63	Sorcoll-072/07	South Tigray		118	Sorcoll-137/07	North Wello
9	*Sorcoll-009/07*	Central Tigray		64	Sorcoll-073/07	South Tigray		119	Sorcoll-138/07	North Wello
10	*Sorcoll-011/07*	Central Tigray		65	Sorcoll-074/07	South Tigray		120	Sorcoll-139/07	North Wello
11	*Sorcoll-012/07*	Central Tigray		66	Sorcoll-075/07	South Tigray		121	Sorcoll-140/07	North Wello
12	*Sorcoll-013/07*	Central Tigray		67	Sorcoll-076/07	South Tigray		122	Sorcoll-141/07	North Wello
13	*Sorcoll-014/07*	Central Tigray		68	Sorcoll-077/07	South Tigray		123	Sorcoll-142/07	North Wello
14	*Sorcoll-015/07*	Central Tigray		69	Sorcoll-078/07	South Tigray		124	Sorcoll-143/07	North Wello
15	*Sorcoll-016/07*	Central Tigray		70	Sorcoll-079/07	South Tigray		125	Sorcoll-144/07	North Wello
16	*Sorcoll-017/07*	Central Tigray		71	Sorcoll-080/07	South Tigray		126	Sorcoll-145/07	North Wello
17	*Sorcoll-018/07*	Central Tigray		72	Sorcoll-081/07	South Tigray		127	Sorcoll-146/07	North Wello
18	*Sorcoll-019/07*	Central Tigray		73	Sorcoll-082/07	South Tigray		128	Sorcoll-147/07	North Wello
19	*Sorcoll-020/07*	Central Tigray		74	Sorcoll-083/07	South Tigray		129	Sorcoll-148/07	North Wello
20	*Sorcoll-021/07*	Central Tigray		75	Sorcoll-084/07	South Tigray		130	Sorcoll-149/07	North Wello
21	*Sorcoll-022/07*	Central Tigray		76	Sorcoll-085/07	South Tigray		131	Sorcoll-150/07	North Wello
22	*Sorcoll-023/07*	Central Tigray		77	Sorcoll-086/07	South Tigray		132	Sorcoll-151/07	North Wello
23	*Sorcoll-024/07*	Central Tigray		78	Sorcoll-087/07	South Tigray		133	Sorcoll-152/07	North Wello
24	*Sorcoll-026/07*	Central Tigray		79	Sorcoll-088/07	South Tigray		134	Sorcoll-153/07	North Wello
25	*Sorcoll-027/07*	Central Tigray		80	Sorcoll-089/07	South Tigray		135	Sorcoll-154/07	North Wello
26	*Sorcoll-028/07*	Central Tigray		81	Sorcoll-090/07	South Tigray		136	Sorcoll-155/07	North Wello
27	*Sorcoll-029/07*	Central Tigray		82	Sorcoll-091/07	South Tigray		137	Sorcoll-156/07	North Wello
28	*Sorcoll-030/07*	Central Tigray		83	Sorcoll-093/07	South Tigray		138	Sorcoll-159/07	North Wello
29	*Sorcoll-031/07*	Central Tigray		84	Sorcoll-094/07	South Tigray		139	Sorcoll-160/07	North Wello
30	*Sorcoll-032/07*	Central Tigray		85	Sorcoll-095/07	South Tigray		140	Sorcoll-161/07	North Wello
31	*Sorcoll-033/07*	Central Tigray		86	Sorcoll-096/07	South Tigray		141	Sorcoll-162/07	North Wello
32	*Sorcoll-034/07*	Central Tigray		87	Sorcoll-097/07	South Tigray		142	Sorcoll-163/07	North Wello
33	*Sorcoll-035/07*	Central Tigray		88	Sorcoll-098/07	South Tigray		143	Sorcoll-164/07	North Wello
34	*Sorcoll-036/07*	Central Tigray		89	Sorcoll-099/07	South Tigray		144	Sorcoll-165/07	North Wello
35	*Sorcoll-037/07*	Central Tigray		90	Sorcoll-100/07	South Tigray		145	Sorcoll-166/07	North Wello
36	*Sorcoll-038/07*	Central Tigray		91	Sorcoll-101/07	South Tigray		146	Sorcoll-167/07	North Wello
37	*Sorcoll-039/07*	Central Tigray		92	Sorcoll-102/07	South Tigray		147	Sorcoll-168/07	North Wello
38	*Sorcoll-040/07*	South Tigray		93	Sorcoll-103/07	South Tigray		148	Sorcoll-169/07	North Wello
39	*Sorcoll-041/07*	South Tigray		94	Sorcoll-104/07	South Tigray		149	Sorcoll-173/07	South Wello
40	*Sorcoll-044/07*	South Tigray		95	Sorcoll-107/07	South Tigray		150	Sorcoll-174/07	South Wello

41	*Sorcoll-045/07*	South Tigray		96	Sorcoll-108/07	South Tigray		151	Sorcoll-175/07	South Wello
42	*Sorcoll-046/07*	South Tigray		97	Sorcoll-110/07	South Tigray		152	Sorcoll-176/07	South Wello
43	*Sorcoll-047/07*	South Tigray		98	Sorcoll-111/07	South Tigray		153	Sorcoll-177/07	South Wello
44	*Sorcoll-048/07*	South Tigray		99	Sorcoll-112/07	South Tigray		154	Sorcoll-178/07	South Wello
45	*Sorcoll-049/07*	South Tigray		100	Sorcoll-113/07	South Tigray		155	Sorcoll-179/07	South Wello
46	*Sorcoll-050/07*	South Tigray		101	Sorcoll-114/07	South Tigray		156	Sorcoll-180/07	South Wello
47	*Sorcoll-051/07*	South Tigray		102	Sorcoll-115/07	South Tigray		157	Sorcoll-181/07	South Wello
48	*Sorcoll-052/07*	South Tigray		103	Sorcoll-116/07	South Tigray		158	Sorcoll-182/07	South Wello
49	*Sorcoll-054/07*	South Tigray		104	Sorcoll-117/07	South Tigray		159	Sorcoll-183/07	South Wello
50	*Sorcoll-055/07*	South Tigray		105	Sorcoll-119/07	South Tigray		160	Sorcoll-184/07	South Wello
51	*Sorcoll-056/07*	South Tigray		106	Sorcoll-120/07	South Tigray		161	Sorcoll-185/07	South Wello
52	*Sorcoll-053/07*	South Tigray		107	Sorcoll-123/07	North Wello		162	Sorcoll-188/07	South Wello
53	*Sorcoll-058/07*	South Tigray		108	Sorcoll-124/07	North Wello		163	Sorcoll-189/07	South Wello
54	*Sorcoll-060/07*	South Tigray		109	Sorcoll-125/07	North Wello		164	Sorcoll-190/07	South Wello
55	*Sorcoll-061/07*	South Tigray		110	Sorcoll-127/07	North Wello		165	Sorcoll-194/07	South Wello

Appendix 2. Accessions and the block they are occurring in

Accessions	**Block**		**Accessions**	**Block**		**Block**	**Block**		**Accessions**	**Block**
Sorcoll-009/07	1		Sorcoll-045/07	2		Sorcoll-085/07	3		Sorcoll-142/07	4
Sorcoll-011/07	1		Sorcoll-046/07	2		Sorcoll-086/07	3		Sorcoll-146/07	4
Sorcoll-012/07	1		Sorcoll-047/07	2		Sorcoll-087/07	3		Sorcoll-155/07	5
Sorcoll-013/07	1		Sorcoll-054/07	2		Sorcoll-089/07	3		Sorcoll-156/07	5
Sorcoll-015/07	1		Sorcoll-056/07	2		Sorcoll-090/07	3		Sorcoll-159/07	5
Sorcoll-026/07	1		Sorcoll-053/07	2		Sorcoll-091/07	3		Sorcoll-160/07	5
Sorcoll-027/07	1		Sorcoll-060/07	2		Sorcoll-101/07	3		Sorcoll-162/07	5
Sorcoll-028/07	1		Sorcoll-062/07	2		Sorcoll-119/07	4		Sorcoll-163/07	5
Sorcoll-029/07	1		Sorcoll-063/07	2		Sorcoll-124/07	4		Sorcoll-164/07	5
Sorcoll-032/07	1		Sorcoll-068/07	2		Sorcoll-127/07	4		Sorcoll-168/07	5
Sorcoll-035/07	1		Sorcoll-070/07	2		Sorcoll-137/07	4		Sorcoll-176/07	5
Sorcoll-038/07	2		Sorcoll-076/07	3		Sorcoll-138/07	4		Sorcoll-178/07	5
Sorcoll-039/07	2		Sorcoll-080/07	3		Sorcoll-139/07	4		Sorcoll-179/07	5
Sorcoll-040/07	2		Sorcoll-081/07	3		Sorcoll-141/07	4		Sorcoll-180/07	5

Appendix 2. Means of ten characters taken

Accession No.	GLN	R15DA	R13DA	GLAA	PH	TL	SPAD	RWC	NC	GYP
Sorcoll-009/07	9.247	0.9787	0.5587	336.39	208.26	2.6035	18.652	22.863	3.538	45.5
Sorcoll-011/07	11.58	1.0406	0.4462	495.58	227.26	2.6035	32.185	31.465	3.278	43.2
Sorcoll-012/07	10.58	1.0129	0.4883	520.25	287.26	2.2635	29.252	32.039	3.318	50.1
Sorcoll-013/07	11.24	0.9529	0.489	345.35	284.01	0.9335	25.452	42.55	3.138	
Sorcoll-015/07	10.91	1.0431	0.565	504.35	319.26	0.2635	29.818	32.983	3.168	
Sorcoll-026/07	12.24	1.0384	0.8301	476.41	257.26	0.9335	47.218	30.892	3.278	-
Sorcoll-027/07	10.24	1.0459	0.4066	452.35	261.26	3.6035	34.818	29.875	2.858	74.2
Sorcoll-028/07	9.580	1.0143	0.5741	289.31[L]	245.26	4.2635	32.385	26.225	3.178	-
Sorcoll-029/07	10.91	0.982	0.5345	347.28	280.26	2.6035	25.718	26.73	3.348	89.1
Sorcoll-032/07	10.91	0.9209	0.3512[L]	542.63	168.26	3.6035	43.885	51.86	3.138	49.9
Sorcoll-035/07	11.24	0.9825	0.6668	509.14	222.26	2.6035	58.018	34.877	3.168	45.9
Sorcoll-038/07	10	0.9133	0.4999	427.84	239.91	1.7685	35.968	28.239	2.500	56.2
Sorcoll-039/07	7.333	0.9273	0.6362	424.23	226.91	1.7685	36.202	22.686	2.780	58.4
Sorcoll-040/07	10.66	0.95	0.5624	579.1	154.91	1.7685	47.602	37.729	3.240	54.4
Sorcoll-045/07	10.33	0.9484	0.5805	475.82	274.91	0.7685	36.102	32.906	3.040	74.1
Sorcoll-046/07	10	0.98	0.4332	383.85	265.91	1.7685	29.302	24.56	3.060	54.5
Sorcoll-047/07	12.66	0.8789	0.4736	526.49	242.91	0.7685	39.868	26.597	2.990	-
Sorcoll-054/07	12.33	0.9027	0.5674	615.74	241.91	1.0985	36.802	24.361	2.670	-
Sorcoll-056/07	12.66	0.7474[L]	0.3946	525.81	277.91	1.7685	33.768	33.559	2.980	-
Sorcoll-053/07	9.666	0.9793	0.655	466.81	253.91	2.4385	37.335	34.833	3.410	52.6
Sorcoll-060/07	10.33	0.9806	0.4192	645.76	209.91	0.7685	44.668	46.701	3.240	-
Sorcoll-062/07	12.33	0.9838	0.4053	601.51	244.91	1.7685	47.135	29.648	3.280	-
Sorcoll-063/07	10.33	0.9161	0.645	601.94	219.91	0.7685	36.102	40.032	2.830	-
Sorcoll-068/07	10.66	0.8875	0.4374	428.19	206.91	0.0985	33.135	60.057	2.940	49.0
Sorcoll-070/07	11	0.9515	0.6059	492	213.91	1.0985	44.102	54.866	3.000	50.6
Sorcoll-076/07	11.25	0.8784	0.5261	543.25	262.41	3.261	27.243	46.694	3.158	43.3
Sorcoll-080/07	10.91	0.9357	0.5422	710.85	296.41	0.931	38.477	42.189	2.808	58.5
Sorcoll-081/07	11.58	0.9682	0.7124	481.85	269.41	0.931	45.043	48.861	2.918	54.2
Sorcoll-085/07	10.91	0.9052	0.6643	639.04	237.41	1.931	33.743	50.778	3.278	-
Sorcoll-086/07	10.25	0.9641	0.675	548.64	213.41	1.261	33.043	59.888	3.088	32.9
Sorcoll-087/07	9.250	0.9242	0.82	696	253.41	0.601	32.377	45.194	2.848	47.7
Sorcoll-089/07	11.91	0.9971	0.8323	439.61	276.41	0.601	36.51	46.231	2.928	-
Sorcoll-090/07	11.91	0.9132	0.6925	589.12	251.41	0.601	42.477	58.073	2.688	-
Sorcoll-091/07	11.91	0.9132	0.6925	637.69	278.41	0.931	41.71	36.555	2.698	56.4
Sorcoll-101/07	11.91	0.9971	0.6645	631.4	299.41	1.261	41.177	26.418	2.318	-
Sorcoll-119/07	12.33	0.9027	0.52	506.69	246.78	1.936	31.143	31.867	3.013	-
Sorcoll-124/07	12.00	0.9556	0.5345	494.66	280.78	2.266	47.477	46.962	3.243	-
Sorcoll-127/07	11.33	0.9824	0.6541	587.45	273.78	0.936	43.31	45.417	3.093	64.7
Sorcoll-137/07	8.669	0.9769	0.5862	436.41	251.78	1.596	41.677	32.427	2.813	38.2
Sorcoll-138/07	11.00	0.9818	0.6134	534.63	268.78	1.266	43.543	31.698	3.113	-
Sorcoll-139/07	11.33	0.953	0.6835	611.75	263.78	0.936	38.843	36.78	2.833	-
Sorcoll-141/07	12.00	0.9833	0.7011	599.64	275.78	0.936	53.677	36.027	2.783	-

Appendix 3 continued………

Sorcoll-142/07	11.336	0.9824	0.6835	591.13	230.78	2.266	32.41	40.297	2.833	-
Sorcoll-146/07	10.669	0.9813	0.7575	623.83	263.78	1.596	47.977	53.056	2.883	-
Sorcoll-155/07	9.4992	0.9963	0.579	543.86	187.66	1.431	41.993	43.078	3.2905	-
Sorcoll-156/07	9.1658	0.9598	0.491	577.4	178.66	2.101	35.86	30.667	3.2105	35.9
Sorcoll-159/07	12.166	0.9971	0.8905^{H}	518.41	112.66^{L}	2.101	43.627	53.654	2.8505	-
Sorcoll-160/07	13.499^{H}	0.9974	0.6791	482.42	175.66	0.771	31.16	37.869	2.5405	-
Sorcoll-162/07	9.4992	0.9963	0.5439	535.15	187.66	2.101	34.86	37.407	2.8705	68.1
Sorcoll-163/07	11.166	0.9969	0.7613	589.64	213.66	1.431	33.427	49.88	2.8805	52.8
Sorcoll-164/07	10.833	0.966	0.6616	458.79	203.66	1.771	42.993	34.136	2.8205	45.8
Sorcoll-168/07	12.499	0.9705	0.6001	634.19	202.66	1.431	36.46	26.531	2.8805	-
Sorcoll-176/07	10.499	1.0919^{H}	0.4921	681.16	163.16	1.101	36.327	53.398	3.0705	91.5
Sorcoll-178/07	10.499	0.9649	0.6826	536.15	214.66	2.101	41.76	48.28	3.4705	47.8
Sorcoll-179/07	10.166	0.9638	0.705	688.26	157.66	7.431^{H}	44.127	43.567	2.9205	59.4
Sorcoll-180/07	11.499	0.997	0.7392	768.05^{H}	216.66	5.431	46.793	59.647	2.9505	-

NB: - **H=**Highest, **L=**Lowest

Appendix 4. **Relative water content at dawn of the 10 randomly selected candidate materials**

ACCESSION No.	RWC (%)
Sorcoll-026/07	75.29976
Sorcoll-035/07	99.11504
Sorcoll-040/07	97.34345
Sorcoll-053/07	67.61488
Sorcoll-070/07	74.79167
Sorcoll-086/07	58.3196
Sorcoll-087/07	84.75336
Sorcoll-142/07	87.97251
Sorcoll-146/07	75.29412
Sorcoll-179/07	84.39201
Sorcoll-180/07	76.42857

Photo by Zelalem

Slide 1. **Sample candidate stay-green sorghum accessions (above) and senescent sorghum accessions (below).**