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Selecting Drought Tolerant Early Set Soybean (*Glycine max*) Genotype in Northwestern Ethiopia

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ABSTRACT

Soybean is an important crop for both human and livestock nutrition. However, its production and productivity are affected by biotic and abiotic stresses particularly drought stress is the main production limiting factor. Therefore, the primary objective of this study was to investigate the impact of drought, identify soybean genotypes that exhibit tolerance to drought conditions for commercial production, and identify potential parental lines that can be utilized to enhance drought tolerance in soybean breeding programs. The experiment was simple lattice design in two separate field experiments for full irrigated (control) and drought stressed conditions. Analysis of variance revealed that there were highly significant differences in days to maturity, plant height, pod and seed per plant, hundred seed weight and seed yield under both conditions. In general, drought stress reduced days to maturity in 5.1%, plant height 13.38%, number of pods per plant 25.39%, seeds per pod 9.28%, hundred seed weight 4.75% and grain yield 33.46% in average. The level of yield reduction due to drought stress was reneged in between 2.49 % genotype Go-0391 to 62.85 % genotype AGS-214 which is 33.46 % in average. In the current study, G2, G17, G20, G21, G29, G6 and G35 were performed above the mean under both conditions and identified as high yielder and drought tolerant soybean genotypes. Whereas G1, G10, G12, G16, G24, G25, G26, G27, G28, and G30 genotypes were performed below the mean performance which are low yielder drought tolerant. Finally, we recommended TGx 1989-40F variety for commercial production in drought prone areas of Ethiopia as drought tolerant early.

Keywords: Drought effect, genotypes, indices, performance, susceptible, tolerance

Introduction

Soybean (*Glycine max*) is one of the most cultivated crops worldwide. Soybean is widely utilized as a primary source of edible vegetable oil, high-protein livestock feed, and for various industrial purposes. This is mainly attributed to the abundant oil and protein content in its seeds. Moreover, soybean plants have a significant impact on crop diversification and benefits from the growth of other crops, enriching the soil with nitrogen during crop rotation (Yahoueian *et al.,* 2017). Prolonged drought was affected more than two thirds of the population worldwide (Naumann *et al.,* 2018). Such offers a threat to the world's food security (FAO, 2018).

Unbiased estimation of variance components under both droughts stressed and well irrigated conditions is important for the evaluation of genotypes and prediction of the success of the breeding program. Nowadays, several drought indices have been found to quantify drought stress (Sánchez-Reinoso *et al.,* 2020). Selection indices are an essential selection method that provides researchers with information about genotype traits that are correlated. They allow one to perform indirect selection particularly for characters that are difficult to select phenotypically and ultimately makes it possible for simultaneous selection of multiple traits (Michel *et al.,* 2019) and improving selection efficiency, and increasing chances of plant improvement in breeding programs (Lopez-Cruz *et al.*), 2020).

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Drought has different effects depending on the duration and severity of the stress, as well as the time of the cropping cycle when it occurs, making phonotypical screening of genotypes for drought tolerance difficult. Furthermore, there is not a unique or universal response to drought, many traits can be evaluated, and their contribution should be considered in terms of the targeted environment (Demicheli *et al.,* 2023) The primary breeding goals associated with soybeans include developing superior cultivars, improved yield, seed quality and resistance to biotic and abiotic stresses (Chigeza *et al.,* 2019) One of the best ways to make soybean production more stable and sustainable is by developing varieties with drought tolerance. As a result, drought tolerance has been identified as a major focus area for crop enhancement (Pennisi, 2008).

In Ethiopia, there were released over 38 soybean improved varieties by both regional and national research institutes up to 2024 for potential environments. So far, research in regards to drought tolerance and drought effects are not well studied on soybean genotypes which developed by soybean breeding programs and introduced from abroad world. Therefore, the main aim of this study was to figure out drought effects, selecting drought tolerant soybean genotypes for commercial production, and parental line for further drought tolerance improvement for soybean breeding programs.

2. Materials and methods

2.1. Experimental Site and Conditions

The present study was conducted during the 2021 winter seasons at Jawi district Tana Beles sugar factory Research irrigation site, which is found in Amhara national Regional State in Awi Zone. Experiment location was 1225 m above sea level and it was situated within 11° 33’22.68’’N latitude and 36° 29’17.58’’′ E longitude. The soil textural class was clay with 50.7% clay, 6.3% silt and 43% sand and a pH of five (5) from composite sampled taken form 0-30, 30-60, 60-90 and 90-100 cm depths.

2.2. Experimental Materials

Thirty-six early maturing genotypes and released soybean varieties were used for this study. These materials were introduced in various times from Nigeria, Malawi, USA, some were crossing promising lines, and registered improved varieties which released by federal and regional agricultural research institute in the country. The lists of materials used for this experiment are preset in Table 1.

2.3. Experimental Design and Cultural Practices

The experiment was two separate (first was fully irrigated control experiment and the 2nd stressed experiment) which arranged in simple lattice design. Each entry was planted on 2.4 m × 4m plot area and 100 kg ha-1 DAP which applied during plantings. The experiment was sown in January 2021 which is off season in North-western Ethiopia situations. The experiment was performed in conventional furrow irrigation with spacing of 60 cm between rows and around 20 cm raising bed (ridge depth). The seeds were planted in spaces of 5 cm between plants on one side of the ridges. Irrigation applied for both experiments every seven days interval from planting to 50% first flowering (R1 stage) at 100% FC (field capacity). The water application for control (fully irrigated experiment) was done in a week interval, planting to 95% physiological maturity (R7).

The stress created for stressed experiment at R1-R7 (Beginning maturity, one normal pod on the main stem that has reached its physiologically mature pod color) stages the irrigation water was applied in two weeks (14 days) intervals. Because soybean’s water requirement rate peaks at flowering to mid reproductive stages (7 to 8 mm per day). The most critical stage for drought stress in soybeans is flowering and a period after flowering (Yan *et al.,* 2020).

2.4. Data Collected

The phenological, yield and yield contributed traits data were recorded. At maturity, five plants were randomly selected from the two central rows of each plot and the following traits were measured: days to maturity, plant height (cm), number of pods plant^{-1}, and number of seeds pod^{-1}. Hundred seed weight, and seed yield kg ha^{-1} was calculated over all plants in the two central rows of the plot. Canopy wilting: data were recording for leaf wilting using a 1-5 scale (1= no wilting, 2= few top leaves wilting, 3=half of the leaves showed wilting, 4= sever wilting, ~75% of leaves wilting and 5= severely wilted) (Ye *et al.,* 2020). Rating of canopy wilting was taken on sunny and calm days between noon and 3:00

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Table 1: List of experimental materials used for this experiment

S.no.	Genotype	Source	Year of introduced/ Released	S.no.	Genotype	Source	Year of introduced/ Released
1	**Go-0391**	Jimma ARC	2012	19	Davis	Released Variety	1981/82
2	**FB-7636**	Jimma ARC	2012	20	TGx 1989-40F	IITA, Nigeria	2015
3	**SPRY**	Jimma ARC	2012	21	TGx 1990-55FP	IITA, Nigeria	2015
4	**Go-3705**	Jimma ARC	2012	22	TGx 2011-7F	IITA, Nigeria	2016
5	**L-13-S-5**	Awassa95 x Belesa 95	2013	23	Choska	Jimma ARC	2012
6	**TGx 1987-14F**	IITA, Malawi	2012	24	H16	CIMMYT	2012
7	**Primus**	Awassa ARC	2011	25	IPB-144-189	USA	2012
8	**TGx 2007-8F**	IITA, Nigeria	2016	26	TGx 1988-5E	IITA, Nigeria	2015
9	**AGS-214**	USA	2012	27	H5-822136	CIMMYT	2012
10	**TGx 1987-23F**	IITA, Malawi	2012	28	PROTONA2	Jimma ARC	2012
11	**T4-EL-LG-65-JM17-C18**	USA/Jimma ARC	2018	29	SR-4-1	Jimma ARC	2012
12	**Promveria**	Jimma ARC	2012	30	Awassa-95	Released Variety	2005
13	**L-6-S-5**	Hawassa 04 x Belesa 95	2013	31	T16-15-T31-16-5KL	USA/Jimma ARC	2018
14	**T24-15-T46-16-5A2**	USA/Jimma ARC	2018	32	TGx 1740-2F	IITA, Malawi	2012
15	**Hawassa 04**	Released Variety	2012	33	T1-EL-OS-JM17-E31	USA/Jimma ARC	2018
16	**Wiliams**	Released Variety	-	34	TGx 1987-11F	IITA, Malawi	2012
17	**H9**	CIMMYT/Jimma	2012	35	SR-4-3	Jimma ARC	2012
18	**Gazale**	Released Variety	2015	36	Nyala	Released Variety	2014

PM. In this study, canopy wilting was recorded 14 days after irrigation under stress environment. Drought Resistance Index (DRI): DRI is a simple and precise field technique to detect genotypic differences in drought resistance and quantify loss in yield under moisture stress conditions (Fischer and Maurer, 1978). DRI, GTI, SSI, PYR, and SSPI are calculated as:

Drought resistance index (DRI) = $\frac{Ys}{Yp} / \frac{Ys\mu}{Yp\mu}$

Genotype tolerance index (GTI) = $\frac{Ys}{Ys\mu} / (\frac{Yp}{Yp\mu})$

Stress susceptible index (SSI) = $\left(1 - \frac{Ys}{Yp}\right) / \left(1 - \frac{Ys\mu}{Yp\mu}\right)$

Percent of yield reduction (PYR) = $\frac{\text{yield under full irrigation} - \text{yield on stressed}}{\text{Yield under full irrigation}} X100$

Stress susceptible Percentage index (SSPI) = $\frac{\text{yield under full irrigation} - \text{yield on stressed}}{2*(\text{over all mean Yield under full irrigation})} X100$

Where Ys and Yp are genotype yields under stress and non-stress conditions, respectively, and Ysµ and Ypµ are the mean yields over all genotypes under stress and non-stress conditions, respectively.

2.5. Statistical Data analysis

For the data analysis variances, we were used META-R (2016) version 6.0 and Package 'AgroR' version 1.3.4 for correlation and principal component analysis (Shimizu *et al.,* 2023).

3. Results and Discussion

3.1. Mean performance and drought effects

The analysis result confirmed the there is a highly significant difference ($P<0.01$) among tested genotypes at both well irrigated (control) and partially irrigated (stressed) environments on numbers of pods plant-1 (Table 2). Similar significant results were reported for the trait pod numbers per plant in earlier studies (García Rodríguez *et al.,* 2017; Wijewardana *et al.,* 2018 and Giordani *et al.,* 2019). At control environment, the lowest number of pod plant-1 was recorded by Nyala (14.35) and the highest recorded SR-4-1 (49.42), TGx 1987-11F (47.17) and T24-15-T46-16-5A2 (39.07). While at drought stressed environment the lowest pod number plant recorded on TGx 2007-8F (9.6) and the largest was recorded on TGx 1987-11F, TGx 1987-23F and, SR-4-1 (40.72), (34.8), (34.42) respectively (Table 2). In this investigation, from a range of 3.5 to 64.3% on individual genotypes and 25.39% on average number of pods plant-1 were reduced due to drought stress (Table 3). Bhatia and Jumrani (2016) reported 31% average and 10–44 % range of number of pods per plant reduced. The smallest percent of reduction in pods per plant was obtained on genotype T16-15-T31-16-5KL (3.5 %) and Primus (3.85 %) and the largest reduction on genotype AGS-214, TGx 2007-8F, and L-13-S-5, (64.3 %), (57.87 %), (52.73 %), respectively. Previously, number of pods plant-1 reduced due to water deficit stress range from 22 to 51 % at R1 stage and 15 to 41% at R4 stage (Mimi *et al.,* 2016), and Riduan *et al.* (2022) reported 15.5%-82.4% pod reduction.

The statistical analysis of variance for yield is present in Table 3. The genotype variance was highly significant ($P<0.01$) at both well irrigated and drought stress environment on grain yield kg ha ^{1}. Similar significant results were reported for seed yield in earlier studies (Wijewardana *et al.,* 2018; Giordani *et al.,* 2019 and Mathonsi, 2021). The presence of variations among genotypes for the traits shows the higher chance of improving the crop through selection. Mean grain yield kg ha^{-1} in well irrigated environment was ranged from 573.16 for genotype TGx 1988-5E to 1057.44 for genotype L-13-S-5) with a mean of 750.22, while grain yield on drought stress environment ranged from 259.58 for genotype AGS-214 to 736.95 for TGx 1989-40F with mean of 499.19 kg ha^{-1} (Table 3). The genotype L-13-S-5, SPRY, GO-3705, T4-EL-LG-65-JM17-C18 and, TGx 2007-8F were presented outstanding performance on control environment where as genotype TGx 1989-40F, TGx 1990-55FP, G00391 and Promveria presented an outstanding performance on drought environment.

The investigation showed that, the level of yield reduction due to drought stress varies significantly from genotype to genotypes on a range of 2.49 % to 62.85 % which was recorded on average 33.46 % (Table 3). Based on this result, low yield reduction was seen on Go-0391, Promveria, TGx 1990-55FP, TGx 1987-23F, TGx 1989-40F, and SR-4-1 range from 2.49 % to 17.01 %. On the other hand, above 50 % significant yield reductions were obtained AGS-214 (62.85 %), TGx 2007-8F (61.57 %), Go-3705 (59.38 %), Primus (55.13 %), and Hawassa 04 (50.18 %) genotypes which are more susceptible to drought stress (Table 3). Previously reported yield reduction due to drought stress (Dalzotto, 2016) ranged between 14 to 42% in 2014 and from 16 to 49% in 2015; Makbul *et al*. (2011) 48.7%; Sadeghipour and Abbasi (2012) 24 to 50% both in the field and in the greenhouse experiment; Bhatia and Jumrani (2016) 19-57%; García Rodríguez *et al*. (2017) 41.55%; Wijewardana *et al*. (2018) 50 to 64%; and Riabukha *et al*. (2023) reported 70 to 77.2%, and 85.9 to 88.1 % of yield reduction due to drought severity for high and low resistant soybean cultivars, respectively.

Highly significant variations among tested genotypes were shown in days to 50 % flowering, 95 % days to maturity (DTM), plant height (PHT), number of seeds pod^{-1} (SdPP), a hundred seed weight (HSW) in both control and drought stress environment (Table 2). Similar significant results were reported for days to maturity and a hundred seed weight, (García Rodríguez *et al.,* 2017 and Wijewardana *et al.,* 2018), and Giordani *et al.,* (2019) and Poudel *et al.,* (2023) for a hundred seed weight, traits in earlier studies. According to the analysis result, Choska, TGx 2011-7F, TGx 2007-8F, IPB-144-189 early flowering on less than 30 days and TGx 1740-2F, TGx 1987-11F, PROTONA2, TGx 1989-40F, and TGx 1987-14F late flowering genotypes which were above 44 days in control environment. On the other side, TGx 1987-11F, TGx 1740-2F, TGx 1987-14F, SR-4-3, PROTONA2, SR-4-1, TGx 1988-5E, and TGx 1989-40F late flowering whereas Choska, TGx 2011-7F, TGx 2007-8F, IPB-144-189, T4-EL-LG-65-JM17-C18 and GO-3705 early flowering genotypes under drought stress environments (Table 2).

Following (Table 2), genotype FB-7636, IPB-144-189, Hawassa 04, PROTONA2, H5-822136, T4-EL-LG-65-JM17-C18, TGx 1987-14F, H_9 in full irrigated environment (control) and Hawassa 04, Davis, FB-7636, and IPB-144-189, H5-822136 were matured early in drought environment. Similarly, TGx 1987-11F, TGx 1740-2F, T16-15-T31-16-5KL, Primus, GO-3705, G00391, TGx 1987-23F, TGx 1989-40F, TGx 1988-5E, Awassa-95, SR-4-3, and Nyala were late matured genotypes at both environments. In this research, drought reduces 5.1 % of days to 95% physiological maturity on average (Table 3). Percent of reduction days to maturity was ranged between <1 % to 29.78 % due to drought stress. The largest percent of reduction in days to maturity were recorded in genotypes Davis (29.78%), Hawassa 04 (23.78%), TGx 2007-8F (16.91%), and TGx 2011-7F (16.21%) while the minimum reduction saw in TGx 1989-40F (0.04%), Choska (0.58%), H16 (0.61%).

A highly significant genotypic variation in plant height was noticed under both drought stress and well irrigated conditions (Table 2). Similar significant results were reported for this trait in earlier studies (Wijewardana *et al.,* 2018; Mathonsi, 2021 and Poudel *et al.,* 2023). Short plant height performance noticed in genotypes Davis, H5-822136, T1-EL-OS-JM17-E31, Primus, and Nyala on the other hand the long plant height was seen in genotypes TGx 1740-2F, SR-4-1, and L-13-S-5 under both conditions. Plant height was decreased due to drought stress in all genotypes evaluated ranging from 1.2 % to 36.58 % which is 13.38% on average (Table 3). Low percent of reduction due to drought stress in plant height was obtained in genotype Go-0391, Davis, T4-EL-LG-65-JM17-C18, SR-4-1, H16, and H5-822136 which were presented less than 5 % reduction. Contrastingly, substantial reduction in plant height was presented in genotypes FB-7636 (36.57 %), TGx 1987-14F (32.79%), Gazale (28.95%), H_9 (28.59%), Choska (28.05%), and Wiliams (26.56%).

The mean performance result confirmed that, a considerable number of seeds pod^{-1} was seen at drought stressed and control conditions (Table 2). Mean number of seeds pod-1 ranged from 1.91 for genotype IPB-144-189 to 2.32 for Wiliams with mean value of 2.08 at control environment. On the other hand, mean number of seed pod^{-1} in drought stressed environment ranged from 1.70 for genotypes TGx 1987-14F, and IPB-144-189 to 2.15 for a variety Awassa-95 with a mean value of 2.08. 1.88. Likewise, highly significant genotypic variation explained in seed size among evaluated genotypes under both environments.

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Table 2: Genotype mean performance under both full irrigated and drought stress environments.

Genotype	Days to flowering		Days to maturity		Plant height (cm)		Pods plant^{-1}		Seeds plant^{1}		Hundred seed weight	
	Optimum	Stressed	Optimum	Stressed	Optimum	stressed	Optimum	Stressed	Optimum	Stressed	Optimum	Stressed
G00391	40.86	40.83	92.97	90.55	36.97	36.53	19.81	17.90	2.10	1.84	**17.74**	**17.10**
FB-7636	34.99	33.54	73.08	72.11	39.82	25.25	18.76	15.04	2.11	2.01	14.47	14.18
SPRY	35.53	34.99	79.05	75.60	42.57	40.42	32.55	22.77	2.13	1.97	14.66	13.72
GO-3705	39.42	29.48	93.47	90.55	32.16	27.68	36.96	24.59	1.99	1.95	14.01	12.81
L-13-S-5	41.41	39.92	91.48	89.55	59.46	45.38	36.87	17.43	2.19	2.12	15.17	14.54
TGx 1987-14F	45.37	43.00	76.06	74.07	46.40	31.18	34.18	19.14	2.10	1.70	14.47	13.49
Primus	35.52	34.99	93.47	90.02	23.51	21.75	17.03	16.38	2.02	1.93	12.14	11.66
TGx 2007-8F	27.55	25.54	91.48	76.01	26.36	21.85	22.78	9.60	2.16	2.02	14.70	13.95
AGS-214	34.49	33.50	92.97	89.98	33.24	26.13	27.95	9.98	2.15	1.91	12.56	12.12
TGx 1987-23F	42.00	41.39	92.47	90.49	35.89	32.06	37.73	34.80	2.09	1.89	14.10	13.45
T4-EL-LG-65-JM17-C18	32.46	29.07	76.06	75.01	30.68	30.11	16.74	15.42	2.11	1.89	13.21	12.58
Promveria	41.39	41.00	90.98	89.99	34.51	32.64	18.47	15.90	2.01	1.84	17.74	16.92
L-6-S-5	37.49	37.48	89.49	74.02	38.84	32.83	22.11	13.42	2.21	2.03	14.94	14.09
T24-15-T46-16-5A2	36.04	36.03	90.98	87.98	42.67	34.29	39.07	21.15	2.02	1.86	15.17	14.18
Hawassa 04	34.02	33.58	75.57	57.59	25.28	22.92	21.82	15.52	1.95	1.74	12.14	11.66
Wiliams	35.07	34.55	91.48	81.03	34.51	25.35	19.62	14.28	2.32	2.00	12.14	11.89
H9	35.94	35.91	77.56	74.02	35.50	25.35	23.74	18.67	2.16	2.05	13.12	12.58
Gazale	34.95	34.91	90.48	89.49	36.08	25.64	21.92	19.81	2.07	1.85	13.31	13.04

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Davis	33.13	31.98	90.48	63.54	19.51	19.19	18.28	11.98	2.10	1.86	14.70	13.72
TGx 1989-40F	44.49	42.95	91.01	90.98	28.33	25.15	31.69	22.10	1.97	1.81	14.01	13.95
TGx 1990-55FP	43.52	41.93	88.50	87.46	37.66	36.04	37.34	32.41	1.97	1.72	13.77	13.26
TGx 2011-7F	25.16	24.52	89.49	74.98	23.76	22.63	18.09	16.71	2.01	1.83	13.77	12.58
Choska	25.12	23.98	88.99	88.47	25.77	18.54	18.18	12.37	2.11	1.92	14.01	12.58
H16	36.52	35.01	87.50	86.96	28.23	27.58	22.59	16.85	2.26	2.07	12.37	11.21
IPB-144-189	29.51	27.59	75.07	73.94	39.33	32.54	22.97	20.58	1.91	1.70	12.61	12.35
TGx 1988-5E	42.92	42.92	92.47	90.92	36.97	35.17	35.43	29.65	1.98	1.78	14.94	14.52
H5-822136	35.52	30.04	76.56	73.94	21.94	21.17	18.95	14.28	1.97	1.77	12.98	12.58
PROTONA2	44.42	42.99	76.56	74.50	39.52	31.38	36.77	32.61	2.02	1.86	11.91	10.75
SR-4-1	42.93	42.00	90.98	88.97	57.69	56.46	49.42	34.42	2.17	1.84	14.47	13.95
Awassa-95	37.53	36.00	91.48	90.44	38.44	36.53	16.74	13.99	2.28	2.15	15.26	14.68
T16-15-T31-16-5KL	36.04	35.50	94.46	90.45	38.18	34.61	18.95	18.29	2.01	1.85	14.64	14.20
TGx 1740-2F	45.47	43.46	93.97	91.95	62.60	51.11	36.48	21.53	1.99	1.82	13.91	13.49
T1-EL-OS-JM17-E31	33.07	32.52	93.47	89.45	22.83	21.56	23.26	20.29	2.02	1.77	12.61	12.12
TGx 1987-11F	44.54	44.11	94.46	91.49	45.22	38.38	47.12	40.72	1.96	1.78	14.10	13.63
SR-4-3	43.06	42.62	90.98	90.00	30.49	29.04	34.37	30.41	2.05	1.81	16.10	13.95
Nyala	34.61	34.59	92.47	90.45	22.24	21.17	14.35	12.08	2.11	1.92	15.31	14.86
Heritability	0.99	0.99	0.99	1.00	0.98	0.97	0.96	0.95	0.53	0.69	0.93	0.91
Genotype Variance	30.68	33.48	49.03	83.53	108.06	78.07	93.09	62.23	0.02	0.02	2.10	2.05
Residual Variance	0.48	0.36	0.54	0.32	3.92	4.45	8.13	5.91	0.03	0.02	0.30	0.38
Grand Mean	37.22	36.01	87.72	83.25	35.26	30.54	26.92	20.08	2.08	1.88	14.08	13.41
CV	1.85	1.67	0.84	0.68	5.62	6.91	10.59	12.10	8.81	6.96	3.91	4.62
LSD	1.46**	1.29**	1.50**	1.19**	4.00**	4.24**	5.69**	4.84**	0.27*	0.22*	1.08**	1.21**

The largest hundred seed weight was recorded by genotype G00391 (17.74 g), (17.1 g) at best and drought stressed environments respectively, while the smallest seed size by PROTONA2 (11.91 g), (10.75 g) at best and stressed conditions respectively (Table 3). In this research circumstance, confirmed that from 2.03 % to 13.38 % with an average 4.755 hundred seed weight and 2.08 % to 15.25 % with an average 9.28 % of seed numbers pod^{-1} were reduced in case of drought stress (Table 3). On average, 5% in number of seeds pod^{-1} and 23% a hundred seed weight reduction were in their earlier finding reported Bhatia and Jumrani (2016). However, Poudel *et al.* (2023) reported on average, most cultivars showed a high hundred seed weight under drought stress. In their finding wrote down that, among the cultivars, the highest increase in a hundred seed weight (40%) under drought stress and 26% in control environments. Hence, there is different from our result findings. From the earlier studies, it was well established that the reduction of seed size is due to the shortening of the seed-filling duration rather than affecting seed growth rate underwater deficit cited in (Wijewardana *et al.,* 2018).

In the present study, leaf wilting score pattern varied highly significantly among tested genotypes in this experiment (Table 3). King *et al*. (2009) noted that, Genotypes often differ in the severity of canopy wilting symptoms, which in turn constitutes selection criteria for breeders. Severe leaf canopy wilting with relatively substantially seed reduction were presented in Hawassa 04 (4.3), AGS-214 (3.73), Primus (3.14), T16-15-T31-16-5KL (3.96), and T1-EL-OS-JM17-E31 (3.67) which means above 75% of leaves were shown wilted. On the other hand, Promveria, (0.98), and TGx 1987-23F (1.48) noticed the smallest wilting scores. Hence, almost there was no leave canopy wilted and minimum yield reduction because of drought has been conceded in these genotypes. Earlier studies supported that, slow canopy wilting is a valuable trait that can improve drought tolerance, and it is the primary visual symptom seen in a crop under water-deficit conditions (Charlson *et al.,* 2009).

3.2. Genotype tolerance and susceptible indices

For every genotype, a substantial difference was found in the mean grain yield under drought stress compared to the well irrigated condition, showing a variation in performance between the two scenarios. Promveria, TGx 1989-40F, TGx 1990-55FP, SR-4-1, and TGx 1987-23F were statistically comparable to Go-0391's highest drought resistance index (DRI) score of 1.46 (Table 3). A genotype ability to withstand drought stress is shown by a higher DRI number. According to the stress susceptibility index (SSI), Go-0391, Promveria, TGx 1987-23F, TGx 1990-55FP, TGx 1989-40F, SR-4-1, TGx 1988-5E, and FB-7636 were shown lower values in arrange of 0.07 to 0.59 SSI. Greater yield stability is suggested by the lower SSI value. Similarly, these genotypes were displayed lower stress susceptible percentage index (SSPI) values from 1.11% to 9.14 % and percent of yield reduction due to drought stress from 2.49 % to 19.69 %. Hence, these genotypes were relatively tolerant to drought stress as compare to the rest of materials tested in this experiment. Large stress susceptible percentage index (SSPI) value had presented in genotype Go-3705 (38.36%), TGx 2007-8F (37.24%), T4-EL-LG-65-JM17-C18, AGS-214, L-13-S-5, SPRY, Hawassa 04, Primus and T16-15-T31-16-5KL in a ranging from 26.2% to 38.36%. These genotypes were also showed consistence yield reduction from 41.84% to 62.85%, which implies the highly susceptible for drought stress.

3.3. Correlation of drought indices

To figure out the most desirable drought tolerance criteria, the correlation coefficient between yield under the well irrigated (YI), drought stress conditions (Ys), and indices of drought tolerance and susceptible were found (Fig.1). The results of the correlation analysis showed that both positive and negative associations, showing that some of the indices are generally similar and dissimilar in genotypic ranking, respectively. A significant positive association among PYR, SSPI, SSI and YI and significant ($P<0.01$) negative correlation between PYR, SSPI, SSI and Ys implied that choice genotypes based on PYR, SSPI, SSI well leads to yield rewarding for drought stress and reduction of yield under well irrigated condition (Fig. 1). The significant negative association of PYR, SSPI, and SSI with yield under drought stress condition Consistence with low PYR, SSPI, SSI value, showed that genotypes had low yield difference between well irrigated and stressed environments. On the other hand, the genotype tolerance index (GTI) had significant ($P<0.01$) positive correlation with grain yield under both drought stress and normal conditions. Therefore, this decided that choice based on GTI is effective for well irrigated as well as drought stress environments.

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Table 3: Mean yield performance, tolerance and susceptible indices of yield and other related trait

		Yield kg ha^{-1}						Percent of reduction due to drought stress (%)						Wilting
	Genotype	**Optimum**	**Stressed**	**DRI**	**GTI**	**SSI**	**SSPI**	**Yield**	**DTM**	**PHT**	**PPP**	**SdPP**	**HSW**	**stressed**
1	**Go-0391**	671.27	654.55	1.46	1.17	0.07	1.11	2.49	2.61	1.19	9.63	12.37	3.57	2.41
2	**FB-7636**	730.23	584.97	1.20	1.14	0.59	9.68	19.89	1.33	36.58	19.82	4.81	2.03	2.2
3	**SPRY**	980.43	552.64	0.84	1.45	1.30	28.51	43.63	4.36	5.05	30.05	7.58	6.39	2.7
4	**Go-3705**	969.21	393.70	0.61	1.02	1.77	38.36	59.38	3.12	13.92	33.48	2.08	8.56	2.92
5	**L-13-S-5**	1057.44	614.96	0.87	1.74	1.25	29.49	41.84	2.11	23.69	52.73	3.45	4.14	2.42
6	**TGx 1987-14F**	841.93	603.22	1.07	1.36	0.85	15.91	28.35	2.62	32.79	43.99	18.83	6.77	2.03
7	**Primus**	713.09	319.98	0.67	0.61	1.65	26.20	55.13	3.69	7.50	3.85	4.80	3.92	3.14
8	**TGx 2007-8F**	907.56	348.80	0.57	0.85	1.84	37.24	61.57	16.91	17.12	57.87	6.47	5.14	2.73
9	**AGS-214**	698.82	259.58	0.55	0.48	1.88	29.27	62.85	3.21	21.39	64.30	11.21	3.49	3.73
10	**TGx 1987-23F**	661.61	571.97	1.29	1.01	0.40	5.97	13.55	2.15	10.68	7.76	9.57	4.62	1.48
11	**T4-EL-LG-65-JM17-C18**	963.13	512.77	0.79	1.32	1.40	30.02	46.76	1.38	1.86	7.90	10.41	4.80	2.98
12	**Promveria**	701.63	653.79	1.39	1.22	0.20	3.19	6.82	1.09	5.43	13.92	8.58	4.60	0.98
13	**L-6-S-5**	839.24	489.41	0.87	1.10	1.25	23.32	41.68	17.29	15.45	39.32	8.30	5.70	2.32
14	**T24-15-T46-16-5A2**	843.18	513.49	0.91	1.16	1.17	21.97	39.10	3.30	19.62	45.87	8.04	6.55	2.19
15	**Hawassa 04**	799.68	398.39	0.74	0.85	1.50	26.75	50.18	23.78	9.35	28.90	11.15	3.92	4.3
16	**Wiliams**	719.46	504.00	1.05	0.97	0.90	14.36	29.95	11.43	26.56	27.23	13.67	2.04	2.6
17	**H9**	827.30	615.80	1.11	1.36	0.76	14.10	25.56	4.56	28.59	21.36	4.88	4.12	2.82
18	**Gazale**	642.96	416.47	0.97	0.72	1.05	15.09	35.23	1.10	28.95	9.61	10.92	2.03	2.32
19	**Davis**	591.24	350.74	0.89	0.55	1.22	16.03	40.68	29.78	1.64	34.43	11.28	6.69	2.77
20	**TGx 1989-40F**	874.15	736.95	1.26	1.72	0.47	9.14	15.70	0.04	11.20	30.25	7.77	0.40	2.96

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21	**TGx 1990-55FP**	794.60	690.80	1.30	1.47	0.39	6.92	13.06	1.17	4.28	13.20	12.45	3.69	3.36
22	**TGx 2011-7F**	628.13	377.16	0.90	0.63	1.19	16.73	39.96	16.21	4.77	7.61	8.86	8.67	2.36
23	**Choska**	587.59	311.01	0.79	0.49	1.41	18.43	47.07	0.58	28.05	31.98	8.66	10.19	2.49
24	**H16**	619.37	491.06	1.18	0.81	0.62	8.55	20.72	0.61	2.28	25.39	8.66	9.43	1.6
25	**IPB-144-189**	605.98	482.86	1.19	0.78	0.61	8.21	20.32	1.50	17.25	10.43	11.23	2.04	2.62
26	**TGx 1988-5E**	573.16	460.33	1.20	0.70	0.59	7.52	19.69	1.68	4.87	16.32	10.20	2.79	2.51
27	**H5-822136**	699.19	541.47	1.16	1.01	0.67	10.51	22.56	3.43	3.53	24.66	9.82	3.09	2.37
28	**PROTONA2**	640.53	489.54	1.14	0.84	0.70	10.06	23.57	2.70	20.61	11.32	7.87	9.72	3.48
29	**SR-4-1**	763.88	633.97	1.24	1.29	0.51	8.66	17.01	2.21	2.13	30.35	15.25	3.61	2.48
30	**Awassa-95**	685.66	530.01	1.15	0.97	0.68	10.37	22.70	1.13	4.98	16.45	6.04	3.82	2.29
31	**T16-15-T31-16-5KL**	868.76	466.11	0.80	1.08	1.39	26.84	46.35	4.25	9.35	3.50	7.95	3.01	3.96
32	**TGx 1740-2F**	632.18	373.61	0.88	0.63	1.22	17.23	40.90	2.15	18.35	40.98	8.77	3.02	2.67
33	**T1-EL-OS-JM17-E31**	686.00	418.94	0.91	0.77	1.16	17.80	38.93	4.30	5.56	12.77	12.35	3.85	3.67
34	**TGx 1987-11F**	725.48	569.58	1.17	1.10	0.64	10.39	21.49	3.14	15.13	13.58	9.16	3.33	2.65
35	**SR-4-3**	751.64	572.26	1.14	1.15	0.71	11.96	23.87	1.08	4.74	11.53	11.63	13.38	3.15
36	**Nyala**	712.17	465.83	0.98	0.89	1.03	16.42	34.59	2.18	4.81	15.81	9.11	2.92	2.67
	Heritability	0.81	0.83											
	Genotype Variance	19618.26	16497.21											
	Residual Variance	9313.52	6670.38											
	Grand Mean	750.22	499.19					33.46	5.10	13.38	25.39	9.28	4.75	2.66
	CV	12.86	16.36											30.27
	LSD	190.45**	166.62**											1.79**

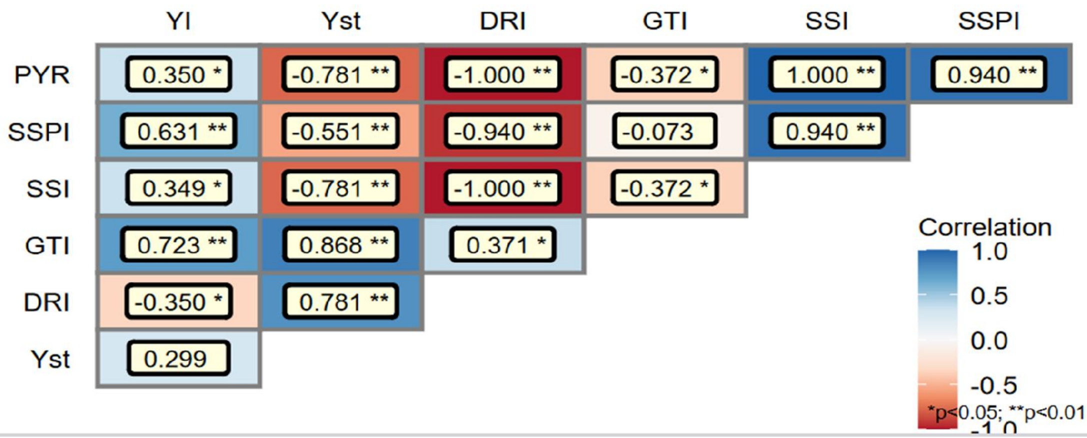

Fig. 1: Pearson correlation of different indices

Where: - YI=yield under well irrigated, Yst=yield under drought stress condition, DRI= drought resistance index, GTI= genotype tolerance index, SSI=stress susceptible index, and SSPI=stress susceptible percentage index, and PYR= percent of yield reduction due to drought stress

3.4. Principal component analysis

The principal components of grain yield under both irrigated and stressed environments with drought susceptible and tolerance indices of soybean genotypes are presented in (Fig. 2). The PC analysis was performed to find the association between all attributes to find outstanding genotypes under both environments. The principal components were able to explain 99.57% of the total variation in soybean yield under both well irrigated and drought stress conditions. The first principal component explained 68.33% and the second principal component were explained 31.24% of the variation in yield, Yp, Yst, GTI, DRI, SSPI, and SSI in this study (Fig. 2).

The principal analysis result groups the genotypes into four zones (Fig. 2). The first zone is top right of the biplot which stands for low yielder in drought stress condition, below average performance under both conditions and susceptible to drought stress. Among the 36 genotypes, nine genotypes are found in this zone which had 34.59 % to 62.85 % yield reduction (Table 3 and Fig. 2). The second zone, top left of the graphs. Eleven genotypes were found in these groups with drought tolerant genotypes below average performance under full irrigated conditions, high drought resistance index (DRI), and yield reduction ranging from 2.49 % to 29.95%. Among the genotypes in this zone, G1, G12, and G10 were relatively the best drought tolerant. Therefore, these genotypes could be important used in soybean breeding program for drought tolerance improvements. On the other hand, in the bottom left parts seven genotypes with above average mean performance under both conditions, tolerant and high yielder under stress condition, and high genotype tolerance index (GTI) had existed. From those genotypes, G21, G20 and G29 were relatively tolerant with below 18 % yield reductions due to drought stress. Among the genotypes G20 (TGx 1989-40F) is new released early set soybean variety which released in 2024. Therefore, we recommended this variety for commercial production in drought prone areas of Ethiopia. The fourth zone is bottoming right, ten genotypes with high yielder at well irrigated condition, high SSI, SSPI and PYR (Fig. 2). These genotypes are susceptible to drought stress with a percentage yield reduction between 39.1 % (G14) to 61.57 % (G8) Table 3.

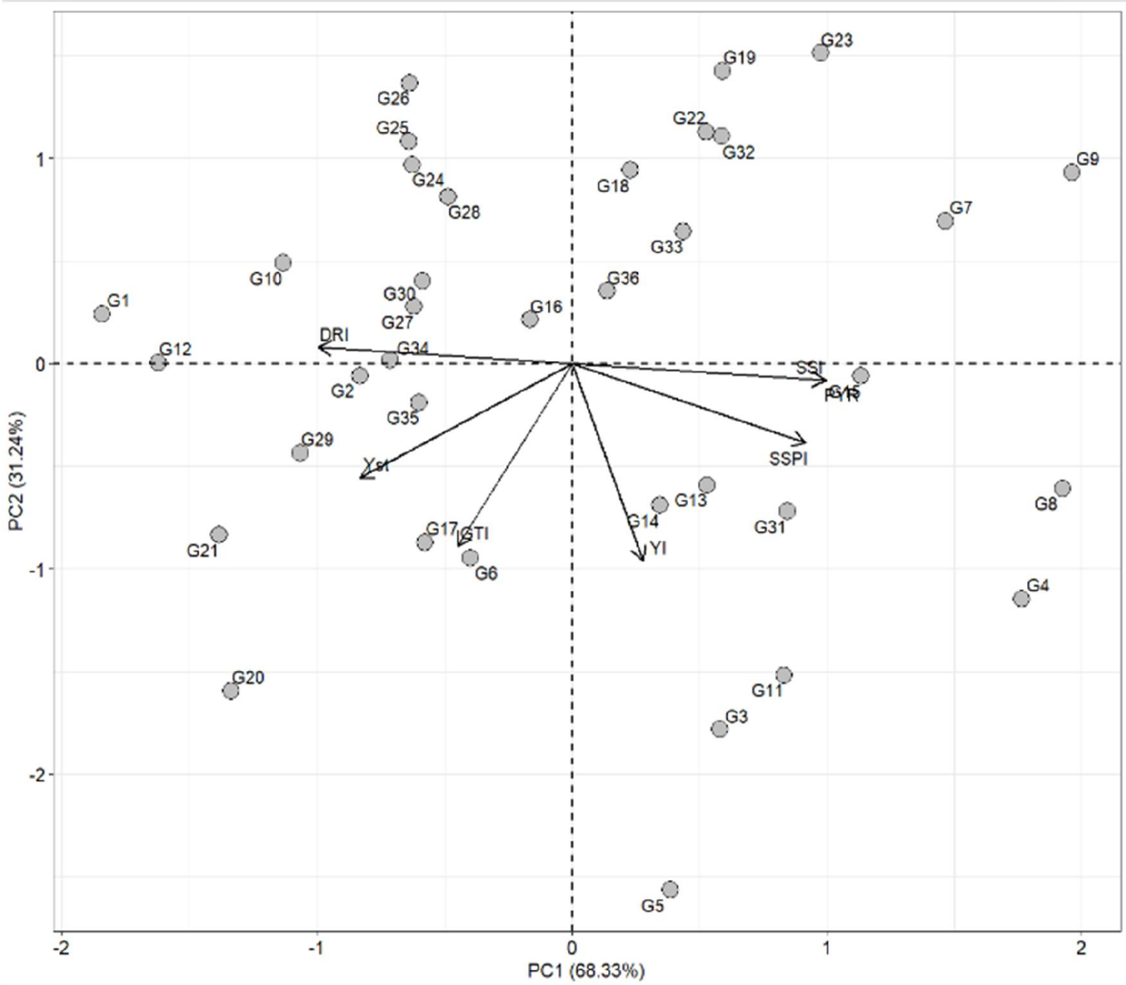

Fig. 2: Biplot based on yield under full irrigated, drought and drought tolerance indices of PC analysis

Where: - YI=yield under well irrigated, Yst=yield under drought stress condition, DRI= drought resistance index, GTI= genotype tolerance index, SSI=stress susceptible index, and SSPI=stress susceptible percentage index, and PYR= percent of yield reduction due to drought stress

4. Conclusions

This experiment was done under two separate growing environments, that full irrigation (optimal), and drought conditions. The results pointed out significant variations among the tested genotypes, resulting in considerable variations in yield and drought tolerance that should be exploited in soybean variety improvement. Based on the indices used in the present study had resulted that, seven genotypes were high yielder drought tolerant, eleven genotypes were low yielder drought tolerant, nine genotypes high yielder drought susceptible, and other nine genotypes were identified as low yielder drought susceptible. Therefore, G21 (TGx 1990-55FP), G2 (FB-7636), G29 (SR-4-1), G1 (Go-0391), G12 (Promveria), and G10 (TGx 1987-23F) are identified as best potential parental genotypes that can be used to enhance drought tolerance in future soybean breeding. Whereas G20 (TGx 1989-40F) was ranked 1st under drought stress environment and 6th under optimal environment. This genotype had relative high drought resistance index (1.26), genotype tolerance index (1.72), low stress susceptible index (0.47), and stress susceptible percentage index (9.14%). It was released as a new early maturing variety in 2024. Hence, we recommended this variety for commercial production in drought prone areas of Ethiopia.

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References

Bhatia, V.S. and K. Jumrani, 2016. A maximin–minimax approach for classifying soybean genotypes for drought tolerance based on yield potential and loss. Plant Breeding 135(6): 691-700.

Charlson, D.V., S. Bhatnagar, C.A. King, J.D. Ray, C.H. Sneller, T.E. Carter, and L.C. Purcell, 2009. Polygenic inheritance of canopy wilting in soybean [Glycine max (L.) Merr.]. Theoretical and Applied Genetics, 119: 587-594.

Chigeza, G., S. Boahen, M. Gedil, E. Agoyi, H. Mushoriwa, N. Denwar, T. Gondwe, A. Tesfaye, A. Kamara, O.E. Alamu, and D. Chikoye, 2019. Public sector soybean (Glycine max) breeding: Advances in cultivar development in the African tropics. Plant Breeding, 138(4): 455-464.

Dalzotto, M.B., 2016. Selection of Drought-Tolerant Soybean Lines Using a Field Screening Method and Identification of QTLs for Slow Wilting and Nitrogen Fixation Associated with Drought Tolerance. Graduate Theses and Dissertations Retrieved from https: //scholar works. uark.edu/etd/1761

Demicheli, J., I. Sabljic, G. Beguy, E. Ploschuk, M. Sahrawy, A.J. Serrato, and E.A. Pagano, 2023. Improving drought tolerance in soybean by classical breeding leads to physiological adjustments of photosynthesis and stomata functioning. *Plant Stress,* 10: 100275.

FAO, F.A.O.S.T.A.T., 2018. Food and agriculture organization of the United Nations. Rome, URL: http://faostat. fao. org, pp.403-403.

Fischer, R.A. and Maurer, R., 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Australian Journal of Agricultural Research, 29(5): 897-912.

García Rodríguez, J.C., A. Muñoz Orozco, N. Maldonado Moreno, S. Cruz Izquierdo, and G. Ascencio Luciano, 2017. Resistance to drought in soybean genotypes considering morphological, physiological and agronomic characters. Revista mexicana de ciencias agrícolas, 8(2): 431-437.

Giordani, W., L.S.A. Gonçalves, L.A.C. Moraes, L.C. Ferreira, N. Neumaier, J.R.B. Farias, A.L. Nepomuceno, M.C.N. de Oliveira, and L.M. Mertz-Henning, 2019. Identification of agronomical and morphological traits contributing to drought stress tolerance in soybean. Australian Journal of Crop Science, 13(1): 35-44.

Gregorio, A., L. Marco, V. Mateo, P. Angela, R. Fransisco, B. Juan, and C. Jose, 2016/11/30. META-R (Multi environment trial analysis with R for windows) version 6.0 http://hdl.handle.net/11529/10201 International Maize and Wheat improvement center.

King, C.A., L.C. Purcell, and K.R. Brye, 2009. Differential wilting among soybean genotypes in response to water deficit. Crop science, 49(1): 290-298.

Lopez-Cruz, M., E. Olson, G. Rovere, J. Crossa, S. Dreisigacker, S. Mondal, R. Singh, and G.D.L. Campos, 2020. Regularized selection indices for breeding value prediction using hyper-spectral image data. *Scientific Reports*, 10(1): 8195.

Makbul, S., G.N. Saruhan, N. Durmuş and S. Güven, 2011. Changes in anatomical and physiological parameters of soybean under drought stress. Turky Journal of Botany, 35: 369-377.

Mathonsi, T.L., 2021. Evaluation of soybean (Glycine max L. Merr.) lines for grain yield and drought-tolerance (Ph.D Thesis).

Michel, S., F. Löschenberger, C. Ametz, B. Pachler, E. Sparry, and H. Bürstmayr, 2019. Simultaneous selection for grain yield and protein content in genomics-assisted wheat breeding. Theoretical and Applied Genetics, 132: 1745-1760.

Mimi, A., M.A. Mannan, Q.A. Khaliq, and M.B. Mia, 2016. Yield response of soybean (Glycine max L.) genotypes to water deficit stress. Bangladesh Agronomy Journal 19(2): 51-60.

Naumann, G., L. Alfieri, K. Wyser, L. Mentaschi, R.A. Betts, H. Carrao, J. Spinoni, J. Vogt, and L. Feyen, 2018. Global changes in drought conditions under different levels of warming. Geophysical Research Letters, 45(7): 3285-3296.

Pennisi, E., 2008. Getting to the root of drought responses. Science, 320(5873): 173-173.

Poudel, S., R.R. Vennam, A. Shrestha, K.R. Reddy, N.K. Wijewardane, K.N. Reddy, and R. Bheemanahalli, 2023. Resilience of soybean cultivars to drought stress during flowering and early-seed setting stages. *Scientific Reports*, 13(1): 1277.

Riabukha, S.S., P.V. Chernyshenko, I.M. Bezuhlyi, and M.H. Holokhorynska, 2023. Determination of drought resistance of soybean breeding material. UDC 635.655:631.527:581.1910. DOI:10.30835/2413-7510.2023.283655.

Riduan, A., R. Rainiyati, Y. Alia, and S. Nusifera, 2022. Tolerance some soybean cultivars to stress drought at vegetative to generative phase. Journal Penelitian Pendidikan IPA, 8:1-11.

Sadeghipour, O. and S. Abbasi, 2012. Soybean response to drought and seed inoculation. World Applied Science Journal, 17:55-60.

Sánchez-Reinoso, A.D., G.A. Ligarreto-Moreno, and H. Restrepo-Díaz, 2020. Evaluation of drought indices to identify tolerant genotypes in common bean bush (*Phaseolus vulgaris* L.). Journal of Integrative Agriculture, 19(1): 99-107.

Shimizu, G., R. Marubayashi, and L. Goncalves, 2023. *AgroR: Experimental Statistics and Graphics for Agricultural Sciences*. https://agronomiar.github.io/AgroR package/index.html, https://fisher.uel.br/AgroR_shiny, https://fisher.uel.br/AgroR_shiny.pt.

Wijewardana, C., K.R. Reddy, F.A. Alsajri, J.T. Irby, J. Krutz, and B. Golden, 2018. Quantifying soil moisture deficit effects on soybean yield and yield component distribution patterns. Irrigation Science, 36: 241-255

Yahoueian S.H., M.R. Behamta, H.R. Babaie and M. Mohammadibazar gani, 2017. Screening of drought tolerant genotypes in soybean using different methods. International Journal of Agricultural Research, Innovation and Technology, 7(2): 7-17.

Yan, C., S. Song, W. Wang, C. Wang, H. Li, F. Wang, S. Li, and X. Sun, 2020. Screening diverse soybean genotypes for drought tolerance by membership function value based on multiple traits and drought-tolerant coefficient of yield. BMC Plant Biology, 20: 1-15.

Ye, H., L. Song, W.T. Schapaugh, M.L. Ali, T.R. Sinclair, M.K. Riar, R.N. Mutava, Y. Li, T. Vuong, B. Valliyodan, and A. Pizolato Neto, 2020. The importance of slow canopy wilting in drought tolerance in soybean. Journal of Experimental Botany, 71(2): 642-652.