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Evaluation of sesame (*Sesamum indicum* L.) varieties for drought tolerance using agromorphological traits and drought tolerance indices

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Sesame (*Sesamum indicum* L.) is an important cash crop cultivated under rain-fed condition and contributing a significant proportion of Ethiopia's foreign exchange earnings. However, its productivity is constrained by drought stress. The present study aimed to identify drought tolerant varieties using agromorphological traits and drought tolerance indices. The sesame varieties were evaluated under well watered (WW) and water stressed (WS) conditions in a field with a factorial design laid down in randomized complete block design in three replications. The results revealed a significant variation in agromorphological and drought tolerance indices due to water levels, varieties and interactive effect. On average, a 21.8, 49.6, 48.4, 47.9 and 21.7% reduction was recorded in plant height, number of leaves, leaf length, leaf width and relative growth rate (RGR), respectively under WS condition. Similarly, a significant reduction in shoot biomass, root biomass, biological yield, numbers of pods per plant and seed yield was found under WS condition in the study varieties. These traits showed an average reduction of 52.2, 72.5, 54.0, 51.9 and 52.8%, respectively as compared to WW condition. The highest yield reduction was recorded in wollega, while the lowest was in abasena. Wollega variety produced the highest seed yield ha^{-1} under WW condition, while gondar-1 and humera-1 had the highest yield ha^{-1} under WS condition. Under both water levels, abasena produced the lowest yield ha^{-1}. Moreover, gondar-1 and humera-1 varieties had a comparatively higher values of stress tolerance index (STI), yield stress score index (YSSI), yield potential score index (YPSI), geometric mean productivity (GMP) and mean productivity (MP) that are significantly and positively correlated with yield under WS, indicating higher yield performance under water stress. The biplot analysis clustered the varieties as low yielding (abasena) and relatively above average performing varieties (humera-1, gondar-1 and wollega). According to the rank sum of all indices, humera-1 was identified as drought tolerant, while abasena as the most susceptible and low yielding varieties. Thus, humera-1 followed by gondar-1 are found to be drought tolerant and high yielding varieties. However, further studies focusing on drought tolerance mechanisms of the varieties are recommended.

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Abstract

Sesame (*Sesamum indicum* L.) is an important cash crop cultivated under rain-fed condition and contributing a significant proportion of Ethiopia's foreign exchange earnings. However, its productivity is constrained by drought stress. The present study aimed to identify drought tolerant varieties using agromorphological traits and drought tolerance indices. The sesame varieties were evaluated under well watered (WW) and water stressed (WS) conditions ~~in a field~~ with a factorial design laid down in randomized complete block design in three replications. The results revealed a significant variation in agromorphological and drought tolerance indices due to water levels, varieties and interactive effect. On average, a 21.8, 49.6, 48.4, 47.9 and 21.7% reduction was recorded in plant height, number of leaves, leaf length, leaf width and relative growth rate (RGR), respectively under WS condition. Similarly, a significant reduction in shoot biomass, root biomass, biological yield, numbers of pods per plant and seed yield was found under WS condition in the study varieties. These traits showed an average reduction of 52.2, 72.5, 54.0, 51.9 and 52.8%, respectively as compared to WW condition. The highest yield reduction was recorded in wollega, while the lowest was in abasena. Wollega variety produced the highest seed yield ha^{-1} under WW condition, while gondar-1 and humera-1 had the highest yield ha^{-1} under WS condition. Under both water levels, abasena produced the lowest yield ha^{-1}. Moreover, gondar-1 and humera-1 varieties had a comparatively higher values of stress tolerance index (STI), yield stress score index (YSSI), yield potential score index (YPSI), geometric mean productivity (GMP) and mean productivity (MP) that are significantly and positively correlated with yield under WS, indicating higher yield performance under water stress. The biplot analysis clustered the varieties as low yielding (abasena) and relatively above average performing varieties (humera-1, gondar-1 and wollega). According to the rank sum of all indices, humera-1 was identified as drought tolerant, while abasena as the most susceptible and low yielding varieties. Thus, humera-1 followed by gondar-1 are found to be drought tolerant and high yielding varieties. However, further studies focusing on drought tolerance mechanisms of the varieties are recommended.

Keywords: Abasena, drought tolerance indices, humera-1, gondar-1, wollega, stress tolerance index, seed yield

Introduction

Sesame (*Sesamum indicum* L.) is an annual oil seed crop widely grown in arid and semiarid tropical and sub-tropical regions (*Weiss, 1983*). It belongs to *Pedaliaceae* family and *Sesamum* genus. The genus consists of 20 species native to Africa and Asia (*Bedigian, 2015*). However, *S. indicum* has been recognized as a cultivated species. It is one of the oldest and most traditional oilseed crops, valued for its high-quality seed composed of 44–57% oil, 18–25% protein, 13–14% carbohydrates (*Borchani et al*., 2010). Evidences about the origin of sesame are debatable.

Nevertheless, most researchers claim that sesame was first cultivated in Africa and later taken to India (*Alegbejo et al*., *2003*).

In Ethiopia, the production of sesame is rain-fed, characterized by intensive labour and low levels of inputs (*Coates et al*., *2011*). It grows in a wide variety of soil types. However, the crop thrives best on well drained and medium textured fertile soil with pH range of 5 to 8. It also needs adequate moisture for germination and early growth. Precipitation of 300-800 mm per season is necessary for reasonable yields (*Terefe et al., 2012*). Sesame is temperature sensitive that requires hot conditions during growth to produce maximum yields. It shows optimum development and yield at 25 to 37ºC temperature throughout its growth period. Generally, the crop grows to a height of 1.5 to 2.0 m depending on the variety and growing conditions (*Terefe et al., 2012*).

Sesame is produced in different parts of Ethiopia starting from an elevation of 1500 meter above sea level. The major producers that contribute over 83% to the national production (*CSA, 2011*), are located in the regions of Tigray (West Tigray), Amhara (North Gondar) and most recently, in Benishangul-Gumuz Region (Metekel). In the years 2005-2012, on average, almost 37% of the country's total seed production is contributed by the Amhara Regional state, 30% from Tigray and 16% from Oromia (*CSA, 2013*). Sesame production shows an increasing trend through the years. In 2014/15 cropping season, 464 000 metric tons sesame seed was produced. This increased to 487 000 metric tons in 2015/16. It showed 5% increment. The increment has been brought mainly by expansion of production area (*Francom, 2016*) due to the fast growing nature of the oilseed sector in the country. It has become the second largest source of foreign exchange earnings after coffee (*FAO, 2012*).

The average yield of sesame is low in Ethiopia. For the years 2005-2012; the highest average productivity of sesame for Tigray was about 9 quintals/hectare, followed by Amhara region about 8 quintals/hectare. This is lower almost by half than the potential yield of the crop estimated by FAO, which is 16 quintals/ha (*FAO, 2015*). According to *Gelalcha* (*2009*), the low sesame productivity is attributed to a combination of various factors. The major constraints include lack of improved seeds (*Teklu et al., 2021*), drought stress, low fertilizer input, biotic stress, heat, indeterminate flowering nature and shattering of capsules at maturity and paucity of knowledge on postharvest crop management practices (*Endale, 2017*). As a rainfed crop commonly cultivated in arid and semiarid tropics, sesame is frequently exposed to terminal drought (*Pandey et al., 2021*) and such exposure has reduced grain yield by 52% as compared to the non-stressed ones (*Kim, Park & Jenks, 2007; Golestani & Pakniyat, 2015*). Moreover, the rainfall distribution in the study area is significantly erratic that impedes the productivity of sesame. The crop is sensitive to drought, especially at the vegetative stage (Boureima *et al.*, 2011). This is reflected in the changes that occur subsequently in plant metabolism, growth, development and yield. However, the effect of drought is more severe on seed yield than other morphological characters. According to *Kim, Park & Jenks, (2007*) sesame yield reduction owes to the decreased number of seeds under drought stress. Research reports have revealed that various sesame varieties show variable responses to drought, with some varieties being highly tolerant and others more susceptible (*Boureima et al., 2011*).

Despite the high genetic diversity of sesame in the country; more than 870 accessions (*Teshome, Tesfaye & Bekele, 2015*), studies focusing on evaluation of sesame genotypes under drought stress conditions using agromorphological traits and drought tolerance indices are scarce. Selecting genotypes with optimal performance under both stress and non-stress conditions from other groups is the best tool for identifying genotypes for drought tolerance (*Fernandez, 1992*). Several such criteria have been proposed, most of which were used in this study to select the best sesame varieties for drought tolerance and recommend suitable sesame varietiesa in drought prone areas in the country.

MATERIAL and METHODS

Description of the experimental area

The experiment was conducted at Liben senior secondary and preparatory school found in Amhara Region, western Gojjam zone, North Achefer district (Fig. 1). The school is located at 11°41'51"N latitude and 36°56' 35' east longitude. The area has arid and semi-arid climatic conditions with soil suitable for irrigation. The altitude of the district ranges 1500 to 1800 meter above sea level (m.a.s.l). It is also characterized by unimodal rainfall with an average annual rainfall ranging from 1000 to 1500mm. The minimum and maximum daily temperatures are 25°C and 30°C, respectively (NADoA, 2013 cited in *Demeke, Mekuriaw & Asmare, 2017*).

Study plant materials

A total of four sesame varieties were used in this study. All of them were released varieties; T-85, Kelafo-74, Mehado-80 and Abasena. The former two were released in 1976 and the later in 1989. They are the main export varieties and well known by their market names as humera-1, gondar-1, wollega and abasena, respectively. Then after, the market names are used. Humera-1 is characterized by whitish, large & sweet taste seeds, high productivity, high shattering property, 45-50% oil content, maturity time of 110-115 and adapted to the Humera plains (*Jelata, 2012*). Gondar-1 has light brown and good uniformity of seed, a maturity date ranging from 110-120 days. It is released and adapted to the Gode region (*Endale, 2017*). Similarly, wollega is characterized by its small grey seeds, high oil content (49-56%), low sweetness, maturity date of

100-110 days and released and adapted to irrigated areas of Awash valley (*Jelata, 2012;Endale, 2017*). Abasena on the other hand is characterized by gray, large and sweet taste seeds, high productivity, high shattering property, 44-48% oil content, maturity time of 110-120 days and adapted to high rainfall (*Bekora, 2013*). Seeds of humera-1, gondar-1 and abasena were collected from Amhara Agricultural Research Institute, Gondar Agricultural Center, and seed of wollega variety was collected from local farmers around the study area.

Experimental Design and Treatments

The experimental field was tilled using human power. All the weeds and large plant debris were removed manually from the experimental field. Then, it was exposed to sunshine for 6 days prior to the next tilling. The land ploughed again and again until smooth soil particles were obtained as this is necessary for the better growth of the crop. The field was ploughed, leveled, ridged and divided into plots before sowing.

The field experiment was carried out using factorial design laid down in a randomized complete block design (RCBD) with three replications. The size of the experimental field was $39m^2$ (9.75m x 4m) consisting of 24 plots each with $1m^2$ area, distributed in three replications that are 0.5m far apart. Each replication consisted of eight plots with 0.25m spacing to prevent lateral penetration of water. Each plot had three rows with 37cm spacing. There was 18.5cm spacing between sesame plants. Around each plot, 13cm area was left to avoid edge effect. Four holes were prepared along each row and three seeds were hand sown in each. The sesame varieties were assigned to plots randomly by lottery method. Thinning to one plant/hole was carried out after complete emergence. N and P inorganic fertilizers were applied at the rate of 100kg/ha (*Zenawi & Mizan, 2019*) and 46kg/ha (*Gebremariam, 2015*), respectively. All the P and half of the N fertilizers were applied at the time of sowing and the remaining half N at branching stage.

The common management practices such as weeding, pesticide and other parasites monitoring and control were carried out as needed.

Treatments consisted of four sesame varieties grown under two water levels. The water levels were determined gravimetrically as described by *Turner (2018)*. Bottom perforated pots filled with dry soil were weighed and then flooded with water for adequate period of time. The saturated soil was left overnight to drain the excess water by the force of gravity and then weighed. At this condition, the soil water is at its field capacity equivalent to pot capacity. The water level at field capacity was considered as well watered and 50% of the field capacity was taken as water stress treatments. The water level of all treatments was maintained to field capacity until the imposition of water stress. Water stress was imposed 30 days after sowing (DAS). Sesame plants grown under well watered treatment in each plot were irrigated with 333ml of water for every three days and those in the water deficit stressed received half of this volume at the same time interval.

Soil analysis

Soil samples representative of the experimental field were randomly collected from different points and thoroughly mixed together to form a composite soil sample. The sample was dried, ground and passed through a 2mm sieve and used for further soil property analysis. The pH was determined in 1:1 soil/water ratio using pH meter. The total percent nitrogen was determined by Kjeldahl digestion method, organic carbon content and organic matter were measured by volumetric method as described by *Walkley & Black, (1934)*. The analysis result revealed that the soil had a pH of 6.5, total percent nitrogen (0.084), percent organic carbon content (0.49) and organic matter (0.85).

Data collection

Growth and physiological data of the study species were gathered from three randomly selected and tagged plants in each plot. When the tagged plants are lost due to various reasons, data were collected from other plants in the same plot. Data of both types were collected 30 and 60 days after water deficit stress imposition.

Growth parameters

Plant height of tagged plants was measured from the ground level to the tip of the youngest leaf and expressed in centimeter (cm). Number of leaves and branches of the same plants were counted and recorded. The length of leaves was measured from the leaf base to the tip and width at the maximum area of the blade. Relative growth rate (RGR) was assessed based on height and determined according to *Hunt (1990)* as $RGR_H = (\log H_{t2} - \log H_{t1})/t_2 - t_1$ where, H_{t1} is height of the plant measured at t_1 and H_{t2} is height of the plant measured at t_2, t_1 and t_2 is time of the first and second height measurements, respectively.

Physiological parameters

Relative water content (RWC)

Relative water content was estimated according to *Barrs & Weatherly (1962b)*. Fully expanded leaves from tagged plants were collected and weighed, producing fresh weight (FW). These leaves were preserved in plastic bags and transported to laboratory. Each leaf was floated on distilled water in a Petri dish for 24 hrs. The leaves were then blotted gently with tissue paper and weighed again to produce turgid weight (TW). The leaves were then oven dried at 70ºCs for 24 hrs and dry weight (DW) were recorded. Finally, leaf relative water content was calculated as (FW-DW) / (TW-DW)*100.

Yield and Biomass parameters

The number of days required to 50% flowering was noted when 50% of the plants in each plot flowered and expressed in days. The average number was recorded and used for description. The numbers of capsules/pods per plant in each plot were counted from three tagged plants and recorded during data collection periods. All the pods from each plant and plot were collected and dried in an oven at 80°C to constant weight and threshed plot wise. Grain yield was determined for each plot ($1m^2$) and reported in terms of kg/ha as described by *Nadeem et al., (2015)*.

After harvesting the pods, each plant was uprooted and parts were separated into shoot (stem and root) and root. The roots were carefully detached from soils and thoroughly washed with tap water. The shoot and root parts were dried in an oven at 80°C to constant weight and weighed separately. Harvest index was calculated from biological yield (shoot and root dry weight) and grain yield in kg/ha according to *Nadeem et al., (2015)* as follows:

$$\text{Harvest index} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

Drought tolerance indices

Drought tolerance indices are important tools that provide better opportunities to select genotypes with good performance under normal and stress conditions. Several of the tolerance indices were calculated as follow:

Stress tolerance index (STI) = $Ys*Yp/\bar{Y}p^2$………………..Fernandez, (1992)

Mean productivity (MP) = $Ys+Yp/2$ ……………*Rosielle & Hamblin, (1981)*

Stress tolerance (TOL) = $Yp-Ys$ ………………. *Rosielle & Hamblin, (1981)*

Geometric mean productivity (GMP) = $\sqrt{Ys \times Yp}$ ……………*Fernandez, (1992)* Yield index (YI) = Ys/ Ȳp …………………………*Gavuzzi et al. (1997)*

Yield stability index (YSI) = Ys/Yp ………..*Bouslama & Schapaugh, (1984)*

Stress susceptibility index (SSI) = 1-(Ys/Yp)/1- (Ȳs/Ȳp) …*Fischer & Maurer, (1978)*

% Reduction = Yp-Ys/Yp*100 …………………………… *Choukan et al. (2006)*

Stress inte

Yield potential score index (YPSI) = 0.5 (MP + STI) – 0.5 (SSI + TOL) …*Malinowska et al. 2020)*

Yield stress score index (YSSI) = 0.5 (STI + SSI) …………………*Malinowska et al. (2020)*

Where,

Ys is the yield of each genotype under stress; Yp is the yield of each genotype under non-stress condition; Ȳs is the mean yield of each genotype under stress and Ȳp is the mean yield each genotype under non-stress condition.

Ranking of sesame varieties

Different drought tolerance indices discriminate different sesame varieties as drought resistant; hence identifying drought tolerant genotypes based on a single index does not produce clear results. To identify desirable drought tolerant varieties, the mean rank, standard deviation of ranks, and rank sum of all indices were calculated. For screening drought tolerant varieties a rank sum (RS) was calculated by using the following relationship formula:

Rank Sum = Mean ranks (MR) + standard deviation of ranks (SDR)…*Noorifarjam, Farshadfar, Saeidi, (2013)*

Data analysis

All the data were analyzed using Statistical Package for Social Sciences (SPSS, version 23). Multiple comparisons of means were carried out with Tukey HSD test to see variations between treatments at 30 and 60 days after drought imposition. Factorial Analysis of variance (ANOVA) was conducted for each trait under WW and WS conditions and results were considered significant at $p < 0.05$. Furthermore, principal component analysis (PCA) was used to characterize trait variation and correlation analysis between grain yield and drought tolerance indices were analyzed with R software. The biplot was generated using factor analysis and data processing with R package.

RESULTS

The sesame varieties showed notable variation among most of the traits between WW and WS conditions. The analysis of variance of the data from the field experiment showed that the differences between treatments and varieties were statistically significant at $P < 0.05$, 60 days after water stress imposition (Table 1). In this period, plant height was reduced under WS by 23.2, 27.6, 28.9 and 27.4% in abasena, gondar-1, humera-1 and wollega sesame varieties, respectively. The reduction in RGR was nearly similar to the reduction in plant height for all the varieties as it was derived from plant height. Greater reduction was observed in number of leaves, leaf length and leaf width. Accordingly, the number of leaves was reduced by 48.2, 51.2, 48.3 and 50.8 under WS in abasena, gondar-1, humera-1 and wollega varieties. Almost a similar pattern was recorded for leaf length and leaf width (Table 1). The growth of branches was completely suppressed under WS condition in all sesame varieties. An insignificant difference in leaf RWC was observed between plants under WW and WS conditions in all varieties, indicating that leaf RWC is not an important parameter for screening sesame varieties for drought tolerance.

The results also demonstrated a highly significant difference among varieties under the different water levels, 60 days after water stress imposition at $P < 0.05$. Until 30 days, the effect of WS on some growth parameters was not visible. A significant difference was recorded in number of leaves between abasena (6.89) and humera-1 (8.00) varieties under WS condition at 30 days after water stress imposition (Table 1). Plants of gondar-1 variety performed the highest in terms of number of leaves, leaf width, and plant height under WW condition at 30 and 60 days after water stress imposition. This difference was statistically significant at $P < 0.05$ (Table 1). Although insignificant, higher numbers of branches were recorded in wollega variety under WW conditions, 60 days after stress imposition (Table 1), which might have implication to yield. Plants of gondar-1 had also significantly higher number of leaves than abasena under WS condition. It also showed considerably faster RGR than abasena under WW condition. The average reduction in plant height, number of leaves, leaf length, leaf width and RGR under WS was found to be 21.8, 49.6, 48.4, 47.9 and 21.7%, respectively, 60 days after water stress imposition. In general, gondar-1 and abasena sesame varieties performed the best and least, respectively under the present study experimental conditions (WW and WS). Plants of humera-1 and wollega showed moderate growth performance under both water levels (Table 1).

Plant height showed positive and significant correlation with RGR in all sesame varieties both under WW and WS conditions at $P < 0.01$. Number of leaves and RWC had higher positive correlation with yield in abasena variety under WW conditions (Data not shown). In contrast, almost all the parameters had negative correlation with yield under WS condition. In gondar-1 and humera-1 sesame varieties, almost all growth and physiological parameters had negative correlation with yield both under WW and WS conditions except RWC under WS conditions in humera-1 variety. On the other hand, plant height and RGR had a significantly positive correlation with yield in wollega variety under WS condition (Data not shown).

A significant variation in plant height, number of branches, number of leaves and RGR was recorded due to the separate effect of variety and water levels, 60 days after water stress imposition (Table 2). According to the analysis of the result, variety had no significant influence on the leaf length and width of the studied varieties. The water levels had greater and significant effect size than variety. In this regard, the highest reduction in plant height and RGR under WS was recorded by humera-1 variety followed by gondar-1 and wollega, while the lowest reduction was recorded in abasena variety. The difference in reduction due to WS in plant height, number of leaves, leaf length and width ranged from 23.2-27.4, 48.2-51.2, 43.9-53.9 and 45.4-49.8%, respectively (Table 1). The biggest reduction in number of leaves and leaf length was observed in gondar-1 variety followed by wollega. Similarly, humera-1 and wollega varieties showed the biggest reduction in plant height and leaf width under WS condition (Table 1). In the same period, the interactive effect of variety and water levels on growth parameters was insignificant except number of branches where the synergistic effect of the two independent variables was greater (Table 2).

Mean performance of sesame varieties

The sesame varieties demonstrated a statistically significant variation in biomass production, yield and yield related traits under the two water levels (WW and WS) at $P < 0.05$. A significant reduction in shoot biomass, root biomass, biological yield, number of pods per plant and seed yield was recorded under WS condition among sesame varieties. These traits showed an average reduction of 52.2, 72.5, 54.0, 51.9, and 52.8%, respectively as compared to WW condition. The highest reduction in yield and yield related traits between WW and WS conditions was found in wollega followed by humera-1, while the lowest was found in abasena followed by gondar-1 (Table 3). There was insignificant difference in shoot biomass, harvest index and seed yield between water levels in abasena variety (Table 3). Significant differences were also recorded among varieties both under similar and different water levels (Table 3). Accordingly, wollega, gondar-1 and humera-1 varieties produced considerably greater shoot biomass and biological yield than abasena under WW condition. The variation in shoot biomass between the varieties under WS condition was insignificant at $P < 0.05$. All varieties under WS had significantly lower root biomass than those in WW condition, implying that enhanced root growth and the consequent increased root/shoot ratio is not a drought tolerance strategy in the study sesame varieties. In this regard, abasena variety had a relatively greater root biomass than the others. Sesame plants of wollega variety produced a relatively higher biological yield followed by gondar-1 both under WW and WS conditions than others (Table 3 and 4).

In terms of yield and related traits, gondar-1 variety had greater number of pods per plant followed by humera-1 and wollega varieties under WW and WS conditions (Table 3 and 4). Wollega sesame variety produced a significantly greater seed yield per cm^2 under WW condition followed by humera-1 and gondar-1 varieties. Correspondingly, variety gondar-1 had better seed yield than others followed by humera-1 under WS condition. However, the variation among the varieties in seed yield/cm^2 under WS condition was insignificant. Wollega sesame variety had higher harvest index under WW condition attributed to the highest seed yield/cm^2, while a relatively higher harvest index was recorded under WS condition in abasena and gondar-1 varieties which might be due to the lower biological yield caused by the WS condition. Plants of abasena performed the least in most parameters under both water levels (Table 3 and 4).

When variety, water levels and their interactive effects are analyzed, they produced a statistically significant difference in biological yield, number of pods per plant, Ys, Yp, shoot and root biomass at $P < 0.01$, 60 days after water stress imposition (Table 4). Harvest index was not significantly affected by variety and water levels. Similarly, the interactive effect (variety * water levels) had no remarkable effect on number of pods per plant. The partial eta squared value revealed that water levels had greater effect on Ys, Yp, biological yield, number of pods per plant, shoot and root biomass followed by variety (Table 4).

Drought tolerance indices

Analysis of variance of Ys, Yp and drought tolerance indices showed a highly significant difference among sesame varieties under the different water levels, indicating the presence of high genetic variability. Drought tolerance indices were calculated on the basis of seed yield ha^{-1} of 4 sesame varieties from Ys and Yp. The mean seed yield under WW conditions ranged from 2144.44 to 5177.78 kg/ha, while 1344.44 to 1811.11 kg/ha was obtained under water stressed condition. Wollega sesame variety had the highest and the second lowest mean seed yield/ha^{-1} under WW and WS conditions, respectively (Fig. 2). Gondar-1 and humera-1 varieties achieved the highest seed yield/ha under WS condition. In both water levels, plants of abasena performed the least and the variation was found to be significantly lower than other sesame varieties (Fig. 2).

The study sesame varieties showed a significant difference in drought tolerance indices (Table 5). Wollega sesame variety had significantly higher MP, GMP and TOL than others followed by humera-1 variety. According to these indices, wollega and humera-1 varieties were found more desirable and comparatively drought tolerant. Unlike this, wollega variety had lower STI than gondar-1 and humera-1 varieties (Table 5). The mean STI values demonstrated that gondar-1 and humera-1 have better drought tolerance characteristics. In the present study, abasena sesame variety had the lowest TOL, SSI and the highest YI and YSI of all the study varieties (Table 5). The difference between Ys and Yp values in abasena variety was the lowest indicating the lower sensitivity of the variety to drought stress. Varieties with lower TOL, SSI, higher YI and YSI values are more stable and tolerant, respectively under drought conditions. Based on these indices thus, abasena could be identified as stable and tolerant variety. Plants of wollega variety demonstrated a significantly higher percent reduction than abasena that showed the lowest reduction. The studied varieties revealed a significantly different stress intensity of which the weakest was seen in abasena variety. Similarly, plants of gondar-1 and humera-1 had higher YSSI and YPSI values as compared to others (Table 5).

Correlation

A strong association between Yp, Ys and drought tolerance indices is an important indicator to select the most desirable drought tolerance indices. Ys had positive and significant correlation with Yp. Moreover, Ys revealed a significantly positive correlation with MP, STI, GMP, YSSI and YPSI at $P < 0.01$ (Table 6). Similarly, Yp had significantly positive association with MP, STI, GMP, TOL, PR, SI and YSSI at $P < 0.01$ probability level (Table 6). This showed that MP, STI, GMP and YSSI had significantly higher correlation with yield under WW and WS conditions so that these indices can be used as criteria to select varieties for drought tolerance.

According to MP and GMP values, wollega and humera-1 were found to be the most desirable and drought tolerant varieties, respectively, while gondar-1 and humera-1 had higher STI and YSSI indicating higher yield performance under drought conditions. Furthermore, TOL had positive and significant correlation with MP, GMP, PR, SSI and SI at $P < 0.01$. Its correlation with YI, YSI and YPSI was negative and significant (Table 6).

Principal Component Analysis

The minimum number of principal components that account for most of the variations in drought tolerance indices was determined based on eigen value. Principal components with the highest eigen values greater than 1 were selected. Accordingly, two principal components fulfilled the acceptable level/variance of the dataset. The first and second principal components (PC1) and (PC2) explained 86.2 % and 12.7 % of the variation, respectively. The PC1 and PC2 together cover 98.9 % of the variation in the dataset (Table 7). The results of the analysis showed that PC1 had large positive association with Yp, TOL, MP and GMP. Others such as YI, YSI and YPSI had negative correlation with PC1. PC2 had large positive association with YPSI, Ys, STI, GMP, MP and YSSI, while negatively correlated with TOL (Table 7). The large positive and negative values of drought tolerance indices indicate the strong effect of each index on each principal component.

The biplot analysis showed that Yp, TOL, GMP, MP, Ys and YSSI orient in similar direction and had tight angles indicating a positive correlation and strong effect on PC1. Similarly, YPSI, Ys, STI and GMP contributed higher proportion to PC2 (Fig. 3). The biplot analysis clustered the study varieties roughly into two groups as low yielding (abasena) and relatively above average performing varieties (humera-1, gondar-1 and wollega) under well watered and stressed conditions (Fig. 3). This was corroborated with the values of STI, MP and GMP where the varieties in the second group had higher average yield values under well watered and water stressed conditions (Table 7 and Fig. 3).

Ranking of sesame varieties

Rank sum was calculated due to the fact that identification of genotypes for drought tolerance using individual indices is difficult. Different indices identified different sesame varieties for drought tolerance. Rank sum for all indices was used as an indicator to select the best varieties. Lower and higher rank sum values indicate high drought tolerant and susceptible genotypes, respectively. Accordingly, humera-1 sesame variety had the lowest rank sum value followed by gondar-1 variety. These varieties represent the best varieties with the highest performance under well watered and water deficit stressed conditions (Table 8). The rank sum result identified abasena sesame variety as the most susceptible and low yielding variety (Table 8).

DISCUSSION

The results of the present study showed that the different agromorphological traits significantly vary among varieties due to water stress and genetic variability. The results revealed that water stress had a remarkable influence on growth parameters specifically plant height, leaf number and number of branches unlike physiological processes. The growth of branches was completely suppressed under WS condition in all varieties. Humera-1 and wollega varieties showed the highest reduction in growth parammeters. Of the sesame varieties, gondar-1 outperformed in agromorphological traits, while abasena was the lowest. This is in line with the findings of *Hassen, (2022), Mewcha et al., (2020), Mekonnen and Sintayehu, (2020)* and *Gebremichael & Parzies*, (2011). *Hassen (2022)* has reported the high heritability of plant height and harvest index of 100 sesame genotypes at Amibara, Ethiopia. Furthermore, nearly similar results of leaf length and number of branches have been found in gondar-1, humera-1, wollega and argene sesame varieties (*Mewcha et al., 2020*). However, these and other varieties have shown a significantly higher plant height and number of leaves (*Mekonnen &Sintayehu, 2020; Mewcha et al., 2020*). This deviation might be caused by the difference in the type of irrigation system, time of drought imposition, agroecology of the experimental sites that vary in soil fertility and other environmental factors. Furthermore, findings have indicated that the agromorphological performance of sesame varieties varies across seasons (*Hailu et al., 2018; Hassen, 2020; Baraki et al., 2020*).

The data in the present study demonstrated a significant reduction in yield and yield related traits under water stress. The highest reduction was recorded from wollega variety followed by humera-1. Gondar-1 had greater number of pods per plant and yield under WS condition followed by humera-1. Wollega variety had greater seed yield under WW condition. Almost similar, lower and higher yield performances of sesame varieties have been reported so far. According to *Mawcha et al. (2020)*, gondar-1, humera-1 and wollega sesame varieties have produced seed yield of 3432.09, 2194.44 and 2377.78kg/ha, respectively, at Humera under supplementary irrigation; a common sesame production area, which is almost similar to the present study (Fig. 2). On the other hand, gondar-1 and humera-1 varieties produced significantly higher yield in the present study (Fig 2) than the same varieties at Dansha grown under normal moisture conditions (588 kg/ha and 542 kg/ha, respectively). This higher yield deviation might be attributed to the high prevalence of bacterial blight disease, as the area is a hotspot for the disease (*Golla, Kebede & kindeya, 2020*). A higher seed yield of abasena variety was obtained under WW condition (Figure 2) in the present study as compared to *Mekonnen and*

Sintayehu, (2020). The authors have reported 1840 kg/ha and 670 kg/ha seed yield under uniform optimum irrigation and 50% uniform deficit irrigation, respectively at Metema; another hub of sesame production. The yield of the variety under WS condition (Fig. 2) has been lower than 75% water deficit imposed at the development stage, 1785 kg/ha (Mekonnen and Sintayehu, 2020). Comparatively, close yield performance as to the present study has been found in adi sesame variety treated with 100, 75 and 50% of the evapotranspiration of the crop applied through convention furrow irrigation method in 2015, at Werer research center (*Hailu et al., 2018*). On the other hand, the study varieties produced significantly greater seed yield than several other varieties and accessions such as serkamo white, adi, acc-00048, acc-00016, acc-00025, acc-00049 and others that have bee evaluated at Werer (Afar Region), Bonta (Afar Region) and Miesso (Oromia) under normal growth conditions (*Hassen, 2022*). This is corroborated by *Bakari et al., (2020)* and found to be due to environmental and genetic variation among the sesame varieties. The authors have pointed out that about 42.62, 6.22 and 25.09% of sesame agronomic performance are determined by the environment, genotype and their interactive effect, respectively (*Baraki et al., 2020*).

Selection of crop varieties for drought tolerance drought tolerance indices based on yield under normal and stressed conditions is one of the tools widely used in agriculture. In this study, wollega sesame variety had the highest MP, GMP and TOL values, which agrees with the findings of *Fernandez (1992)* and *Farshadfar, Jamshidi & Aghaee (2012*). The highest TOL value indicates the high sensitivity of the variety to water stress. This was evident from the highest percent reduction under water stressed condition (Table 2). On the other hand, gondar-1 and humera-1 varieties had higher STI values showing better performance than other varieties. Several studies such as Fernandez (1992), *Pireilvatlou, Masjedlou & Aliyou, (2010)*, *Farshadfar,* *Jamshidi & Aghaee (2012), Zare (2012)*, *Noorifarjam, Farshadfar, Saeidi, (2013)* and *Baghery et al. (2022)* have identified STI as a reliable index in mungbean, wheat, wheat, barley, wheat and sesame, respectively, for selecting varieties with high drought tolerance and yield under normal and water stressed conditions. This might due to the fact that STI considers potential yield under normal condition, yield under stressful environments and stress intensity (*Fernandez, 1992*). Variety abasena had the lowest TOL and SSI and the highest YI and YSI as compared to the other varieties. The TOL and SSI values for the variety showed the lower yield potential under non-stress condition and higher yield under stressed condition, evidently proved by the lowest percent reduction under the two contrasting conditions (Table 2). The variety also characterized by a closer Yp and Ys, implying the lower sensitivity of the variety to water stress which subsequently results in smaller SSI. This is consistent with the findings of *Fernandez, (1992)* in mungbean, *Zare, (2012)* in barley, and *Baghery et al. (2022)* in sesame varieties.

The best drought tolerance index is the one that has discernable association with yield under normal and water stress conditions. In the present study, MP, GMP and STI had a significantly higher positive correlation with Yp and Ys. This shows that these indices are effective in identifying varieties under different water stress conditions as supported by the findings of *Siahsar, Ganjali & Allahdo, (2010)* in lentil. Moreover, Yp had significantly higher positive correlation with TOL, SI and YSSI and, Ys with YSSI and YPSI. These findings are in line with the reports of *Zare, (2012), Farshadfar, Jamshidi & Aghaee, (2012)*, *Noorifarjam, Farshadfar, Saedid, (2013), Baghery et al. (2022)* and *Sun et al. (2023*). Drought tolerance Indices correlated with both Yp and Ys have been found suitable for the selection of varieties for water stress (*Baghery et al., 2022*), indicating increase in yield under water stressed and normal conditions *Farshadfar, Jamshidi & Aghaee, (2012)*. The result of the PCA also revealed that only PC1 and

PC2 with eigen value greater than 1 explained 98.9% of the variation, which agrees with the reports of *Zare, (2012)* in barley and *Baghery et al. (2022)*. According to the analysis, Yp, TOL, MP and GMP had a relatively strong effect on PC1 indicating the high yield potential of indices and PC2 strongly associated to YPSI, Ys, STI and GMP, predictors of drought tolerance. Similar results have been reported in barley *(Zare, 2012),* sesame (*Baghery et al., 2022*) and cotton (*Sun et al., 2023*). Furthermore, the biplot analysis identified two categories of sesame varieties; low yielding (abasena) and above average performing varieties such gondar-1, humera-1 and Wollega (Figure 3). This corresponds with the categorization of *Fernadez, (1992)* and *Sofi et al. (2018)* where abasena roughly belongs to group D (poor yield performance under WW and WS conditions), Wollega to group B (good performance under WW, not under WS conditions) and gondar-1 and humera-1 varieties to group A (relatively higher performance in both WW and WS conditions. This might be related to the agroecology where the varieties are released that is characterized by high temperature and transpiration that lead to water stress in the plant.

Since identifying the most drought tolerant variety using the indices is difficult, the rank sum and standard deviation of ranks of all indices were calculated. Accordingly, humera-1 followed by gondar-1 were identified as drought tolerant and high yielding, while abasena as the most susceptible and low yielding variety. Similar findings for other species and varieties have been reported by *Noorifarjam, Farshadfar, Saeidi, (2013)* and *Anter & Ashraf, (2018).*

CONCLUSION

The present study aimed to identify drought tolerant sesame varieties using agromorphological and drought tolerance indices. Our findings showed a significant variation in agromorphological, seed yield and drought tolerance indices due to water levels, variety and their interaction. However, the effect of water levels was stronger than others. In support of this, a significant reduction was observed in growth and yield parameters under water stressed conditions.The highest reduction was recorded in wollega. Abasena performed the lowest under both water levels. Humera-1 and gondar-1 varieties performed better both under water levels. They also had higher stress tolerance index, yield stress score index, yield potential score index, geometric mean productivity and mean productivity, implying better tolerance to water stress. In general, humera-1 followed by gondar-1 are identified as high yielding and drought tolerant varieties based on drought tolerance indices, biplot analysis and rank sum of all drought tolerance indices.

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Table 1(on next page)

Growth and relative water content responses of sesame varieties under well watered (WW) and water stressed (WS) conditions. Mean values ±SE (n = 9)

Table 1:

Growth and relative water content responses of sesame varieties under well watered (WW) and water stressed (WS) conditions. Mean values ±SE (n = 9)

Plant parameters	Treatments	30 days after water stress imposition				60 days after water stress imposition			
		Sesame varieties				Sesame varieties			
		Abasena	Gondar-1	Humera-1	Wollega	Abasena	Gondar-1	Humera-1	Wollega
Plant height (cm)	WW	42.17±0.30^{aA}	40.67±0.67^{aA}	41.89±0.45^{aA}	41.83±0.41^{aA}	51.33±0.55^{aB}	56.33±1.83^{aA}	54.67±0.44a^{AB}	53.39±0.60^{aAB}
	WS	35.89±0.81^{bA}	34.67±0.73^{bA}	35.61±0.44^{bA}	34.78±0.92^{bA}	39.44±0.29^{bA}	40.78±1.23^{bA}	38.89±0.65^{bA}	38.78±0.32^{bA}
Number of branches	WW	0.00±0.00^{aA}	0.67±0.33^{aA}	0.67±0.47^{aA}	1.33±0.75^{aA}	0.00±0.00^{aA}	2.00±0.00^{aB}	2.00±0.00^{aB}	2.44±0.44^{aB}
	WS	0.00±0.00^{aA}	0.00±0.00^{aA}	0.00±0.00^{aA}	0.00±0.00^{aA}	0.00±0.00^{aA}	0.00±0.00^{bA}	0.00±0.00^{bA}	0.00±0.00^{bA}
Number of leaves	WW	9.56±0.75^{aA}	12.67±1.37^{aA}	9.22±0.57^{aA}	10.33±0.82^{aA}	12.44±0.65^{aB}	17.33±1.41^{aA}	13.33±0.67^{aB}	14.44±1.04^{aAB}
	WS	6.89±0.39^{aB}	8.67±0.83^{bAB}	7.44±0.38^{aA}	7.56±0.53^{aAB}	6.44±0.44^{bA}	8.44±1.09^{bA}	6.89±0.59^{bA}	7.11±0.75^{bA}
Leaf length (cm)	WW	8.72±0.35^{aA}	9.72±0.19^{aA}	8.00±0.49^{aA}	8.89±0.49^{aA}	11.39±0.73^{aA}	12.89±0.78^{aA}	11.00±0.52^{aA}	11.56±0.48^{aA}
	WS	5.11±0.31^{bA}	4.67±0.41^{bA}	4.67±0.29^{bA}	4.33±0.24^{bA}	6.39±0.37^{bA}	5.94±0.13^{bA}	5.89±0.11^{bA}	5.89±0.26^{bA}
Leaf width (cm)	WW	4.39±0.14^{aAB}	5.39±0.20^{aA}	4.11±0.42^{aB}	4.67±0.34^{aAB}	6.61±0.22^{aA}	6.56±0.24^{aA}	6.11±0.30^{aA}	6.61±0.26^{aA}
	WS	2.78±0.15^{bA}	2.93±0.13^{bA}	2.53±0.17^{bA}	2.82±0.11^{bA}	3.43±0.15^{bA}	3.58±0.15^{bA}	3.17±0.12^{bA}	3.32±0.14^{bA}
Relative water content (%)	WW	61.40±4.24^{aA}	61.61±2.64^{aA}	65.31±2.93^{aA}	73.77±9.01^{aA}	46.42±3.79^{aA}	42.85±0.82^{aA}	62.24±14.91^{aA}	58.79±7.67^{aA}
	WS	50.42±3.10^{aA}	62.34±2.86^{aA}	58.50±4.80^{aA}	81.14±15.68^{aA}	47.79±24.26^{aA}	51.91±4.05^{aA}	38.49±4.04^{aA}	21.43±14.87^{aA}
Relative growth rate (cm/day)	WW	0.86±0.01^{aA}	0.94±0.03^{aB}	0.91±0.01^{aAB}	0.89±0.01^{aAB}				
	WS	0.66±0.01^{bA}	0.68±0.02^{bA}	0.65±0.01^{bA}	0.65±0.01^{bA}				

Mean values in a column followed by different small case letters within the same parameter and mean values in a row followed by different upper case letters are significantly different at $P < 0.05$.

Table 2(on next page)

Two ways ANOVA tests of between subjects effects

Table 2:

Two ways ANOVA tests of between subjects effects

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
Variety	Plant height	3	33.3	4.7	0.005	0.2
	Number of branches	3	5.4	24.3	0.000	0.5
	Number of leaves	3	40.1	5.7	0.002	0.2
	Leaf Length	3	3.0	1.5	0.242	0.1
	Leaf width	3	0.7	1.8	0.162	0.1
	RWC	3	121.6	0.3	0.864	0.0
	RGR	3	0.01	4.6	0.006	0.2
Water levels	Plant height	1	3762.8	526.9	0.000	0.9
	Number of branches	1	46.7	210.3	0.000	0.8
	Number of leaves	1	924.5	131.3	0.000	0.7
	Leaf Length	1	580.9	275.6	0.000	0.8
	Leaf width	1	172.7	450.3	0.000	0.9
	RWC	1	297.0	0.6	0.442	0.0
	RGR	1	1.1	520.9	0.000	0.9
Variety * Water levels	Plant height	3	14.4	2.0	0.121	0.1
	Number of branches	3	5.4	24.3	0.000	0.5
	Number of leaves	3	7.3	1.0	0.382	0.1
	Leaf Length	3	3.6	1.7	0.176	0.1
	Leaf width	3	0.12	0.3	0.814	0.0
	RWC	3	157.0	0.3	0.813	0.0
	RGR	3	0.0	2.2	0.103	0.1

Notes: RWC = Relative water content; RGR = Relative growth rate

Table 3(on next page)

Mean biomass and yield responses of sesame varieties grown under well watered (WW) and water stressed (WS) conditions. Mean ±SE (n= 9)

Table 3:

Mean biomass and yield responses of sesame varieties grown under well watered (WW) and water stressed (WS) conditions. Mean ±SE (n= 9)

Sesame varieties	**Water levels**	**Shoot biomass (g)**	**Root biomass (g)**	**Biological yield (g)**	**Number of pods/plant**	**Seed yield/cm^2 (g)**	**Harvest Index (%)**
Abasena	WW	3.11±0.15^{b}	0.70±0.04^{a}	3.81±0.15^{b}	6.00±0.33b	2.14±0.15^{c}	56.65±3.82^{a}
	WS	1.68±0.14^{b}	0.39±0.08^{b}	2.07±0.17^{d}	3.11±0.35^{c}	1.42±0.17^{c}	68.40±5.22^{a}
Gondar-1	WW	6.11±0.51^{a}	0.78±0.05^{a}	6.89±0.53^{a}	8.67±0.58^{a}	3.67±0.14^{b}	55.84±4.97^{a}
	WS	2.56±0.24^{b}	0.11±0.01^{c}	2.67±0.25^{c}	4.44±0.44^{c}	1.81±0.08^{c}	70.63±4.28^{a}
Humera-1	WW	6.00±0.67^{a}	0.44±0.06^{b}	6.54±0.69^{a}	8.22±0.62^{ab}	4.14±0.36^{b}	68.27±6.73^{a}
	WS	2.78±0.28^{b}	0.04±0.01^{c}	2.82±0.28^{c}	3.78±0.52^{c}	1.71±0.15^{c}	65.13±7.89^{a}
Wollega	WW	6.56±0.44^{a}	0.45±0.07^{b}	7.11±0.42^{a}	8.22±0.70^{ab}	5.18±0.23^{a}	75.02±5.51^{a}
	WS	3.23±0.26^{b}	0.14±0.08^{c}	3.41±0.22^{c}	3.56±0.44^{c}	1.66±0.12^{c}	50.66±5.68^{a}

Mean values in each column that don't share similar letters are significantly different at $P < 0.05$.

Table 4(on next page)

(on next page)

Two ways ANOVA tests on the effects of variety, water levels and their interaction on yield and yield components of sesame varieties

Table 4:

Two ways ANOVA tests on the effects of variety, water levels and their interaction on yield and yield components of sesame varieties

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
Variety	Biological yield	3	18.5	14.0	.000	0.4
	Harvest index	3	67.7	0.236	.871	0.0
	Number of pods per plant	3	12.9	5.5	.002	0.2
	Shoot biomass	3	21.8	16.8	.000	0.4
	Root biomass	3	0.4	12.3	.000	0.4
	Ys	3	217777.8	4.8	0.005	0.2
	Yp	3	7161666.7	28.8	0.000	0.6
Water levels	Biological yield	1	201.1	152.6	.000	0.7
	Harvest index	1	1.1	0.0	.952	0.0
	Number of pods per plant	1	296.1	124.7	.000	0.7
	Shoot biomass	1	149.5	115.5	.000	0.6
	Root biomass	1	3.2	109.8	.000	0.6
	Ys	1	49335555.6	1078.7	0.000	0.9
	Yp	1	257645000.0	1034.5	0.000	0.9
Variety * Water levels	Biological yield	3	5.4	4.1	.010	0.2
	Harvest index	3	1439.6	5.0	.003	0.2
	Number of pods per plant	3	2.9	1.2	.314	0.1
	Shoot biomass	3	4.317	3.3	.025	0.1
	Root biomass	3	0.1	4.3	.007	0.2
	Ys	3	217777.8	4.8	0.005	0.2
	Yp	3	7161666.7	28.8	0.000	0.6

Note: Ys = Yield under water stress condition; Yp = Yield under well watered condition

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Table 5(on next page)

Drought tolerance index values of sesame varieties grown under well watered (WW) and water stressed (WS) conditions

Table 5:

Drought tolerance index values of sesame varieties grown under well watered (WW) and water stressed (WS) conditions

Drought indices	Sesame varieties			
	Abasena	**Gondar-1**	**Humera-1**	**Wollega**
MP	1744.44±67.41[c]	2738.89±78.07[b]	2977.78±181.07[ab]	3416.67±136.49[a]
STI	1310.91±96.59[a]	1810.89±100.28[a]	1809.94±180.26[a]	1659.86±152.93[a]
GMP	1667.12±63.07[c]	2568.40±73.58[b]	2709.39±141.57[ab]	2906.88±134.41[a]
TOL	800.00±232.74[c]	1855.56±157.33[b]	2333.33±365.53[b]	3522.22±251.68[a]
YI	0.63±0.05[a]	0.49±0.02[b]	0.44±0.02[bc]	0.32±0.02[c]
YSI	0.66±0.08[a]	0.50±0.03[ab]	0.48±0.07[ab]	0.32±0.03[b]
% Reduction	33.84±7.95[a]	50.00±2.94[ab]	52.07±6.95[ab]	67.52±2.93[b]
SSI	0.91±0.21[a]	0.99±0.06[a]	0.93±0.12[a]	0.99±0.04[a]
SI	0.37±0.00[d]	0.51±0.00[c]	0.56±0.00[b]	0.68±0.00[a]
YSSI	655.91±46.25[a]	905.94±50.14[a]	905.43±90.17[a]	830.43±76.45[a]
YPSI	1127.22±142.67[ab]	1346.62±96.11[a]	1226.73±98.94[ab]	776.66±152.20[b]

Mean values in a row that share different letters are significantly different at $P < 0.05$. (Mean ± SE and n = 9). MP = Mean productivity; STI = Stress tolerance index; GMP = Geometric mean productivity; TOL = Drought tolerance; YI = Yield index; YSI = Yield stability index; SSI = Stress susceptibility index; SI = Stress intensity; YSSI = Yield stress score index and YPSI = Yield potential index.

Table 6(on next page)

Correlation coefficient between drought tolerance indices with seed yield under well watered (WW) and water stressed (WS) growing conditions

Table 6:

Correlation coefficient between drought tolerance indices with seed yield under well watered (WW) and water stressed (WS) growing conditions

	Ys	Yp	MP	STI	GMP	TOL	YI	YSI	%Reduction	SSI	SI	YSSI	YPSI
Ys	1	0.28	0.50**	0.74**	0.68**	0.01	0.24	0.25	-0.25	-0.52**	0.34*	0.74**	0.80**
Yp	0.28	1	0.97**	0.59**	0.89**	0.96**	-0.70**	-0.80**	0.80**	0.38*	0.85**	0.59**	-0.29
MP	0.50**	0.97**	1	0.72**	0.97**	0.88**	-0.57**	-0.66**	0.66**	0.22	0.85**	0.72**	-0.06
STI	0.74**	0.59**	0.72**	1	0.81**	0.41*	0.09	-0.24	0.24	0.06	0.29	1.00**	0.53**
GMP	0.68**	0.89**	0.97**	0.81**	1	0.74**	-0.43**	-0.52**	0.52**	0.10	0.79**	0.81**	0.16
TOL	0.01	0.96**	0.88**	0.41*	0.74**	1	-0.79**	-0.90**	0.90**	0.54**	0.79**	0.41*	-0.52**
YI	0.24	-0.70**	-0.57**	0.09	-0.43**	-0.79**	1	0.84**	-0.84**	-0.56**	-0.77**	0.09	0.74**
YSI	0.247	-0.80**	-0.66**	-0.24	-0.52**	-0.90**	0.84**	1	-1.00**	-0.83**	-0.60**	-0.24	0.65**
%Reduction	-0.25	0.80**	0.66**	0.24	0.52**	0.90**	-0.84**	-1.00**	1	0.83**	0.59**	0.24	-0.65**
SSI	-0.52**	0.38*	0.22	0.06	0.10	0.54**	-0.56**	-0.83**	0.83**	1	0.10	0.06	-0.59**
SI	0.34*	0.85**	0.85**	0.29	0.79**	0.79**	-0.77**	-0.60**	0.59**	0.10	1	0.29	-0.29
YSSI	0.74**	0.59**	0.75**	1.00**	0.81**	0.41*	0.09	-0.24	0.24	0.10	0.29	1	0.53**
YPSI	0.80**	-0.29	-0.06	0.53**	0.16	-0.52**	0.74**	0.65**	-0.65**	-0.59**	-0.29	0.53**	1

** and * indicate significant differences at $P < 0.01$ and $P < 0.05$ probability levels, respectively. MP = Mean productivity; STI = Stress tolerance index; GMP = Geometric mean productivity; TOL = Drought tolerance; YI = Yield index; YSI = Yield stability index; SSI = Stress susceptibility index; SI = Stress intensity; YSSI = Yield stress score index and YPSI = Yield potential index.

Table 7(on next page)

Eigen analysis of the correlation matrix and weight of each parameter

Table 7:

Eigen analysis of the correlation matrix and weight of each parameter

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
Eigen value	2.88	1.68	0.76	0.50	0.20	0.09	0.06	0.02	0.00	0.00	0.00	0.00	0.00
Proportion of variance	0.862	0.127	0.011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative proportion	0.862	0.989	0.999	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

	Cum.(%)	Ys	Yp	MP	STI	GMP	TOL	YI	YSI	% Reduction	SSI	SI	YSSI	YPSI
Principal component 1	86.24	0.05	0.65	0.35	0.13	0.25	0.60	-0.00	-0.00	0.01	0.00	-0.00	0.07	-0.07
Principal component 2	98.86	0.42	0.03	0.23	0.42	0.34	-0.40	0.00	0.00	-0.01	-0.00	-0.00	0.21	0.52

MP = Mean productivity; STI = Stress tolerance index; GMP = Geometric mean productivity; TOL = Drought tolerance; YI = Yield index; YSI = Yield stability index; SSI = Stress susceptibility index; SI = Stress intensity; YSSI = Yield stress score index and YPSI = Yield potential index.

Table 8(on next page)

Rank mean, standard deviation of rank and rank sum derived from all drought tolerance indices

Table 8:

Rank mean, standard deviation of rank and rank sum derived from all drought tolerance indices

Varieties	Rank mean	Standard Deviation of Rank (SDR)	Rank Sum (RS)
Abasena	3.46	1.13	4.59
Gondar-1	2.15	0.90	3.05
Humera-1	2.08	0.64	2.72
Wollega	2.15	1.35	3.5

Figure 1

Map of the study area showing the experimental site

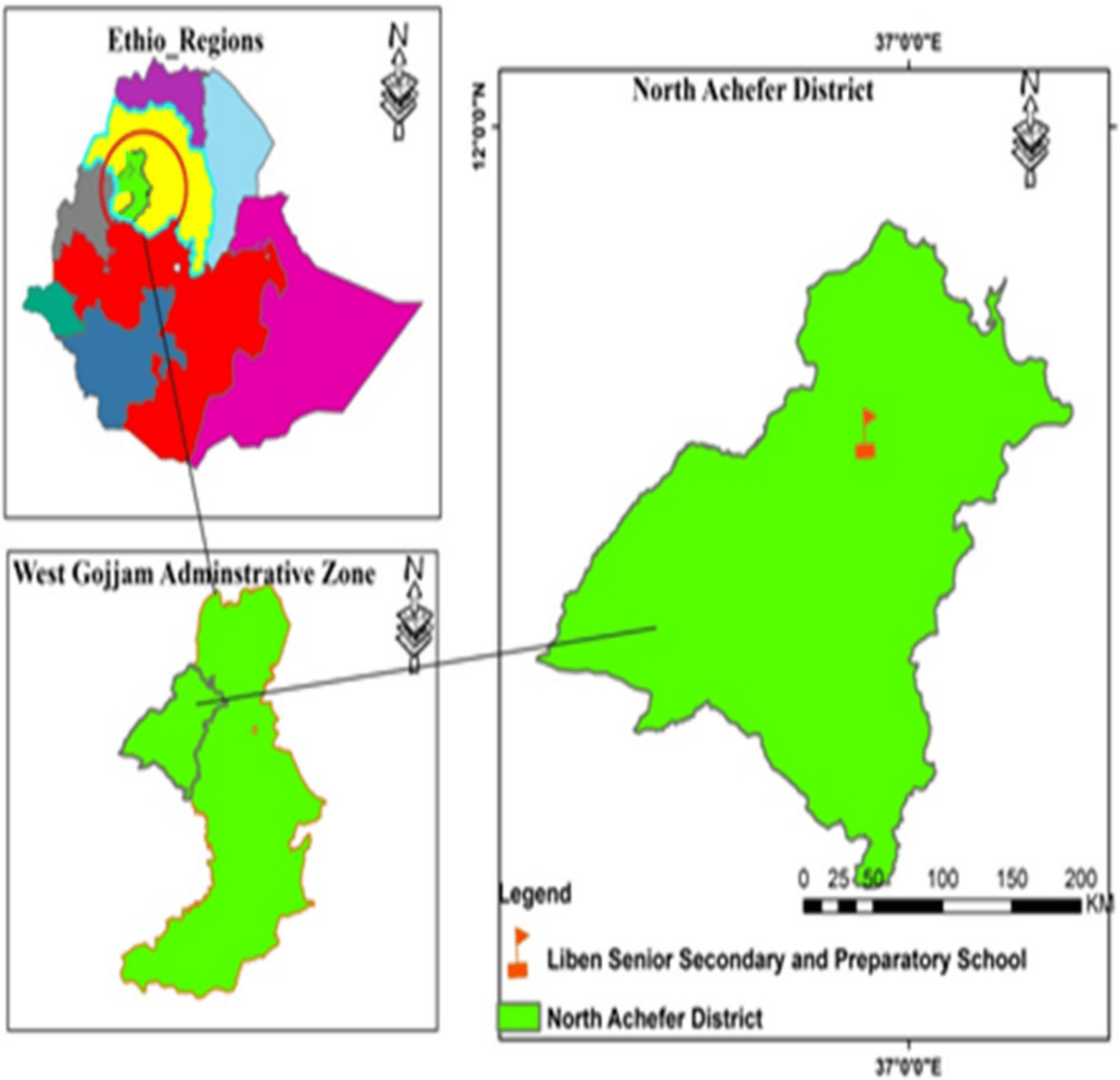

Figure 2

Mean seed yield of sesame varieties grown under water deficit stress (Ys) and well watered conditions (Yp). Mean values followed by different English alphabets are statistically significant at $P < 0.05$. Mean ± SE ($n = 9$).

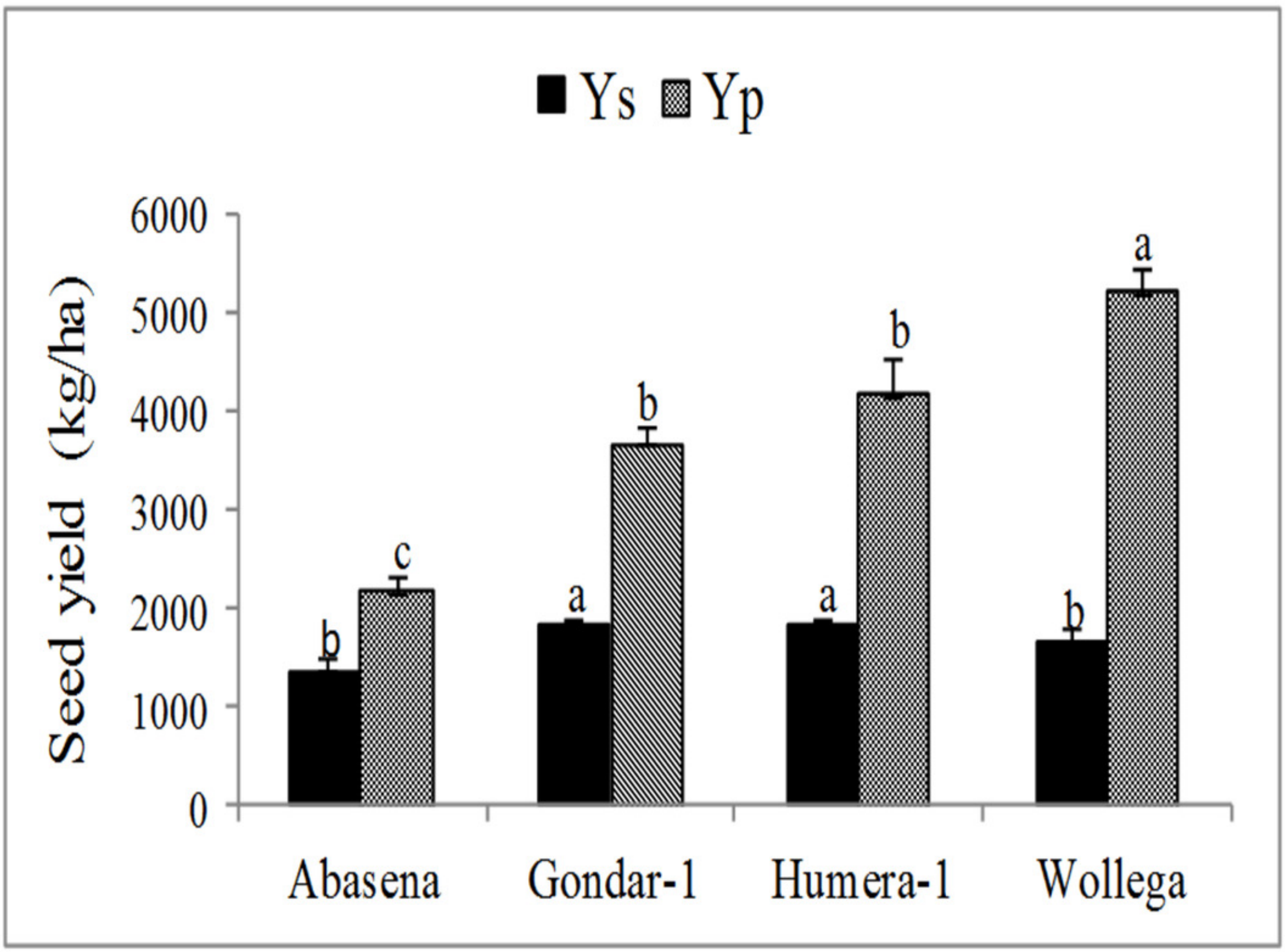

Figure 3

Biplot of principal component analysis of sesame genotypes for Ys, Yp and drought tolerance indices.