OAT (*Avena sativa* L.) ADVANCED LINES OUTPERFORM EXISTING CULTIVARS FOR FORAGE YIELD AND ITS COMPONENTS UNDER TERMINAL HEAT STRESS

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Genotype, environment and their interactions are important determinant of crop phenotypes. In present study, oat genotypes including advanced lines (candidate varieties), approved cultivars, obsolete cultivars and germplasm accessions were evaluated at three sites under terminal phase heat stress to study the response of heat resistant elite advanced oat lines. Genotype + Genotype × Environment was used to select better genotype across three experimental sites. Advanced lines such as "Sgd-1", "Sgd-oat-2011" and "Fsd-oat" were selected for better yield under the terminal heat stress which had better green fodder yield (GFY) and also showed stable performance when compared at three locations. These advanced lines provided a yield advantage of 10% when compared with standard checks under heat stress. Among the yield components, plant height (PH) had positive association with GFY at all locations and this trait may be prioritized for the selection of high yielding genotypes. "S-2000" showed better performance for leaf area, "Sgd-oat-2011" and "CK-1" had been stable for tiller number and "Fsd-Oat" showed stable performance for stem thickness at all three locations. The results showed that candidate variety "Sgd-1" found to be superior cultivar for general cultivation due to its higher GFY, tiller number and PH. Moreover, Sgd-1 was heat tolerant cultivar and can be recommended for general cultivation subjected to terminal phase heat stress.
Keywords: Cultivar, fodder yield, hay, plant phenology, stover.

INTRODUCTION

Oat (*Avena sativa* L.) is an important forage and grain crop of the world being cultivated in 78 countries and it occupies the largest area in Russian Federation (FAO, 2016). In Pakistan, oat crop is major winter grass forage. The crop has succulent soft leaves and stem with high palatability for the milk animals, horses and donkeys which may be fed as green or processed as silage and hay (Stevens *et al.,* 2004). Average yield of the green forage oat crop was about 20-30 tons ha^{-1} and was also affected by various biotic and abiotic factors (Peterson *et al.,* 2005, Lodhi *et al.,* 2009). However, improved varieties may be developed with the potential to provide 60-80 tons ha^{-1} due to better stability and resistance to biotic and abiotic factors.

Increasing forage yield is an ambitious oat breeding objective. Breeders generally select high yielding cultivar through transgressive segregation and establish pure lines. However, oat forage or grain yield was threatened by various factors including late terminal phase high temperature. Rising temperature due to increasing CO_2 is one of the major factors affecting crop yield (Prasad *et al.,* 2008, Kalyar *et al.,* 2014, Niazi *et al.,* 2015). Therefore, development of temperature resilient crops is fundamental

for reducing the yield losses. In oat, heat stress during late terminal phase induces early senescence of crop and reduces the crop duration period which ultimately reduces crop forage yield (Quiles, 2006). A few studies have been conducted to develop heat resistant oat genotypes, despite terminal phase heat stress is an important yield limiting factor in arid or semi-arid environment. Terminal heat stress in wheat (*T. durum* and *T. aestivum*) caused a yield reduction of 44% and 26% respectively in both species (Modhej *et al.,* 2012). Forage yield *per se* is an important criterion to determine the sustainable forage yield of elite cultivars subjected to the selection for heat tolerance during early transgressive segregation especially for stays green related traits. The objective of the study was to compare newly developed advanced lines against the approved and germplasm accessions for yield and its components under terminal heat stress.

MATERIALS AND METHODS

The studies were carried out at the Fodder Research Institute, Sargodha during the year 2016-17. Advanced lines were (F_6) selected for high forage yield, late maturity and

Table 1. Salient features of improved varieties and breeding lines of oat (*Avena sativa* L.) used in experiments

Varieties/Line	Status	Characteristics
Sgd-1	Advanced line	High yield candidate lines for varietal approval. High green fodder Yield due to higher no. of tillers plant^{-1}, rust resistance, drought and heat resistance (stay green).
Domount	Obsolete cultivar	Exotic germplasm accession
Sgd-oat-2011	Approved variety	High yielding approved heat resistant variety
Ck-1	Advanced line	High yield candidate lines for varietal approval for general cultivation. Broad Leafed canopy with cold tolerance, rust resistance, high leaf palatability.
FSD-oat	Approved variety	High yielding approved heat resistant and lodging resistant variety.
S-2000	Approved variety	High yielding approved variety.
No-632	Advanced line	High yield advanced lines. Broad Leafed rust resistance canopy with acceptable palatability.
No. 75525	Germplasm line	Germplasm accessions

better tolerance to high temperature for sustainable forage yield (Table 1).

***Experimental conditions*:** Plant material including approved varieties, advanced and gemplasm lines (Table 1) were sown at three locations i.e. Farooqabad (31.7501° N, 73.8066° E, altitude 210 m), Faisalabad (31.4504° N, 73.1350° E, altitude 184 m) and Sargodha (32.0740° N, 72.6861° E, altitude 155m) to test their performance for forage yield and its various components. All locations were situated in the Punjab province, Pakistan under subtropical and semi-arid climate with terminal phase heat stress. Total average yearly rainfall during year 2017-18 at was 431mm Farooqabad, 346 mm at Faisalabad and 410 mm at Sargodha. The soil was loam at Sargodha having organic matter 0.61%, pH 7.85 ± 0.11, N% 0.06 ± 0.01, K$^+$ 174 ± 6.34 mg Kg^{-1}, and P 5.6 ± 0.41 while soil at Faisalabad was characterized as sandy loam with organic matter = 0.72 % , pH 7.12 0.29, N% 0.05 ± 0.01, K$^+$ 152 ± 3.29 mg Kg^{-1}, and P 6.34 ± 0.35. However, Faroqabad soil was characterized as clayey having organic matter 0.91 %, pH 7.54 ± 0.32, N% 0.04 ± 0.02, K$^+$ 174±5.31 mg Kg^{-1}, and P 8.34 ± 0.52. Genotypes were sown on 16 October at Faisalabad, 18 October at Sargodha, 21 October at Farooqabad, Pakistan. Each genotype was sown in 6m × 1.5m plot with row to row distance of 30 cm. Experiment was laid out as Randomized Complete Block Design within each location. There were three blocks at each experimental site. The fertility of each experimental site was raised by adding inorganic fertilizer @ rate of 60 kg ha^{-1} nitrogen and 30 kg phosphorus ha^{-1}. Field capacity of the soil was measured through gravimetric method and was 18% by weight for Sargodha and 21% for Farooqabad and 19% for Faisalabad. Maximum and minimum temperatures at experimental sites are given in Fig. 1. Experimental plots were irrigated with supplemental irrigational water to avoid water stress. The genotypes were harvested at milking stage when foliage moisture contents fell to 60%. Foliage moisture contents were determined by weighing the fresh mass and

then drying it in oven at 60 ºC at constant weight. Moisture contents were determined by following formula:

Moisture contents % = {(Fresh biomass – Dried mass)/Fresh mass} × 100
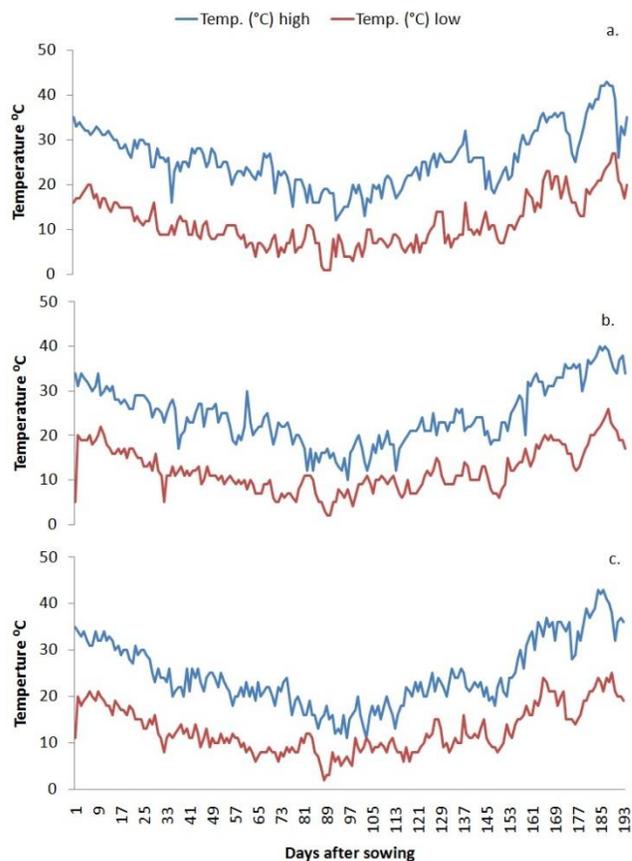
Figure 1. **Maximum and minimum air temperature of 3 experimental sites at (a). Sargodha (b). Faisalabad and (c). Farooqabad**

The following traits were measured at the time of harvest:

Green fodder yield (Kg ha^{-1}) was determined after harvesting all plants of a genotype when leaf moisture contents fell below 60% and weighed on digital field balance. Five plants from the middle row were uprooted and separated to determine number of tillers plant^{-1}, stem thickness, plant height and leaf area. Number of tillers plant^{-1} were counted manually while stem thickness was determined by Vernier caliper. Plant height was determined by measuring the length of tiller from base to shoot apex through measuring tape. Leaf area was determined by digital leaf area meter (CI-202, Camas, USA).

***Statistical Analysis*:** Measured traits were subjected to the analysis of variance and traits showing significant variation were further used to determine the (GGE) biplot analysis considering environments and genotypes as two factors. Genotype and Genotype × Trait biplot analysis was carried out within each experimental site to determine the association between traits and genotypes. All statistical analysis was carried out in the excel addin sheets.

RESULTS

Analysis of variance showed significant (*P ≤ 0.01*) variation due to genotypes, locations and genotypes × location interactions for all traits (Table 2). Highly significant (*P ≤ 0.01*) variation due to genotype × location interactions showed that genotypes performance was affected due to three locations and genotypes changed their relative ranking across the locations. Therefore, genotypes performance was shown across the locations (Table 2).

Genotype and Genotype × Environment (GGE) biplot analysis of GFY has been shown in Figure 2a. Genotypes had the highest GFY at "Faisalabad" while "Farooqabad" had the lowest yield (Fig. 2a). "Sgd-1", "Sgd-oat-2011" and "Fsd-oat" had the highest average GFY yield at all locations and were closed to middle of axis showing that these varieties were also stable across three locations (Fig. 2a). Line "CK-1" was also high yielding but its performance was specific to the locations. "CK-1" had the highest GFY at "Farooqabad" and may be suitable for this location. The performance of "Domount" was also location specific and showed the highest GFY at "Faisalabad" followed by "Sargodha". Genotype performance was comparatively similar at "Faisalabad" and "Sargodha" as both locations were close to each other on the axis (Fig. 2a) which may be due to similar agro-meteorological conditions. Contrastingly, "Farooqabad" spotted at distance from other locations and may have provided different agro-meteorological condition and genotypes failed to give high yield in this environment (Fig. 2a). "S-2000" had the lowest average GFY and was unstable over the locations. "No.632" had better yield but yield was variable across the environment (Fig. 2a).

Leaf area (LA) of genotypes at three locations has been shown in biplot Fig. 2b. "S-2000" was the most stable genotype for LA (Fig. 2b). "75525" had the highest average LA at three locations followed by Sgd-1. Genotype Sgd-1 and "75525" had the highest LA formation at Sargodha and Faisalabad while "No.632" had the highest LA at Farooqabad location (Fig. 2b).
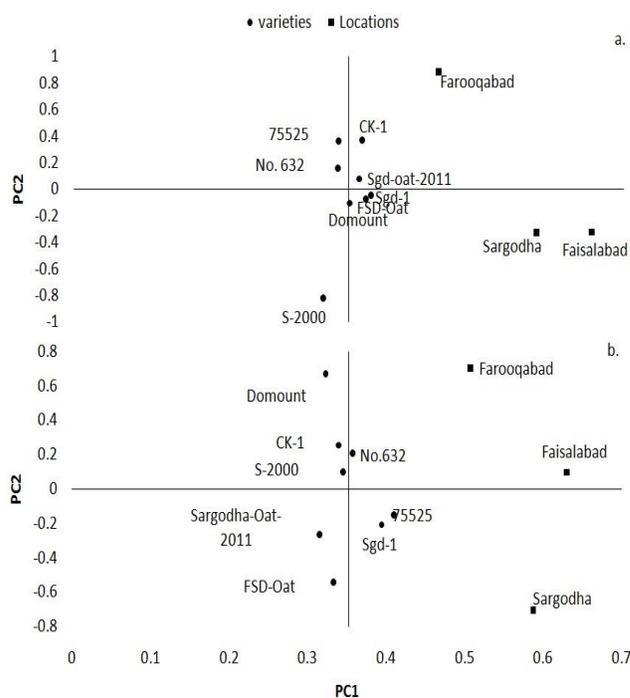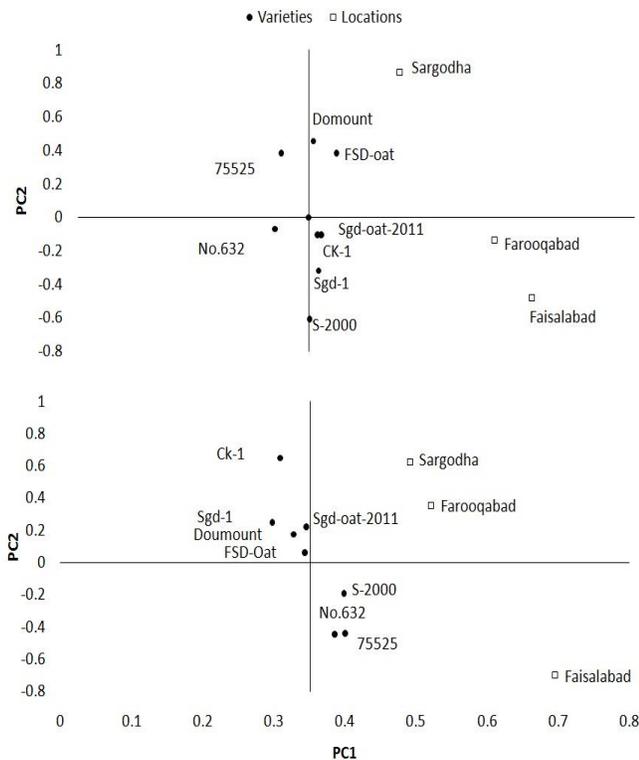

Figure 2. GGE biplot analysis of varieties and (a). green fodder yield (b). leaf area (cm^2)

Table 2. Analyses of variance for green fodder yield (GFY kg ha^{-1}), and contributing traits plant height (PH cm), Leaf area (LA cm), stem thickness (ST cm^2), number of tillers (NT) in oat (*Avena Sativa* L.)

S.O.V.	DF	Mean sum of square				
		PH	LA	ST	NT	GFY
Blocks	2	5.06[NS]	27.12[NS]	0.00[NS]	0.18[NS]	169.01[NS]
Genotypes	7	242.18**	1028.94**	0.02**	3.39**	442.62**
Locations	2	5363.78**	3482.58**	0.20**	32.86**	8529.01**
genotypes × Locations	14	205.09**	729.35**	0.03**	0.65*	315.95**
Residual	46	9.88	74.85	0.00	0.26	63.30
Total	71	221.95	392.62	0.02	1.56	391.97

** highly significant (P ≤ 0.01)

Genotypes showed the highest number of tiller (NT) at Faisalabad and Farooqabada (Fig. 3a). "Sgd-oat-2011" and "CK-1" had been stable for TN at three locations while other genotypes had mean values subjected to the specific location (Fig. 3a). "Fsd-oat" had the highest average TN at three locations. "CK-1" had the highest TN at Faisalabad while "Sgd-oat-2011" and "CK-1" had the highest TN at Farooqabad (Fig. 3a). The genotype "No.632" had the lowest average TN followed by "75525" (Fig. 3a). "Fsd-oat" had the most stable performance for stem thickness (ST) across three locations (Fig. 3b). Accession "75525" had the highest average ST across the locations followed by No.632 and "S-2000". "75525" showed the highest ST at Faisalabad while "CK-1" showed the best performance at "Sargodha" (Fig 2b). "Sgd-oat-2011" had the highest ST at "Farooqabad" (Fig. 3b).

"CK-1" and "Sgd-1" were the promising genotypes at Sargodha location having higher than average traits values at Sargodha location (Fig. 4b). Sgd-1 had the highest GFY. "FSD-oat" and "Sgd-oat-2011" had the highest number of tillers (NT). FSD-oat had also high GFY due to higher NT. "Sgd-1" had comparatively better LA but "Domount" and "No.632" had the highest LA (Fig. 4b). "S-2000" had the highest ST. A positive association was also identified between GFY and PH.

Trait by genotype interaction for Faisalabad location has been in biplot (Fig. 4c). "CK-1" had average or higher than average value of all traits under study. "Sgd-1" had the highest GFY and PH at Faisalabad (Fig. 4c). "Fsd-oat" and "Sgd-oat-2011" had the highest NT while "75525" had the highest LA (Fig. 4c).
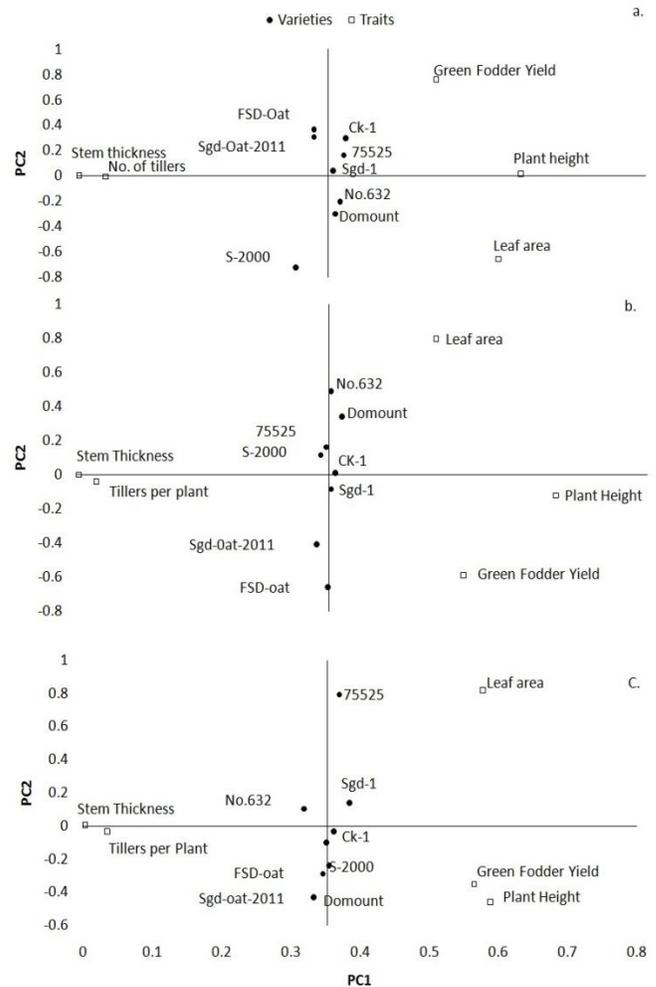

Figure 3. GGE biplot analysis of (a). number of tillers per plant (b). stem thickness (cm^2)

Trait by genotype analysis at Farooqabad location has been shown in biplot (Fig. 4a). "Sgd-1" had the average or higher than average of traits values at this location. "CK-1" and "Sgd-1" had the highest GFY at this location. "CK-1" and "75525" had the highest PH (Fig. 4a). "Domount" had the highest LA while "FSD-oat" had the highest tillers per plant at "Farooqabad" (Fig. 4a). There was positive relationship between GFY and PH. Similarly, PH and LA also had positive association (Fig. 4a).

Figure 4. Genotype + Genotype × Trait biplot analysis of varieties, yield and contributing traits a various agro-ecological locations (a) Farooqabad (b). Sargodha (c). Faisalabad

DISCUSSIONS

Genotype and environment are an important determinant of crop phenotypes. Therefore, oat genotypes were tested under multiple environments for traits related to fodder and grain yield (Peterson *et al.,* 2005). Significant genotypes × environment showed that varieties changed their relative ranking across the environment and stability of the genotypes was determined to identify promising varieties for general and environment specific cultivation. Genotypes at three locations were subjected to later terminal heat stress of varying duration (Fig. 1). Thus heat stress was a common factor for reducing growth and duration at three locations. High temperature and light intensity inactivated the photosynthetic apparatus and reduced the quantum yield of PSII (Quiles, 2006). Therefore, genotypes having better tolerance to the terminal heat stress may able to produce high yields at the studied locations. Physiological traits such as lower cell membrane injury, compatible solutes, canopy architecture, better recovery from heat stress have been induced to reduce yield losses under heat stress (Quiles, 2006, Kalyar *et al.,* 2014, Niaizi *et al.,* 2015). The genotypes have been screened for these traits and resistant genotypes were selected without determining their productivity. Yield performance under targeted environment was also an important criterion and thus could be used to select productive genotypes for targeted environment (Kalyar *et al.,* 2014). Direct selection for yield *per see* under targeted stress condition has been recommended in oat due to low heritability of physiological traits (Atlin and Frey, 1989). Genotypes such as "Sgd-1", "Sgd-oat-2011" and "Fsd-oat" selected for better yield under the terminal heat stress had better GFY at three locations and showed stable performance when compared at three locations (Fig. 2a). These genotypes provided a yield advantage of 10% when compared with other genotypes under heat stress. Among the yield components, plant height had association with GFY at all locations and this trait may be prioritized for the selection of high yielding genotypes. The genotype having better yield component such as "S-2000" showed better performance for LA. "Sgd-oat-2011" and "CK-1" had been stable for TN and "Fsd-Oat" showed stable performance for ST at all three locations. "Sgd-1" was superior cultivar due to its higher GFY, TN and PH and resistant to heat stress. The cultivar may be recommended for general cultivation.

***Conclusion*:** Development of high yielding and temperature resilient cultivars is important breeding objectives of oat breeding. Therefore, present study evaluated the candidate varieties along with standard checks and germplasm accessions under terminal heat stress. These candidate varieties especially "Sgd-1" surpassed the standard checks and may be helpful in achieving the sustainable forage yield supplies under heat stress prone areas of Punjab.

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