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SOIL PHYSICO-CHEMICAL AND MORPHOLOGICAL ADAPTATIONS OF *ARISTIDA* L. SPECIES IN VARIED ECOLOGICAL ZONES OF PAKISTAN

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Abstract

In Pakistan, the widespread grass genus *Aristida* (Family Poaceae) was studied for its ecological distribution and adaptive features, focusing on soil and morphological characteristics. Four species—*Aristida adscensionis*, *Aristida cyanantha*, *Aristida funiculata*, and *Aristida mutabilis*—were collected from various ecological zones of Punjab. The study revealed significant differences in soil physico-chemical properties such as electrical conductivity (ECe), pH, organic matter, saturation percentage, and nutrient content, which varied across populations and influenced plant growth. Populations from different habitats exhibited variations in plant height, flag leaf area, and root and shoot biomass, reflecting the species' ability to adapt to diverse environmental conditions. For instance, *A. mutabilis* populations in nutrient-rich environments displayed greater root and shoot biomass, whereas populations in stress-prone regions showed reduced growth. Similarly, *A. adscensionis* populations from arid regions demonstrated enhanced biomass and plant height, indicating superior adaptation to semi-arid conditions. These morphological differences underline the adaptive strategies of *Aristida* species in coping with varied ecological stresses. The study emphasizes the importance of *Aristida* species in ecological research and conservation, providing insights into plant resilience and adaptation mechanisms in response to environmental stressors.

Keywords: *Aristida* Species**,** Soil Physico-Chemical Properties**,** Morphological Adaptations**,** Ecological Zones**,** Environmental Stress Tolerance**,** Biomass Variation**,** Plant Resilience.

1. INTRODUCTION

Grasses inhabit a range of habitat types and are very significant commercially. Poaceae is the world's fourth-largest family of flowering plants, with over 1,800 genera and 1,000 species most of these are monotypic or diatypic (Martinez *et al*., 2023). Poaceae is crucial to steppe, shrub, marsh, and forest ecosystems. Because its members can withstand a wide range of environmental conditions, they are frequently employed in genetic, ecological, and systemic studies (Smith *et al*., 2021). The annual habit and C4 photosynthetic pathway are the two most notable traits that have led to the creation of many radiations within the Poaceae family.

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Aristida is the largest and most widely distributed genus, with almost 300 species. Most species are adapted to survive in dry environments. It is known as three-awn grass because it has three bristles on each tiny flower part (Ahmad *et al*., 2020). Because of its morphological appearance, it is also known as spear grass, wiregrass, or needle grass. (Turner *et al*., 2022).

Various types of stress in grasses lead to growth, development, yield, pigment composition and photosynthesis changes. Depending on the level and severity of stress, the responses of different plant species to these changing environments vary. In cold environments, plants often face below-zero temperatures during autumn, spring, and winter (Napieraj *et al*., 2023). To survive in such frigid conditions, plants make morpho-anatomical and physiological adjustments and changes at the molecular level to minimize frost damage, which could otherwise be fatal. Cold acclimation (CA) is a process where plants growing in above-freezing temperatures make biological adjustments to enhance their ability to tolerate frost. During this process, plants undergo various biological changes. These include adjustments in gene expression, protein synthesis and breakdown, sugar level alterations, and photosystem modifications (Zanotto *et al*., 2023).

Grass species possess morphological adaptations that enable them to survive in diverse ecological regions. These adaptations include variations in leaf morphology and anatomy, the establishment of intricate root systems, and the development of diverse reproductive tactics, such as the dispersal of seeds by wind and the effective germination of seeds, which play a significant role in their growth in these habitats (Ahmad *et al*., 2020). Grasses in arid environments adapt to less water availability by developing narrow leaves, reducing leaf area, and developing deep root systems. These adaptations help them maximize water uptake and minimize water loss (Ameer *et al*., 2023).

This stress might range from a reduction in water potential to the lethal desiccation limit. Among various environmental stressors, drought is globally destructive. Although range plants possess mechanisms to mitigate water stress, prolonged water deficiency over a month can significantly reduce herbage production. Drought is a leading cause of crop loss worldwide, often halving average yields. Water-stressed plants become more susceptible to other stresses, such as pathogens, cold temperatures, or air pollution, further hindering plant productivity (Fatima *et al*., 2018). Researchers study plant stress resistance at molecular, cellular, and physiological levels. During water stress, Grass height and biomass decrease, and leaf aging accelerates, leading to lower forage quality. Sexual reproduction diminishes due to reduced seed stalks and seed head numbers, while vegetative reproduction declines because of fewer axillary buds and secondary tillers. Grasses have evolved the ability to detect stressful conditions like drought, leading to the production of numerous newly synthesized mRNAs and polypeptides. Drought responses are diverse, resulting in decreased growth, lower chlorophyll pigment and water content, and alterations in fluorescence parameters. Rangelands, although unsuitable for cultivation, serve as a source of forage for animals (Zhao *et al*., 2016).

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Reduced plant yields mostly evidence the degradation of rangeland. When actively restoring vegetation in degraded areas, the dispersal of seeds is crucial, especially since their seed banks typically lack viable seeds. A significant challenge in restoration ecology lies in selecting seed types or cultivars that can rapidly produce ample biomass and cover. Rangeland conditions are chiefly influenced by grazing from domestic animals and rainfall patterns. Seedling germination and growth are adversely affected by the presence of herbivores and pathogens, sand covering, soil crusting, high soil salinity, extreme temperatures, and drought.

It is hypothesized that Genus *Aristida* species must have particular morphological modifications to cope with harsh environmental conditions. The study was, therefore, conducted with a special focus on the following objectives: To evaluate the pattern of distribution of *Aristida L* species and to integrate soil physiochemical characteristics with morphological characteristics.

2. MATERIALS AND METHODS

Recent research aimed to analyse the ecology, distribution, and adaptive components of the widely distributed grass *Aristida* L. (Family Poaceae). A species' naturally adapted populations were investigated in several ecological zones of the Punjab province and then taken to the University of Agriculture, Faisalabad's Plant Taxonomy and Anatomy Research Laboratory for additional examination.

Study surveys and sample Collection:

Frequent surveys were conducted in the spring of 2020 to collect naturally adapted *Aristida* L populations. From every research site, three or more average-sized plants were randomly selected as duplicates. The group was made based on soil physiochemical characteristics and habitat types. Thirty populations were gathered from six environmentally distinct areas.

Edaphology:

Soil Texture:

Soil samples (2 Kg) were collected from each site at two depths (15 and 30cm) and then thoroughly blended to make a combined sample. The samples were kept within a polythene bag and labelled, and the soil's physiochemical characteristics were later examined. The soil structure was determined using the hydrometer approach. Put a soil sample (100 g) into a glass container (400 ml).

Purified water (200 ml) and 1% Hexa-metaphosphate sodium (125 ml) in the form of were also mixed. The samples were soaked overnight. After being moved to a distribution cup, the sample was mixed using an electric mixer. After being moved to a distribution cup, the sample was mixed using an electric mixer. After being moved to a distribution cup, the sample was mixed using an electrical mixer (5 min).

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The condensation cylinder held one liter of content, to which distilled water was added to bring the volume up to one liter. For Silt and clay fractions, a Bouycous-hydrometer was used, while sand was computed by subtraction. The texture class of every soil sample was ascertained using a textural triangle showing in (Fig. 1), (Brady, 1996).

Saturation Percentage: Following saturation with distilled water and drying at 70 °C, 200g of soil was turned into soil saturation paste. The following formulas were used to get the saturation percentage:

$$ofSP\ (\%) = \frac{\text{Amount of H2O added (g)}}{Mass\ of\ oven\ dried\ soil\ (g)x\ [100 - Pw\}}$$

PW is the known water content, and SP% represents the saturation percentage.

Soil pH and electrical conductivity (EC): Using a combination pH meter, the pH and electrical conductivity (EC) of the soil extract were assessed. (WTW series InoLab pH).

Organic matter (Walbley): The organic matter was quantified using Walkley and Black's titration method after the sample had been purified of debris. Its readings expressed as a percentage. The following formula was applied in the end:

$$Organic\ matter\ (\%age) = \frac{-\text{S} - \text{T x 6.7}}{S}$$

S is a blank reading, and T is the volume of $FeSO_4$ utilized.

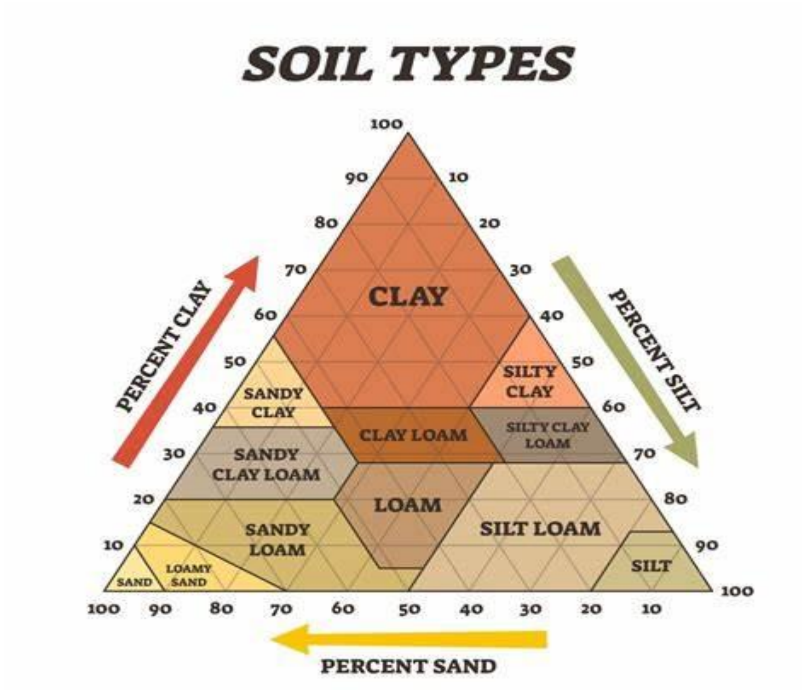

Fig 1: Using the textural triangle, identify the grades of soil texture

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Soil ionic content

Using a flame photometer, the ionic contents of the soil (K^+,Ca^{2+} and Na^+) were examined from the soil water extract. 100 mg of plant materials were mixed with 10 ml of H_2O to prepare the quote for Cl^- measurement.

The mixture was then crushed and heated to 80 ºC until the desired volume was reached. After that, the extract was read using a chloride meter (Jenway, PCLM 3).

Vegetation sampling

To gather phytosociology data, 75 transect lines, each measuring 100 meters, were placed at each study site and spaced 20 meters apart, in addition to a combination of systematic quadrats, each measuring 1 meter. In every instance, the following phytosociological characteristics were measured.

$$Relative\ density = \frac{\text{No of individuals of the species}}{\text{No of individuals of all species}} \quad \text{x} \quad 100$$

$$Relative\ frequency = species \quad \text{x} \quad 100$$

$$Relative\ density = \frac{coverage, or\ domination, of\ a\ specific\ species}{total\ (dominance)\ of\ all\ species\ within\ a\ specific\ area} \quad \text{x} \quad 100$$

$$Importance\ value = Relative\ density + Relative\ frequency + Relative\ cover$$

Morphological characteristics

Root length (cm), shoot length (cm), and plant height (cm), the fresh and dried weight of root and shoot (g), flag leaf area (cm^2), No of leaves plant^{-1}, number of adventitious root plant-1, number of tiller plant^{-1}, and length of inflorescence (cm) were the morphological parameters that were the focus of the investigation.

Five plants from each site were chosen for morphological studies. Plants were dried in a hot oven at 65 °C till the dry weight reached a consistent mass. A digital balance was used to measure the sample's weight, and a measuring scale was used to record its length.

Statistical analysis

Statistical analysis and data visualization were performed by using R statistical software[60] through the R integrated development environment RStudio[60]. Data were subjected to a two-way analysis of variance (ANOVA) at a significance level ($p \leq 0.05$) to evaluate the interaction between ecotypes of *Aristida* species to check the modifications.

Mean and standard errors (SE) of means ($p \leq 0.05$) of significant ANOVA traits of each ecotype and species were compared by using Tukey's HSD (honestly significant difference) by using the "agricolae" package of the R software[32].

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3. RESULTS

Soil Physico-Chemical Characteristics

There were significant variations in the physico-chemical characteristics among the collection sites of different *Aristida* species. Among *Aristida adscensionis*, Soil ECe, Na^+, and Cl^- were recorded at their highest levels in Layyah (LY) and at their lowest in Bansra Gali (BG). The soil pH was highest in Layyah (LY) and lowest in BG. The site MI had the highest increase in soil organic matter, while the lowest levels were observed at Patriata (PT) and Chakwal (CK).

The Layyah (LY) site exhibited the maximum saturation percentage (SP%) with loamy sand (LS) soil texture, while the minimum was recorded at Bansra Gali (BG) with a clayey loam (CL) soil texture. The concentration of Ca^{2+} was highest in Layyah (LY) and lowest in Bansra Gali (BG). Soil K^+ was also highest in Layyah (LY) and lowest in Bansra Gali (BG). The highest concentration of soil nitrate (NO_3^-) was observed in Layyah (LY), while the lowest was recorded in Murree (MR). Soil phosphate (PO_4^{3-}) showed maximum values in Mianwali (MI), and the lowest concentration was found in sardari (SR).

For *Aristida cyanantha*, the highest values for ECe, Na^+, and Cl^- were observed at Shahdra (SH), Lawat (LW), and Muzafarabad (MZ), respectively, while the lowest values for these parameters were recorded at Kail (KA) and Halmat (HL). The highest soil pH was noted in Shahdra (SH), while the lowest was observed in Dawarian (DW). Soil organic matter was highest in Lawat (LW) and lowest in Kail (KA).

The maximum saturation percentage (SP%) was recorded in Shahdra (SH) and Muzafarabad (MZ) with loamy sand (LS) soil texture, while the minimum was observed in Dononial (DD), Kail (KA), and Halmat (HL) sites, which exhibited loamy (L) soil texture. The highest levels of Ca^{2+} were observed in Lawat (LW), Dononial (DD), and Kail (KA) sites, while the lowest were recorded in Halmat (HL) site. Soil K^+ was highest in Lawat (LW) and Shahdra (SH) site, while the lowest levels were recorded in Halmat (HL) site. The highest concentration of NO_3^- was found in Lawat (LW), Dononial (DD), and Muzafarabad (MZ) sites, whereas the lowest was observed in Dawarian (DW), Kail (KA), Halmat (HL), and Murree (MR) sites. Soil phosphate (PO_4^{3-}) was highest in Muzafarabad (MZ) and lowest in Dawarian (DW) sites.

For *Aristida funiculata*, the highest levels of ECe, Na^+, and Cl^- were observed in Thal (TL), while the lowest values for these parameters were recorded in Bahawalpur (BW). The soil pH was highest in Thal (TL) and lowest in Bahwalpur (BW). The maximum soil organic matter was found in Kail (KL), while the lowest values were observed in Bahawalpur (BW). The highest saturation percentage (SP%) was recorded in Thal (TL), and the minimum was observed in Bahwalpur (BW). Ca^{2+} was at its highest concentration in Thal (TL), while its lowest value was recorded in Bahawalpur (BW). Soil K^+ was highest in Thal (TL), with the minimum observed in BW (Bahawalpur). The highest concentration of soil nitrate (NO_3^-) was found in Thal (TL), while the lowest was observed in Bahwalpur (BW). PO_4^{3-} was highest in Kail (KL), while the minimum was found in Bahawalpur (BW).

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For *Aristida mutabilis*, the highest values for ECe, Na^+, and Cl^- were recorded in Hazara (HZ), while the lowest levels were observed in Nagdar (NG). Soil pH was highest in Kallar kahar (KH) and lowest in Nagdar (NG) site. The highest soil organic matter was observed in Hazara (HZ), while the lowest was in NG. The saturation percentage (SP%) was highest in HZ and lowest in NG. The highest concentration of Ca^{2+} was found in Hazara (HZ), while the lowest values were recorded in Nagdar (NG) site. Soil K^+ was at its highest in Hazara (HZ), and the lowest was observed in Nagdar (NG) site. The highest concentration of soil nitrate (NO_3^-) was found in Chakri (CR), while the lowest was observed in Nagdar (NG) site. PO_4^{3-} was highest in Chakri (CR) site, while the minimum was found in Nagdar (NG) site.

Aristida adscenionis										
Sample	E.Ce (mS c	pH	Organic M	Saturation	Ca^{2+} (mg L	K^+ (mg L^{-1})	Na^+ (mg L^-	Cl^- (mg L^{-1})	NO_3^- (mg L	PO_4^{3-} (mg l
MR	1.53	7.2	0.82	19	29	89	268	290	2	4
PT	2.07	7.5	0.64	21	32	95	279	502	3.5	6.1
BG	0.56	6.4	0.61	17	20	47	137	150	2.6	5.5
CK	2.13	7.8	0.6	23	29	84	253	510	4.1	8.2
KK	2.35	8.1	0.74	26	32	93	290	520	3.7	7.4
SR	1.52	7.3	0.85	21	31	91	272	283	2.1	4.1
LY	4.2	8.5	0.76	28	41	120	370	575	4	7.2
MD	1.41	8	0.81	20	31	91	270	298	2.2	4
MI	2.79	8.1	1.31	27	33	104	310	550	3.9	9
Aristida cyanantha										
Sample	E.Ce (mS c	pH	Organic M	Saturation	Ca^{2+} (mg L	K^+ (mg L^{-1})	Na^+ (mg L^-	Cl^- (mg L^{-1})	NO_3^- (mg L	PO_4^{3-} (mg l
LW	1.19	6.2	0.6	15	12	34	100	98	1.8	3.2
DW	2.02	6.1	0.54	16	10.7	32	95	97	1.9	2.8
DD	2.98	6	0.58	15	10	32	92	97	1.9	3.1
SH	2.52	6.5	0.56	18	12	34	101	101	1.9	3
KA	1.92	6	0.52	15	12	30	96	100	1.9	3.2
HL	4.05	6.3	0.58	14	11	31	93	95	1.9	2.9
MZ	2.91	6.3	0.58	17	10.5	32	99	100	2	3.3
Aristida funiculata										
Sample	E.Ce (mS c	pH	Organic M	Saturation	Ca^{2+} (mg L	K^+ (mg L^{-1})	Na^+ (mg L^-	Cl^- (mg L^{-1})	NO_3^- (mg L	PO_4^{3-} (mg l
BW	1.25	7.1	0.56	20	27	82	251	280	2.05	2.9
BH	2.92	7.8	0.61	21	30	90	270	275	2.06	3.2
LS	2.05	7.5	0.62	21	29	90	270	280	2.15	2.4
TL	4.18	8.5	0.76	28	41	121	365	570	4	7.3
DG	3.53	8.4	0.73	27	40	122	360	565	3.8	7.1
KL	2.15	8.1	1.34	27	34	103	310	550	3.6	8.1
Aristida mutabilis										
Sample	E.Ce (mS c	pH	Organic M	Saturation	Ca^{2+} (mg L	K^+ (mg L^{-1})	Na^+ (mg L^-	Cl^- (mg L^{-1})	NO_3^- (mg L	PO_4^{3-} (mg l
LP	2.98	6.8	0.63	18	27	86	258	278	2.2	3.6
NT	2.72	7.1	0.64	17	29	84	258	280	2.3	2.5
AY	2.38	7	0.65	18	22	71	215	225	1.9	2.1
HZ	4.5	7.8	0.85	21	31	91	273	275	2.1	3.4
CR	3.37	7.3	0.61	19	30	88	270	275	3.2	5
KH	4.5	8.8	0.77	18	31	91	275	275	3.1	3.7
NG	2.1	6.3	0.58	15	29	83	92	94	1.8	3

Table 1: Showing soil physiochemical attributes of genus *Aristida* L collected from different ecological zones of pakistan

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Table 1 legends: Collection sites of: Collection sites of: 1. ***A. adscensionis*** (MR-Murree; PA-Patriata; BG-Bansra Gali; CK-Chakwal; KK-Kallar Kahar; SA-Sardari; LY-Layyah; MB-Mandi Bahauddin; MI-Mianwali); 2. ***A. cynantha*** (LW-Lawat; DW-Dawarian; DD-Dodonial; SH-Shahdra; KA-Kail; HL-Halmat; MG-Muzaffarabad); 3. ***A. funiculata*** (BH-Bahawalpur; BH-Bhakhar; LP-Lal Suhanra Park; TL-Thal; DG-Dera Ghazi Khan; KL-Khanewal); 4. ***A. mutabilis*** (LP-Lalazar Park; NT-Nathia Gali; AY-Ayubia; HZ-Hazara; CR-Chakri; KH-Khushab; NG-Nagdar). Soil attributes: ECe-electrical conductivity, pH-soil pH, OM-organic matter, AvP-available phosphorus, AvK-available potassium, SP-saturation percentage, Ca-soil calcium, K+-soil potassium, Na+-soil sodium, Cl–-soil chloride, NO3-nitrate, PO4-phosphate.

Morphological characteristics

The plant height (PH) analysis across different populations of four *Aristida* species reveals significant variations. For *Aristida adscensionis*, the highest plant heights were seen in the BG, LY, and MD populations, while the CK, KK, and SR populations had the shortest plants. *Aristida cyanantha* had the tallest plants in the LW population and the shortest in the SH population. In *Aristida funiculata*, the DG and KL populations reached the greatest heights, unlike the BH and BW populations, which were the shortest.

Lastly, *Aristida mutabilis* showed the tallest plants in the CR and KH populations, with the NG and NT populations having the lowest heights. These findings indicate substantial variation in plant height within species across different populations. Environmental or genetic factors may influence this variation. Understanding these differences provides valuable insights into the growth patterns of each Aristida species and offers a basis for further research.

In *Aristida adscensionis*, flag leaf area (FLA) showed an increase in SR and decreased in PT population. Population of *Aristida cyanantha*, showed a greater (FLA) in DD and reduction in LW and MZ population. (FLA) in population *Aristida funicualta*, was maximum in TL and minimum in BW and KL population. In population of *Aristida mutabilis*, FLA was maximum in HZ and least in KH populations.

Aristida adscensionis population had maximum leaves in CK and SR and minimum in LY. In *Aristida cyanantha* leaf number (LN) was increased in DW and decreased in HL population.

The *Aristida funicualta* population (LN) had maximum leaves in BW and TL and minimum leaves in LS. In the *Aristida mutabilis* population, maximum (LN) was indicated in AY and KH and minimum in CR.

In the ***Aristida adscensionis*** populations, the longest inflorescence length was found in the SR population, while the shortest was in the PT population. For ***Aristida cyanantha***, the DD and KA populations had the longest inflorescence lengths, with the MZ population showing the shortest. In ***Aristida funiculata***, the TL population exhibited the greatest inflorescence length, whereas the BW population had the shortest. Among ***Aristida***

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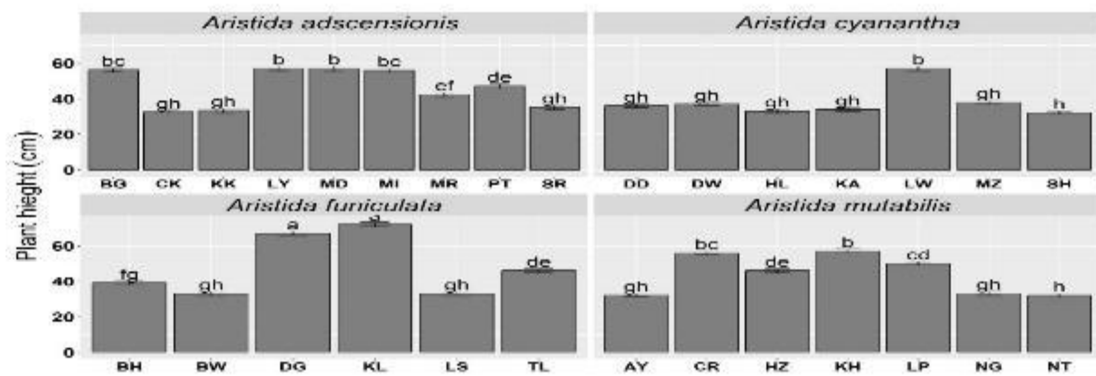
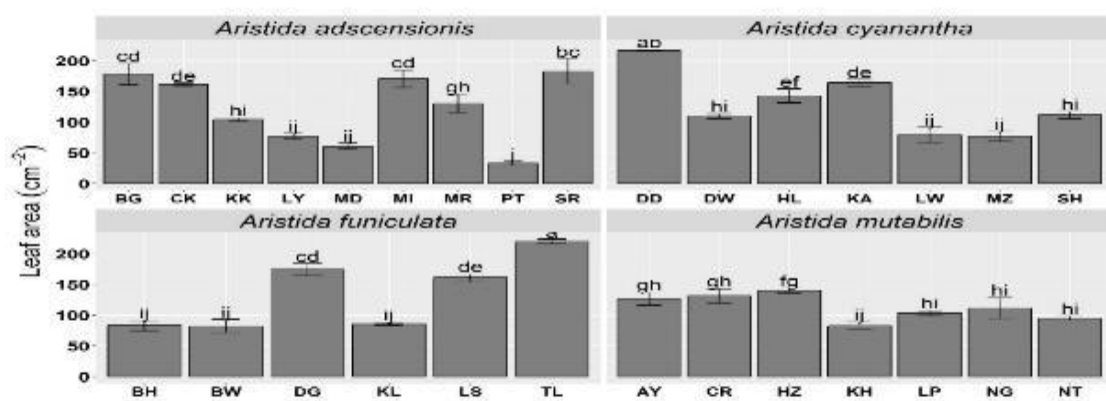
mutabilis populations, the CR population had the longest inflorescence length, and the KH population had the shortest.

In *Aristida adscensionis*, root dry and fresh weight (RDW, RFW) was maximum in MD, while there is no significant difference in other populations. *Aristida cyanantha* showed maximum root fresh and dry weights in LW and minimum in DW, HL, MZ and SH populations. *Aristida funicualta*, root dry and fresh weight was maximum in KL, and there are no significant differences among other populations. Root dry and fresh weight were increased in KH and KL and decreased in HZ populations.

Among *Aristida adscensionis***,** highest shoot fresh weight at the MI site, with the lowest observed at the PT site. The MD site has the maximum shoot dry weight, whereas the CK site records the minimum. For *Aristida cyanatha*, the LW site shows the highest shoot fresh weight, while the MZ site has the lowest. The dry weight is also highest at the LW site, with the SH site showing the lowest value. In case of *Aristida funiculata***,** the KL site records the highest shoot fresh weight for *Aristida funiculata*, and the LS site shows the lowest. In terms of dry weight, the TL site has the maximum, while the BW site has the minimum. For *Aristida mutabilis*, this species reaches its highest shoot fresh weight at the CR site, with the AY site showing the lowest. The KH site exhibits the highest shoot dry weight, while both the AY and CR sites record the minimum.





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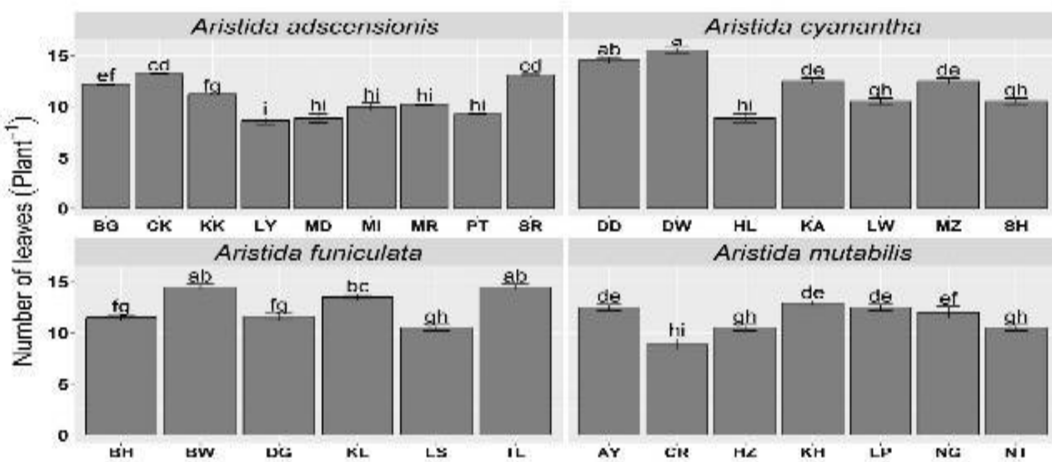
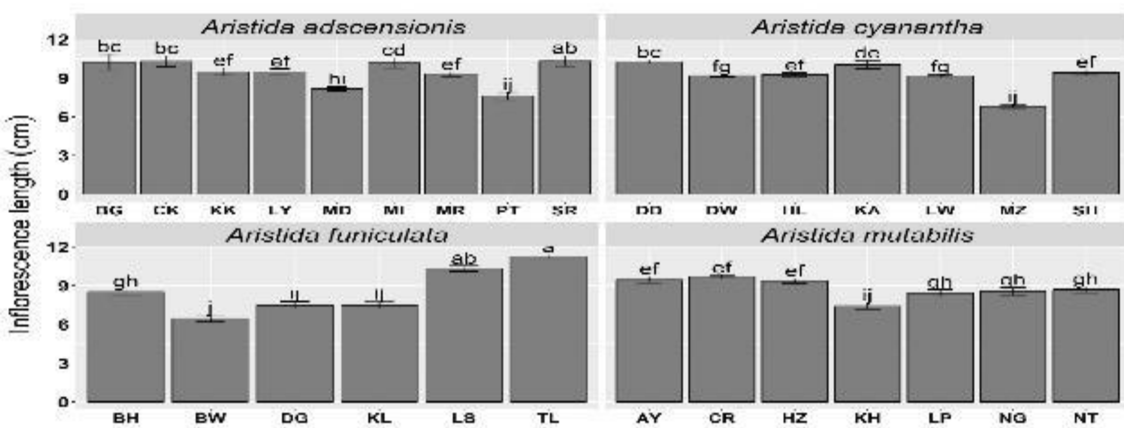
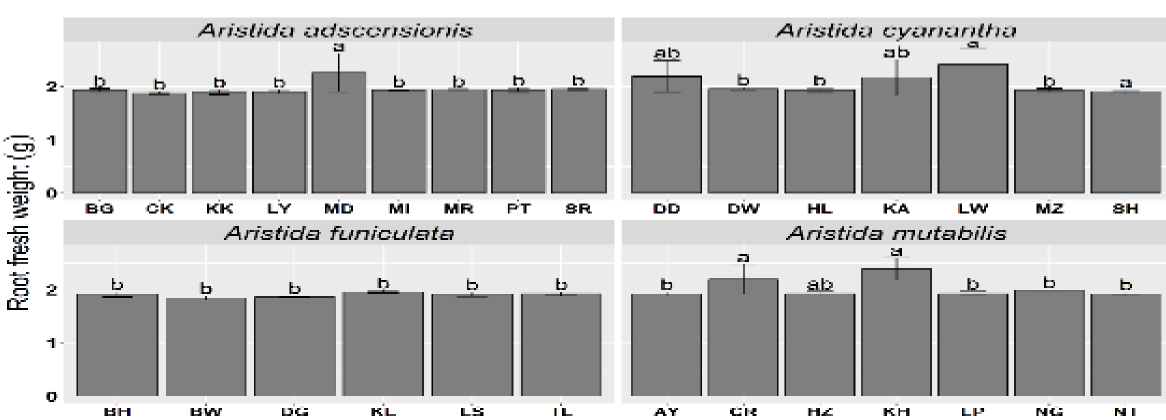


Fig 2: Morphological characteristics (Plant height, Leaf area and Number of leaves)





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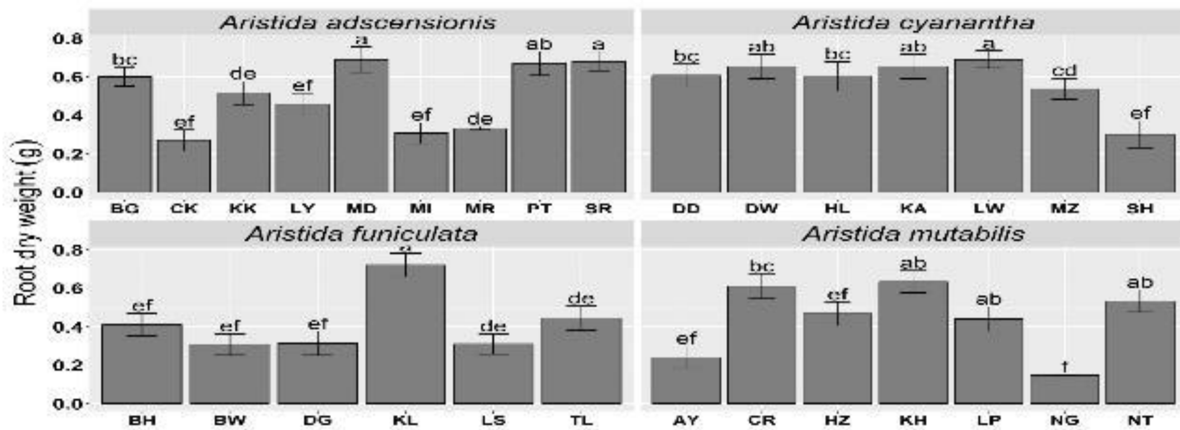

Fig 3: Morphological characteristics (Inflorescence length, Root fresh weight, Root dry weight)

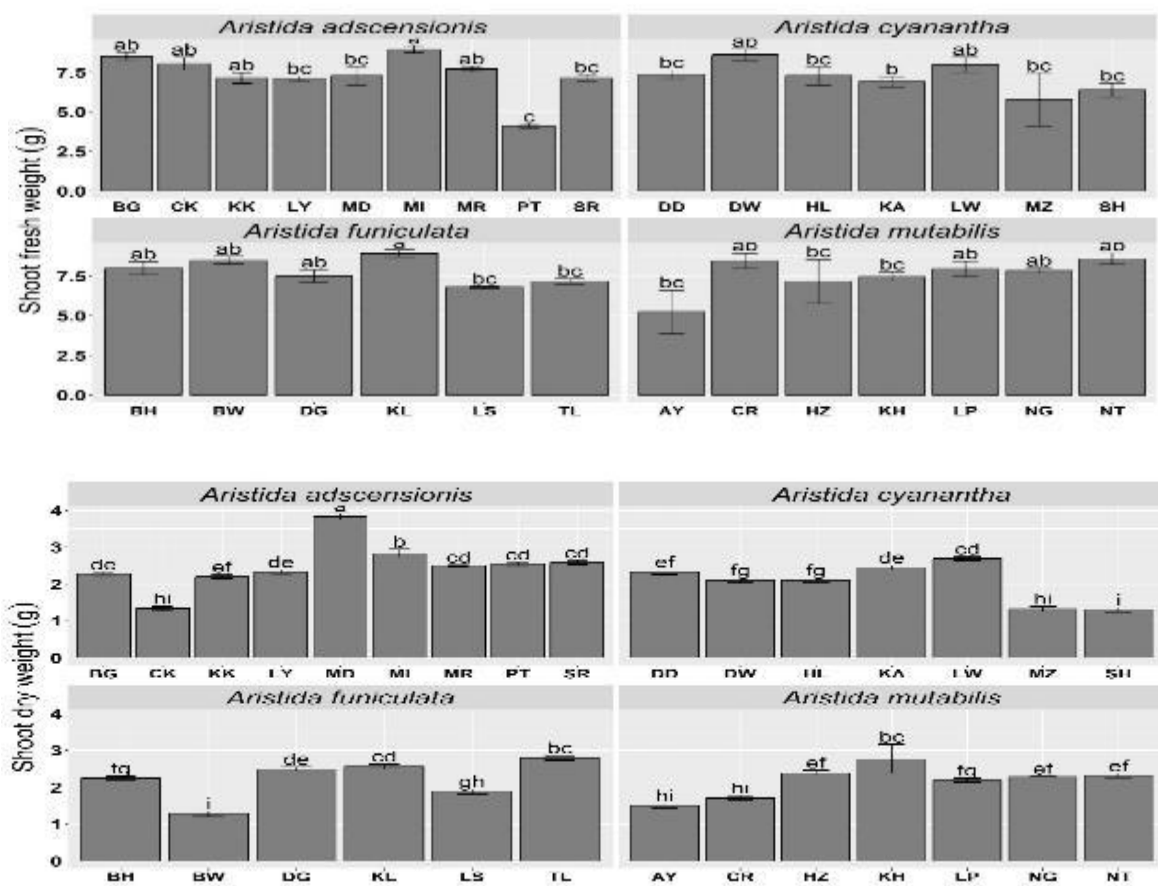

Fig 4: Morphological characteristics (Shoot fresh weight and shoot dry weight)

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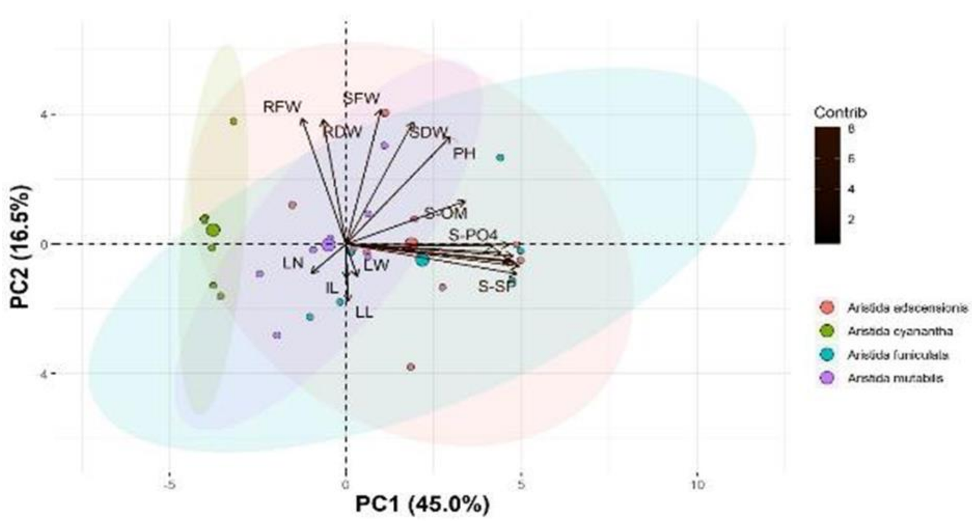
Multivariate and correlation analysis

Multivariate analysis and correlation between growth and soil physico chemical characters

PCA results demonstrated the relationships between *Aristida* species based on morphological and soil physico-chemical variables, with PC1 (45.0%) and PC2 (16.5%) explaining 61.5% of the variance. Each species forms distinct clusters, with *A. adscensionis* and *A. cyanantha* clearly separated along PC1 due to significant differences in traits like shoot and root weights, plant height, and soil nutrients. *A. funiculata* and *A. mutabilis* show more overlap which indicate their similarity. The biplot suggests that *A. adscensionis* is associated with higher values of these influential variables, while *A. cyanantha* has lower values. This analysis demonstrate the role of environmental factors and morphological traits in differentiating *Aristida* species, offering insights into their ecological adaptations and growth conditions.

The correlation matrix demonstrates the complex interactions between soil properties and plant traits. Soil electrical conductivity (S-ECe) is positively correlated with nutrients like organic matter (S-OM), sulfate phosphorus (S-SP), and others, indicating nutrient-rich soils. Plant biomass traits such as shoot and root weights are closely linked, with taller plants (PH) typically having more biomass and thriving in nutrient-rich soils. Some soil properties, like chloride (S-Cl) and sodium (S-Na), show weak negative correlations with plant traits, suggesting higher levels may slightly hinder growth. The matrix reveals relationships between soil nutrients and plant growth, providing valuable insights for ecological and agricultural improvements.



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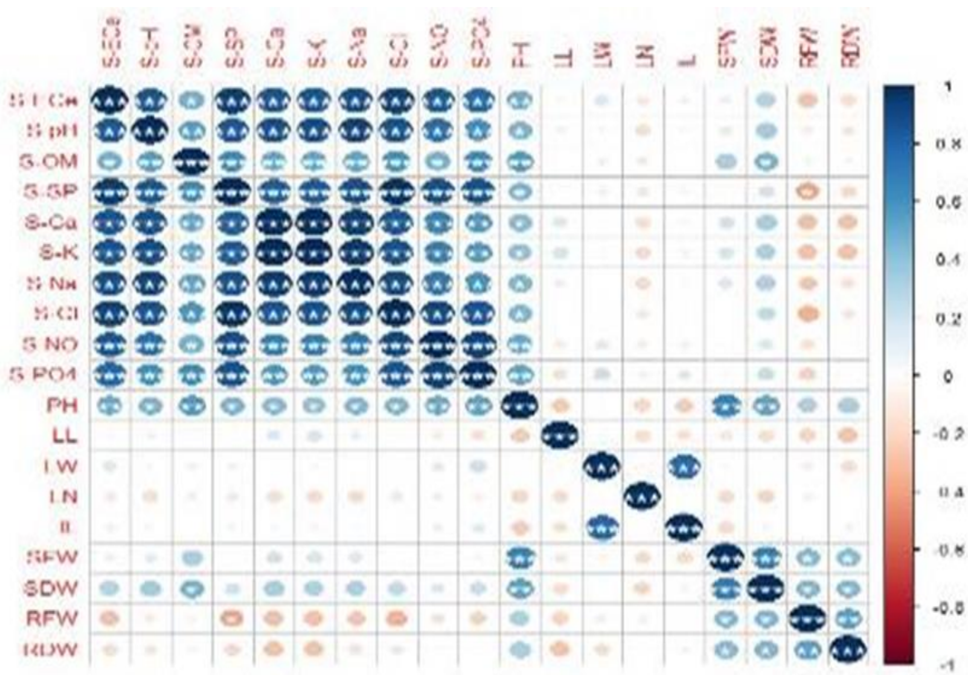

Fig 5: PCA biplot of a) growth and soil physico chemical characters b) Pearson correlation matrix between soil physico chemical character and growth of different *Aristida* species

4. DISCUSSION

The present study was aimed to evaluate the distribution, ecology, and adaptive components of a widely spread *Aristida* that highlights the adaptability of Poaceae members to environmental stresses. 30 differently adapted populations belonging to 4 *Aristida* species were collected from thirty ecologically different regions. These species were: i) ***Aristida adscensionis***, ii) ***Aristida cyanantha***, iii) ***Aristida funiculata***, iv) ***Aristida mutabilis***; samples were thoroughly cleaned with distilled water, preserved for anatomy in FAA (Formaline Acetic Alcohol) solutions and for physiology in ice bag, and brought towards scientific laboratory of University of Agriculture, Faisalabad for further findings. Some morphological parameters like plant height and fresh weight (of root and shoot) was measured during the sampling time, while the remaining parameters were recorded at the institute.

The differences in plant height among the four *Aristida* species across various populations highlight the role of environmental and genetic factors in growth patterns. Research has shown that plant height variations within Poaceae species are adaptive responses to their surroundings, indicating a genetic basis for height regulation influenced by environmental conditions (Ahmad *et al*., 2020). For example, taller plants are often found in less competitive environments where they can capture more light, whereas shorter plants are more common in resource-limited areas to conserve energy (Khan *et al*., 2021).

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Aristida adscensionis is a wide spread specie and its populations collected from varied habitats, such as roadsides, motorways, Salt Range, and mountains, exhibit diverse growth characteristics and adaptations. The population from LY, and MD populations along roadsode warm areas showed maximum plant height and shoot biomass, indicating better adaptation to arid and semi-arid regions (Manssor *et al*., 2019).

At high elevations, plant height was effected in *Aristida adscensionis* (Fatima *et al*., 2018), which was due to much cooler environment and less suitable habitat for growth at higher elevations. (Fatima *et al*., 2022), while shortest plants were in CK, KK, and SR populations.

Aristida cyanantha exhibits diverse growth and physiological traits across different mountainous populations. The LW population had the tallest plants and highest root and shoot weights, indicating favorable conditions. In contrast, the SH population had the shortest plants and lowest shoot dry weight, likely due to environmental stress. The DD population had the largest flag leaf area and longest inflorescence, enhancing photosynthesis and reproductive success, whereas the MZ population showed minimal values in these traits, likely due to stress. The DW population had the most leaves, improving light capture, while the HL population had fewer leaves, reducing water loss (Fatima *et al*., 2022; Shi *et al*., 2015; De-Oliveira *et al.*, 2013; Vega *et al*., 2020).

Aristida funiculata, a desert species that can thrive in various habitats like cool mountains, roadsides, and semiarid regions, shows a range of growth traits and adaptations across different populations. The tallest plants are found in the DG and KL populations, likely due to better conditions, while the shortest plants are in the BH and BW populations, suggesting less favorable environments in those areas.

The TL population stands out with the largest flag leaf area (FLA), which boosts photosynthesis. Conversely, the BW and KL populations have smaller FLAs, likely an adaptation to reduce water loss in dry conditions. The BW and TL populations have the most leaves, aiding in light capture and photosynthesis, while the LS population has the fewest, likely to conserve water and energy. The TL population also has the longest inflorescence, aiding in reproductive success, whereas the BW population has the shortest, likely due to environmental stress.

KL has the highest root weights (both dry and fresh), showing strong root systems for better nutrient and water uptake. The KL site also boasts the highest shoot fresh weight (SFW), indicating optimal growth. The TL site has the highest shoot dry weight (SDW), reflecting efficient biomass accumulation. On the other hand, the LS site has the lowest SFW, and the BW site has the lowest SDW, likely due to stress factors affecting growth. Flag leaf area variations in *Aristida* species reflect their ability to adjust leaf morphology for optimal photosynthesis, and water use efficiency in different environments.

Studies on other grasses have found that such adjustments are crucial for managing water loss and maximizing photosynthesis under varying conditions (Rao *et al*., 2019). In water-scarce environments, smaller leaf areas help reduce water loss through

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transpiration, while in more favorable environments, larger leaf areas enhance photosynthetic capacity.

The number of leaves also demonstrates significant adaptability. Populations with more leaves may be better suited for photosynthesis and growth in favorable conditions, whereas fewer leaves can indicate an adaptation to conserve water in arid environments. Similar traits have been observed in other grass species, where leaf production is linked to environmental stress adaptation (Iqbal *et al*., 2022). Increased leaf production can improve a plant's ability to capture light, which is especially beneficial in resource-rich environments. Variations in inflorescence length, root dry and fresh weight, and shoot fresh and dry weight further emphasize the diverse strategies used by *Aristida* species for reproduction and resource allocation. Research indicates that plants in stressful environments often prioritize survival over growth, as seen in the reduced growth attributes of *Aristida* populations in harsher conditions (Ahmed *et al*., 2020). For example, lower root and shoot weights in some populations might reflect a strategy to conserve energy and resources when growing conditions are not ideal.

Aristida mutabilis were collected from diverse habitats, ranging from, cool to warm mountainous regions, roadsides, along highway***,*** showed a variety of growth characteristics and adaptations across different populations. The tallest plants were found in the CR and KH populations, likely due to favorable conditions, while the shortest plants were in the NG and NT populations (Fatima et al., 2022).

The HZ population had the largest flag leaf area (FLA), enhancing photosynthesis, while the KH population had the smallest FLA, possibly to reduce water loss in dry conditions (Shi *et al*., 2015). The AY and KH populations had the most leaves, which likely improves light capture and photosynthesis. In contrast, the CR population had the fewest leaves, possibly to conserve water and energy (Shi *et al*., 2015). The CR population also had the longest inflorescence, which helps with reproductive success, while the KH population had the shortest, possibly due to environmental stress.

Root dry and fresh weights (RDW, RFW) were highest in the KH and KL populations, indicating strong root systems for better nutrient and water uptake. Conversely, the HZ population had decreased root weights, reflecting limited root development possibly due to soil or moisture stress (De-Oliveira *et al*., 2013). The CR site had the highest shoot fresh weight (SFW), indicating optimal shoot growth, while the AY site had the lowest. The KH site had the maximum shoot dry weight (SDW), showing efficient biomass accumulation, while the AY and CR sites had the lowest, likely due to stress factors affecting shoot development (Vega *et al*., 2020).

Conflict of Interest

The Authors have no Conflict of Interest

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