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Iranian Biology Society

Functional Diversity on the effect of Grazing Intensity in Golestan National Park

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https://doi.org/ 10.22034/bsr.2026.579391.1019

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ARTICLE INFO

Article Type

Original Article

Article History

Received: 23 April 2026

Accepted: 02 June 2026

Published: 31 May 2026

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ABSTRACT

Ruminants and vegetation in natural ecosystems are inherently interdependent, and grazing, as a major ecological disturbance, exerts profound impacts on plant functional traits. This study conducted to evaluate the effects of sheep grazing intensity and topographic aspect on plant functional traits and functional components of grasslands in Golestan National Park. Based on the distance from a watering point, three grazing sites were selected: Site 1 (nearest to the watering point) to Site 3 (farthest), across both western and eastern aspects (six sites in total). From each plant species, five plants were sampled, and two leaves per each species were collected to measure functional traits including leaf area, leaf thickness, leaf length, leaf width, leaf dry matter content (LDMC), and specific leaf area (SLA). At each site, ten 4m^2 quadrats were established to estimate vegetation cover, and functional indices including community-weighted mean (CWM) traits, functional diversity (FD), and Rao's quadratic entropy were calculated. Results indicated that grazing significantly affected Rao's index, functional diversity, and CWM of SLA, LDMC, leaf area, thickness, width, and length. Topographic aspect had no significant effect on any trait; however, the magnitude of variation differed between aspects. Overall, livestock grazing exerted relatively lower effects on Rao's index, while its impact on FD was more pronounced under moderate grazing intensity. The CWM of leaf traits revealed divergent strategies, with plants tending to increase leaf area rather than leaf thickness as an adaptive response to grazing pressure.

Keywords: watering point, grazing intensity, leaf thickness, Rao's index, functional diversity

How to cite this paper

Hoseini, SV., Abedi, M., Gross, G., 2026. Functional Diversity on the effect of Grazing Intensity in Golestan National Park. *Biospecies Research*, 2, pp. 136-149.

Introduction

Global environmental changes, including land use, climate warming, grazing, and fire, strongly affect vegetation dynamics and ecosystem services. This concept was initially emphasized by Díaz et al. (2007) and has been further elaborated in recent global assessments (e.g., Díaz et al., 2019). Grazing influences the morphology and physiology of plants as well as the structure and functioning of rangeland ecosystems, such that plants adopt various strategies to minimize the negative effects of herbivory (Gordon et al., 2008). Vegetation is a key component of the natural environment, shaping the visual character of landscapes and serving as a direct reflection of ecological conditions. Because of this, plant cover is widely recognized as one of the most effective indicators for assessing environmental and ecological factors within a given region (Cui et al., 2023). Therefore, by measuring the amount, variation, and distribution of plant traits within plant communities, it is possible to examine ecosystem functioning (Lefcheck et al., 2015). Plant functional traits serve as reliable tools for predicting the effects of grazing on ecosystems and the resulting changes in ecosystem functioning. Recent studies highlight that grazing intensity modifies trait-dependent community composition and functional diversity, which in turn drive ecosystem productivity and multifunctionality (Guo et al., 2024; Zhang et al., 2023). Nowadays, functional components are used to describe functional traits (Butterfield and Suding, 2013), to represent the overall processes of communities (Mason et al., 2013), and to quantify them (Lavorel et al., 2008). They are considered key tools for understanding the relationship between ecosystem functioning and biodiversity (Schmera et al., 2009).

Recent studies have highlighted the importance of grazing intensity and environmental factors in shaping plant functional traits and ecosystem functioning. For instance, in the steppic rangelands of Nodoushan, Yazd, Gholami and Fakhimi (2023) reported that functional groups such as annuals and geophytes declined under heavy grazing, while hemicryptophytes increased, emphasizing that plant traits can serve as reliable indicators for dryland rangeland management. Jalili (2023) stressed the necessity of adopting an ecosystem-based approach in rangeland management in Iran, warning that focusing solely on grazing without considering ecological structural diversity accelerates rangeland degradation. A study in Mazandaran (2024) demonstrated that species diversity indices (richness, Shannon, Simpson) and functional indices were directly correlated with aboveground biomass, suggesting that appropriate grazing management can simultaneously sustain biodiversity and ecosystem functioning. On a broader scale, Zhang et al. (2023) showed that the effects of grazing on biodiversity and ecosystem multifunctionality are strongly dependent on aridity, with severe reductions in functional diversity in dry regions compared to milder impacts in more humid areas.

Complementary international findings reinforce these patterns. Bahreini et al. (2024), working in the mountainous grasslands of northern Iran, reported that high grazing intensity reduced species richness but increased functional diversity, indicating a shift in plant strategies toward stress-tolerant forms. Zhang et al. (2023) demonstrated that the long-term impacts of grazing on biodiversity and ecosystem multifunctionality are strongly mediated by aridity, with more severe negative effects observed in drier regions. In semiarid rangelands, Taylor et al., (2025) found that soil health indicators such as saturated hydraulic conductivity and mineralizable carbon declined under heavy grazing, emphasizing the link between grazing pressure and soil ecosystem services. In Golestan National Park, Madadi et al., (2024) identified distance from roads and water sources as key drivers of illegal grazing, while Alinaghizadeh and Aslani Kordkandi (2024) showed that climate change and drought significantly reduced vegetation cover, as reflected in declining NDVI values.

Altogether, these studies suggest that grazing intensity, environmental stressors, and human activities interact to influence vegetation dynamics, functional diversity, and ecosystem resilience in rangelands. Despite the various effects of grazing on plant traits (Nikan et al., 2010; Díaz et al., 2007) and on species diversity and richness (Gholami et al., 2012), functional components are considered new and useful tools for predicting changes in rangeland communities and enhancing biodiversity (Komac et al., 2015). It is hoped that by considering the effects of grazing on vegetation cover and ecosystem functioning, more effective information will be provided for rangeland management. Moreover, these components provide better insights into environmental constraints within community structure (Ricotta and Moretti, 2011). Environmental factors also influence the extent of grazing effects; therefore, the impact of topography must be considered as environmental stress conditions change (Collins et al., 2012). Given the limited knowledge regarding species responses to livestock grazing and vegetation degradation, while accounting for aspect and functional components in the protected rangelands of Golestan National Park, this study was conducted to achieve the above objectives.

Methodology

Study Area and Sampling

The study area is located in the northeastern part of Golestan National Park. Its geographical coordinates range from 37°21′50″ N to 37°56′11″ N latitude and from 50°50′52″ E to 51°11′50″ E longitude. The average elevation of the sites is 1,070 meters above sea level. The area consists of small rolling hills, with high plant diversity and a considerable presence of stones and calcareous gravel. The dominant vegetation cover is composed of *Artemisia* (sagebrush) and *Salsola* shrubs. To investigate the effects of sheep grazing intensity, a campsite and a permanent watering point located outside the park were selected as reference sites. Based on the distance from the watering point, three sites were selected: Site 1 with the shortest distance to the watering point, and Site 3 located approximately 2 km away, representing the farthest distance. Site 3 was situated inside the park and subjected to light grazing by gazelles. In each of the three study sites, both eastern and western aspects were considered to account for the effect of topography. Thus, a total of six sites were selected to examine grazing intensity (Figure 1).

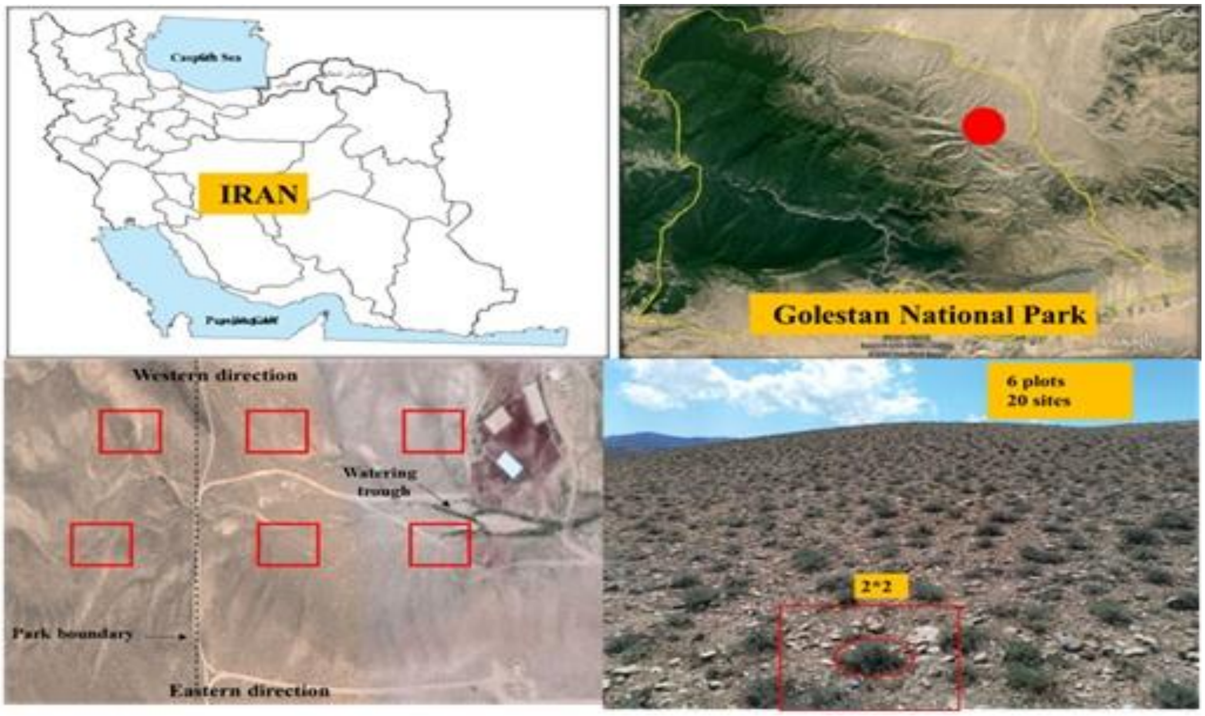

Figure 1. Location of the study area in Iran and the position of the sampling sites

Trait Measurements

For analyzing the effects of grazing intensity, five plant species were randomly selected in each site (a total of 6 sites were randomly selected, with 5 plant stands), and two leaves were collected from each plant. For measuring leaf thickness, area, width, length, dry matter content, and specific leaf area, the leaves were immediately placed in zip-lock bags after collection to preserve fresh weight and transported to the laboratory. Leaf thickness was determined using a micrometer (Mitutoyo 3109A). To assess other leaf traits, leaves were scanned with a flatbed scanner (Canon LiDE 120), and leaf area was calculated using ImageJ software (Version 1.51k 1) following the protocol of Pérez-Harguindeguy et al., (2013). Specific leaf area (SLA) is the one-sided area of a fresh leaf, divided by its oven-dry mass. Note that leaf mass per area (LMA), specific leaf mass (SLM) and specific leaf weight (SLW), are simply 1/SLA).

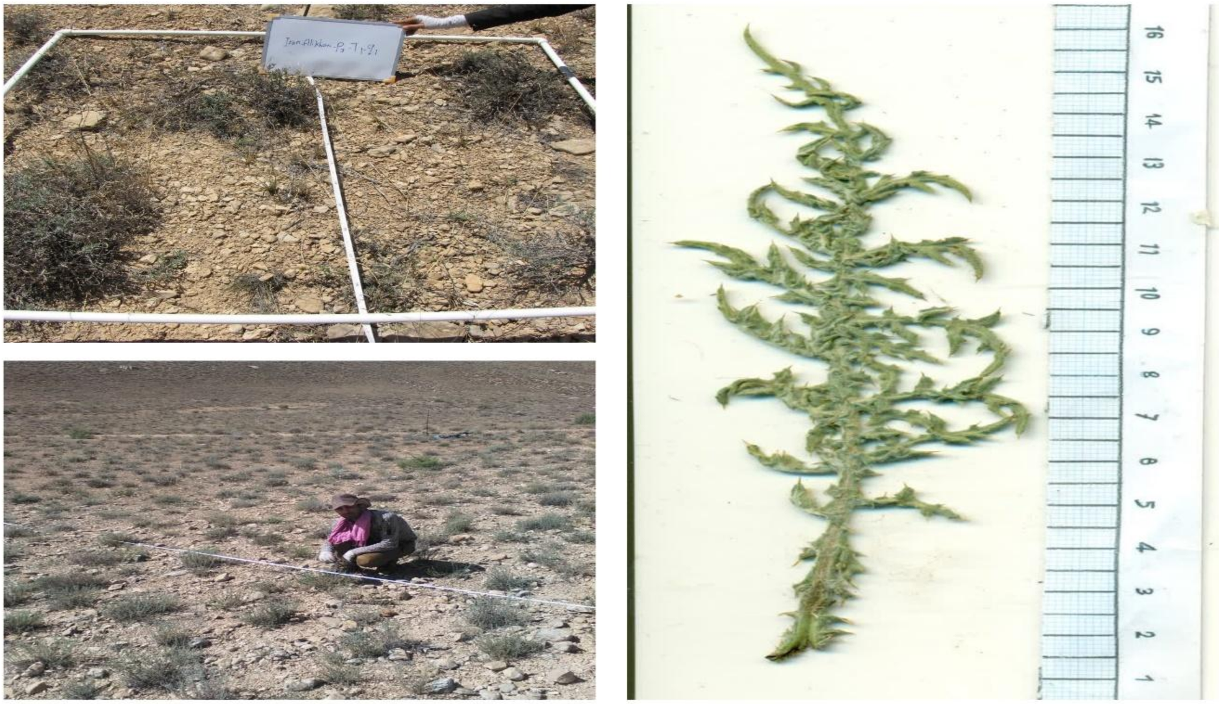

Figure 2. Leaf sampling and measurement of morphological traits

Specific Leaf Area (SLA)

SLA = Leaf area (cm^2) ÷ Leaf dry weight (g)

Leaf Dry Matter Content (LDMC)

LDMC = Mean leaf dry weight (mg) ÷ Mean leaf fresh weight (mg)

Leaf Volume

Leaf Volume = Leaf thickness × Leaf area

Calculation of Components

The components calculated in this study included the community-weighted mean traits (CWM), Rao's quadratic entropy (Rao's index) (Carmona et al., 2015), and functional diversity (FD) (Valencia et al., 2015). Community-Weighted Mean Traits (CWM) The community-weighted mean of traits is calculated as the percentage cover of each species divided by the total percentage cover of all species, where Xi represents the trait value and Wi denotes the percentage cover of the species.

Community-Weighted Mean Traits (CWM) CWM = Σ (Wi × Xi)

- Xi: trait value of species i

- Wi: percentage cover of species i

Rao's Quadratic Entropy (Rao's Index) $\text{Rao} = \Sigma \Sigma\, dij \times pi \times pj$

- dij: Euclidean distance between species i and j
- pi, pj: relative abundance (percentage cover) of species i and j

Functional Diversity (FD) Functional diversity represents the dispersion of traits within plant communities and is analogous to variance. It is derived from a weighted distribution based on the frequency of each trait in the community. The formula is expressed as:

Functional Diversity (FD) $FDj = \Sigma\, pij\ (\,|Tij - CWMj| \,/\, \Sigma\, |Tij - CWMj|\,)$

- FDj: functional diversity for community j
- pij: relative abundance of species i in community j
- Tij: trait value of species i in community j
- CWMj: community-weighted mean traits in community j

Vegetation Cover Measurement

To assess the cumulative effects of livestock grazing at each study site, vegetation changes a long distance-from-water gradients was used as an indicator. Along these gradients, four groups of variables were recorded: (1) measures of grazing pressure, including consumption, utilization, fecal density, and a defoliation index; (2) primary productivity, which reflects a core ecosystem response to grazing; (3) plant community composition, providing insight into population- and community-level responses; and (4) soil organic matter, used as an indicator of grazing effects on long-term productivity potential. For this study, we selected One distinct permanent water point within each of the six study areas, typically situated in separate pastures. We specifically chose grazing lands where management practices, including stocking rates and the spatial arrangement of fences and water points, had been stable for two decades. At each location, we established five to seven sampling sites at different distances from the water. Beyond the direct assessments of herbivory and grazing pressure conducted via temporary exclosures, we also employed two indirect methods to estimate grazing intensity across all study locations. The primary indirect measure involved quantifying livestock fecal density. Specifically, within the PAT study area, we calculated the density of individual fecal pellets using two 40 × 0.2 m belt transects per site, a methodology consistent with the approach described by Fernández et al. After selecting the focal species, individuals were chosen that were healthy and growing under adequate ambient light conditions. This is an especially important consideration for leaf-related functional traits. Leaves were collected from plant species experiencing minimal shading and showing no signs of discoloration or stress. To assess vegetation cover at each site, a total of 6 sites were randomly selected, with 5 plant stands, totaling 6 plots. At each site, all encountered species were pressed for herbarium preparation and subsequently identified using the herbarium of Golestan National Park.

Statistical Analysis

To determine the most important factors influencing species distribution across different aspects under grazing, a generalized linear mixed model (GLMM) was applied. In the model, plots were considered as random factors, while aspect and grazing were treated as fixed effects. A Gaussian distribution and a log-link function were used (5). Random effects were specified based on the number of plots within each site. Model evaluation was conducted using Fisher's F-statistic. For treatment mean comparisons, least squares means and independent t-tests were applied. All statistical analyses were performed in R software (Version 2.2.3). The *lme4* package was used for computations, as it is specifically designed for fitting mixed models. A Gaussian distribution was applied in the modeling since the data were continuous. For mean comparisons, the lsmean package was employed, which calculates least squares means for pairwise comparisons.

Results

According to Table 2, a total of 79 plant species belonging to 27 families were identified under different grazing intensities in the eastern and western aspects of the study area. The most important plant families included: Poaceae (33.33%), Asteraceae (29.62%), Caryophyllaceae (29.62%), Berberidaceae (25.92%), and Brassicaceae (22.22%). The dominant vegetation type in the study area was Artemisia–Salsola. Species richness was lower in the heavily grazed site, whereas the lightly grazed site exhibited higher species richness. Results of the analysis of variance indicated that grazing had a significant effect on Rao's index, functional diversity, community-weighted mean specific leaf area, dry matter content, leaf area, leaf width, leaf thickness, and leaf length. Geographic aspect showed no significant effect on any of these traits. However, the interaction between grazing and aspect had a significant effect on the community-weighted mean of specific leaf content and leaf area (Table 1).

Table 1. Analysis of variance results for the interaction effect of grazing and direction on functional components

Component		Grazing		direction		Grazing and direction	
	df	P value	F value	P value	F value	P value	F value
Functional Diversity Indicators	1	0	6.41	0.28	1.13	0.22	1.44
Rao's quadratic entropy (Rao)	1	0.03	2.77	0.72	0.12	0.83	0.31
Community-weighted mean specific leaf area (CWM-SLA)	1	0.00	34.58	0.24	1.38	0.63	0.56
Community-weighted mean leaf dry matter content (CWM-LDMC)	1	0.00	35.66	0.58	0.30	0.00	4.63
Community-weighted mean leaf area (CWM-LA)	1	0.00	4.06	0.14	2.12	0.30	1.23
Community-weighted mean leaf length (CWM-LL)	1	0.00	3.93	0.34	0.61	0.41	0.99
Community-weighted mean leaf width (CWM-LW)	1	0.00	10.58	0.80	0.05	0	3.82
Community-weighted mean leaf thickness (CWM-LT)	1	0.00	16.14	0.33	0.92	0.25	1.36

The results of the mean comparison indicate that:

1. Geographical Orientation Effects on Traits and Indices

Geographical orientation exerted significant effects only under heavy grazing, specifically on functional diversity, Rao's quadratic entropy (Rao's Q), leaf dry matter content (LDMC), and leaf area. In contrast, community-weighted mean specific leaf area (SLA), leaf thickness, leaf length, and leaf width consistently varied across all sites, irrespective of grazing intensity (Figure 3).

2. Influence of Grazing Intensity on Leaf Morphological Traits

Grazing intensity markedly altered leaf morphological attributes. SLA, LDMC, leaf area, and leaf width increased with grazing pressure, whereas leaf thickness and leaf length decreased. These trait shifts reflect adaptive strategies of plant communities in response to herbivory along the grazing gradient (Figure 3 A).

3. Functional Diversity and Rao's Q Across the Grazing Gradient

Functional diversity declined progressively with increasing grazing intensity, with the most pronounced reduction observed at the moderately grazed site. Similarly, Rao's Q decreased under moderate grazing, while changes were comparatively minor under low and heavy grazing. These findings highlight the sensitivity of community functional structure to intermediate levels of disturbance (Figure 3 B).

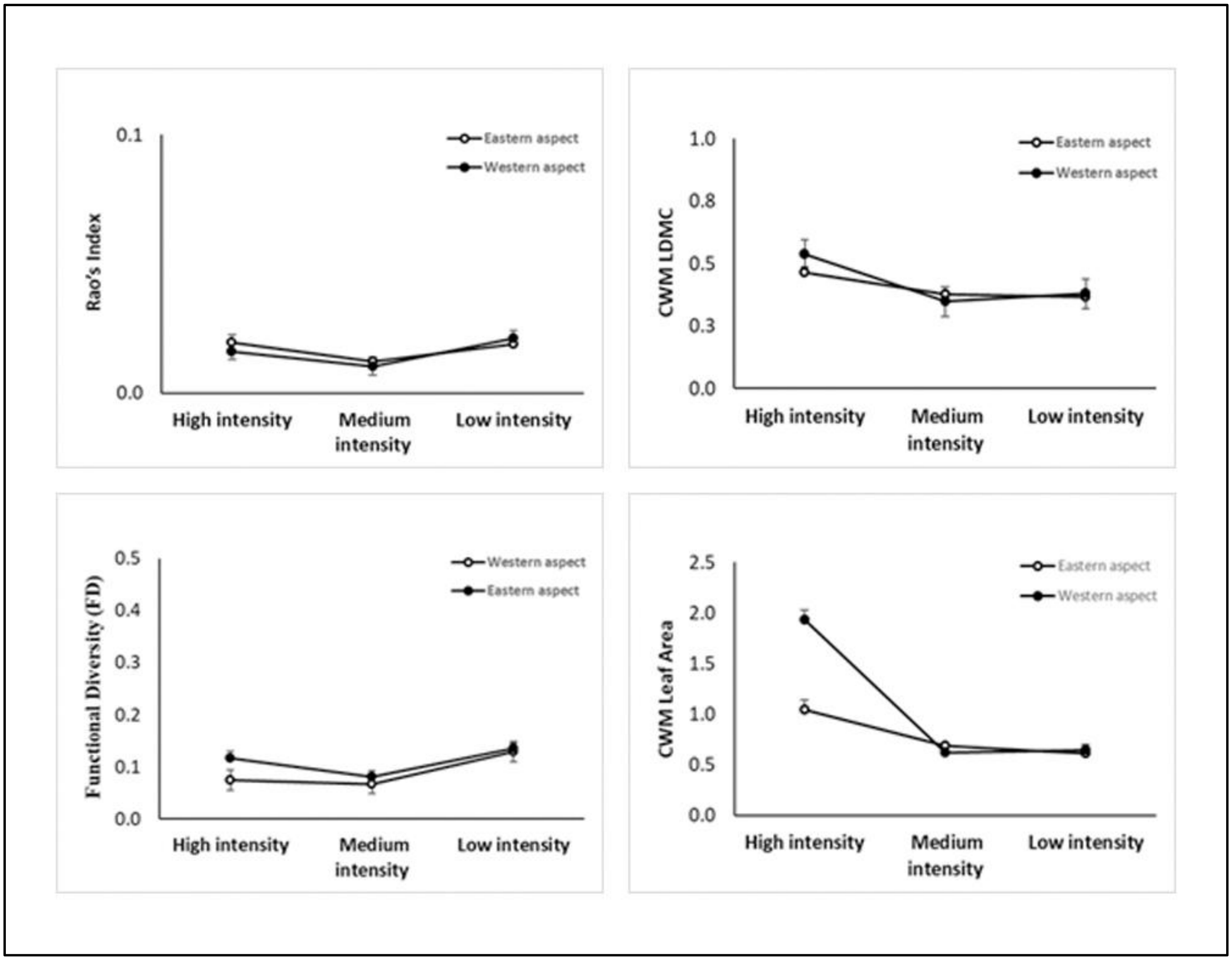

Figure 3 A. Variation of functional components across grazing intensities

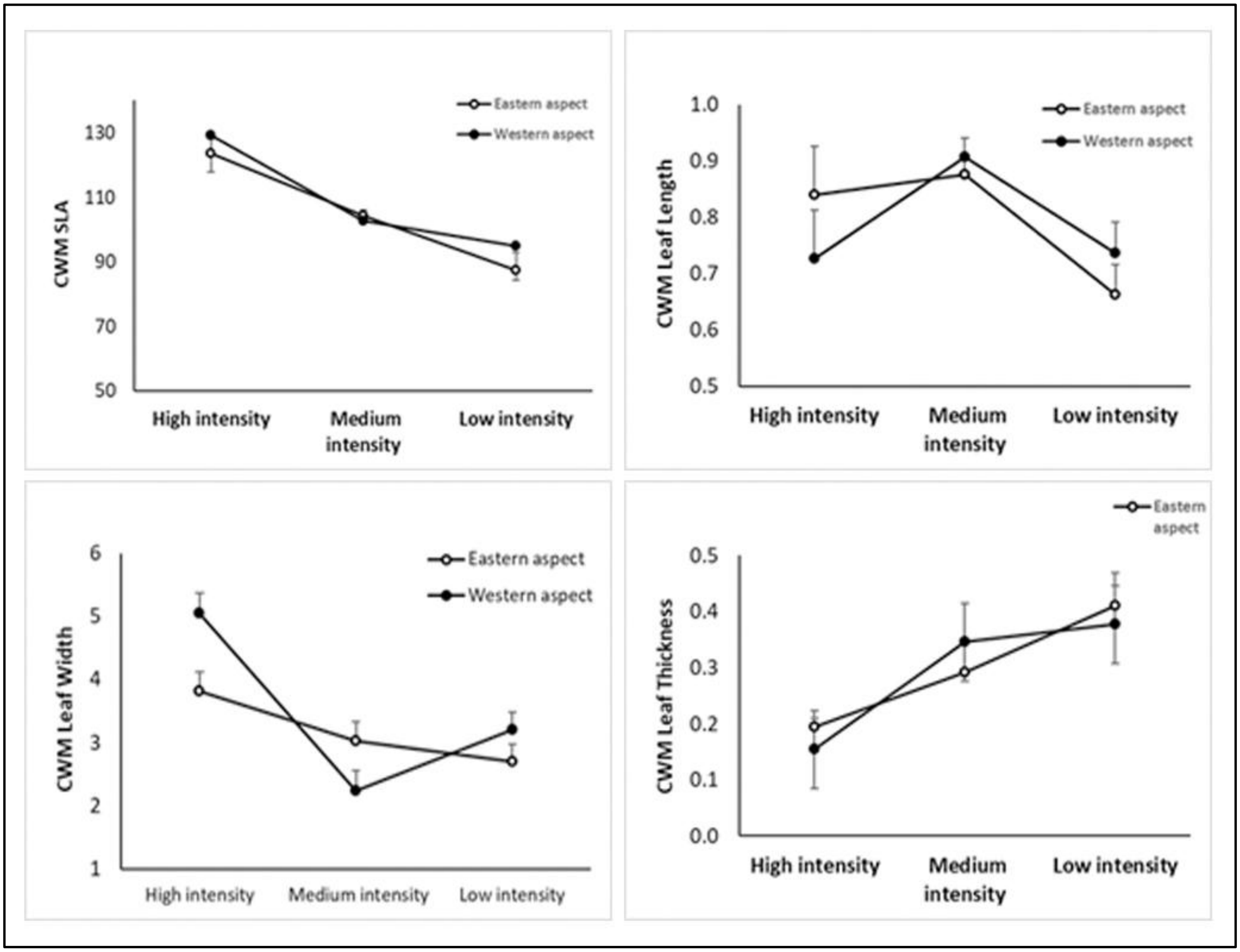

Figure 3 B. Variation of functional components across grazing intensities

Table 2. Annex – List of Species Coverage Values in the Sites

Functional Group	**Family**	**Species Name**	**Functional Group**	**Family**	**Species Name**
PH	Apiaceae	*Ferula* L.	L	Fabaceae	*Trigonella monantha* C.A.Mey.
PH	Asteraceae	*Achillea tenuifolia* Lam.	AH	Geraniaceae	*Erodium ciconium* (L.) L'Hér.
S	Asteraceae	*Artemisia* L.	G	Iridaceae	*Iris acutiloba* C.A.Mey.
PH	Asteraceae	*Cousinia arctotidifolia* Bunge	Cu	Juglandaceae	*Teucrium polium* L.
PH	Asteraceae	*Cousinia decipiens* Boiss. & Buhse	PH	Juglandaceae	*Ziziphora* L.
PH	Asteraceae	*Cousinia turcomanica* Bunge	G	Lamiaceae	*Eremostachys macrophylla* Montbret & Aucher ex Benth.
AH	Asteraceae	*Crepis sancta* (L.) Babe	Cu	Lamiaceae	*Lagochilus cabulicus* Benth.

AH	Asteraceae	*Crupina vulgaris* Cass	PH	Lamiaceae	*Phlomis cancellata* Bunge
AG	Asteraceae	*Koelpinia linearis* Pall	Cu	Lamiaceae	*Stachys turcomanica* Trautv
PH	Berberidaceae	*Berberis integerrima* Bunge	AH	Lamiaceae	*Ziziphora tenuior* L.
AH	Boraginaceae	*Arnebia decumbens (*Vent.*)* Coss	G	Liliaceae	*Allium rubellum* M.Bieb.
AH	Boraginaceae	*Lappula Moench* L.	G	Liliaceae	*Muscari caucasicum* (Griseb.)
PH	Boraginaceae	*Lappula barbata* (M.Bieb.)	G	Liliaceae	*Tulipa* L.
AH	Boraginaceae	*Nonea caspica* (Willd.) G.Don	AH	Malvaceae	*Gypsophila bicolor* (Freyn & Sint.)
AH	Boraginaceae	*Nonea lutea (*Desr.*)*	PH	Malvaceae	*Malva neglecta* Wallr.
PH	Boraginaceae	*Onosma* L.	AH	Papaveraceae	*Roemeria hybrida* (L.) DC.
AH	Brassicaceae	*Aethionema carneum* (Banks & Sol.) B.Fedtsch.	Cu	Plumbaginaceae	*Acantholimon pterostegium*
AH	*Brassicaceae*	*Alyssum desertorum* Stapf	AG	Poaceae	*Bromus danthoniae* Trin.
AH	Brassicaceae	*Alyssum meniocoides* Boiss	AG	poaceae	*Bromus tectorum* L.
AH	Brassicaceae	*Conringia* Heist. ex Fabr.	AG	Poaceae	*Eremopyrum triticeum (*Gaertn.*)*
S	Brassicaceae	*Matthiola farinosa* Bunge *ex* Boiss	AG	Poaceae	*Hordeum murinum* L.
AH	Brassicaceae	*Rapistrum rugosum* (L.) All.	AG	poaceae	*Loliolum subulatum* (Banks & Sol.) Eig
Cu	Caryophyllaceae	*Acanthophyllum pungens (*Bunge*)* Boiss	PG	Poaceae	*Piptatherum holciforme* (M. Bieb.*)*
Cu	Caryophyllaceae	*Ferula* L.	PG	Poaceae	*Poa bulbosa* L.
PH	Caryophyllaceae	*Gypsophila bicolor (*Freyn & Sint.*)*	PG	Poaceae	*Stipa barbata* Desf.
Cu	Caryophyllaceae	*Herniaria incana* Lam.	AH	poaceae	*Taeniatherum caput-medusae* L.
AH	Caryophyllaceae	*Holosteum glutinosum (*M. Bieb.*)*	G	Podophyllaceae	*Bongardia chrysogonum* L.
AH	Caryophyllaceae	*Minuartia hamata* (Hausskn. & Bornm.) Mattf.	AH	Primulaceae	*Androsace maxima* L.
AH	Caryophyllaceae	*Minuartia meyeri (*Boiss.*)*	AH	Ranunculaceae	*Adonis aestivalis* L.
AH	Caryophyllaceae	*Silene conoidea* L.	AH	Ranunculaceae	*Ceratocephala falcata (*L.) Pers.
Cu	Chenopodiaceae	*Krascheninnikovia ceratoides* L.	PH	Rosaceae	*Potentilla recta* L.
S	Chenopodiaceae	*Salsola arbusculiformis* Drobnick	AH	Rubiaceae	*Callipeltis cucullaris* L.
PG	Cistaceae	*Festuca valesiaca* Schleich. ex-Gaudin	AH	Rubiaceae	*Galium ghilanicum* Stapf

S	Cistaceae	*Fumana procumbens* (Dun.)	S	*Rubiaceae*	*Rubia tinctorum L.*
AH	Cistaceae	*Helianthemum salicifolium* L.	PH	Rutaceae	*Haplophyllum obtusifolium* (Ledeb.*)*
AH	Convolvulaceae	*Convolvulus commutatus* Boiss.	Cu	Tamaricaceae	*Reaumuria alternifolia (*Labill.*)*
AH	Dipsacaceae	*Scabiosa rotata* M.Bieb.	AG	Typhaceae	*Vulpia myuros* L.
PH	Euphorbiaceae	*Andrachne telephioides* L.	PH	Zygophyllaceae	*Malva neglecta* L.
L	Fabaceae	*Astragalus* L.			
L	Fabaceae	*Lathyrus inconspicus* L.			

Discussion

Effects of Sheep Grazing on Rao's Index and Functional Diversity

The diversity of plant communities and ecosystem functioning depends on competition among species for various resources. In the present study, Rao's quadratic entropy and functional diversity changed primarily under moderate grazing intensity, whereas light and heavy grazing did not lead to significant dispersion in plant traits. These results suggest that moderate grazing promotes trait differentiation and species coexistence, while heavy grazing reduces aboveground biomass and diversity, and light grazing allows annual species to establish. Similar findings were reported by Lv et al., (2024), who showed that species diversity in meadow steppes followed a unimodal curve under grazing intensity, consistent with the intermediate disturbance hypothesis. The observed changes in the moderately grazed site are likely due to the disappearance of annual species prior to sampling.

This finding contrasts with previous studies that reported increases in Rao's index and functional diversity under higher grazing intensities (Niu et al., 2016; Komac et al., 2015). However, the decline in functional diversity along the grazing gradient observed here aligns with Bahreini et al., (2024), who found that heavy grazing reduced species richness and phylogenetic diversity in mountainous grasslands of northern Iran. Meta-analyses further support these results: Yu Zheng et al., (2025) demonstrated that heavy grazing consistently reduces soil organic carbon and aboveground biomass, while light grazing may enhance soil organic matter in certain grassland types. Similarly, Zhang et al., (2023) highlighted that grazing impacts on biodiversity and ecosystem multifunctionality are strongly mediated by aridity, with dry ecosystems showing sharper declines in functional diversity under grazing pressure.

Effects of Sheep Grazing on Community-Weighted Leaf Traits

Livestock grazing is an abiotic disturbance that alters plant species traits and functional strategies (Bahreini et al., 2024). In this study, specific leaf area (SLA), leaf dry matter content (LDMC), leaf area, leaf length, leaf width, and leaf thickness were all affected by grazing. Heavy grazing reduced leaf thickness while increasing SLA, LDMC, and leaf area. According to Gillison et al., (2013), such trait shifts reflect plant strategies to cope with grazing pressure and competition for light following biomass removal. These findings are consistent with studies reporting that grazing increases SLA and LDMC as plants attempt to balance nutrient limitation and water stress (Zheng et al., 2010; 2015With increasing grazing intensity, plant species richness declines, while the proportion of stress-tolerant and prostrate species increases (Bahreini et al., 2024). Moreno García et al., (2014), studying grazing gradients in semi-arid African rangelands, found that plants near watering points (heavy grazing) exhibited higher nitrogen content, lower cell wall components, greater SLA, and consequently absorbed light more rapidly and efficiently, resulting in higher leaf surface and biomass efficiency. Furthermore, selective grazing by livestock alters leaf functional traits, as grazing intensity shifts specific leaf area (SLA) and leaf dry matter content (LDMC), with shorter species exhibiting higher SLA values compared to taller plants (Caram et al., 2024; Ronk et al., 2024).

Effects of Slope Aspect

According to the results of the analysis of variance, slope aspect had no significant effect on most measured traits. However, under heavy grazing, differences between eastern and western slopes became more pronounced, particularly for leaf area. This may be explained by differences in solar radiation, soil properties, and grazing behavior, since the watering point was located only on one side Shokrollahi et al., (2012). In mountainous regions, variations in snowmelt timing, slope aspect, and soil heterogeneity strongly influence ecological stress, often resulting in shifts in species composition and potential species loss (Schaefer et al., 2024). Functional diversity is an essential component of biodiversity and is considered a key factor for understanding ecosystem processes and the functioning of plant communities (Song et al., 2014). Plant functional diversity plays a critical role in predicting ecosystem permeability, nutrient cycling, and ecosystem stability (Zhang et al., 2023; Guo et al., 2024). Livestock grazing has detrimental effects not only on plant structural characteristics such as species composition but also on soil properties among plant communities (Arzani and Abedi, 2006). Therefore, integrating plant trait responses with soil ecosystem changes provides valuable insights for rangeland managers in estimating and forecasting ecosystem resilience under varying grazing.

Under heavy grazing, greater changes were observed in Rao's index, FD, LDMC, and leaf area, while other traits exhibited variable responses across sites. Overall, livestock grazing exerted relatively lower effects on Rao's index, while its impact on FD was more pronounced under moderate grazing intensity.

Conclusion

The results showed that livestock grazing had a significant effect on all leaf components, including RAO, functional diversity, and the community weighted mean of specific leaf area, dry matter content, leaf area, thickness, width, and length. Geographical aspect had no significant effect on any of these components. However, in the heavily grazed site, RAO, functional diversity, leaf dry matter content, and leaf area differed between the two aspects, while the remaining traits varied across all sites. Overall, it can be concluded that the effect of livestock grazing on RAO was relatively weak, whereas its effect on functional diversity was stronger, particularly in the moderately grazed site. The community weighted means of leaf traits also responded differently: plants tended to increase leaf area rather than leaf thickness as a compensatory strategy under grazing pressure.

Acknowledgments

The financial support for this project was provided by the research fund of Tarbiat Modares University. We would also like to express our gratitude to the Department of Environment, the Protection Unit of Golestan National Park, and all the park rangers for their assistance during this study.

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