https://jksus.org

Journal of King Saud University – Science

2026 38 (3) 17532025

Research Article

Comparison of forage yield and quality of local and commercial barley (*Hordeum vulgare* L.) varieties under semi-arid conditions

Yasir Tufan[a,*], Mahir Özkurt[a], Ayşe Nida Kurt[a]

[a]*Faculty of Applied Sciences, Plant Production and Technologies, Muş Alparslan University, Muş, 49100, Turkey*

ARTICLE INFO

Keywords:
Barley forage
Crude protein concentration
Eastern anatolia (Türkiye)
Fiber fractions (ADF, NDF)
Genotype × environment interaction
Rainfed production systems

ABSTRACT

Livestock farming in semi-arid Eastern Anatolia is facing an increasing forage shortage due to changing climate, degraded pastures, and low-yielding genotypes of conventional forage crops. Therefore, alternative forage crops are necessary to sustain livestock production in such regions. Muş province in the Eastern Anatolia region of Türkiye has a semi-arid climate with significant livestock production potential. Nevertheless, forage shortage is a major hurdle to sustainable livestock production. This two-year study evaluated local and commercial barley (*Hordeum vulgare* L.) genotypes as an alternative forage crop under natural field conditions. Fourteen genotypes were assessed based on fresh forage yield (FFY), dry matter yield (DMY), crude protein (CP), fiber fractions Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), digestible dry matter (DDM), and relative feed value (RFV). FFY ranged from 11330 to 20146 kg ha^{-1}, while the DMY varied from 2945 to 5127 kg ha^{-1}. The 'Olgun' and 'Aydanhanım' consistently produced higher yields. The CP content ranged from 15.28% to 16.34%, yielding 469 to 775 kg ha^{-1} of CP, and 'Olgun' and 'Line 1' proved the most efficient genotypes. The ADF (27.64–28.95%) and NDF (54.57–60.22%) values confirmed a DDM of 66.8% and the calculated RFV indicated a forage quality level exceeding the standard benchmark. Notably, the genotypes 'Bolayır' and 'Hazar' exhibited lower fiber concentrations, which corresponded to comparatively higher RFV and enhanced overall forage quality. The notable year, genotype, and year × genotype interactions revealed genotypic susceptibility to climatic variations. Although similar research exists, this study provides a region-specific and multi-parameter assessment of forage yield and quality under the semi-arid environmental conditions of Muş province. The results indicated that 'Olgun' and 'Aydanhanım' genotypes are best suited for high-yield, whereas 'Bolayır' and 'Hazar' are better suited for quality-focused roughage production. The results will help to improve resilient livestock feeding strategies under rainfed environments.

1. Introduction

Türkiye sustains rural communities through its large cattle, sheep, and goat population, which supports domestic food security and fuels the red meat and dairy sectors (Daskiran *et al.*, 2018). The latest statistics show that Türkiye maintains a cattle population of 16 million alongside 52 million small ruminants (TÜİK, 2024). The demand for forage has increased because of fast cattle farming development, together with natural rangeland destruction and rising feed costs, and unpredictable weather patterns (Tubb & Seba, 2021). The quantity and quality of on-farm roughage often remain insufficient to support superior animal performance in Türkiye (Hanoğlu Oral & Gökkuş, 2021). These constraints have heightened interest in drought-tolerant and water-efficient forage crops that help maintain feed availability and strengthen the resilience of livestock production (Koçak, 2023).

The Muş province in Eastern Anatolia has significant potential for livestock production, with rangelands representing a considerable fraction of the overall agricultural area (Kurt & Gülalp, 2021; Özkurt & Çınar, 2020). The combination of improper land management and excessive grazing has led to a significant drop in both rangeland productivity and biodiversity, thereby limiting the availability of high-quality forage (Kurt & Güllap, 2021). The region traditionally grows alfalfa together with silage maize (Karadağ *et al.*, 2024). Alfalfa farming has declined sharply, while production costs have risen, and silage maize performance has become unreliable during drought conditions, exacerbating feed supply challenges. These constraints highlight the need for high-yielding, nutritionally adequate, and better-adapted varieties to the rainfed, semi-arid conditions of Muş.

Barley (*Hordeum vulgare* L.) serves as a vital crop for animal feeding while thriving under dry environmental conditions (Newton *et al.*, 2011). Barley not only provides an energy source for ruminants, pigs and poultry, but also serves as a source of protein. The protein content fluctuates between 9.6 and 14.1% while its fat content is about 2%. Barley serves as a low-lysine, low-threonine energy source but is high in tryptophan. The plant demonstrates suitability for semi-arid regions through its ability to withstand cold and drought conditions and produce reliable yields in poor soil environments during its short growing season (Carter *et al.*, 2019; Mansour *et al.*, 2018). The flexible harvesting schedule of barley allows farmers to integrate the crop into different farming systems as grain, green fodder, hay, or silage (Newton

***Corresponding author:**
E-mail address: yasirtufan@gmail.com (Y Tufan)

Received: 07 November, 2025 **Accepted:** 21 January, 2026 **Epub Ahead of Print:** 12 March, 2026 **Published:** 17 March, 2026

DOI: 10.25259/JKSUS_1753_2025

This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-Share Alike 4.0 License, which allows others to remix, transform, and build upon the work non-commercially, as long as the author is credited and the new creations are licensed under the identical terms.

© 2026 Journal of King Saud University – Science - Published by Scientific Scholar

et al., 2011). The optimal harvesting time of barley fodder results in high energy content and suitable protein amount, and acceptable fiber content, which makes it ideal for complete ruminant feed formulations (Nikkhah, 2013). Identifying barley varieties with strong forage yield and quality characteristics can support more sustainable livestock systems in Eastern Anatolia.

A crop's suitability for ruminant nutrition depends equally on the quality of its forage and its total biomass production (Capstaff & Miller, 2018). The essential characteristics include crude protein (CP) content and cell wall components, such as acid detergent fiber (ADF) and neutral detergent fiber (NDF), digestible dry matter (DDM), and relative feed value (RFV) (Capstaff & Miller, 2018). The two fiber components, i.e., ADF and NDF, are at high levels, resulting in decreased digestibility and voluntary intake. In contrast, better animal performance occurs when CP and fiber fractions are at their optimum levels. These characteristics are significantly affected by genotype, environment, and their interaction, harvest time, and management factors. In semi-arid, high-altitude regions like Muş, significant interannual fluctuation in temperature and precipitation challenges the selection of stable and high-performing forage genotypes. Therefore, it is important to carry out region-specific assessments of several barley cultivars in realistic field conditions to select genotypes with high forage production, acceptable nutritional quality, and consistent stability across the years.

While numerous studies have evaluated the grain yield of barley varieties across various areas of Türkiye and abroad (Akdogan *et al.*, 2025; Bouhraoua *et al.*, 2025; Güngör *et al.*, 2024), thorough comparisons of forage yield and quality under the semi-arid conditions of Muş province are scarce. Specifically, data that combines agronomic performance (fresh forage and dry matter production) with extensive quality indicators (CP, ADF, NDF, DDM, RFV) across an extensive range of local and commercial genotypes is limited. This knowledge gap restricts evidence-based variety recommendations for farmers and hinders the optimization of regional forage production methods. The current study aimed to evaluate the forage yield and quality characteristics of 14 barley genotypes, including widely cultivated commercial varieties and promising lines, under rainfed circumstances in Muş during two successive growing seasons.

2. Materials and Methods

2.1 Experimental site description

This research was conducted out in the research field of Muş Alparslan University during the 2019–2020 and 2020–2021 growing seasons. The experimental site for the 2019–2020 season was located at 38.79649° N, 41.50273° E, while the 2020–2021 experiment was established at 38.77131° N, 41.421265° E. The study area lies within the boundaries of Muş province at an altitude of approximately 1,300–1,350 m above sea level and is characterized by a continental climate, classified as cold semi-arid (BSk) according to the Köppen–Geiger system. Temperature, precipitation, and relative humidity data for the study area for 2020 and 2021, alongside long-term averages, are presented in Fig. 1.

Soil samples were collected separately for each growing season from the 0–30 cm soil layer. According to the USDA soil texture classification, the 2019–2020 experimental site exhibited a clay texture, consisting of 36.64% sand, 17.45% silt, and 45.91% clay, with a pH of 7.40, electrical conductivity (EC) of 0.40 dS m^{-1}, calcareous content of 0.26%, organic matter of 1.28%, available phosphorus of 1020 kg ha^{-1}, and available potassium of 908 kg ha^{-1}. The 2020–2021 experimental site was characterized as clay loam, containing 30.47% sand, 19.87% silt, and 41.87% clay, with a slightly acidic pH (6.61), an EC of 0.20 dS m^{-1}, calcareous content of 1.10%, organic matter of 1.23%, available phosphorus of 851 kg ha^{-1}, and available potassium of 741 kg ha^{-1}. These results indicate notable differences in soil texture and nutrient status between the two growing seasons, which may have influenced the performance of the barley genotypes evaluated in this study (Table 1).

2.2 Treatments

The study included 14 unique barley (*Hordeum vulgare* L.) genotypes. The experiment employed a randomized block design including three replications. Table 2 illustrates 14 genotypes used in the study along with their institutions of origin. Several varieties were obtained from the Field Crops Research Institute Directorate and the Thrace Agricultural Research Institute Directorate, while two lines were acquired from growers in the Muş area. Each experimental plot was 4 meters in length, with a row spacing of 20 cm, and had 6 rows planted to a depth of 5 cm in furrows created with a hand drill. Seeds were planted on November 7, 2019, and November 13, 2020. Fertilization was conducted at a rate of 80 kg/ha of nitrogen and 50 kg/ha of phosphorus. The whole phosphorus and half of the nitrogen were applied at sowing, while the remaining nitrogen was applied during the stem elongation phase.

2.3 Data collection

The plants were harvested when they reached the dough stage. One row from each side of the experimental plots and 50 cm from both

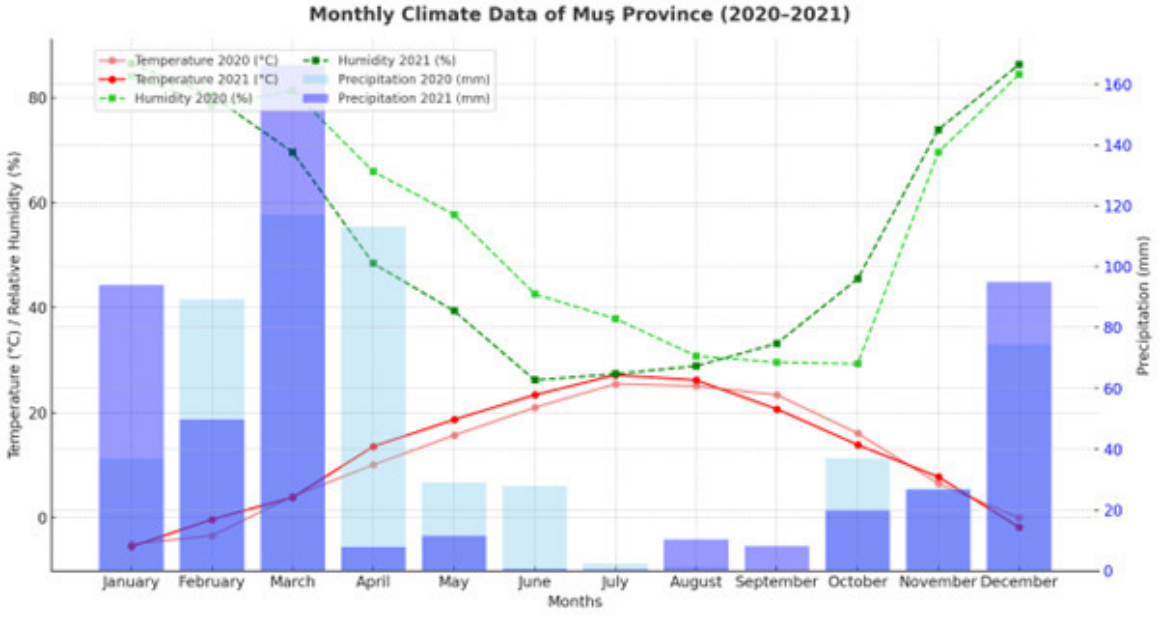

Fig. 1. Monthly variations in temperature (°C), precipitation (mm), and relative humidity (%) for Muş Province during the 2020–2021 growing seasons. Red lines represent the monthly mean temperature, green dashed lines show the relative humidity, and blue bars indicate total monthly precipitation.

Table 1.
Cultivars and their sources.

Cultivar	Source code
Olgun	DAAE
Mert	OLTR
Aydanhanım	TBAE
Burakbey	TBAE
TARM-92	TBAE
Sladoran	TRAE
Zeynel Ağa	TBAE
Harman	TRAE
Yaprak	TRAE
Martı	TRAE
Hazar	TRAE
Bolayır	TRAE
Line 1	MAU
Line 2	MAU

DAAE: Doğu Anadolu Agricultural Research Institute (Erzurum, Türkiye); TBAE: Tarla Bitkileri Central Research Institute (Ankara, Türkiye); TRAE: Trakya Agricultural Research Institute (Edirne, Türkiye); OLTR: Olgunlar Turizm Tarım Enerji Üretim Tic. Paz. Ltd.; MAU: Muş Alparslan University.

Table 2.
Soil physical and chemical characteristics of the experimental sites in the 2019–2020 and 2020–2021 growing seasons.

Parameter	2019–2020	2020–2021
Sand (%)	36.64	30.47
Silt (%)	17.45	19.87
Clay (%)	45.91	41.87
USDA texture class	Clay	Clay Loam
pH	7.40	6.61
Electrical conductivity (dS m^{-1})	0.40	0.20
Calcareous content (%)	0.26	1.1
Organic matter (%)	1.28	1.23
Available phosphorus (kg ha^{-1})	1020	851
Available potassium (kg ha^{-1})	908	741

ends was left intact to account for edge effects, while the remaining 2.4 m^2 area was manually harvested. Each genotype was monitored individually and harvested upon reaching the dough stage, ensuring comparable physiological maturity across entries. Heights of ten randomly selected plants were measured and averaged. The collected samples were weighed to determine the fresh forage yield, and 500 g subsamples were dried at 60 °C until a consistent weight. The dried samples were ground to a sieve size of 1 mm, and the dry matter content was determined by keeping them at 105 °C for 4 h. The dry matter yield per hectare was calculated by multiplying the dry matter content by the fresh forage yield. CP, ADF, and NDF were analyzed using Near infrared reflectance spectroscopy (NIRS, Foss 6500, IC-0904FE software) with the manufacturer's standard Hay/Grass calibration library. Independent wet-chemistry validation was not conducted; therefore, the results rely on the robustness of the manufacturer's calibration library, which should be considered when interpreting the findings.

Digestible dry matter ratio (DDMR), Dry matter consumption (DMC), and Relative feeding value (RFV) were computed using the Eqs. (1-3).

$$\text{Digestible dry matter ratio (DDMR)} = 88.9 - (0.779 \times \text{ADF\%}) \quad (1)$$

$$\text{Dry matter consumption (DMC)} = 120/(NDF\%) \quad (2)$$

$$RFV = (DDMR \times DMC)/1.29 \quad (3)$$

2.4 Statistical analysis

The data were analyzed using a two-way Analysis of variance (ANOVA) with year and genotype as fixed factors, and blocks nested within year. Prior to analysis, the normality and homogeneity of variances were checked. When ANOVA indicated significant differences ($P < 0.05$ or $P < 0.01$), mean separation was performed using Duncan's multiple range test at the 5% level. Pearson correlation coefficients among major yield and quality traits were calculated using the annual means of the 14 genotypes (n = 28), treating each year–genotype combination as an independent observation to better capture the stability of trait associations under varying environmental conditions. Significance levels for correlations were indicated as * ($P < 0.05$) and ** ($P < 0.01$). All ANOVA procedures were performed using MSTAT-C, while correlation analyses were conducted in SPSS.

3. Results

There were significant differences in plant height due to the year, genotype, and their interaction ($P < 0.01$). The plant height on average decreased from 77.81 cm in 2020 to 70.09 cm in the following year, which was a sign of less favorable rainfall distribution in 2021. The values for two-year averages were between 62.98 and 84.86 cm (Table 3). The genotype 'Hazar', along with 'Sladoran', 'Zeynel Ağa', 'Yaprak', 'Martı', and 'Bolayır', were in the shortest group, while 'Aydanhanım', 'Olgun', 'Burakbey', and 'Tarm-92' developed taller canopies, thereby increasing their biomass potential.

The analysis of fresh forage yield (FFY) data showed highly significant differences among genotypes and years and the combined effect of these factors ($P < 0.01$). Annual FFY values showed a substantial drop from 17766 kg ha^{-1} in 2020 to 10527 kg ha^{-1} in 2021 due to lower amounts of in-season precipitation. Two-year averages showed that 'Olgun' had the highest yield, while 'Zeynel Ağa', 'Martı', 'Hazar', 'Bolayır', 'Line 1', and 'Line 2' were the lowest performing genotypes. The 2020 results showed 'Aydanhanım' and 'Burakbey' as the top two performers before 'Aydanhanım' and 'Olgun' took the lead in 2021, proving different strains perform better in changing conditions (Table 3).

The dry matter ratio (DMR) exhibited substantial variation across years ($P < 0.01$), averaging 92.03% in 2020 and 87.62% in 2021, with greater rainfall in 2021 associated with a lower DMR. Genotypic variations were significant, ranging from 89.49% to 91.03%, with 'Olgun', 'Aydanhanım', 'Sladoran', 'Harman', 'Hazar', 'Bolayır', 'Line 1', and 'Line 2' constituting the high-DMR group (Table 4). The DMY was significantly affected by the year, genotype, and their interaction. The average DMY declined from 5039 to 3097 kg ha^{-1} between 2020 and 2021. Two-year averages varied from 2945 to 5127 kg ha^{-1}, with 'Olgun' demonstrating evident superiority and 'Harman' exhibiting the lowest performance, indicating divergent adaptability.

The average ADF content was 28.43% and showed no significant variation across genotypes; however, the considerable year effect revealed higher ADF levels in 2020 compared to 2021, aligning with increased structural tissue under optimal development conditions (Table 5). The NDF concentration exhibited considerable variation across genotypes and throughout the years ($P < 0.01$), with values ranging from 54.57% ('Bolayır') to 60.22% ('Burakbey'). The mean NDF decreased from 58.74% in 2020 to 56.18% in 2021, and a significant year × genotype interaction revealed that specific variety altered their rankings between the two years.

The CP concentration was influenced by both the year and the genotype. The means increased from 14.89% in 2020 to 16.79% in 2021, with two-year averages ranging from 15.28% ('Olgun') to 16.34% ('Yaprak') (Table 6). The CP yield, including CP content and DMY, varied from 459 to 775 kg ha^{-1}. The 'Olgun', 'Mert', 'Aydanhanım', 'Burakbey', 'Tarm-92', and 'Sladoran' constituted the group with the greatest CP yield. At the same time, 'Zeynel Ağa', 'Harman', 'Martı', and 'Hazar' represented the lowest, therefore confirming the significance of biomass accumulation for protein production.

The DDM increased and was consistently stable, averaging 66.76% (range 66.35–67.12%) with no significant genotypic variations (Table 7). Digestible dry matter yield (DDMY) exhibited significant variation across genotypes (about 1950–3434 kg ha^{-1}), with 'Olgun' consistently

Table 3.
Average plant height (cm) and fresh forage yield (kg ha^{-1})for the varieties studied in the research.

	Plant height (cm)			Fresh forage yield (kg ha^{-1})		
Varieties	**1st year**	**2nd year**	**Average**	**1st year**	**2nd year**	**Average**
Olgun	90.20 a	74.67 c-h	82.43 a	21.926 a	18.365 cd	20.146 a
Mert	78.80 a-e	68.91 d-i	73.85 cde	18.514 cd	16.665 de	17.590 bc
Aydanhanım	90.67 a	79.05 a-d	84.86 a	21.622 ab	18.628 cd	20.125 a
Burakbey	87.13 ab	73.64 d-h	80.38 abc	20.061 abc	16.636 de	18.349 b
TARM-92	87.10 ab	77.39 b-f	82.23 ab	19.514 bc	15.221 ef	17.367 bc
Sladoran	64.33 ghi	64.01 ghi	64.17 f	18.171 cd	14.775 efg	16.473 c
Zeynel Ağa	66.43 e-i	67.99 d-i	67.12 ef	13.438 fgh	10.828 j	12.133 e
Harman	76.40 b-g	72.39 d-i	74.40 b-e	16.361 de	11.088 ij	13.724 d
Yaprak	71.00 d-i	70.82 d-i	70.91 def	18.451 cd	11.260 ij	14.856 d
Martı	69.90 d-i	70.44 d-i	70.17 def	12.235 hij	10.425 j	11.330 e
Hazar	60.27 i	65.69 f-i	62.98 f	13.042 ghi	10.357 j	11.700 e
Bolayır	72.90 d-h	68.91 d-i	70.91 def	17.917 cd	10.276 j	14.097 d
Line 1	88.10 ab	63.93 ghi	76.00 bcd	19.615 bc	10.239 j	14.927 d
Line 2	86.13 abc	63.44 hi	74.79 b-e	17.864 cd	10.527 j	14.195 d
Average	77.81 a	70.09 b	73.94	17.766 a	13.235 b	15.500

Means followed by the same letters in the same column are similar, P>0.05.

Table 4.
Average dry matter ratio and dry matter yield of the varieties examined in the study.

	Dry matter ratio (%)			Dry matter yield (kg ha^{-1})		
Varieties	**1st year**	**2nd year**	**Average**	**1st year**	**2nd year**	**Average**
Olgun	92.86	89.20	91.03 a	591.7 a	433.7 d	512.7 a
Mert	92.25	86.72	89.49 b	511.9 c	380.8 efg	446.3 cd
Aydanhanım	92.00	87.82	89.91 ab	570.2 ab	416.9 def	493.5 ab
Burakbey	92.12	83.10	87.61 c	559.4 abc	351.8 g	455.5 c
TARM-92	92.16	87.35	89.76 b	529.3 bc	341.0 g	436.1 cde
Sladoran	92.26	87.76	90.01 ab	553.5 abc	368.6 fg	461.1 bc
Zeynel Ağa	91.85	87.38	89.62 b	354.4 g	234.6 h	294.5 g
Harman	92.38	88.45	90.42 ab	424.0 de	238.8 h	331.4 f
Yaprak	92.00	87.52	89.74 b	548.1 abc	280.8 h	414.4 de
Martı	91.74	87.86	89.80 b	355.0 g	242.7 h	298.9 fg
Hazar	92.33	88.55	90.44 ab	386.6 d-g	258.8 h	322.7 fg
Bolayır	92.30	87.75	90.03 ab	557.6 abc	256.6 h	407.1 e
Line 1	91.93	88.21	90.08 ab	567.8 ab	248.7 h	408.2 e
Line 2	91.95	89.02	90.49 ab	544.6 abc	282.0 h	413.3 de
Average	92.15 a	87.62 b	89.88	503.9 a	309.7 b	406.8

Means Followed By The Same Letters In The Same Column Are Similar, P>0.05.

Table 5.
Average ADF and NDF ratios of the varieties examined in the study.

	Acid detergent fiber ratio (%)			Neutral detergent fiber ratio (%)		
Varieties	**1st year**	**2nd year**	**Average**	**1st year**	**2nd year**	**Average**
Olgun	28.95 b-f	26.97 hi	27.96	59.58 b-e	59.27 b-f	59.43 ab
Mert	29.24 b-e	26.04 i	27.64	59.01 b-f	56.16 h-l	57.61 de
Aydanhanım	31.09 a	26.05 i	28.57	59.80 bcd	55.44 k-m	57.62 de
Burakbey	30.30 ab	27.01 hi	28.70	62.26 a	58.18 d-g	60.22 a
TARM-92	29.48 bc	27.38 hi	28.43	59.79 bcd	56.14 h-l	57.96 cde
Sladoran	29.56 bc	27.53 h	28.54	57.85 e-h	55.79 i-j	56.82 ef
Zeynel Ağa	29.86 abc	27.97 e-h	28.92	57.40 f-i	54.76 klm	56.09 fg
Harman	28.87 c-g	27.41 hi	28.14	60.12 bc	54.40 g-l	58.26 bcd
Yaprak	30.29 ab	27.60 gh	28.95	59.63 b-e	56.97 g-j	58.30 bcd
Martı	29.29 b-e	27.01 hi	28.15	57.16 g-j	54.75 klm	55.96 fg
Hazar	29.48 bc	26.87 hi	28.18	55.77 i-l	54.52 lm	55.15 gh
Bolayır	30.03 abc	27.64 fgh	28.84	55.35 j-m	53.78 m	54.57 h
Line 1	29.61bc	26.95 hı	28.28	58.24 c-g	56.53 g-k	57.39 de
Line 2	29.34 bcd	28.09 d-h	28.72	60.37 b	57.78 e-h	59.08 abc
Average	29.67 a	27.19 b	28.43	58.74 a	56.18 b	57.46

Means followed by the same letters in the same column are similar, P>0.05.

Table 6.
Average crude protein content and crude protein yield of the varieties examined in the study.

	Crude protein content (%)			Crude protein yield (kg ha^{-1})		
Varieties	**1st year**	**2nd year**	**Average**	**1st year**	**2nd year**	**Average**
Olgun	14.26	16.30	15.28 c	8.42 ab	7.08 d	7.75 a
Mert	14.72	16.96	15.84 abc	7.52 cd	6.44 e	6.98 a-d
Aydanhanım	13.82	17.13	15.48 bc	7.88 abc	7.12 d	7.50 ab
Burakbey	14.72	16.33	15.53 bc	8.22 ab	5.74 fg	6.98 a-d
TARM-92	14.83	16.42	15.62 abc	7.85 bc	5.60 g	6.73 bcd
Sladoran	15.14	16.92	16.03 ab	8.38 ab	6.24 eg	7.31 abc
Zeynel Ağa	15.15	17.17	16.16 ab	5.66 gh	4.02 k	4.69 e
Harman	15.41	16.98	16.20 ab	6.52 e	4.05 k	5.28 e
Yaprak	15.73	17.31	16.34 a	8.42 ab	4.85 hi	6.64 bcd
Martı	14.16	16.83	15.99 abc	5.37 gh	4.08 k	4.72 e
Hazar	14.83	16.21	15.52 bc	5.73 fg	4.19 jk	4.96 e
Bolayır	14.97	16.60	15.78 abc	8.34 ab	4.26 jk	6.30 d
Line 1	14.99	17.04	16.02 ab	8.51 a	4.23 jk	6.37 d
Line 2	15.10	16.86	15.98 abc	8.22 ab	4.75 ij	6.49 cd
Average	14.89 b	16.79 a	15.84	7.48 a	5.19 b	6.34

Means followed by the same letters in the same column are similar, P>0.05.

ranking highest and 'Zeynel Ağa' lowest, reflecting the trends seen in DMY. The RFV was significantly affected by year, genotype, and their interaction. The RFV values mostly increased in 2021 (reaching around 112), owing to reduced NDF and ADF levels. The greatest RFV was recorded in 'Bolayır' in 2021, whereas 'Burakbey' in the same year had one of the lowest values, highlighting diverse quality profiles (Table 8).

Correlation analysis (Fig. 2) revealed a strong positive correlation among plant height, FFY, and DMY, suggesting that taller, more vigorous genotypes produce greater biomass. ADF and NDF exhibited a positive correlation with one another and a negative association with DDM, RFV, and crude protein content efficiency, confirming that increased fiber content decreases forage quality and intake potential. These correlations provide a solid physiological foundation for differentiating "yield-oriented" genotypes (e.g., 'Olgun', 'Aydanhanım') from "quality-oriented" genotypes (e.g., 'Bolayır', 'Hazar', 'Yaprak').

4. Discussion

The current assessment of 14 local and commercial barley genotypes under rainfed semi-arid conditions in Muş offers a thorough examination of forage yield, nutritional quality, and genotype × environment interactions, directly tackling the regional forage deficit in Eastern Türkiye. The notable annual variations in plant height, FFY, DMY, and CP yield illustrate the adaptability of forage performance to interannual climatic fluctuations, underscoring the need for variety recommendations in semi-arid systems to ensure stability

Table 7.
The averages of the average digestible dry matter ratio (%) and average digestible dry matter yield (kg/ha) of the varieties examined in the study

	Digestible dry matter ratio (%)			Digestible dry matter yield (kg ha^{-1})		
Varieties	**1st year**	**2nd year**	**Average**	**1st year**	**2nd year**	**Average**
Olgun	66.35 efg	67.89 ab	67.12	392.52 a	294.38 c	343.45 a
Mert	66.12 fgh	68.61 a	67.37	338.63 b	261.10 c-f	299.87 c
Aydanhanım	64.68 j	68.61 a	66.65	368.77 ab	285.99 cd	327.38 ab
Burakbey	65.30 ij	67.79 bc	66.55	365.5 ab	238.45 f	301.90 c
TARM-92	65.94 f-i	67.57 bcd	66.75	349.15 b	230.42 f	289.79 cd
Sladoran	65.88 f-i	67.46 bcd	66.67	364.59 ab	248.62 ef	306.61 bc
Zeynel Ağa	65.64 ghi	67.11 cd	66.38	232.66 f	157.48 g	195.07 f
Harman	66.41 ef	67.55 bcd	66.98	281.48 cde	161.34 g	221.41 e
Yaprak	65.30 ij	67.40 bcd	66.35	357.96 ab	189.16 g	273.56 d
Martı	66.8 fgh	67.86 bc	66.97	234.55 f	164.69 g	199.62 ef
Hazar	65.93 f-i	67.97 ab	66.95	254.75 def	175.92 g	215.34 ef
Bolayır	65.51 hi	67.36 bcd	66.44	364.32 ab	172.92 g	269.10 d
Line 1	65.83 f-i	67.91 ab	66.87	373.77 ab	168.85 g	271.31 d
Line 2	66.05 f-i	67.01 de	66.53	359.57 ab	188.97 g	274.27 d
Average	65.79 b	67.78 a	66.76	331.36 a	209.88 b	270.62

Means followed by the same letters in the same column are similar, P>0.05.

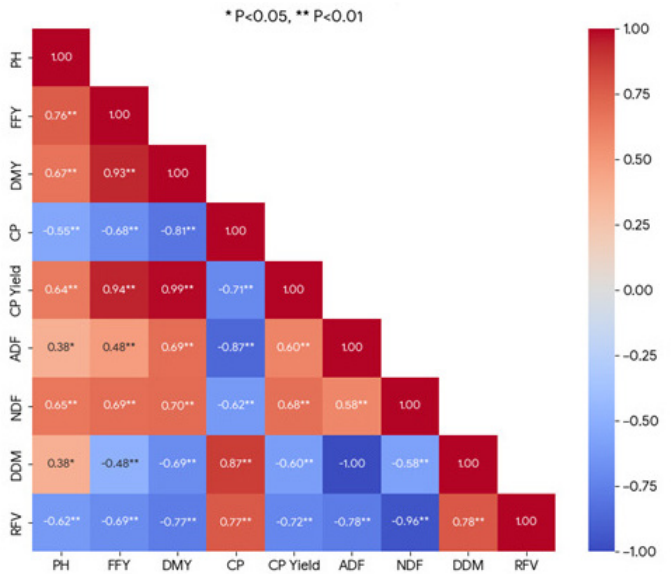

Fig. 2. Correlation between the characteristics examined in the study. PH: Plant Height FFY: Fresh Forage Yield; DMY: Dry Matter Yield; CP: Crude Protein; ADF: Acid Detergent Fiber; NDF: Neutral Detergent Fiber; DDM: Digestible Dry Matter; RFV: Relative Feed Value. * Significant at $P < 0.05$; ** Significant at $P < 0.01$.

under changing conditions. These patterns collectively illustrate the physiological basis of genotype differences. Although the present study captured consistent yield–quality trends, the two-year dataset may not fully represent the broader interannual climate variability characteristic of Eastern Anatolia, and longer-term datasets would be required to capture these dynamics better.

It was confirmed that there is a positive relationship between canopy structure and biomass accumulation when taller genotypes produced more FFY and DMY. The fact that "Olgun" and "Aydanhanım" have performed better over the years shows that they are very adaptable and use resources well. On the other hand, some genotypes have performed poorly, which shows that they are not very well suited to these conditions. The findings confirm earlier research demonstrating that

Table 8.
DMC and RFV averages of the varieties examined in the study.

	Dry matter consumption			Relative feed value		
Varieties	**1st year**	**2nd year**	**Average**	**1st year**	**2nd year**	**Average**
Olgun	2.01 kl	2.02 jkl	2.08 g	103.61 k-o	106.66 h-k	105.13 fg
Mert	2.03 jkl	2.13 c-h	2.08 de	104.15 j-o	113.6 a-e	108.91 cd
Aydanhanım	2.01 kl	2.16 b-e	2.09 de	100.62 op	115.12 a-d	107.87 cde
Burakbey	1.93 m	2.06 i-l	2.00 g	97.60 p	108.39 f-i	102.99 g
TARM-92	2.01 kl	2.14 b-g	2.07 de	102.65 mno	111.98 c-f	107.32 def
Sladoran	2.07 hij	2.15 b-f	2.11 cd	106.00 i-m	112.49 b-e	109.24 bcd
Zeynel Ağa	2.09 ghi	2.19 abc	2.14 bc	106.40 h-l	114.00 a-d	110.20 bc
Harman	2.00 i	2.13 d-h	2.06 ef	102.78 l-o	111.40 d-g	107.09 def
Yaprak	2.01 kl	2.11 e-i	2.06 ef	101.92 no	110.06 e-h	105.99 ef
Martı	2.10 f-i	2.19 abc	2.15 bc	107.58 hij	115.30 abc	111.44 ab
Hazar	2.15 b-f	2.20 ab	2.18 ab	109.99 e-h	115.96 ab	112.98 a
Bolayır	2.17 bcd	2.23 a	2.20 a	110.12 e-h	116.52 a	113.32 a
Line 1	2.06 ıjk	2.12 d-h	2.09 de	105.17 i-n	111.75 c-f	108.46 cde
Line 2	1.99 i	2.08 hij	2.03 fg	101.79 no	107.90 ghi	104.84 fg
Average	2.05 b	2.14 a	2.09	104.31 b	112.23 a	108.27

Means followed by the same letters in the same column are similar, P>0.05.

genotypic variations, precipitation patterns, and temperature conditions significantly affect barley biomass production in arid regions (Bratković *et al.*, 2024; Högy *et al.*, 2013). These demonstrations show the trend of differentiation among genotypes in terms of yield and quality, and these demonstrations are considered as interpretive observations based on this development rather than as a methodology.

This study further indicates that higher biomass production does not uniformly lower forage quality. The average CP levels (15–17%) were often higher than or the same as the values for barley fodder in different places, where 8–14% is common (Çaçan & Kökten, 2019; Çöken & Akman, 2016). The 'Olgun', 'Mert', 'Aydanhanım', 'Burakbey', 'Tarm-92', and 'Sladoran' genotypes exhibited a notable CP concentration with higher dry matter yield, resulting in an exceptional CP yield. This supports the view that CP yield, rather than only CP %, might guide cultivar selection in forage systems (Temel & Keskin, 2022). The comparatively high CP concentrations (15–17%) may, in part, reflect the nitrogen fertilization rate used in the experiment, as nitrogen supply is known to enhance protein accumulation in cereal forages. Therefore, the fertilization regime likely contributed to the elevated CP levels observed in this study. The study identifies genotypes that provide both biomass and protein, surpassing grain-focused assessments and offering directly applicable insights for roughage-based livestock systems in Eastern Anatolia.

Fiber fractions and related quality traits demonstrate a distinct yield-quality variation among genotypes. The NDF values (55–60%) and ADF values (28%) show that barley forage is moderately digestible and has acceptable intake potential, which is in line with or falls within the ranges found in earlier studies on barley and small-grain forages in semi-arid areas (Acıkgoz *et al.*, 2022). Similar patterns have been reported in recent studies evaluating barley forage nutritive value under semi-arid growing conditions (Abdelhalim *et al.*, 2023; Karimi & Ghasemi, 2022). The 'Bolayır' and 'Hazar' genotypes, distinguished by lower NDF and higher RFV, have been recognized as quality-oriented genotypes, indicating their suitability for scenarios requiring improved fodder intake and digestibility. On the other hand, Burakbey and many other high-biomass varieties had higher NDF and lower RFV, which shows the traditional trade-off between structural development and nutritional quality. The strong negative links between ADF/NDF and DDM, RFV, and CP efficiency found in this study are in line with early research on forage quality (Van Soest, 2018).

The DDM and RFV remained at or above the levels for "good–very good" quality hay. This shows that barley that is managed effectively can provide both energy and fiber in semi-arid agricultural areas. The

distinct classification of "quantity genotypes" ('Olgun', 'Aydanhanım') and "quality genotypes" ('Bolayır', 'Hazar', 'Yaprak') establishes a functional framework. This qualitative differentiation is supported by the significant inverse relationships observed in the correlation analysis, particularly between NDF–ADF and RFV, and the classification is an interpretation based on these physiological tendencies. Commercial farms with higher stocking densities and large concentrate utilization may prioritize high-yield varieties, whereas smallholders aiming to enhance on-farm forage quality without incurring significant expenses may find value in quality-focused cultivars. Research on barley forage management and mixed systems in semi-arid areas has shown similar yield–quality structuring.

This study did not include direct measurements of lignin (ADL), mineral composition, WSC, or *in vitro* digestibility (e.g., IVOMD). Because RFV and DDM are estimative indices, the absence of direct digestibility assays represents a limitation and should be considered when interpreting forage quality outcomes.

This study makes an important contribution by offering a region-specific, forage-focused assessment of a wide range of genotypes in Muş under actual rainfed conditions. This study, in contrast to various Turkish and international barley research that concentrate solely on grain yield or particular quality metrics, simultaneously evaluated FFY, DMY, CP, ADF, NDF, DDM, DDMY, and RFV across two different years, thereby describing genotype × year interactions that relate to climate-sensitive systems. This method changes from broad statements like "barley is good for drylands" to specific cultivar suggestions based on evidence: Olgun and Aydanhanım as the best options for getting the most forage. Bolayır and Hazar are specific choices for better quality, and Yaprak is a good choice for places where there isn't enough protein. Although not directly measured in this study, increasing forage availability through suitable barley cultivars could indirectly lessen pressure on degraded rangelands. The preceding findings suggest that appropriately selected barley cultivars may serve as strategic, climate-resilient fodder sources for Muş and comparable semi-arid regions, offering an efficient means to improve Türkiye's livestock feed security while mitigating pressure on degraded rangelands. The terms "yield-oriented" and "quality-oriented" used in this study are not categories created as a result of a formal clustering analysis; rather, they are practical observations based on the consistent yield and quality trends shown by the genotypes over two years.

5. Conclusions

This two-year study in rainfed semi-arid regions of Muş demonstrated significant genotype and the year effects on fodder productivity and quality. Olgun and Aydanhanım consistently yielded greater biomass and protein, whereas Bolayır and Hazar provided higher relative feed value and digestibility. Collectively, these differentiated performance profiles permit more explicit agronomic recommendations: high-yielding cultivars such as 'Olgun' and 'Aydanhanım' are more appropriate for intensive, high-stocking commercial systems requiring substantial forage supply, whereas quality-oriented genotypes, notably 'Bolayır' and 'Hazar,' are better aligned with smallholder or resource-limited operations seeking to maximize nutrient density and intake efficiency. Accordingly, the findings provide a functional basis for region-specific forage planning aimed at enhancing feed security and resilience within semi-arid livestock production systems. We acknowledge that this classification represents patterns emerging from two years of single-location data, and broader validation would require multi-year, multi-location trials to confirm the stability of these yield–quality groupings under diverse environmental conditions.

CRediT authorship contribution statement

All authors contributed equally to this work

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data will be available form corresponding author on reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI.

References

Acikgoz, M., Salih, S., Ozdemir, B., Oral, E., 2022. Determination of yield and yield characteristics of some barley *(Hordeum vulgare* L.) genotypes under supplemental irrigation conditions in Van. UASVMCN-AGR 79, 1-7. https://doi.org/10.15835/buasvmcn-agr:2022.0005

Akdogan, G., Benlioglu, B., Ahmed, H.A.A., Bilir, M., Ergun, N., Aydogan, S., Türkoğlu, A., Demirel, F., Nowosad, K., Bocianowski, J., 2025. Agro-morphological characterization and machine learning-based prediction of genetic diversity in six-row barley genotypes from türkiye. Euphytica 221, 69. https://doi.org/10.1007/s10681-025-03522-7

Bouhraoua, S., Ferioun, M., Boussakouran, A., Belahcen, D., Srhiouar, N., Hammani, K., Louahlia, S., 2025. Physio-biochemical responses and yield performance of North African barley genotypes submitted to moderate and severe salinity. Cereal Res Commun 53, 337-353. https://doi.org/10.1007/s42976-024-00549-9

Bratković, K., Luković, K., Perišić, V., Savić, J., Maksimović, J., Adžić, S., Rakonjac, A., Matković Stojšin, M., 2024. Interpreting the interaction of genotype with environmental factors in barley using a partial least squares regression model. Agronomy 14, 194. https://doi.org/10.3390/agronomy14010194

Çaçan, E., Kökten, K., 2019. Tahıl türlerinin kaba yem olarak değerlendirilmesi üzerine bir araştirma, A Research on the evaluation of the cereal species as roughage. Ege Üniversitesi Ziraat Fakültesi Dergisi 56, 221-229. https://doi.org/10.20289/zfdergi.459694

Capstaff, N.M., Miller, A.J., 2018. Improving the yield and nutritional quality of forage crops. Front Plant Sci 9, 535. https://doi.org/10.3389/fpls.2018.00535

Carter, A.Y., Hawes, M.C., Ottman, M.J., 2019. Drought-tolerant barley: I field observations of growth and development. Agronomy 9, 221. https://doi.org/10.3390/agronomy9050221

Çöken, İ, Akman, Z., 2016. Isparta Ekolojik Koşullarında Bazı Arpa (*Hordeum vulgare* L.) Çeşitlerinin Verim ve Kalite Özelliklerinin Belirlenmesi. SDÜ Fen Bil Enst Der 20(1), 91-97. https://doi.org/10.19113/sdufbed.23066

Daskiran, I., Savas, T., Koyuncu, M., Koluman, N., Keskin, M., Esenbuga, N., Konyali, A., Cemal, İbrahim, Gül, S., Elmaz, O., Kosum, N., Dellal, G., Bingöl, M., 2018. Goat production systems of Turkey: Nomadic to industrial. Small Rumin Res 163, 15-20. https://doi.org/10.1016/j.smallrumres.2017.10.001

Güngör, H., Türkoğlu, A., Çakır, M.F., Dumlupınar, Z., Piekutowska, M., Wojciechowski, T., Niedbała, G., 2024. GT biplot and cluster analysis of barley (*Hordeum vulgare* L.) germplasm from various geographical regions based on agro-morphological traits. Agronomy 14, 2188. https://doi.org/10.3390/agronomy14102188

Hanoğlu Oral, H., Gökkuş, A., 2021. Evaluation of total roughage production and its sufficiency for livestock in Turkey. Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi 11, 2423-2433. https://doi.org/10.21597/jist.899304

Högy, P., Poll, C., Marhan, S., Kandeler, E., Fangmeier, A., 2013. Impacts of temperature increase and change in precipitation pattern on crop yield and yield quality of barley. Food Chem 136, 1470-1477. https://doi.org/10.1016/j.foodchem.2012.09.056

Karadağ, Y., Özkurt, M., Tufan, Y., Kurt, A.N., 2024. Muş Ekolojik Koşullarında Farklı Yonca (*Medicago sativa* L.) Popülasyonlarının Verim ve Kalite Parametrelerinin Belirlenmesi. MAS J Appl Sci 9, 1078-1094. http://dx.doi.org/10.5281/zenodo.14354468

Koçak, E., 2023. A review of the current status of forage crops cultivation and evaluation in Türkiye. Turkish J Range Forage Sci 4, 59-65. https://doi.org/10.51801/turkjrfs.1327064

Kurt, A.N., Güllap, M.K., 2021. The current situation, problems, and suggestions for forage crops in muş province. Turkish J Range Forage Sci 2, 63-72. https://doi.org/10.51801/turkjrfs.942253

Mansour, E., Moustafa, E.S.A., Qabil, N., Abdelsalam, A., Wafa, H.A., Kenawy, A.E., Casas, A.M., Igartua, E., 2018. Assessing different barley growth habits under Egyptian conditions for enhancing resilience to climate change. Field Crops Res 224, 67-75. https://doi.org/10.1016/j.fcr.2018.04.016

Newton, A.C., Flavell, A.J., George, T.S., Leat, P., Mullholland, B., Ramsay, L., Revoredo-Giha, C., Russell, J., Steffenson, B.J., Swanston, J.S., Thomas, W.T.B., Waugh, R., White, P.J., Bingham, I.J., 2011. Crops that feed the world 4 barley: A resilient crop? Strengths and weaknesses in the context of food security. Food Sec 3, 141-178. https://doi.org/10.1007/s12571-011-0126-3

Nikkhah, A., 2013. Barley forages for modern global ruminant agriculture: A review. Russ Agricult Sci 39, 206-213. https://doi.org/10.3103/s1068367413030038

Özkurt, M., Çınar, S., 2020. Türkiye, Doğu Anadolu bölgesi ve Muş İlinde Çayır Mera Yem Bitkileri ve Hayvancılığın Bugünkü Durumu. Turkish JAF Sci Tech 8, 2191-2201. https://doi.org/10.24925/turjaf.v8i10.2191-2201.3656

Steel, R., Torrie, J., Dickey, D., 1997. Principles and procedure of statistics. A biometrical approach, in: McGraw hill book co, Inc, New York 3, 352–358.

Temel, S., Keskin, B., 2022. Determination of forage quality properties of plant parts in different amaranth varieties cultivated under irrigated and rainfed conditions. Ataturk Univ J Agricultural Faculty 53, 122-132. https://doi.org/10.54614/auaf.2022.1034402

Tubb, C., Seba, T., 2021. Rethinking food and agriculture 2020-2030: The second domestication of plants and animals, the disruption of the cow, and the collapse of industrial livestock farming. Ind Biotechnol 17, 57-72. https://doi.org/10.1089/ind.2021.29240.ctu

Turkish Statistical Institute. (2024). Livestock statistics, 2023: Number of cattle and small ruminants. https://data.tuik.gov.tr

Van Soest, P.J., (2018). Nutritional ecology of the ruminant. Cornell University Press.3rd ed., pp. 105–15. https://doi.org/10.7591/9781501732355