

Adaptation and growth of forage crops suitable for agroforestry in high-altitude cold arid region of Ladakh, India

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Abstract

The scarcity of quality fodder is one of the major constraints limiting livestock production in the cold arid region of Ladakh. The present study was conducted during 2023 at the ICAR–Central Arid Zone Research Institute (CAZRI), Regional Research Station, Leh, to evaluate the survival, adaptation, and early growth performance of introduced and native forage grass species under high-altitude cold arid conditions. The experiment was laid out in a Randomized Block Design with three replications. Growth parameters including survival percentage, plant height, plant spread, number of tillers/branches, fresh biomass, and forage quality attributes were recorded. Significant differences were observed among the evaluated forage species for all growth parameters. Survival percentage ranged from 66.6 to 90.0%, with the highest survival recorded in native yellow Alfalfa and blue Alfalfa (90.0%), followed by sainfoin (84.6%). Among the introduced species, bulbous canary grass exhibited superior growth, recording the maximum plant height (132.0 cm), plant spread (58.5 cm), and fresh biomass (85.0 g plant⁻¹). Tall fescue produced the highest number of tillers (150 plant⁻¹), whereas sainfoin showed excellent branching ability. Native yellow alfalfa and blue alfalfa produced the highest fresh biomass (112.0 and 108.0 g plant⁻¹, respectively), demonstrating superior adaptation to the harsh cold arid environment. The enhanced performance of these species is attributed to their perennial growth habit, efficient resource utilization, and tolerance to low temperatures and moisture stress. The study identified bulbous canary grass, sainfoin, and red fescue as promising introduced forage species, while confirming the superior adaptation of native yellow alfalfa and blue alfalfa under Ladakh conditions. These findings provide valuable information for selecting suitable forage species for pasture improvement, sustainable fodder production, and strengthening livestock-based production systems in the high-altitude cold arid region of Ladakh.

Keywords: Cold arid region, Ladakh, forage crops, survival and adaptation, pasture improvement.

Introduction

The cold arid region of the Trans-Himalaya represents one of the most fragile and extreme ecosystems of the world, extending across eastern Ladakh, the Zaskar range, and parts of Lahaul-Spiti. This region is characterized by high elevation, severe climatic conditions, sparse vegetation, and limited agricultural productivity. The landscape occurs mainly between 3000 and 5500 m above mean sea level and experiences extremely low precipitation (80–300 mm annually), low relative humidity, high wind velocity, intense solar radiation, low atmospheric pressure, and prolonged freezing temperatures that may decline below -40°C during winter months (Verma et al., 2018; Noor mohamed et al., 2025). The rain-shadow effect of the Himalayas creates a cold desert environment where water availability remains the major limiting factor for plant growth. The soils are generally shallow, coarse textured, alkaline, poor in organic matter, and susceptible to erosion, thereby restricting agricultural and forage production (Gupta and Arora, 2016).

Livestock-based pastoralism is the backbone of the socio-economic system of Ladakh, where animal husbandry contributes significantly to livelihood security, food supply, and cultural identity. Indigenous livestock breeds including Changthangi goats, Changluk sheep, yak, dzomo, horses, and Bactrian camels possess unique physiological adaptations that enable survival under hypobaric hypoxia, extreme cold, and limited feed resources (Verma et al., 2018; Vyas et al., 2015; Vyas & Bissa, 2019). These animals provide milk, meat, fibre, manure, transportation, and valuable products such as pashmina wool, making livestock production an integral component of the mountain economy (Akand et al., 2017). However, livestock productivity in this region is primarily constrained by seasonal fluctuations in feed availability, particularly during the prolonged winter period when grazing lands remain inaccessible due to snowfall. Exposure of organisms to hypoxia and cold stress, a situation which exists at high altitude, requires a higher rate of metabolism to cope up with increased energy demands (Vyas et al., 2014).

Natural rangelands constitute the major source of livestock feed in Ladakh; however, increasing grazing pressure, degradation of pasturelands, changing climatic conditions, and socio-economic transformations have resulted in declining forage availability and quality. The livestock are dependent on alpine pastures during the short growing season and require stall feeding for several months during winter, creating a substantial demand for conserved fodder resources. Studies have reported considerable fodder deficits in cold arid Ladakh, with limited cultivated land, short crop-growing periods, and harsh environmental conditions restricting fodder production (Tewari et al., 2016).

Existing fodder production systems mainly depend on alfalfa (*Medicago sativa* and *M. falcata*), cereal residues of barley and wheat, oats, peas, and naturally occurring grasses. Among cultivated fodders, alfalfa is considered one of the most important forage crops because of its high nutritive value, perennial nature, drought tolerance, and adaptability to cold arid environments (Tewari et al., 2016). However, dependence on a limited number of fodder crops may not be sufficient to overcome the increasing feed demand, particularly under changing climatic conditions. Therefore, diversification of forage resources through the identification and introduction of suitable grass species is essential for sustainable livestock production and restoration of degraded rangelands.

Forage grasses have significant potential in improving fodder availability, enhancing soil stability, reducing erosion, and supporting ecological restoration in fragile mountain ecosystems. Nevertheless, successful establishment of forage grasses in cold arid regions depends on their ability to withstand multiple environmental stresses, including freezing temperatures, drought, high ultraviolet radiation, short growing seasons, nutrient deficiency, and limited moisture availability. Species exhibiting better germination, survival, biomass accumulation, and physiological adaptation under such conditions can serve as valuable resources for pasture rehabilitation and fodder development programmes.

Despite the importance of forage resources in sustaining livestock-based livelihoods, systematic evaluation of forage grasses for survival and early growth performance under Ladakh's extreme environment remains limited. Identification of suitable forage species adapted to different microclimatic conditions is therefore essential for developing location-specific fodder production strategies. Evaluation of early establishment characteristics provides a reliable basis for selecting promising forage grasses capable of long-term persistence and productivity under cold arid conditions.

The selection of forage species for the present study was based on their potential adaptability to the extreme climatic conditions of the high-altitude cold-arid region of Ladakh. Identifying suitable forage species can help diversify existing fodder resources and improve livestock feed availability during prolonged winters. Additionally, hardy perennial forage grasses and legumes may have potential for integration with locally adapted trees and shrubs in future agroforestry-based land-use systems. Therefore, the present study aimed to identify promising forage species and to assess the survival and establishment potential for sustainable fodder production under the cold-arid conditions of Ladakh.

Materials and Methods

Experimental Site

The experiment was conducted during 2023-25 at the ICAR–Central Arid Zone Research Institute (CAZRI), Regional Research Station, Leh, Ladakh (Union Territory), India. The research station is located at Stakna, approximately 30 km southeast of Leh city on the Hemis Road, at 33°58'18"N latitude and 77°41'49"E longitude, with an elevation of approximately 3,500 m above mean sea level. The experimental site falls within the cold arid ecosystem of the Trans-Himalayan region and is characterized by an extremely harsh climate, low atmospheric pressure, intense solar radiation, and scarce precipitation.

The region receives an average annual precipitation of approximately 30 mm, with most occurring in the form of snowfall during winter. The climate is marked by a short growing season and large diurnal and seasonal temperature fluctuations. July and August are the warmest months, recording a mean maximum temperature of 29°C and a mean minimum temperature of 16°C, whereas December and January are the coldest months, with mean maximum and minimum temperatures of 1°C and –13°C, respectively.

Experimental design and crop management

The experiment was conducted during 2023-24 at the ICAR–Central Arid Zone Research Institute (CAZRI), Regional Research Station, Leh, Ladakh (UT) using a Randomized Block Design (RBD) with three replications. Seeds of nine forage grass species including two native forage plants (yellow alfalfa (*Medicago falcata*) and blue alfalfa (*Medicago sativa*)) and were sown directly in well-prepared plots (10X10m) during April at the recommended spacing for each species. After sowing, the seeds were covered with a thin layer of sand to ensure proper seed soil contact. Well-decomposed farmyard manure (FYM) was applied uniformly as a basal dose before sowing. Irrigation was provided at regular intervals to maintain adequate soil moisture for seed germination and seedling establishment, and all recommended agronomic practices were followed uniformly throughout the experiment.

Nine forage crops comprising four grasses and five legumes were evaluated for their adaptation and growth under the high-altitude, cold-arid conditions of Ladakh. The grasses included bulbous canary grass (*Phalaris aquatica*), planted at 45 × 45 cm spacing, and red fescue (*Festuca rubra*), timothy (*Phleum pratense*), and tall fescue (*Lolium arundinaceum*), planted at 30 × 30 cm spacing. The legumes comprised white clover (*Trifolium repens*) and sainfoin (*Onobrychis viciifolia*), planted at 45 × 45 cm spacing, and red clover (*Trifolium pratense*), yellow alfalfa (*Medicago falcata*), and blue alfalfa (*Medicago sativa*), planted at 30 × 30 cm spacing. These crops represent diverse perennial grasses and legumes with traits such as deep-rooting systems, cold tolerance, and varied growth habits, making them suitable candidates for evaluating forage production potential in the region.

The forage grasses remained green throughout the growing season until the onset of snowfall, after which they entered winter dormancy. Regrowth was observed with the onset of the subsequent summer season. Survival percentage of each species was recorded after establishment. Growth observations including plant height (cm), plant spread (cm), and number of tillers/ branches were recorded at the vegetative stage. At harvest, fresh biomass yield (g plant⁻¹) was recorded.

Proximate analysis

Fresh forage samples were collected from each treatment at harvest and dried in a forced-air hot air oven at 60 ± 2°C until constant weight. The dried samples were ground to pass through a 1-mm sieve using a Wiley mill and stored in airtight polyethylene containers for subsequent laboratory analyses.

Proximate Composition

Crude protein (CP) was estimated using the Kjeldahl method with an automatic Kjelplus microprocessor-based nitrogen analyzer (Evers and Hughes, 2002). Approximately 0.5 g of the ground sample was digested, distilled, and titrated for nitrogen estimation. Crude protein content was calculated by multiplying the nitrogen content by the conversion factor 6.25, and all analyses were performed in triplicate.

Crude fat (ether extract, EE) was determined by solvent extraction using hexane in a Soxtec extraction unit, whereas crude ash was determined by incinerating 5 g of the sample in a muffle furnace at 550°C until constant weight. Organic matter (OM) content was calculated by subtracting ash content from dry matter and expressed as a percentage.

Fibre fraction analysis

Neutral detergent fibre (NDF) and Acid Detergent Fibre (ADF) were determined according to the detergent fibre analysis method of AOAC (2005). Air-dried forage samples were ground to pass through a 1-mm sieve and refluxed separately with neutral detergent solution (NDS) and acid detergent solution (ADS). The residues were filtered through fritted glass crucibles under vacuum, washed thoroughly, and dried overnight in a hot air oven at 70°C. Fibre fractions were calculated using the following equation:

$$\text{ADF or NDF (\%)} = \frac{\text{Weight of residue}}{\text{Weight of sample}} \times 100$$

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for Randomized Block Design (RBD) following the procedures described by Gomez and Gomez (1984). Treatment effects were tested using the F-test, and whenever significant differences were observed, treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at the 5% probability level ($P \leq 0.05$). Pearson's correlation coefficients were computed to determine the relationships among growth, biomass, and forage quality parameters, and statistical significance was declared at $P < 0.05$.

Results and Discussion

The introduced and native forage species exhibited significant variation in survival, growth, biomass production, and nutritive value under the cold arid conditions of Leh, reflecting differences in their adaptability to the Trans-Himalayan environment. These variations are primarily attributable to the harsh climatic conditions characterized by low precipitation, extreme temperatures, a short growing season, and nutrient-poor soils, which strongly influence forage establishment and productivity (Ahmed et al., 2021; Raj and Sharma, 2013).

Survival Percentage

Survival percentage ranged from 66.6 to 90.0%, with the highest survival recorded in the native yellow alfalfa and blue alfalfa (90.0%), followed by sainfoin (84.6%), while white clover recorded the lowest survival (66.6%). Among the introduced grasses, bulbous canary grass established comparatively better (75.0%) than timothy, tall fescue, and red fescue (70.0%) (Table 1). The superior establishment of the native alfalfa types may be attributed to their deep root systems, drought tolerance, perennial growth habit, and long-term adaptation to the cold desert ecosystem. Similar observations have been reported by Ahmad et al. (2018b), who identified blue alfalfa (*Medicago sativa*) as one of the most suitable perennial forage legumes for Himalayan regions because of its persistence and adaptability under adverse climatic conditions.

Growth Characteristics

Plant height showed significant differences among forage species and ranged from 24.0 to 132.0 cm (Table 1). Phalaris recorded the maximum plant height (132.0 cm) among all the grasses, followed by Timothy (96.0 cm) and Red fescue (91.6 cm). Tall fescue showed the lowest plant height (24.0 cm). Among native forages, *Medicago sativa* and *M. falcate* attained moderate plant heights of 56.0 and 54.0 cm, respectively. The taller growth of Phalaris and Timothy may be attributed to their erect growth habit and rapid stem elongation, whereas both Alfalfa (*Medicago sativa* and *M. falcate*) exhibited comparatively shorter but more productive growth due to greater branching and biomass accumulation.

Plant spread ranging from 22.5 to 58.5 cm (Table 1). Bulbous canary grass recorded the maximum plant spread (58.5 cm), followed by red clover (55.5 cm), white clover and blue alfalfa (52.0 cm each), and yellow alfalfa (50.0 cm). Timothy showed the minimum plant spread (22.5 cm). The wider plant spread of bulbous canary grass, white clover and red clover indicates better canopy development and ground coverage, which may contribute to higher biomass production and improved soil protection under cold arid conditions.

The number of tillers or branches also differed considerably among species. Tall fescue recorded the highest tiller number (150 plant⁻¹), indicating strong vegetative growth potential, whereas sainfoin produced 80 branches per plant. Native blue alfalfa and yellow alfalfa produced 28 and 25 branches per plant, respectively, reflecting their characteristic branching habit that contributes substantially to forage yield. It was observed that significant improvements in pasture productivity through the introduction of improved perennial grasses and legumes, with Tall fescue exhibiting superior vegetative growth among grasses.

Fresh weight

Fresh weight per plant ranged from 20.0 to 112.0 g (Table 1). The highest fresh biomass was recorded in native yellow alfalfa (112.0 g) followed closely by blue alfalfa (108.0 g), whereas white clover produced the lowest biomass (20.0 g). The superior biomass production of native alfalfa species reflects their efficient resource utilization, perennial growth habit, and greater adaptation to the harsh environmental conditions of Leh. Although bulbous canary grass, sainfoin, and red fescue exhibited satisfactory establishment among introduced species, their biomass remained lower than that of native alfalfa. Similar findings have been reported by Tewari et al. (2016), who observed that alfalfa consistently produces high forage yields with superior crude protein content under temperate environments, although productivity declines under Trans-Himalayan conditions due to climatic limitations. Similarly, Kumar et al. (2015) reported that lucerne/ alfalfa produced significantly higher green and dry forage yields than Red clover, demonstrating its superior persistence, dry matter accumulation, and adaptability under temperate pasture conditions.

Table 1. Survival percentage and morphometric characteristics of forage crops grown under cold-arid conditions in Leh, Ladakh.

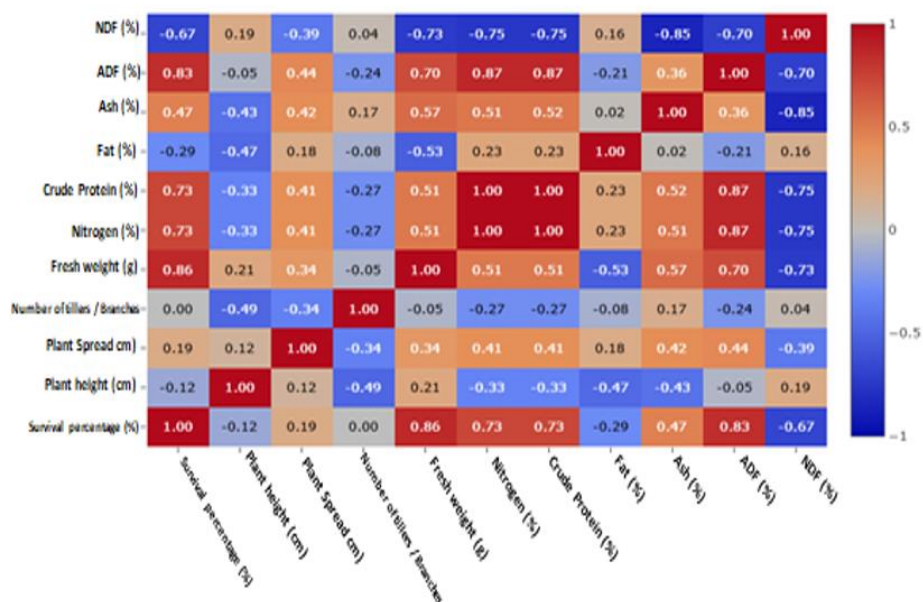
S. N.	Grasses	Survival percentage (%)	Plant height (cm)	Plant spread (cm)	No. of tillers/branches	Fresh wt (per plant) (g)
1	Bulbous canary grass	75.0±3.00b	132.0±5.28a	58.5±2.34a	30.0±1.20c	85.0±3.40b
2	Red fescue	70.0±0.70b	91.6±0.91b	48.5±0.48b	22.0±0.22c	75.0±0.75c
3	Timothy	70.0±1.85b	96.0±2.54b	22.5±0.59e	12.0±0.31d	30.0±0.79e
4	Tall fescue	70.0±3.50b	24.0±1.20e	35.5±1.77d	150.0±7.50a	40.0±2.00d
5	White clover	66.6±3.33c	32.0±1.60d	52.0±2.60b	12.0±0.60d	20.0±1.00f
6	Red clover	70.0±1.40b	58.0±1.16c	55.5±1.11a	15.0±0.30d	25.0±0.50e
7	Sainfoin	84.6±4.23a	38.0±1.90d	41.0±2.05c	80.0±4.00b	75.0±3.75c
8	Yellow Alfalfa	90.0±3.92a	54.0±2.35c	50.0±2.17b	28.0±1.22c	112.0±4.88a
9	Blue Alfalfa	90.0±0.90a	56.0±0.56c	52.0±0.52b	25.0±0.25c	108.0±1.08a
	C.D. (5%)	8.310	7.047	4.923	8.782	7.072
	SE(m)	2.762	2.342	1.636	2.919	2.351
	SE(d)	3.907	3.313	2.314	4.129	3.324

Means followed by the same superscript letter within a column are not significantly different at $p \leq 0.05$ according to Tukey's HSD test under a linear mixed-effects model. SE(m) = standard error of mean; CD = critical difference at 5% level.

Table 2. Proximate composition (%) of forage crops grown under cold-arid conditions in Leh, Ladakh.

S. N.	Grasses	N%	CP%	Fat %	Ash %	Fiber	
						ADF %	NDF %
1	Bulbous canary grass	0.89±0.03e	5.60±0.22e	3.71±0.14c	8.00±0.32c	45.6±1.82c	68.2±2.72b
2	Red fescue	1.03±0.01e	6.47±0.06e	3.04±0.03d	10.00±0.10b	44.2±0.44c	56.2±0.56c
3	Timothy	0.92±0.02e	5.77±0.15e	3.84±0.10c	5.90±0.15d	39.4±1.04d	76.8±2.03a
4	Tall fescue	1.00±0.05e	6.30±0.31e	4.25±0.21b	10.00±0.50b	38.0±1.90d	60.8±3.04c
5	White clover	1.59±0.08d	9.97±0.49d	5.35±0.26a	9.80±0.49b	36.4±1.82d	69.2±3.46b
6	Red clover	2.63±0.05c	16.45±0.32c	4.56±0.09b	7.50±0.15c	54.8±1.09b	64.4±1.28b
7	Sainfoin	1.65±0.08d	10.32±0.51d	3.50±0.17c	8.20±0.41c	51.2±2.56b	71.2±3.56a
8	Yellow Alfalfa	3.30±0.14b	20.65±0.90b	3.46±0.15c	11.60±0.50a	60.8±2.65a	37.2±1.62d
9	Blue Alfalfa	3.94±0.03a	24.67±0.24a	4.51±0.04b	10.80±0.10a	60.2±0.60a	43.6±0.43d
	C.D. (5%)	0.206	1.286	0.461	1.006	5.065	7.097
	SE(m)	0.068	0.427	0.153	0.334	1.683	2.359
	SE(d)	0.096	0.604	0.216	0.472	2.381	3.336

Means followed by the same superscript letter within a column are not significantly different at $p \leq 0.05$ according to Tukey's HSD test under a linear mixed-effects model. SE(m) = standard error of mean; CD = critical difference at 5% level.

**Figure 1.** Pearson correlation matrix heatmap showing the relationships among the evaluated parameters of forage crops grown under cold-arid conditions in Leh, Ladakh.

Overall, among the introduced forages, Phalaris, Sainfoin, and Red fescue showed promising growth characteristics and adaptability under the cold arid conditions of Leh. However, native alfalfa (*Medicago sativa* and *M. falcate*) remained superior in establishment and biomass production, confirming their importance as reliable forage crops for sustainable livestock production in high-altitude cold desert regions. Ahmad et al. (2018a) and Sultan Singh (2023) similarly reported that locally adapted forage species perform better than introduced species under Himalayan conditions because of their ecological adaptation.

Nutritive analysis of Grasses

The performance of introduced forage species under the cold arid conditions of Leh varied significantly with respect to nitrogen (N), crude protein (CP), fat, ash, and fibre fractions (Table 2). The introduced forages included bulbous canary grass, sainfoin, timothy, tall fescue, white clover, red clover, and red fescue, which are primarily adapted to temperate environments. Their nutritional performance under the cold arid ecosystem revealed considerable differences in their ability to establish and accumulate nutrients under low temperature, moisture stress, and short growing season conditions.

Proximate Composition

Among the introduced forage species, red clover exhibited the best nutritional performance, followed by sainfoin and white clover. Red clover recorded the highest nitrogen content (2.63%) and crude protein content (16.45%) among the introduced forages, indicating its better adaptation and higher nitrogen-fixing capacity compared with other introduced species. Sainfoin and white clover showed moderate nutritional quality with crude protein contents of 10.32 and 9.97%, respectively. In contrast, the introduced grasses, including bulbous canary grass, timothy, tall fescue, and red fescue, showed comparatively lower nitrogen and crude protein contents, ranging from 0.89–1.03% and 5.60–6.47%, respectively. Among introduced grasses, tall fescue showed comparatively better nutritional performance, with higher fat (4.25%) and ash (10.00%) contents. Sultan Singh (2023) also reported significantly higher crude protein and lower fibre fractions in legumes than grasses, supporting the present findings.

Neutral detergent fibre (NDF) and Acid Detergent Fibre (ADF)

Red fescue also exhibited favourable fibre characteristics with the lowest NDF value (56.2%) among introduced grasses. Timothy recorded the highest NDF value (76.8%), indicating greater cell wall deposition and comparatively reduced feeding value. The high fibre content in timothy may limit digestibility and voluntary intake by livestock. The fibre composition among introduced forages indicated considerable variation. White clover recorded the lowest ADF content (36.4%) among all introduced species, followed by tall fescue (38.0%) and timothy (39.4%), suggesting comparatively better digestibility potential. However, sainfoin and red clover showed higher ADF values (51.2 and 54.8%, respectively), which may be associated with their greater structural carbohydrate accumulation. In terms of NDF content, red fescue and tall fescue showed relatively lower values (56.2 and 60.8%, respectively), whereas timothy and sainfoin recorded higher NDF levels (76.8 and 71.2%, respectively). Similar trends have been reported by King et al. (2012), who observed that legumes generally provide higher protein while grasses differ considerably in fibre composition depending on species and maturity. Comparable values for Tall fescue, Timothy, and lucerne have also been reported by Sayar et al. (2014).

The superior performance of Red clover among introduced forages indicates its potential for cultivation under cold arid conditions of Leh, particularly due to its higher protein content and nitrogen-fixing ability. Sainfoin and White clover also showed promising nutritional attributes and may be considered suitable introduced legumes. However, the overall performance of introduced forages remained inferior to the locally adapted Alfalfa and Alfalfa blue. Therefore, while selected introduced legumes can contribute to forage diversification, native Alfalfa types should remain the preferred choice for sustainable fodder production and livestock nutrition in the cold arid region of Leh.

Pearson correlation analysis revealed significant relationships among growth attributes and proximate composition of forage species under cold arid conditions of Leh (Figure 1). Survival percentage showed a strong positive correlation with fresh weight ($r=0.86$), nitrogen ($r=0.73$), crude protein ($r=0.73$), and ADF ($r=0.83$), indicating that better-established plants accumulated higher biomass and nutrients. Fresh weight was positively associated with nitrogen, crude protein, ash, and ADF, whereas it showed a strong negative correlation with NDF ($r=-0.73$), suggesting better forage quality in high biomass-producing species. Nitrogen and crude protein exhibited a perfect positive correlation ($r=1.00$), confirming the direct contribution of nitrogen to protein synthesis. NDF showed a strong negative relationship with nitrogen, crude protein, survival, and fresh weight, indicating that species with higher nutritive value contained lower cell wall components. Plant height and tiller number showed weaker associations with nutritional traits, suggesting that taller plants did not always possess better forage quality. Similar relationships between crude protein and fibre fractions have been reported by Homolka et al. (2012).

Conclusion

The study revealed significant variations in the survival, establishment, and growth of forage species under the cold-arid conditions of Ladakh, with yellow and blue alfalfa exhibiting superior adaptation and biomass production. Bulbous canary grass, sainfoin, and red fescue also showed promising potential for forage

diversification and pasture improvement. These species may help enhance fodder availability, reduce grazing pressure on natural rangelands, and support sustainable livestock production. Further multi-location and multi-year trials are needed to validate their adaptability, winter survival, forage quality, and productivity across Ladakh.

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References

- 1) Ahmad, S., Khan, P. A., Verma, D. K., Mir, N. H., Sharma, A., Wani, S. A. (2018a). Forage production and orchard floor management through grass/legume intercropping in apple-based agroforestry systems. *International Journal of Chemical Studies*, 6(1): 953-958.
- 2) Ahmad, S., Mir, N. H., Bhat, S. S., Singh, J. P. (2018b). High altitude pasturelands of Kashmir Himalaya: Current status, issues and future strategies in a changing climatic scenario. *Current Journal of Applied Science and Technology*, 27(2): 1-10.
- 3) Akand, A. H., Singh, B., Mahesh, C. (2017). Contribution of livestock in livelihood: Ladakh region. *Indian Journal of Animal Sciences*, 87(5): 649-652.
- 4) AOAC. (2005). *Official Methods of Analysis*. 18th edn. Association of Official Analytical Chemists, Arlington, Virginia, USA.
- 5) Evers, J. M., Hughes, C. G. (2002). Chemical analysis. In: *Encyclopedia of Dairy Sciences*. Elsevier, Amsterdam, the Netherlands, pp. 34-40. ISBN 978-0-12-227235-6.
- 6) Gomez, K. A., Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*. A Wiley Inter Science Publication, John Wiley and Sons, New York: 680 p.
- 7) Gupta, R. D., Arora, S. (2016). Ecology, soil and crop management for livelihoods in Ladakh region: An Overview. *Journal of Soil and Water Conservation*, 15(2): 178-185.
- 8) Homolka, P., Koukolova, V., Podsedniček, M., Hlavačková, A. (2012). Nutritive value of red clover and lucerne forages for ruminants estimated by *in vitro* and *in vivo* digestibility methods. *Czech Journal of Animal Science*, 57: 454-568.
- 9) Kumar N., Sood BR, Kumar S. 2015. Performance of improved forage species under dry temperate conditions of North Western Himalayas. In *Proceedings of the XXIII International Grassland Congress* (Theme 3: Sustainability of grasslands- social and policy issues, Sub-theme 3.3: Sustainable use of grassland resources, Paper ID 578). New Delhi, India. <https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1973&context=igc>
- 10) Noor mohamed, M. B., Chichaghare, A. R., Shukla, A. K. (2026). Woods specific gravity and carbon ratio of shrubs and trees: an insight from Indian cold desert. *Agroforestry Systems*, 100: 2. <https://doi.org/10.1007/s10457-025-01400-8>.
- 11) Raj, A., Sharma, P. (2013). Is Ladakh a 'cold desert'? *Current Science*, 104(6): 687-688.
- 12) Sayar, M. S., Han, Y., Yolcu, H., Yücel, H. (2014). Yield and quality traits of some perennial forages as both sole crops and intercropping mixtures under irrigated conditions. *Turkish Journal of Field Crops*, 19: 59-65.
- 13) Ahmad Suheel, Singh, J. P., Inder Dev, Sudesh Radotra, Sheeraz Saleem Bhat, Nazim Hamid Mir and Chaurasia, R. S. 2021. Evaluation of high yielding temperate perennial forages for augmenting forage resources in Ladakh (India). *Applied Biological Research*, 23(2): 165-170. DOI: 10.5958/0974-4517.2021.00022.7.
- 14) Sultan Singh, Ahmad, S., Bhat, S. S., Tejveer Singh, Mir, N. H. (2023). Yield and nutritive value of local races of grasses and legumes to rejuvenate pastures for sustaining livestock productivity in sub-Himalayan region of India. *Range Management and Agroforestry*, 44: 353-362.
- 15) Tewari, J. C., Pareek, K., Raghuvanshi, M. S., Kumar, P., Roy, M. M. (2016). Fodder production system-a major challenge in cold arid region of Ladakh, India. *MOJ Ecological and Environmental Science*, 1(1): 1-7.
- 16) Verma, P., Sharma, A., Sodhi, M., Thakur, K., Bharti, V. K., Kumar, P., Giri, A., Kalia, S., Swami, S.K., Mukesh, M. (2018). Overexpression of genes associated with hypoxia in cattle adapted to Trans Himalayan region of Ladakh. *Cell Biology International*, 42(9): 1141-1148. doi: 10.1002/cbin.10981. Epub 2018 Jul 11.
- 17) Vyas, S., Bissa, U.K. 2019. Current status and strategies for conservation of double hump camel (*Camelus dromedarius*) in Ladakh, India. *Journal of Livestock Science* 12: 132-137. doi. 10.33259/JLivestSci.2019.132-13
- 18) Vyas, S., Sharma, N., Sheikh, F. D., Singh, S., Sena, D. S., Bissa, U. K. (2015). Reproductive status of *Camelus bactrianus* during early breeding season in India. *Asian Pacific Journal of Reproduction*, 4(1): 61-64.
- 19) Vyas, S., Sheikh, F.D., Singh, S., Sena, D. S., Bissa, U. K., Sharma, N. (2014). Sea Buckthorn (*Hippophae rhamnoides*)-An important fodder for Bactrian camel in Ladakh region. *Journal of Camel Practice and Research*, 21(1): 89-91.