Pakistan J. Zool., pp 1-11, 2026. **DOI**: https://dx.doi.org/10.17582/journal.pjz/20241211101310

Food Habits and Seasonal Variation in Diet of Himalayan Musk deer (*Moschus leucogaster*) in Azad Jammu and Kashmir, Pakistan

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Article Information
Received 11 December 2024
Revised 10 September 2025
Accepted 27 September 2025
Available online 20 February 2026 (early access)

Authors' Contribution
MBK: Field data collection, writing-original draft, BA: Conceptualization, supervision. RAM: Formal data analysis, writing-review and editing. UA: Formal analysis, methodology, visualization. Shaista A, Sajid A and MJ: Helped in field data collection.

Key words
Himalayan Musk deer, Food habits, Diet variation, AJ&K

ABSTRACT

The Himalayan musk deer (*Moschus leucogaster*) is an endangered species. Its population is reported to be rapidly decreasing owing to habitat loss and overhunting for the highly valuable musk pods. Conservation of this species needs a better understanding of available resources, and their utilization by musk deer in its distribution range. The current study was conducted during the years 2020-2022 to assess the diet composition of Himalayan musk deer (HMD) in Azad Jammu and Kashmir (AJ&K), Pakistan, by using micro-histological techniques. Fecal samples (n=35) were collected from the study area and examined following the standard protocol. Reference slides from the plant species in the area were prepared to identify the dietary items from the fecal pellets. Relative importance value (RIV) for each plant species and their group identified from pellets was calculated. Results revealed the consumption of 51 plant species in its diet. Among them, the most consumed species were *Abies pindrow* (RIV=8.32%), *Picea smithiana* (RIV=6.63%), *Betula utilis* (RIV=5.70%), and *Skimmia laureola* (RIV=4.60%). HMD fed on forbs (43.04%), trees (24.75%), shrubs (23.94%) and graminoids (5.51%). The seasonal diet variation showed that the maximum (n=51) plant species were consumed in summer as compared to winter (n=14). Among different groups, forbs were consumed more in summer (61.88%), while trees were the most preferred diet in winter (61.2%). Similarly, HMD preferred dicots in summer (72.91%) and conifers in winter (51.04%). This study will help in the conservation of an endangered species (HMD) by providing baseline data about its diet selection. Based on these results, a detailed investigation on habitat use, population, threats, and conservation of Himalayan musk deer in AJ&K has been recommended.

INTRODUCTION

Himalayan musk deer (HMD) or white-bellied musk deer (*Moschus leucogaster*) belongs to the family Moschidae and is the largest of all musk deer species (Homes, 1999). The HMD was historically referred to as *Moschus chrysogaster*, but recent genetic analyses have confirmed that populations in the central and eastern Himalayas are correctly identified as *Moschus leucogaster* (Qamar *et al*., 2008; Qureshi *et al*., 2013; Shakeel, 2014; Rasool, 2016; Singh *et al*., 2019). This clarification arose because earlier studies misidentified these populations, confusing them with other musk deer species due to morphological similarities. Mitochondrial DNA analysis distinguished two main lineages: *Moschus leucogaster* (Himalayan musk deer) in the central and eastern Himalayas, and *Moschus cupreus* (Kashmir musk deer) in the western Himalayas (Singh *et al*., 2019; Mainali *et al*., 2023). The Alpine musk deer (*Moschus chrysogaster*) is now recognized as a separate species, not present in the southern Himalayas as previously thought (Timmins and Duckworth, 2015; Singh *et al*., 2019; Mainali *et al*., 2023). The distribution of *Moschus leucogaster* (Himalayan musk deer) is now confirmed to be widespread throughout the central and eastern Himalayas, including Pakistan,

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0030-9923/2026/0001-0001 $ 9.00/0

Nepal, Bhutan, northern India, and adjacent regions of China (Timmins and Duckworth, 2015; Singh *et al*., 2019; Chandra *et al*., 2021; Mainali *et al*., 2023).

The HMD is a sedentary and solitary animal with a home range of 13 to 22 ha (Kattel, 1992; Harris and Guiquan, 1993; Green and Kattel, 1997). The males are territorial in nature and use their habitual defecation sites for social markings (Kattel, 1992; Yang *et al*., 2003; Aryal and Subedi, 2011). The species inhabits in habitats like moist Himalayan forests, sub-alpine scrub, on the southern Himalayan slopes and nearby mountainous areas with an altitudinal range of 2,000 to 4,000m above sea level (asl.).

Studying the foraging ecology is an important aspect of species-specific management (Sandoval *et al*., 2005; Barcia *et al*., 2007). The food quality widely affects the reproduction, growth and survival of animals and therefore influences their population dynamics (Pekins *et al*., 1998). The dietary studies become more valuable for patchily distributed, endangered and low- density animals like HMD (Sharma *et al*., 2014).

Food selection depends upon seasonal variation and availability of plant species (Green, 1986). HMD is herbivore and feeds upon leaves of trees, bushes and forbs. They favor nutrient-rich diets, having high protein content and digestibility (Green, 1987). Being a crepuscular animal, HMD remains active at dawn and dusk for foraging or browsing (Kattle, 1992; Thapamagar *et al*., 2018). Literature reported the dietary items of HMD including *Jasminium officinalis*, *Launea nudicaulis*, *Bergenia* spp., *Holboellia latifolia*, *Viola serpens*, *Chrysanthemum* spp., *Polygonum* spp. *Strobilanthes dalhousianus*, *Pyrus pashia*, *Prunus domestica*, *Rubus nutans*, *Smilax* spp., *Quercus leucotrichophora*, *Quercus glauca*, *Arundinaria falcata*, *Usnea* spp., *Agaricus* spp. and flowers of *Rhododendron arboretum* (Sathyakumar *et al*., 1993) *Gaultheria trichophylla*, *Ophiopogon intermedius, Cyprus* spp. and *Sibbaldia cuneata* (Green, 1986; Syed and Ilyas, 2015). A knowledge gap exists on the food habits of HMD in AJ&K. This study was the first attempt to investigate the food habit and the variation in the diet of HMD in different seasons in the study area.

MATERIALS AND METHODS

Study area

Study area lies at 73°–75° longitude and 33°–36° latitude and comprises of five northern districts of Azad Jammu and Kashmir (Fig. 1). It covers an area of 13,297 km^2 with an altitudinal range of 360–6,325m above sea level. This is a semi-autonomous region administered by Pakistan. In the north, Gilgit Baltistan while in the east Indian-held State of Jammu and Kashmir border it. The south side is bordered by Punjab while the west by Khyber Pakhtunkhwa (KP) provinces of Pakistan. A 555 km long line of Control (LoC) is the border between Azad Jammu and Kashmir and Indian Occupied Kashmir (IoK) (Fig. 1).

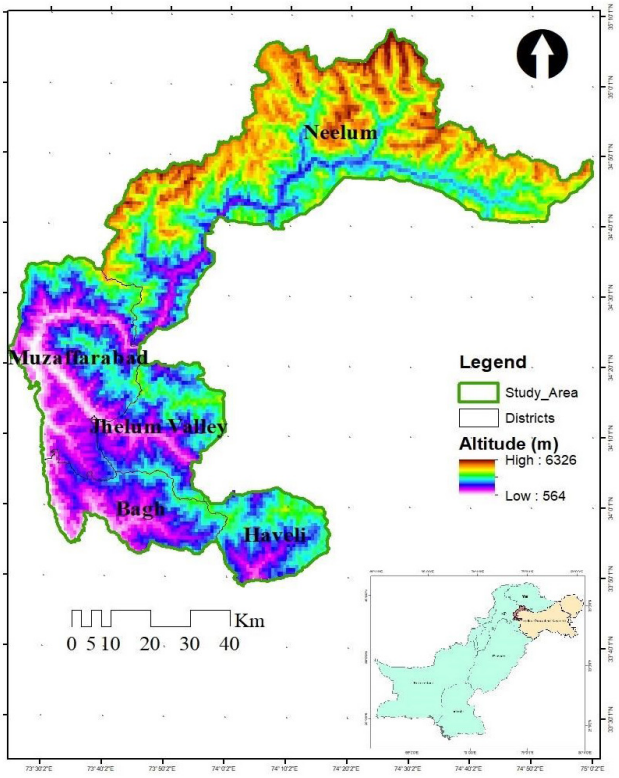

Fig. 1. Map of the study area showing districts and altitudinal range.

Sampling

Fecal pellets of HMD were collected from its habitat from September, 2020 to October, 2022. Mostly the habitat of HMD was within the protected areas with definite boundaries. However, data were also collected from the adjacent non protected habitable areas.

Fecal pellets of HMD were identified by shape, size and color, which were distinct and no other sympatric deer species was recorded in this area. Thirty-five fecal pellets in two seasons, in summer (n=20) and winter (n=15) were collected, packed in zipper polythene bags, labeled with date and area name and brought to the laboratory, where they were stored in the refrigerator till further analysis (Hafeez *et al*., 2015; Ashraf *et al*., 2017; Khan *et al*., 2022).

Reference material

Dominant as well as dietary plant species reported in literature, from indigenous people, shepherds and hunters were collected from the study area. Their vernacular

names were identified with the help of local people and further confirmed with the help of literature and experts from the department of Botany, the University of Azad Jammu and Kashmir. These reference plants were press dried and preserved till further analysis (reference slide preparation). Depending on their characteristics, these plant species were divided into categories (trees, shrubs, herbs (forbs and grasses) and groups (monocots, dicots, conifers and ferns) (Syed and Ilyas, 2015; Kunwar *et al*., 2016; Khadka, 2017).

Analysis

Direct observation, micro-histological technique, fistulation and gut analysis are the main techniques to investigate the diet of an animal. Fistulation and gut analysis (needing the sacrifice of animal) were not possible for such an elusive and threatened species. Direct observation was also not possible for such a crepuscular and elusive species. The microhistological technique is the only frequently used and more reliable technique for diet analysis. Therefore, microhistological procedure was used to explore the diet of HMD (Sparks and Malechek, 1968; Holechek, 1982; Hafeez *et al*., 2014; Ashraf *et al*., 2017; Khan *et al*., 2022).

Slide preparation

Slides were prepared from the fecal samples as well as from the reference plant material following the method developed by Sparks and Malechek (1968) and Vavra and Holechek (1980) that was further validated and used in many recent studies (Shrestha and Wegge, 2006; Abbas *et al*., 2008; Giri *et al*., 2011; Hafeez *et al*., 2015; Syed and Ilyas 2015; Ashraf *et al*., 2017; Khadka, 2017, Khan *et al*., 2022). After the breakdown and grinding in pestle and mortar, air dried fecal samples were mixed thoroughly and passed through a sieve to remove the large and unidentifiable particles. Then the samples were again ground in Vertis Homogenizer after washing with tap water and soaking in a solution (1:1:1) composed of one part each of distilled water, ethyl alcohol and glycerin overnight. These samples were heated for four to six minutes in water bath in labeled test tube containing 5% sodium hydroxide. The dark supernatant was removed after the particles settled down. To produce a clear solution this treatment was repeated for three to seven times. The samples were treated with alcohol of different concentrations (25%, 50%, 75% and 100%) each for 10 min. Xylene and alcohol mixtures (25%, 50%, 75% and 100% xylene) were used to remove the alcohol each for 10 min. except for 100%, which was left overnight. The next day material was transferred, evenly spread, mounted in mounting medium (DPX) on a clean glass slide and covered by the cover slip. Five slides from each sample for each season were prepared. The slides from the reference plant material were prepared by following the same procedure except for using 10% NaOH solution (Abbas *et al*., 2008; Giri *et al*., 2011; Hafeez *et al*. 2014; Syed and Ilyas, 2015; Ashraf *et al*., 2017; Khan *et al*., 2022).

Slide interpretation and diet composition

The micro-photographs were taken from reference slides by using a digital microscope (Nikon- E100) with an attached camera. Plant fragments in the slides prepared from the fecal pellets were cross matched with reference slides and identified up to the primary taxonomic level. Unidentified fragments were categorized as unidentified material. Percent relative frequencies for each plant species, group and category in both the seasons (winter and summer) were calculated and expressed as the relative importance value (RIV) (Shrestha and Wegge, 2006; Shakeel, 2014; Ashraf *et al*., 2017).

$$\text{Relative Importance Value (\%)} = \frac{\text{No. of Fragments ofa Species}}{\text{Total No. of Fragments Analysed in a Sample}} \times 100$$

Diet selection

The diet selection value was calculated by the following equation:

$$\text{Diet Selection Value (DSV)} = \frac{RIVx}{PVx} \times 100$$

Where, RIV is the relative importance value which is the consumption of a species x and PV is the prominence value which is the relative availability value for a species x and was calculated from the following equation (Koirala *et al*., 2000; Shrestha and Wegge, 2006; Shakeel, 2014).

$$PVx = Mx\sqrt{fx}$$

Where M_x is mean percentage cover of a species x and f_x is frequency of occurrence of a species x in sample quadrat.

To calculate the abundance of a particular item in the diet, the frequency of occurrence (FO) was calculated following Hashimoto *et al*. (2003).

$$Fi = ni/N$$

Where, F_i is frequency of occurrence of food item i, ni is the number of samples containing item 'i' and N is the number of all samples analyzed. To determine the importance of each food item in the diet, the percentage of Occurrence (PO) was calculated following Mendes *et al*. (2010) and Ali *et al*. (2017).

$$PO = \frac{n_i}{N} \times 100$$

Where, n_i is frequency of item 'i' and N is the sum of the frequencies of all items.

RESULTS

Diversity in dietary plant species

We analyzed 35 fecal samples (20 in summer and 15 in winter). Results revealed the consumption of 51 plant species by HMD in the study area. Among them, dominant species were *Abies pindrow* (RIV=8.32%), *Picea smithiana* (RIV=6.63%), *Betula utilis* (RIV=5.70%), *Skimmia laureola* (RIV=4.60%) and *Juniperus communis* (RIV=4.38%). Least consumed species were *Senecio* spp. (RIV=0.60%) and *Primula denticulata* (RIV=0.62%) (Table I). Musk deer fed upon forbs (43.04%), tress (24.75%), shrubs (23.94%) and graminoids (5.51%) (Fig. 2A). The selection of plant groups (trees, shrubs, forbs and grasses) was significantly different ($\chi^2 = 53.80$, $p < 0.001$).

The most consumed category was dicots (64.24%) followed by conifers (21.28%), monocots (8.55%) and ferns (3.18%) (Fig. 2B). The selection of plant categories (dicots, monocots, conifers and ferns) was highly significantly different ($\chi^2 = 133.45$, $p < 0.001$).

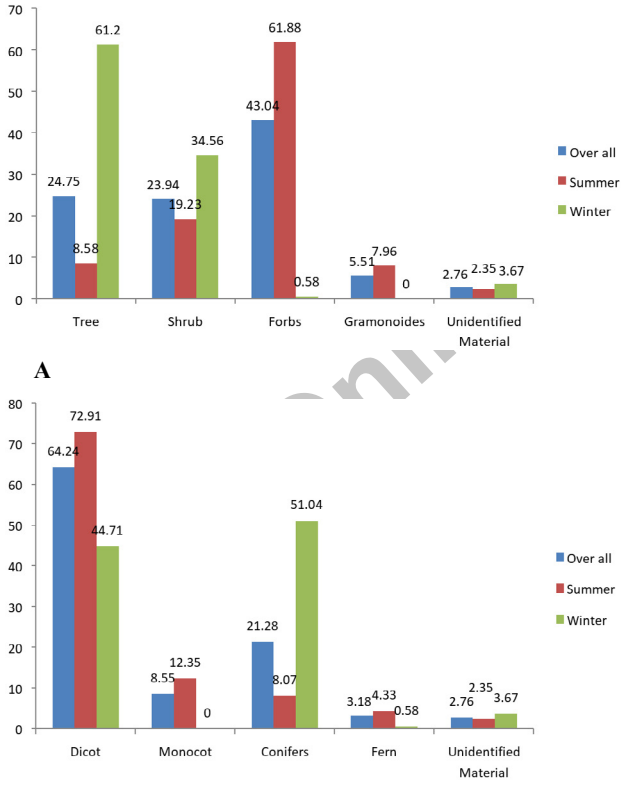

Fig. 2. Plant groups (A) and plant categories (B) recovered from the fecal pellets of musk deer during the study period (2020-2022).

Seasonal variation in diet

The study area comprises of difficult terrain that received a heavy snowfall during the winter. Due to these limitations, less fecal pellets (n=15) were collected in winter season as compared to summer (n=20). Data obtained showed the seasonal variation in the food of HMD.

Summer

Results of fecal pellets analyzed in summer season revealed the consumption of 51 plant species in the diet. Among them, *Dryopteris stewartii* (RIV=4.33%) followed by *Skimmia laureola* (RIV=4.06%), *Geranium wallichianum* (RIV=3.34%), *Viola* spp. (IVI=2.91%) and *Salix denticulata* were highly consumed while *Jasminum humile* and *Prunus cornuta* (RIV=0.78% each) and *Cotoneaster roseus* (RIV=0.58%) were least consumed plant species (Table I).

Results showed that in summer season, the food of HMD comprised of forbs (61.88%), shrubs (19.23%), trees (8.58%) and graminoids (7.96%) (Fig. 2A). Different food categories recovered from the fecal pellets of HMD in summer season were dicots (72.91%), monocots (12.35%), conifers (8.07%) and ferns (4.33%) (Fig. 2B). The selection of plant groups consumed in summer season was significantly different in terms of number of species (χ^2=57.137, df=4, $p<0.001$) and frequency of occurrence in fecal pellets (χ^2=6074, df=4, $p<0.001$).

Winter

During winter season, a total of 14 plant species were recovered from the fecal pellets of HMD. The most consumed plants were *Abies pindrow* (RIV=21.63%), followed by *Picea smithiana* (RIV=17.96%), *Betula utilis* (RIV=12.63%) and *Juniperus communis* (RIV=7.74%), while *Cotoneaster roseus* (RIV=1.69%) and *Dryopteris stewartii* (RIV=0.58%) were the least consumed plant species. The unidentified material (RIV=3.67%) was also recovered from the fecal pellets of HMD in the winter season (Table I). The selection of plant groups consumed in winter season was significantly different in terms of number of species (χ^2=4446.301, df=4, $p<0.001$) and frequency of occurrence in fecal pellets (χ^2=18.142, df=4, $p<0.001$).

Data revealed that the diet of HMD comprised of trees (61.2%), shrubs (34.56%) and forbs (0.58%) during winter season (Fig. 2A). While the plant categories recovered from the fecal pellets during the winter season were conifers (51.04%), dicots (44.71%) and ferns (0.58%) (Fig. 2B). There was a significant difference in the selection of different plant groups (trees, shrub, herbs and grass) in diet (χ^2 =53.50, df=3, $p< 0.001$). Similarly, selection of different plant groups was also significantly different between different seasons (χ^2 =112.45, df=1, $p< 0.001$).

Table I. Relative importance value (RIV) of plant species recovered from the fecal pellets of musk deer during the study period (2020-2022).

S No.	Scientific name/ Vernacular name	Family	Group	Category	Relative importance value (RIV)		
					Overall	Summer	Winter
1	*Abies pindrow* (Fur)	Pinaceae	Tree	Conifer	8.32	2.56	21.31
2	*Achillea millefolium* (Chitti Booti)	Asteraceae	Herb	Dicot	1.37	1.98	0.00
3	*Aconitum heterophyllum* (Patrees)	Ranunculaceae	Herb	Dicot	1.85	2.67	0.00
4	*Ajuga bracteosa* (Thandijari)	Labiatae	Herb	Dicot	0.82	1.18	0.00
5	*Allium wallichii* (Malian Da Pyaz)	Amaryllidaceae	Herb	Monocot	1.67	2.41	0.00
6	*Andropogon gerardii*	Poaceae	Grass	Monocot	1.87	2.70	0.00
7	*Anemone* spp.	Ranunculaceae	Herb	Dicot	1.64	2.36	0.00
8	*Artemisia vulgaris* (Jahoo)	Asteraceae	Herb	Dicot	1.28	1.85	0.00
9	*Asphodelus tenuifolius* (Jangli Pyaz)	Asphodelaceae	Herb	Monocot	1.37	1.98	0.00
10	*Astragalus* spp. (Keanthi Grass)	Fabaceae	Herb	Dicot	1.56	2.25	0.00
11	*Berberis lyceum* (Sumbal)	Berberidaceae	Shrub	Dicot	1.27	1.84	0.00
12	*Bergenia ciliata* (Batpewah)	Saxifragaceae	Herb	Dicot	1.68	2.43	0.00
13	*Betula utilis* (Burjh)	Betulaceae	Tree	Dicot	5.70	2.62	12.63
14	*Bistorta* spp. (Masloon)	Polygonaceae	Herb	Dicot	1.75	2.52	0.00
15	*Chrysopogon* spp. (Booji Grass)	Poaceae	Grass	Monocot	1.64	2.36	0.00
16	*Cotoneaster roseus* (Satberga)	Rosaceae	Shrub	Dicot	0.92	0.58	1.69
17	*Cyperus* spp. (Muther)	Gramineae	Grass	Monocot	1.21	1.74	0.00
18	*Dipsacus inermis* (Pulha)	Caprifoliaceae	Herb	Dicot	1.24	1.79	0.00
19	*Dryopteris stewartii* (Kunji)	Dryopteridaceae	Fern	Fern	3.18	4.33	0.58
20	*Euphorbia* spp. (Hervi)	Euphorbiaceae	Herb	Dicot	0.80	1.15	0.00
21	*Fragaria nubicola* (Budi Meava)	Rosaceae	Herb	Dicot	1.04	1.50	0.00
22	*Geranium wallichianum* (Ratan Jog)	Geraniaceae	Herb	Dicot	2.31	3.34	0.00
23	*Impatiens edgeworthii* (Bantill)	Balsaminaceae	Herb	Dicot	1.36	1.96	0.00
24	*Indigofera heterantha* (Kainthi)	Fabaceae	Shrub	Dicot	2.14	0.91	4.90
25	*Inula royleana* (Poshgar)	Asteraceae	Herb	Dicot	0.74	1.07	0.00
26	*Jasminum humile* (Jangli chambali)	Oleaceae	Shrub	Dicot	1.50	0.78	3.13
27	*Juniperus communis* (Beanthri)	Cupressaceae	Shrub	Conifer	4.38	2.89	7.74
28	*Oxalis* spp. (Khathallo)	Oxalidaceae	Herb	Dicot	1.91	2.76	0.00
29	*Picea smithiana* (Kachhal)	Pinaceae	Tree	Conifer	6.63	1.60	17.96
30	*Poa annua* (Nichhani)	Poaceae	Grass	Monocot	0.80	1.15	0.00
31	*Podophyllum emodi* (BanrKhakhri)	Berberidaceae	Herb	Dicot	0.85	1.23	0.00
32	*Polygala sibirica*	Polygalaceae	Herb	Dicot	0.86	1.25	0.00
33	*Primula denticulata*	Primulaceae	Herb	Dicot	0.62	0.89	0.00
34	*Prunus cornuta* (Parth)	Rosaceae	Tree	Dicot	2.16	0.78	5.26
35	*Rheum australe* (Chityal)	Polygonaceae	Herb	Dicot	1.76	2.54	0.00
36	*Rhododendron* spp.	Ericaceae	Shrub	Dicot	1.59	1.10	2.70
37	*Rosa moschata* (Garachha)	Rosaceae	Shrub	Dicot	1.47	2.12	0.00
38	*Rumex nepalensis* (Holla)	Polygonaceae	Herb	Dicot	0.95	1.37	0.00

Table continues on next page.....

S No.	Scientific name/ Vernacular name	Family	Group	Category	Relative importance value (RIV)		
					Overall	Summer	Winter
39	*Salix denticulata* (Beahrh)	Salicaceae	Shrub	Dicot	3.39	2.89	4.50
40	*Selinum vaginatum*	Umbelliferae	Herb	Dicot	1.22	1.76	0.00
41	*Senecio* spp.	Asteraceae	Herb	Dicot	0.60	0.86	0.00
42	*Skimmia laureola* (Neara)	Rutaceae	Shrub	Dicot	4.60	4.06	5.83
43	*Stachys* spp.	Labiateae	Herb	Dicot	0.63	0.91	0.00
44	*Taraxacum* spp. (Hund)	Asteraceae	Herb	Dicot	0.97	1.41	0.00
45	*Taxus wallichiana* (Barmi)	Taxaceae	Tree	Conifer	1.95	1.02	4.03
46	*Thalictrum* spp.	Ranunculaceae	Herb	Dicot	0.90	1.29	0.00
47	*Trillium govanianum* (Terapatra)	Melanthiaceae	Herb	Dicot	1.97	2.84	0.00
48	*Utrica dioaca* (Kayari)	Urticaceae	Herb	Dicot	0.79	1.13	0.00
49	*Valeriana wallichii* (Mushkbala)	Valerianaceae	Herb	Dicot	1.34	1.93	0.00
50	*Viburnum nervosum* (Guchh)	Adoxaceae	Shrub	Dicot	2.68	2.06	4.07
51	*Viola* spp. (Banafsha)	Violaceae	Herb	Dicot	2.01	2.91	0.00
52	Unidentified material				2.76	2.35	3.67

Diet selection

Diet selection showed that forbs (n=31; 60.78%), shrubs (n=10; 19.61%), and trees (n=5; 9.80%) were the most preferred while fern was the least (n=1; 1.96%) preferred dietary item in the diet of HMD. Among the major selected dietary plants in the diet of HMD were *Dryopteris stewartii* (DSV=1.49), *Allium wallichii* (DSV=1.49) and *Andropogon gerardii* (DSV=1.11) (Table II).

For the abundance of dietary components, frequency of occurrence (FO) was calculated. The most common dietary components of musk deer were *Betula utilis, Skimmia laureola* (FO=68.57%), followed by *Picea smithiana, Juniperus communis* (FO 62.86%), *Abies pindrow* and *Viburnum nervosum* (FO = 60.00% each) (Table II).

DISCUSSION

Understanding the diet preferences and influence of biotic factors on the diet of wild animals plays an important role in exploring the interaction between environmental dynamics and species ecology (Leopold and Krausman, 1987). Despite belonging to a monotypic family Moschidae, the Himalayan musk deer shares dietary affinities with cervids; typically showing traits indicative of concentrate feeding due to its small body size (Kay *et al*., 1980). Food and shelter are fundamental factors influencing the distribution and survival of wild animals.

Due to shy and crepuscular nature, HMD poses challenges for studies of feeding behavior by direct observation in natural conditions. As invasive methods such as stomach content analysis are prohibited due to

Table II. Diet selection values and frequency of occurrence of different plant species in food of musk deer recorded during the study period (2020-2022).

	Scientific name	PV	DSV	FO
1	*Abies pindrow*	8.16	1.02	60.00
2	*Achillea millefolium*	5.18	0.26	34.29
3	*Aconitum heterophyllum*	5.86	0.32	45.71
4	*Ajuga bracteosa*	2.92	0.28	25.71
5	*Allium wallichii*	1.12	1.49	45.71
6	*Andropogon gerardii*	1.69	1.11	37.14
7	*Anemone* spp.	1.65	0.99	45.71
8	*Artemisia vulgaris*	6.35	0.20	34.29
9	*Asphodelus tenuifolius*	2.8	0.49	42.86
10	*Astragalus* spp.	1.77	0.88	34.29
11	*Berberis lyceum*	6.26	0.20	28.57
12	*Bergenia ciliata*	5.81	0.29	42.86
13	*Betula utilis*	7.94	0.72	68.57
14	*Bistorta* spp.	5.62	0.31	45.71
15	*Chrysopogon* spp.	1.5	1.09	37.14
16	*Cotoneaster roseus*	3.56	0.26	31.43
17	*Cyperus* spp.	1.9	0.64	20.00
18	*Dipsacus inermis*	3.23	0.38	37.14
19	*Dryopteris stewartii*	2.13	1.49	51.43
20	*Euphorbia* spp.	3.2	0.25	22.86
21	*Fragaria nubicola*	4.13	0.25	31.43

Table continues on next column.....

	Scientific name	PV	DSV	FO
22	*Geranium wallichianum*	6.53	0.35	51.43
23	*Impatiens edgeworthii*	6.03	0.23	37.14
24	*Indigofera heterantha*	5.41	0.40	45.71
25	*Inula royleana*	2.48	0.30	20.00
26	*Jasminum humile*	3.41	0.44	37.14
27	*Juniperus communis*	8.7	0.50	62.86
28	*Oxalis* spp.	4.45	0.43	42.86
29	*Picea smithiana*	10.03	0.66	62.86
30	*Poa annua*	2.01	0.40	22.86
31	*Podophyllum emodi*	3.21	0.26	28.57
32	*Polygala sibirica*	1.48	0.58	22.86
33	*Primula denticulata*	2.45	0.25	17.14
34	*Prunus cornuta*	6.92	0.31	48.57
35	*Rheum australe*	5.23	0.34	45.71
36	*Rhododendron* spp.	5.18	0.31	34.29
37	*Rosa moschata*	6.33	0.23	40.00
38	*Rumex nepalensis*	7.25	0.13	25.71
39	*Salix denticulata*	6.13	0.55	57.14
40	*Selinum vaginatum*	1.53	0.80	34.29
41	*Senecio* spp.	1.56	0.38	17.14
42	*Skimmia laureola*	4.92	0.93	68.57
43	*Stachys* spp.	1.56	0.40	20.00
44	*Taraxacum* spp.	3.55	0.27	28.57
45	*Taxus wallichiana*	3.23	0.60	54.29
46	*Thalictrum* spp.	1.56	0.58	25.71
47	*Trillium govanianum*	2.27	0.87	45.71
48	*Utrica dioaca*	1.01	0.78	22.86
49	*Valeriana wallichii*	2.73	0.49	31.43
50	*Viburnum nervosum*	6.29	0.43	60.00
51	*Viola* spp.	2.03	0.99	40.00

FO, frequency of occurance; DSV, diet selection value; PV, prominence value

threatened status of the species hence, to study the dietary patterns, researchers use a non-invasive and a reliable method of micro-histological examination of fecal pellets (Hafeez *et al*., 2014; Syed and Ilyas, 2015; Ashraf *et al*., 2017; Khan *et al*., 2022). Therefore, diet ecology of HMD was investigated by using this technique.

Fifty-one plant species were recovered from the analysis of fecal pellets of HMD in summer. Forbs (43.04%) were the most preferred over trees (24.75%) and shrubs (23.94%) while Graminoid (5.51%) had the least preference. The major dietary plant species were *Abies pindrow*, *Picea smithiana*, *Betula utilis*, *Skimmia laureola*, *Juniperus communis*, *Salix denticulata*, *Dryopteris stewartii*, *Viburnum nervosum* and *Prunus cornuta*. Dicot (64.24%) plants were preferred over conifers (21.28%) and monocots (8.55%).

Similar to our study, in Machhiara National Park, Muzaffarabad, Shakeel (2014) identified 28 plant species in the diet of HMD with preference of herbs (64.28%) over shrubs (21.43%) and trees (14.29%). Our results coincide with the finding of Syed and Ilyas (2015) who proposed the browser nature of HMD and identified 36 plant species in the food of HMD in Kedarnath Wildlife Sanctuary, Uttarakhand, India, with preference of dicots (73.62%) over monocots (26.38%). They recorded the major consumed plant species like *Gaultheria trichophylla, Sibbaldia cuneata*, *Cyperus* sp. and *Ophiopogon intermedius* in diet of HMD.

Contrary to our study, in Quinghai Province of China, Zheng and Pi (1979) recorded 77 plant species with preference of forbs (60%) over shrubs (38%) and graminoids (2%). Shaposhnikov (1956) also recovered 50 plant species in the diet of HMD in northeastern Altai, Russia. However, trees and shrubs (28% each), forbs (34%) and graminoids (12%) ratios were different from our finding which might be due to geographical variation of flora. In Kedarnath Wildlife Sanctuary, India, major dietary items in the diet of HMD were *Danthonia cachemyriana Cyperus* spp. and *Thamnocalamus spathiflorus* with preference of dicots (52.02%) over monocots (47.98%) (Syed and Ilyas, 2015).

Selection of diet is based on its digestibility and crude nutritional content of dietary items. Our findings are similar to previous findings where musk deer selected high nutritional forbs (Awasthi *et al*., 2003), *Betula utilis* (Green, 1987) and mosses (Qamar *et al*., 2008). Plant diversity, diet spectrum, nutritional status of forage species and competition of livestock are the key factors that affect the diet selection of a wild animal. In the Himalayan region, dietary preferences were observed both in the wild whereas domestic herbivores changed from graminoids at lower altitudes to forbs at higher elevations (Bhattacharya *et al*., 2012). Higher metabolic rate/body weight unit endorses the species with small body size (musk deer) in selecting a high-energy food item (Jarman, 1974).

Dietary analysis revealed the variation in the seasonal diet of HMD with consumption of 51 plant species in summer, which was reduced to only 14 in winter season. In Kedarnath Wildlife Sanctuary, Uttarakhand, India, Syed and Ilyas (2015) recorded the same dietary trend in the diet of HMD with 34 plant species in summer and 24 in winter. Bhattacharya *et al*. (2012) identified 53 plant species in the food of HMD in the Greater Himalayas while in the mountain range of Russian Far East, Domanov (2013)

identified 64 plant species in the food of musk deer in the winter season.

In summer season HMD preferred forbs over shrubs and trees, and dicots over monocots and ferns. The major dietary items recovered in summer season were *Dryopteris stewartii, Skimmia laureola*, *Geranium wallichianum*, *Viola* spp., *Salix denticulata, Juniperus communis*, *Oxalis* spp., *Aconitum heterophyllum*, *Betula utilis* and *Abies pindrow.*

Summer diet of HMD indicates the primarily consumption of herbaceous flora. The thinning snow in spring and summer facilitates the growth of a diversity of herbs, decreasing food scarcity to HMD. Further, newly growing herbs have a high value of basic nutrients, digestibility and being delicious as compared to shrubs and trees. This opinion is supported by various researchers. Syed and Ilyas (2015) from India, reported the main dietary items of HMD in pre-monsoon as *Dryopteris* spp., *Epilobium* spp., *Galium* spp., *Geumelatum* spp., *Hemiphragma* spp., *Ophiopogon intermedius, Polygonum amplexicaule*, *Polystichum* spp., *Senecio* spp., *Sibbaldia cuneata*, *Stachys* spp., *Viola* spp. and *Cyperus* spp.

However, a slight difference in the diet composition was recorded due to local factors in the context of large geographic variations. HMD consumed higher (16%) percentage of grasses in summer as compared to fern (4%) in Kedarnath Sanctuary of Uttar Pradesh, North India (Green, 1987). He also inferred that HMD preferred dicot plant species to get a higher amount of energy with minimal effort for searching food.

In winter season, diet preference shifted towards easily available trees, shrubs, and conifers, which might be less digestible and low-quality food but served as the only available food item during food scarcity period. Heavy snow cover restricted the availability of herbs and small shrubs in this season, thus herbs presence in fecal pellets of winter season was not recorded. Snow piles might also serve as a support to the HMD to reach branches of larger shrubs and conifers. Qureshi *et al*. (2013) also supported this viewpoint and reported lichens and twigs of conifers, mainly, *Abies pindrow, Picea smithiana* and *Taxus wallichiana* in the diet of HMD during winter season in Neelum valley AJ&K. Green (1987) reported a significant difference in the seasonal diet of HMD and found the browsing nature of this species in the winter season while feeding on forbs throughout the year. While in the Greater Himalayas, most of the wild ungulates fed upon forbs in summer (Bhattacharya *et al*., 2012).

Generally, it is concluded that the HMD is adapted to variations in its seasonal diet in its habitats. It may feed on forbs throughout the year (Green, 1987), supplemented by lichens (Ustinov, 1969), shrubs (Domanov, 2013), herbs (Syed and Ilyas, 2015; Bhattacharya *et al*., 2012) and feeding on leaves, twigs and shrubs in winter (Qureshi *et al*., 2013; Syed and Ilyas, 2015).

In deep snow, evergreen *Rhododendrons* and arboreal lichens may be the only accessible dietary items for HMD. Ustinov (1969) reported the lichens as a main dietary component in winter diet of HMD in Russia and eastern Siberia. The present scenario of climate change may affect the lichen, which in turn may affect the winter diet of HMD causing more stress for its survival along with other factors. The narrow altitudinal range of this species may not permit this to extend its habitat in upper or lower altitudes.

DECLARATIONS

Acknowledgements

Authors are grateful to the management and field staff of the department of Wildlife and Fisheries, Government of AJ&K and local community for their help during field surveys and data collection.

Funding

The study received no external funding.

Ethical statement

All fieldwork and sampling procedures were non-invasive and conducted in accordance with international ethical guidelines for wildlife research. No animal was captured or harmed during the study.

Generative AI and AI-assisted technology statement

No generative AI or AI-assisted technologies were used in the design, data collection, analysis, or writing of this study. All work was performed manually by the authors.

Statement of conflict of interest

The authors have declared no conflict of interest.

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