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Combining Pasture- and Animal-Based Factors to Predict Herbage or Dry Matter Intake of Lambs Grazing on Cocksfoot, Meadow Fescue and Tall Fescue Pastures

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A B S T R A C T

In this study, it was aimed to establish the correlations between actual dry matter intake (DMI) and some animal (body weight, (BW)) and pasture (crude protein (CP); neutral detergent fiber (NDF); *in vitro* dry matter digestibility (IVDMD); dry matter yield (DMY); herbage allowance (HA); herbage mass (HM); metabolizable energy (ME); relative forage quality (RFQ); total digestible nutrients (TDN)) based factors to formulate precise regression equations for DMI prediction. For this purpose, data (n = 36, 2 years × 3 blocks × 6 data collection) were utilized for two grazing seasons (2020–2021) on cocksfoot (*Dactylis glomerata*), meadow fescue (*Festuca pratensis*) and tall fescue (*Festuca arundinacea*) mixed pastures with Karayaka male lambs at an average age of 2 months for 60 days in each season. Positive correlations were determined between DMI and BW (0.777), HA (0.814), DMY (0.844), and NDF (0.609), while DMI had negative correlations with IVDMD (-0.738), RFQ (-0.357), CP (-0.209), TDN (-0.177) and ME (-0.039). In addition, animal and pasture–based factors were evaluated by principal component analysis to determine the in–cooperating variables in variance. As a result, equations were developed by using parameters with high correlation coefficient and the best–fit 3 equations for predicting DMI of lambs grazing cocksfoot, meadow fescue and tall fescue pastures: (I) -1224.09 + 39.90BW (kg) + 33.69HA (kg DM/ kg BW) + 8.22NDF (% of DM), r^2=0.815, II) -701.47 + 18.96BW (kg) + 673.61DMY (kg/ per square meters) + 8.19NDF (% of DM), r^2=0.807, III) -325.32 + 43.49HA (kg DM/kg BW)-2.21IVDMD (%) + 8.57NDF (%), r^2=0.786).

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Introduction

Pastures and forage crops are still significant ingredients in the diets of domestic ruminants (Pollock et al., 2022). Moreover, grazing on natural grasslands and/or sown pastures is the most common practice in feeding small ruminants worldwide (Pulina et al., 2013). As such, the production performance of grazing small ruminants is highly dependent upon the intake of desirable forage crops on the pasture. Farmers and nutritionists should routinely observe the effect of forage quality on animal production. In pasture–based systems (PBS), voluntary herbage intake (HI) or dry matter intake (DMI) by domestic ruminants is controlled by a complex combination of external and internal physical and physiological factors that interact with various environmental, pastoral, and experiential influences on the animal (Decruyenaere et al., 2009; Roca & Gonzalez, 2013; Galyean & Gunter, 2016; Pollock et al., 2022). Therefore, predicting HI or DMI intake on pastures (Akdağ & Ocak, 2019; Woli et al., 2023) is crucial in identifying if animals need supplementations to meet their nutrient requirements, tracking voluntary feed intake, achieving desired growth performance, and maintaining PBS. Because DMI is a function of both the intake potential of the pasture forage crops and the nutrient demand and/or requirement of animals, it can be affected by the dry matter (DM) content of the herbage on offer or the herbage mass (HM), which is the weight of the above–ground herbage DM (Tharmaraj et al., 2003). In the PBS, HI is, therefore, a function of animals' energy requirement or grazing behavior, or HM on pasture, which is unconnected to animal-related factors (Woli et al., 2023).

Contributions of pasture–based factors, such as nutritive value [crude protein (CP) and neutral detergent fiber (NDF) contents, *in vitro* dry matter digestibility (IVDMD), metabolizable energy (ME), total digestible nutrients (TDN), and relative forage quality (RFQ)] and quantity [dry matter yield (DMY) and herbage allowance (HA)] and animal-based factor [body weight (BW)] to variance in HI or DMI is not equal. However, the nature of grazing animals' responses to forage nutritive value (Sollenberger & Vanzant, 2011) or quantity regarding HM or HA has been well characterized (Sollenberger & Vanzant, 2011; Woli et al., 2023).

The widely utilized equations for approximating HI based only on pasture quantity and quality characteristics are DMI (% of body weight (BW)) = 120/% NDF (Undersander, 2003), DMI = –2.318 + 0.442 × CP – 0.010 × CP^2 – 0.0638 × TDN + 0.000922 × TDN^2 + 0.180 × ADF – 0.00196 × ADP^2 – 0.00529 × CP × ADF and DMI= 120/NDF + (NDFD – 45) × 0.374/1350 × 100 (Atalay & Kahriman, 2020; Aydin & Ocak, 2022). On the other hand, the herbage allowance (HA), forage DM (kg) per kg of animal, as defined by Sollenberger et al. (2005), enables the inclusion of indirect BW–related animal factors in predicting herbage or dry matter intake. Animal and pasture–based factors must be jointly considered in estimating HI and/or DMI of grazing ruminants, and precise equations should be formulated to this end.

In many studies conducted on dairy cattle, beef cattle, sheep, and lambs grazing on pastures, many methods have been compared for determining and/or estimating DMI (Piasentier et al., 1995; Malossini et al., 1996; Macoon et al., 2003; Smit et al., 2005; Undi et al., 2008; Decruyenaere et al., 2012). Among the methods used in these studies, some of them are prediction and some are determination; marker techniques, performance–based equations, nutrient requirements–based equations, and clipping method one of the most accurate methods (Decruyenaere et al., 2015) when used with short–term appropriate stocking rate. When scrutinizing the findings of these studies, it becomes apparent that discrepancies of up to 300% exist in the estimation and determination of DMI of grazing ruminants. It is believed that such discrepancies primarily stem from the utilization of techniques that are predominantly reliant on either animal or pasture–based factors, not integrated.

Integrating a continuously detected trait such as BW of grazing animals with the quality and quantity characteristics of the pasture and developing accurate equations will be important for meeting the nutrient requirements of animals, achieving the desired performance, deciding the time and duration of grazing, and sustainable animal husbandry in pastures. Therefore, this study aimed (i) to determine the relationships between actual DMI of lambs grazing on mixed–grass pasture (MGP) (cocksfoot (*Dactylis glomerata*), meadow fescue (*Festuca pratensis*) and tall fescue (*Festuca arundinacea*)) and quality traits of these pastures, (ii) identify the most influential components of variation in a grazing–based lamb growth model in MGP using principal component analysis (PCA) and (iii) establish the correlations between dry matter intake (DMI) and pasture–based factors as well as components deemed influential in the lamb growth model, and subsequently, to formulate precise regression equations for DMI estimation.

Materials and Methods

The data used in this study were obtained from the project numbered TUBITAK 118O197, which took place in 2020 and 2021. The experimental protocol and implemented procedures were approved by the local Ethics Committee for Experimental Animals of Ondokuz Mayis University and also, this committee ascertained that the experiment was not an unnecessary repetition of previous experiments (Protocol code 2016/44).

Materials

In this study, data (n = 36, 2 years × 3 blocks × 6 data collections) were utilized for two grazing seasons (2020–2021) on 33.3% cocksfoot, 33.3% meadow fescue and 33.3% tall fescue MGP with 18 Karayaka male lambs at an average age of 2 months for 60 days in each season. Analyzed or calculated nutrient compositions and some physical characteristics of the pastures and BW of lambs are presented in Table 1.

Methods

After dry samples were ground to pass through a 1 mm sieve, their nutrient contents (CP and NDF) were analyzed according to methods approved by AOAC International (AOAC, 2005). For this purpose, CP (method 954.01) analysis was performed. The NDF content was analyzed in accordance with the ANKOM A200/220 Fiber Analyzer filter bag technique (ANKOM Technology Corp., Fairport, NY, USA). *In vitro* dry matter digestibility (IVDMD) values of the cocksfoot, meadow fescue and tall fescue forages were determined by using the ANKOM Daisy Incubator Fermentation System (ANKOM Technology, Macedon, NY, USA) as described by Hervás et al. (2004).

Table 1. Some quality traits of the cocksfoot, meadow fescue and tall fescue pastures and body weights of lambs

Item	Mean	Minimum	Maximum
Body weight, kg/lamb	29.25	22.93	36.10
Crude protein, %	12.37	9.06	14.90
Neutral detergent fiber, %	60.88	49.24	73.76
In vitro dry matter digestibility, %	56.50	29.57	59.31
Dry matter yield, kg/m^2	0.788	0.514	1.065
Dry matter yield kg/da	788.3	514.5	1065.0
Herbage allowance, kg/lamb	16.39	10.97	21.22
Metabolizable energy, Mcal/kg	2.01	1.98	2.22
Total digestible nutrients, %	62.63	48.73	68.38
Relative forage quality	116.08	81.03	120.50

In addition, the actual DMI values used in the development of the equations were determined daily as defined by Burns et al. (1994).

The HM, which is the expression of total DM on the pasture, was calculated as;

$$HM = DMY \times 1000 \quad (1)$$

Where, HM is herbage mass, DMY is dry matter yield per square meter of pasture, and decare is 1000 square meters.

The HA differs from HM with the BW factor and has been calculated as;

$$HA = HM / (SR \times BW) \quad (2)$$

Where, HA is herbage allowance, SR is stocking rate and BW is the average body weight of the grazing animals.

The metabolizable energy represents the energy that can be used by an animal after accounting for energy lost in feces, urine and gases (such as methane in ruminants), was calculated as (Belyea et al., 1993);

$$ME\ (Mcal/kg) = 0.17 \times (DDM\%) - 2.0 \quad (3)$$

Where, DDM is digestible dry matter.

Digestible dry matter was calculated as;

$$DDM\ (\%) = 88.9 - (0.779 \times ADF), \quad (4)$$

Where, ADF is acid detergent fiber.

Relative forage quality (RFQ) is a forage quality trait including potential dry matter intake and total digestible nutrients of forages, was calculated as;

$$RFQ = (DMI_e(\%\ of\ BW) \times TDN\ (\%\ of\ DM))/1.23 \quad (5)$$

Where, DMI_e is the estimated dry matter intake potential of forages, TDN is total digestible nutrients.

The TDN, NDFn, and NFC values are calculated as stated below;

$$TDN = (NFC \times 0.98) + (CP \times 0.87) + FA \times 0.97 \times 2.25) + NDFn \times NDFDp/100 - 10 \quad (6)$$

$$NDFn = NDF \times 0.93 \quad (7)$$

$$NDFDp = 22.7 + 0.664 \times NDFD \quad (8)$$

$$FA = EE-1 \quad (9)$$

Where, NFC is non-fiber carbohydrates, FA is fatty acids, NDFn is nitrogen-free NDF and NDFD digestibility of NDF.

Both BW and pasture–based factors, presented in Table 1, were determined at 10–day intervals in two grazing seasons, 60 days for each season. Data from three MGPs that provided three observation opportunities (blocks) were used for the equations of herbage and DMI estimation. Initially, the relationship between DMI and animal and pasture–based factors in PBS lamb production was determined by Pearson's correlation (Figure 1). Principal component analysis was then performed for both to strengthen the correlation coefficients and to identify variables that act together or in opposition to each other in generating variation in the existing system (Figure 2). After approximating the effects of variables using PCA and correlation analysis, equations were developed for estimating the DMI of lambs grazing on MGP through both single and multiple linear regression models (Table 2).

Statistical Analysis

To comprehend the impact of each factor within the lamb grazing model, considered simultaneously, principal component analysis (PCA) was applied. The data obtained from a lamb grazing study (n = 36, 1 treatment × 2 years × 3 blocks × 6 data collection, BW of the lambs and pasture quantity and quality traits was determined 6 times with 10–day intervals) was used as the cases. The mean values of each replicate in each data collection time were used to perform PCA. Before performing PCA, the suitability of data for factor analysis was assumed using the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test (KMO = 0.533; $\chi2$ =197.8, $p < 0.001$). Thus, a new set of 10 orthogonal variables was generated by PCA. Principal components (PCs) that had only eigenvalues of > 1.0 were accepted as significant to describe most of the total data variations. Pearson correlation test was used to determine the relationships between DMI and some animal and pasture-based factors. The DMI was estimated by linear multiple regression equation using BW, DMY, HA, NDF, ME, TDN, IVDMD, CP, and RFQ variables. Regression models of DMI were evaluated by the coefficients of determination *(r^2)* and standard error *(S_y)* of estimation. The regression model used was:

$$Y = \alpha + b_1x_1 + b_2x_2 + \ldots\ldots b_nx_n \pm S_y$$

Where *Y* was the dependent variable (DMI) of grazing lambs; *a* was the regression constant; b_k was the regression coefficients of independent variables and x_n was the explanatory variables of independent variables. SPSS software was used in all analyses (Version 17.0).

Results

To determine the parameters to be used in the estimation of herbage and/or dry matter intake of grazing lambs, the relationships between the actual dry matter intake data and some animal and pasture–based factors were determined (Figure 1). Positive correlations were determined between DMI and BW (0.777), HA (0.814), DMY (0.844), and NDF (0.609), while DMI had negative correlations with IVDMD (-0.738), ME (-0.039), RFQ (-0.357), CP (-0.209), and TDN (-0.177).

Principal component analysis was also used to identify animal and pasture–based factors for estimating the DMI of lambs grazing on MGP. The PC1 and PC2 composed 67.36% of the variability in the data set from the grazing lamb model consisting of some animal and pasture–based factors (Figure 2). Factors in the model were distributed to all quadrants of the PCA. By considering this distribution, it may be possible to deduce which factors are more effective and important for developing estimation equations for DMI of lambs grazing on MGP.

Table 2. Regression equations developed to predict the DMI of lambs grazing on cocksfoot, meadow fescue and tall fescue pastures

Model	Regression equations	S_y	r^2
I	-1224.09+39.90BW+33.69HA+8.22NDF	83.504	0.815
II	-701.47+18.96BW+673.61DMY+8.19NDF	85.141	0.807
III	-325.32+43.49HA-2.21IVDMD+8.57NDF	89.784	0.786
IV	-674.96+44.91HA+9.75NDF+75.73ME	90.116	0.784
V	-4723.66+204.07BW+243.65HA-4305.22DMY	95.869	0.756
VI	-1485.51+64.98BW+35.37HA+1.04RFQ	101.400	0.746
VII	2471.13-41.71IVDMD-5.05NDF+4.94RFQ	125.848	0.609
VIII	516.55-19.17IVDMD+7.03NDF+12.36TDN	136.991	0.501
IX	739.00-9.54IVDMD+9.71NDF-6.03CP	145.694	0.436

Body weight (BW; kg); Herbage allowance (HA; kg/head); Dry matter yield (DMY; kg/da); Neutral detergent fiber (NDF; % of DM); *In vitro* dry matter digestibility (IVDMD; %); Metabolizable energy (ME; Mcal/kg); Relative forage quality (RFQ); Crude protein (CP; % of DM); Total digestible nutrient (TDN; %), S_y: Standard error of the estimation, r^2: Regression coefficient.

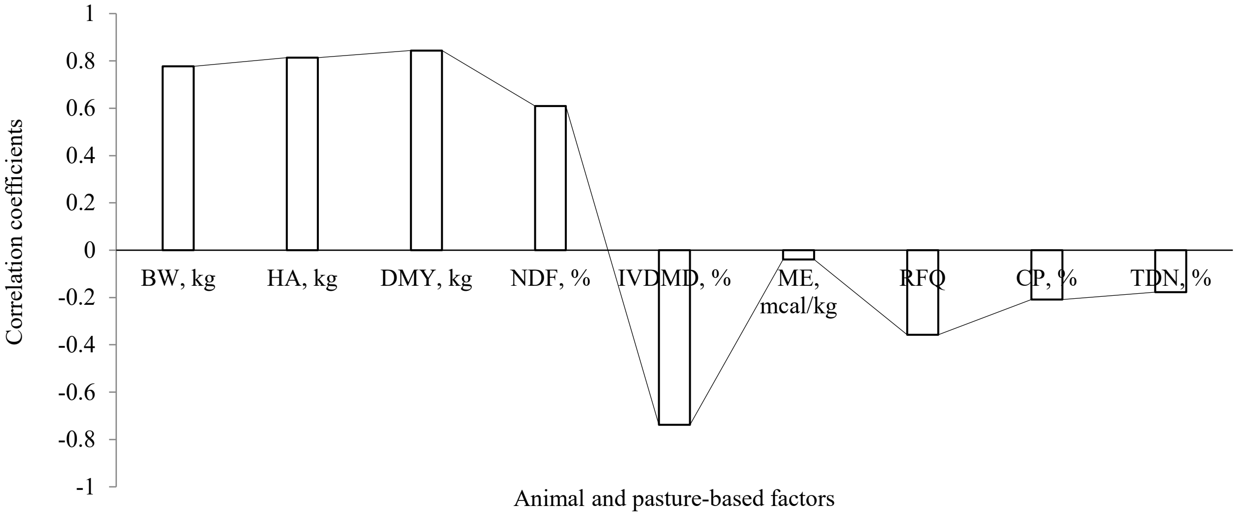

Figure 1. The relationships between the actual dry matter intake (DMI) data and some animal and pasture-based factors.
Body weight (BW; kg); Herbage allowance (HA; kg/head); Dry matter yield (DMY; kg/da); Neutral detergent fiber (NDF; % of DM); *In vitro* dry matter digestibility (IVDMD; %); Metabolizable energy (ME; Mcal/kg); Relative forage quality (RFQ); Crude protein (CP; % of DM); Total digestible nutrient (TDN; %).

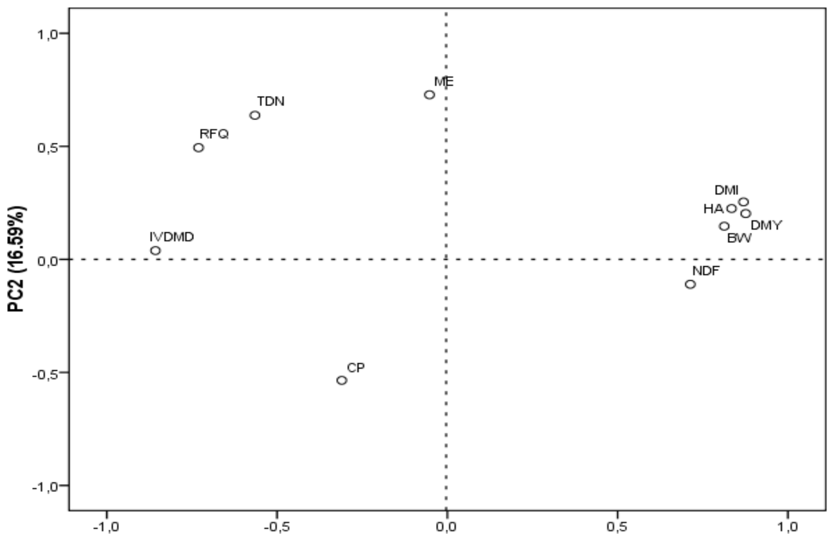

Figure 2. Loading plots of principal components (PC1 and PC2) for some animal and pasture-based factors to be used in the DMI prediction equations for lambs grazing on cocksfoot, meadow fescue and tall fescue.
Body weight (BW; kg); Herbage allowance (HA; kg/head); Dry matter yield (DMY; kg/da); Neutral detergent fiber (NDF; % of DM); *In vitro* dry matter digestibility (IVDMD; %); Metabolizable energy (ME; Mcal/kg); Relative forage quality (RFQ); Crude protein (CP; % of DM); Total digestible nutrient (TDN; %).

The correlation matrix loadings (or scores) from the PCs indicated that the main contributions derive from three groups. The first group was composed of factors with positive loadings for PC1 and PC2 (DMI [0.870 and 0.254], DMY [0.876 and 0.203], BW [0.813 and 0.147], and HA [0.835 and 0.225]. The second group contained NDF with positive loading for PC1 and negative loading for PC2 [0.714 and -0.110]. Group 3 was composed of factors with negative loadings for PC1 (CP [-0.310 and -0.535], IVDMD [-0.857 and 0.039], RFQ [-0.731 and 0.494], TDN [-0.565 and 0.637], and ME [-0.052 and 0.728]. Based on the correlation matrix loadings (≥0.70 and positive factor loadings) of the factors, it may be deduced that HA, DMI, DMY, BW, and NDF are cooperating in the herbage and/or dry matter intake estimation model and contributed most strongly to PC1.

Regression equations for DMI estimation were determined by using one animal–based (BW) and eight pasture–based factors (HA, NDF, DMY, IVDMD, ME, RFQ, TDN, and CP). The DMI was the dependent variable and three others (determined by using correlation coefficients and PCA's loading plots) were independent. The DMI of lambs grazing on MGP was estimated by model I (-1224.09+39.90BW+33.69HA+8.22NDF) with the highest r^2 value (0.815) and the lowest S_y (85.504). Since the HA value was indirectly calculated from DMY model II (-701.47+18.96BW+673.61DMY+8.19NDF) had similar r^2 (0.807) and S_y (85.141) to model I in the DMI estimation. This was followed by Model III, IV, V, and VI with the r^2 and S_y values (0.786–89.784), (0.784–90.116), (0.756–95.869), and (0.746–101.400), respectively. It has been observed that in the first six models where both animal and pasture–based factors were employed together, accurate predictions were achieved, whereas models (VII, VIII, and IX) relying solely on pasture–based factors were less accurate with 0.609–125.848, 0.501–136.991 and 0.436–145.694 r^2 – S_y values, respectively.

Discussion

In this study, DMI prediction equations were developed by integrating animal and pasture–based factors using actual DMI of Karayaka male lambs grazing on MGP for 60 days each over two grazing seasons (2020 and 2021). Correlation analysis showed that there is a strong and positive relation between DMI and BW (0.777). This result is not surprising and is consistent with a significant body of research (Blümmel et al., 1997; Cannas et al., 2004; INRA, 2018; Oliveira et al., 2020). Increasing DMI with increasing BW is inevitable for healthy grazing animals to meet their requirements. Indeed, it should be noted that the relationships between animal and pasture–based factors of the lamb growth model in the present study are based on lambs growing due to grazing, i.e. gaining body weight, and pastures consisting of cocksfoot, meadow fescue, and tall fescue that mature and change in nutrient content during the grazing season. Also in all evaluations, DMI was used in grams, not as a percentage of BW.

It is generally accepted that there is a relationship between plant fiber structure and the amount of fibrous materials with the DMI of grazing animals. Dry matter intake is believed to be regulated by the NDF level and digestion rate due to the effects of NDF digestion/degradation on rumen volume (Chen et al., 2023). In this context, numerous studies have demonstrated a negative correlation between NDF and DMI (Minson, 1990; Meyer et al., 2010; Chen et al., 2023). There are also variations between some results of different studies. Van Soest (1965) has reported that correlations between DMI and NDF can vary between 0.57 and -0.95 in a study with different forage crops. These variations here basically arise according to the animal–rearing model. This situation becomes complicated when we consider lambs grazing on MGP, increasing BW day by day, maturing, and changing in nutrient content of the pasture, which is the only source of nutrients. However, in our study, DMI is g, not a percentage of BW. Indeed, a correlation coefficient of 0.609, indicating that DMI in grams increased despite higher NDF content, is not abnormal. A study by Meyer et al. (2010) assuming that maximum HI occurs when herbage NDF content is 35%, showed how variation in NDF alters HI. According to the results of this study, even if NDF content is 60%, sheep can reach 85% of the potential HI. In addition, the average NDF content of the pasture in two grazing seasons during our study was 60.04%. In this scenario, employing NDF in the DMI prediction equation (Model I) in tandem with HA calculated from BW of grazing animals and pasture yield and BW is deemed acceptable.

A large number of regression models to predict DMI based on animal–based factors have been developed (Yungblut et al., 1981; Kertz et al., 1991; Roseler et al., 1997). On the contrary, many studies used only feed–related factors such as ADF, NDF, CP, and ME as the basis for predicting DMI (Yungblut et al., 1981; Harlan et al., 1991; Holter et al., 1996). In our study, defined as a lamb growth model on MGP, DMI was predicted by combining animal and pasture–based factors. After examining CP and ME, two factors related to pasture, they were deemed unworthy for use in developing equations to estimate DMI, based on correlation and PCA results. Although there is a low and negative relationship between DMI and ME, it was still possible to estimate DMI in a proper way (r^2=0.784) when ME was used with NDF and HA in the regression equation (Model IV). It should also be taken into consideration that, in our study, the ME value in MGP was in a very narrow range (1.98–2.22 Mcal/kg). Correlations between CP level of feed and DMI and ME and DMI have been highlighted in many studies (Yang et al., 2017; Xiao et al., 2020; Chen et al., 2023). It should be considered that, in our study, growing lambs graze on pastures that mature, fibrous structures increase in the pastures during the maturation process and CP and ME tend to decrease proportionally. Moreover, a high concentration of fibrous content (i.e., ADF and NDF) of forage reduces digestibility and affects grazing behavior, as reported by Xiao et al. (2020). Although there was a negative and strong correlation (-0.738) between IVDMD and DMI in this study, the NDF level was never high enough to reduce DMI dramatically. On the other hand, increasing BW prevented a decrease in DMI because of the increasing nutrient requirements. Furthermore, the slight negative correlations between DMI and TDN (-0.177) and RFQ (-0.357) back the hypothesis that a reduction in diet quality and composition in the animals' diet will lead to a rise in DMI (Meyer et al., 2010).

In PBS, it is believed that DMI and/or HI is regulated by energy requirements, grazing behavior, and HM which is a commonly used item because of the simplicity of obtaining data (Herrero et al., 1998; Woli et al., 2023). Herbage allowance (HA) refers to the amount of herbage, expressed in kg of DM per kg of body weight (kg DM/ kg BW) is directly related to DMY and BW of grazing animals. It is a significant factor in estimating herbage intake and animal performance on pasture. The HA can affect the potential DMI of grazing animals. Generally, it is accepted that higher HA results in higher intake levels (Sollenberger et al., 2005). It is important to consider the HA in grazing management as it impacts the nutritional intake and performance of grazing animals (Woli et al., 2023). As HA increases, animals have more opportunities to select and intake herbages, resulting in increased DMI. Besides, when HA decreases, animals have less access to herbage and face restricted nutrition with decreasing DMI and/or HI. In this study, results of Pearson correlation and PCA showed that HA and DMY can accurately be employed to estimate the DMI of lambs grazing on MGP. After all this inference and information, the correlation and PCA results for estimating DMI with HA and/or DMY seem to be quite accurate.

Conclusion

It is crucial to note that DMI is essential for meeting the nutritional requirements of animals and promoting their health and performance. Monitoring and considering DMI and factors such as grazing conditions and forage quality and integrating such factors with animal–based factors can help to ensure proper nutrition for grazing animals. This study found positive and negative correlations between DMI and animal and pasture–based factors as; positive correlations were determined between DMI and BW (0.777), HA (0.814), DMY (0.844), and NDF (0.609) while DMI had negative correlations with IVDMD (-0.738), RFQ (-0.357), CP (-0.209), TDN (-0.177), and ME (-0.039). By using correlation coefficients and PCA results, parameters to be used for estimation equations were selected. Prediction equations were developed and the best–fit 3 equations for predicting DMI of lambs grazing MGP were: I) -1224.09 + 39.90BW (kg) + 33.69HA (kg DM/ kg BW) + 8.22NDF (% of DM), r^2=0.815, II) -701.47 + 18.96BW (kg) + 673.61DMY (kg/ per square meters) + 8.19NDF (% of DM), r^2=0.807, III) -325.32 + 43.49HA (kg DM/kg BW)-2.21IVDMD (%) + 8.57NDF (%), r^2=0.786.

Declarations

Ethical Approval Certificate

The experimental procedures of this study were approved by the Local Animal Care and Ethics Committee for Experimental Animals of Ondokuz Mayıs University (29.08.2016 and number: 2016/44).

Author Contribution Statement

Ahmet Akdağ: Data collection, investigation, formal analysis, methodology and writing the original draft

Nuh Ocak: Project administration, supervision, conceptualization, methodology, review and editing

İbrahim Aydın: Project administration, supervision

Fund Statement

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Conflict of Interest

There is no conflict of interest in this study.

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