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Research Article

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Comparative Pelvic Morphometry of Male and Female Second-Trimester Anatolian Hair Goat (Capra Hircus) Fetuses

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ABSTRACT

This study aimed to investigate pelvic morphometric parameters in second-trimester anatolian hair goat (Capra hircus) fetuses and to compare them between sexes. A total of 14 fetuses (7 females and 7 males) were examined. The crown–rump lengths (CRL) of the fetuses were measured, and gestational ages were estimated using reference tables reported in the literature. Following dissection and isolation of the pelvis, surrounding soft tissues were removed, and the main pelvic parameters were measured using ImageJ software.

The evaluated parameters included vertical diameter (diameter verticalis, VD), transverse diameter (diameter transversa, TD), diagonal conjugate (conjugata diagonalis, DC), tuber coxae width (distantia coxarum, CT), acetabular diameter (diameter acetabuli, AC), narrowest transverse diameter (diameter transversa minor, TDNP), and pelvic length (longitudo pelvis, PL).

The results revealed that TD, TDNP, and PL values were higher in female fetuses, whereas CT values were greater in males. No significant sex-related differences were observed in DC and AC parameters. These findings indicate that sex-related morphological differences in the pelvic structures of anatolian hair goat fetuses begin to emerge during the second trimester.

The data obtained from this study are expected to contribute to a better understanding of goat embryology and prenatal skeletal development, to provide insight into the evaluation of birth canal formation in obstetrics, and to serve as a valuable reference for future comparative anatomical and morphometric studies.

1. INTRODUCTION

Pelvic morphometry is an important field of investigation in both human and veterinary medicine with respect to obstetric, orthopedic, and anatomical research. Since the pelvis is directly related to the birth canal, it plays a critical role in understanding the physiology of parturition, particularly in females (Betti, 2021). Pelvic measurements performed in fetuses contribute to the evaluation of skeletal development during the prenatal period, the estimation of gestational age, and the early identification of sex-related morphological differences (Kananashi et al., 2024; Kliewer et al., 2000). Therefore, detailed examination of pelvic development during the fetal period is of clinical and academic significance in both veterinary and medical sciences.

Studies on pelvic morphometry in small ruminants (sheep and goats) have mostly focused on obstetric problems in adult animals (Amicis et al., 2019). It has been well documented that pelvic canal diameters and angles play a critical role in cases of dystocia (Nogalski & Baranski, 2023). Pelvic measurements have frequently been recommended to prevent obstetrical complications in adult animals (Robalo Silva & Noakes, 1984; Jacobson et al., 2020). However, data regarding pelvic development during the fetal period, particularly in the second trimester, remain scarce (İşbilir & Güzel, 2024; Mogheiseh et al., 2023). This limitation has hindered a comprehensive understanding of morphological changes in the pelvis during prenatal development.

The anatolian hair goat (Capra hircus), a widely reared small ruminant in Turkey, represents a valuable model for morphometric research (Aslan Kanmaz & Atlı, 2025). Detailed morphometric measurements during the fetal period shed light on prenatal developmental biology, contribute to the understanding of growth patterns in the skeletal system, and help predict potential postnatal structural variations (Nourinezhad et al., 2017; Ramirez-Gonzalez et al., 2023). Furthermore, comparisons between sexes may reveal whether the pelvis exhibits different growth patterns in male and female fetuses, thereby reflecting early manifestations of embryological differentiation (Kanahashi et al., 2024; Banankhojasteh, 2006).

Research on human fetuses has demonstrated that sex-related differences in pelvic measurements can emerge during mid-gestation (Fischer & Mitteroecker, 2017; Kanahashi et al., 2024). Similarly, three-dimensional imaging and morphometric studies in ovine fetuses have revealed significant differences between sexes in certain pelvic parameters (İşbilir & Güzel, 2024). Morphometric studies conducted in large animals such as cattle and horses have also shown that pelvic canal measurements are critical for obstetric outcomes (Tsaousioti et al., 2024; Patterson & Herring, 2022). However, studies focusing on goat fetuses are extremely limited, and existing data are insufficient for a systematic evaluation of sex-based differences.

In this study, the main pelvic parameters of second-trimester anatolian hair goat fetuses obtained from the Siirt region were measured manually and compared between sexes. The findings are expected to contribute to the fields of goat embryology and morphometry, to enhance understanding of prenatal birth canal development in obstetrics, and to provide a reference for future comparative anatomical studies.

2. MATERIALS AND METHODS

2.1. Animal Material

In this study, a total of 14 second-trimester anatolian hair goat (Capra hircus) fetuses (7 females, 7 males) obtained from pregnant does that were slaughtered in abattoirs in the Siirt region were used as material.

2.2. Morphometric Measurements

The sexes of the fetuses were determined by macroscopic examination of the external genitalia, and their crown–rump lengths (CRL) were measured to estimate gestational age using reference tables reported in the literature (Amer, 2008; Kuru et al., 2019).

For pelvic morphometry, the pelvic regions of the fetuses were carefully dissected, surrounding soft tissues were removed, and the pelvic bones were isolated. Measurements were performed using ImageJ software (version 1.54p, NIH, USA), which enabled high-precision digital quantification of pelvic parameters.

The pelvic parameters examined in this study were as follows:

- VD (Vertical diameter): The vertical distance between the cranial end of the symphysis pelvina and the ventral surface of the sacrum.
- TD (Transversal diameter): The greatest width between the tubera coxarum.
- DC (Diagonal conjugata): The distance between the promontory and the caudal end of the symphysis pelvina.
- CT (Coxal tuberosities width): The maximum width between the tuber coxae.
- AC (Acetabulum diameter): The greatest internal diameter between the right and left acetabula.
- TDNP (Narrowest transverse diameter): The narrowest transverse diameter of the pelvis.
- PL (Pelvis length): The distance between the tuber coxae and the tuber ischiadicum.

Each parameter was measured twice, and the mean values were recorded. The schematic representation of the pelvic measurements is presented in Figure 1.

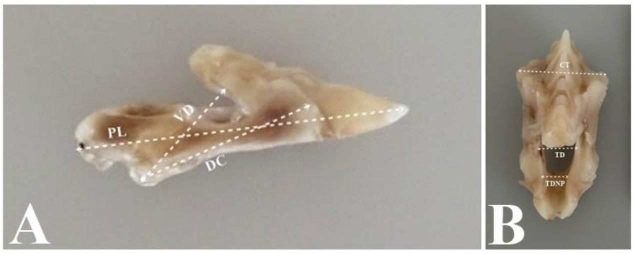

Fig. 1. (A) Pelvic view of a 65-day-old male fetus showing pelvis length (PL), vertical diameter (VD), and diagonal conjugata (DC). (B) Pelvic view of a 70-day-old female fetus demonstrating transverse diameter (TD), narrowest transverse diameter (TDNP), and coxal tuberosities width (CT).

3. RESULTS

The results were organized and presented in tabular form, including mean, standard error (SE), standard deviation (SD), minimum, and maximum values for each parameter. These data are summarized in Table 1.

The pelvic morphometric measurements obtained in this study revealed that sex-related differences emerge in second-trimester anatolian hair goat fetuses. In particular, transverse diameters (TD, TDNP) and pelvic length (PL) were found to be greater in female fetuses compared with males. TD

Table 1. Descriptive statistics data of pelvic morphometric parameters (cm) in male and female second-trimester hair goat (Capra hircus) fetuses.

Parameter	Sex	n	Mean	SE	SD	Minimum	Maximum
VD	Female	7	1.27	0.07	0.19	1.04	1.57
	Male	7	1.17	0.09	0.25	0.94	1.68
TD	Female	7	1.85	0.10	0.28	1.51	2.27
	Male	7	1.71	0.14	0.36	1.38	2.46
DC	Female	7	1.58	0.09	0.24	1.29	1.94
	Male	7	1.57	0.13	0.33	1.26	2.26
CT	Female	7	2.18	0.12	0.33	1.79	2.68
	Male	7	2.23	0.18	0.47	1.80	3.21
AC	Female	7	1.32	0.07	0.20	1.08	1.62
	Male	7	1.32	0.11	0.28	1.06	1.90
TDNP	Female	7	1.34	0.08	0.20	1.10	1.65
	Male	7	1.28	0.10	0.27	1.04	1.85
PL	Female	7	3.34	0.19	0.50	2.73	4.10
	Male	7	3.19	0.26	0.68	2.57	4.61

SE: Standard Error, SD: Standard Deviation

values averaged 1.85 cm in females and 1.71 cm in males; TDNP was 1.34 cm in females and 1.28 cm in males; and PL measured 3.34 cm in females and 3.19 cm in males. These findings suggest that pelvic structures associated with the birth canal in female fetuses may exhibit a wider and longer morphological profile during the second trimester.

In contrast, CT (coxal tuberosities width) values were higher in males than in females (2.23 cm vs. 2.18 cm). This indicates that the lateral expansion of the pelvis may be more pronounced in male fetuses and may reflect a sex-specific growth pattern in these structures.

No remarkable differences were observed between sexes in DC (diagonal conjugata) and AC (acetabulum diameter) measurements. DC averaged 1.57 cm in males and 1.58 cm in females, while AC was 1.32 cm in both sexes. These results suggest that such parameters remain relatively stable during the second trimester and that sex differences have not yet become pronounced at this stage.

Overall, the wider and longer values of birth canal-related parameters (TD, TDNP, PL) in female fetuses may represent early indicators of sex-related differentiation during the embryological period, reflecting adaptations linked to reproductive physiology. Conversely, the higher CT values in males point toward a divergent growth pattern in the lateral walls of the pelvis.

4. DISCUSSION

The findings of the present study are consistent with previously reported results in both human and small ruminant fetuses. The larger transverse diameters and pelvic length observed in female fetuses may be considered an early adaptation for the development of the birth canal, highlighting the influence of sexual differentiation on skeletal structures during gestation. Conversely, the higher coxal tuberosity width (CT) values observed in male fetuses suggest a distinct growth pattern in the lateral development of the pelvis, indicating that sex-specific morphological strategies may begin to emerge during the early stages of development.

Studies on human fetuses have shown that sex-related differences in pelvic measurements can already be detected during mid-gestation. Schulz and Saternus (1984) and Kanahashi et al. (2024) reported that pelvic parameters in males and females may follow different developmental trajectories during this period. Similar findings have been reported in small ruminants: İşbilir and Güzel (2024), through three-dimensional imaging of ovine fetuses, identified significant sex-based differences in several pelvic parameters. Our findings are consistent with these observations and support the notion that pelvic sexual dimorphism is present across species during prenatal development.

Nourinezhad et al. (2017) demonstrated that prenatal pelvic development in sheep follows a largely linear progression, while Parmar et al. (2024) showed that radiographic assessment of pelvic parameters in goat fetuses is a reliable method for estimating fetal age. These findings emphasize the value of pelvic morphometry not only in obstetrics but also as a significant tool in developmental biology and embryology.

Research on large domestic animals such as cattle and horses has demonstrated that pelvic measurements are crucial for understanding the functional capacity of the birth canal, and inadequate pelvic dimensions have been associated with dystocia (Roberts, 1986; Jackson, 1995; Budras et al., 2012). Similarly, studies in companion animals such as dogs and cats have revealed sex-related differences in pelvic morphometry (Salibian & Mendez, 1991; Nganvongpanit et al., 2017; Pitakarnnop et al., 2017). Taken together, these results indicate that the findings of our study are not limited to small ruminants but reflect a more general biological trend across mammalian species.

5. CONCLUSION

In conclusion, this study provides novel data on pelvic development and sex-related morphological differences in second-trimester anatolian hair goat fetuses. These findings contribute to the field of veterinary anatomy and comparative embryology and are expected to serve as a valuable reference for future investigations with larger sample sizes and advanced imaging techniques.

Conflict of Interest

There no conflict of interest.

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Review

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The Role and Physiological Effects of NDF and ADF in Dairy Cattle Nutrition

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ABSTRACT

Roughages play a fundamental role in the nutrition of ruminant animals. Plant-derived carbohydrates are generally classified as structural and non-structural fractions. In ruminant rations, these carbohydrate fractions are evaluated particularly through neutral detergent fiber (NDF) and acid detergent fiber (ADF) values. The NDF level is a crucial parameter in determining the amount of dry matter an animal can consume based on its body weight. In dairy cattle, having NDF at 25-33% and ADF at 17-21% levels in the total dry matter of the ration is considered optimal. These ranges help maintain rumen pH balance by increasing chewing activity and saliva secretion, thereby contributing to the sustainability of milk yield and milk fat ratio. Additionally, maintaining a balanced rumen pH plays a critical role in preventing metabolic disorders. The ADF level is evaluated as an indicator of the digestibility of dry matter in the ration and, consequently, the amount of digestible energy provided. Maintaining the ADF level within the appropriate range directly affects feed intake, rumen function, body weight gain, milk yield, and milk components. Imbalances in NDF and ADF levels can lead to negative consequences on rumen health, milk yield, milk composition, and the frequency of metabolic diseases. Therefore, maintaining NDF and ADF levels in the optimal range in dairy cow rations is of great importance for both animal health and production efficiency.

1. INTRODUCTION

Roughages used in ruminant nutrition are of great importance. The reason is that the fiber content of roughage is because the fiber content of roughage is indispensable for maintaining rumen health and ensuring the healthy continuation of digestive system functions in ruminant animals. In this regard, roughages used in ruminant nutrition must possess specific quality criteria. The most important parameters determining the quality and quantity of fiber are neutral detergent fiber (NDF) and acid detergent fiber (ADF) (Millen et al. 2016). Furthermore, the amount and nutritive value of roughage to be used in the ration are determined primarily by considering the animal's production level and physiological requirements. Therefore, proper planning of both the quality and quantity of roughage is crucial for achieving optimal performance and healthy rumen function (Wu, 2018; Evci 2024). Roughages are feeds that contain more than 18% cellulose in their dry matter, are available in fresh, dried, or ensiled forms, and are poor in energy and protein but contribute to meeting the animals' nutrient requirements as well as regulating digestive system functions (Gençoğlu, 2006). Carbohydrates found in roughages and concentrate feeds are organic compounds consisting of carbon (C), hydrogen (H), and oxygen (O) elements that meet a large portion of the energy needs of ruminant animals (Wu, 2018; Chandel, 2021; Altan & Acar, 2022; Sun et al., 2022;). In plants, carbohydrates are synthesized and stored through the process of photosynthesis. These carbohydrates are categorized into structural and non-structural fractions based on their functional and chemical properties (Wu, 2018; Atalay et al., 2021). Structural carbohydrates found in the cell wall are cellulose, hemicellulose, lignin, and β-glucan.

In contrast, non-structural carbohydrates mainly consist of organic acids, starch, and sugars (Ishler et al., 1996; Atalay et al., 2021). At the same time, the fiber ratio in roughages used in dairy cattle rations can reach 90%, and fiber is essential for normal rumen fermentation, optimal chewing activity, and maintaining milk fat percentage, especially when dry matter intake is high (Yavuz, 2005; Biricik & Gençoğlu, 2010). The quality of roughage becomes important in cows with high milk yield. ADF and NDF can be used as indicators of feed quality in ruminant nutrition. In animal feeding, the fiber content of diets is generally defined as NDF and ADF fractions, and these parameters have significant effects on digestibility, rumen function, and feed utilization (Banakar et al., 2018).

Fig. 1. Structural and non-structural carbohydrate components of plant tissues (Ishler & Varga, 2001).

1.1. NDF

NDF refers to the sum of cell wall structural carbohydrates such as hemicellulose, cellulose, lignin, and silica that remain after the removal of intracellular and easily digestible fractions such as pectin, soluble proteins, sugars, and lipids following treatment of the feed sample with a neutral detergent solution (Ishler & Varga 2001; Yavuz 2005) (Fig. 1). The NDF fiber ratio of diets is used in feed formulation for ruminants, especially dairy cows, to estimate feed intake and fiber digestibility (Moorby & Fraser 2021). Cellulose, one of these structural components of the cell wall, is a homogeneous glucose polymer composed of glucose molecules

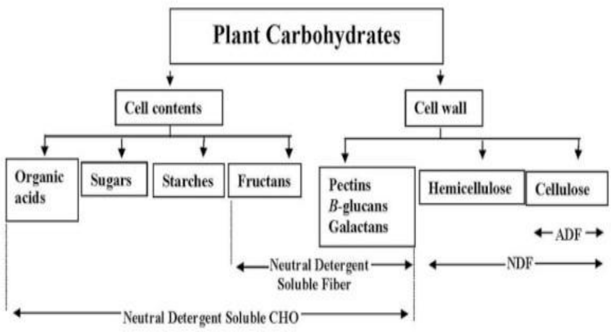

Fig. 1. Structural and non-structural carbohydrate components of plant tissues (Ishler & Varga, 2001).

linked by β-1,4 glycosidic bonds. It plays a role in the production of acetic acid, butyric acid, and propionic acid by being broken down through microbial digestion in the rumen (Tekce & Gül, 2014; Atalay et al., 2021;). At the same time, cellulose helps maintain rumen pH under optimum conditions by increasing saliva production and assists in protecting ruminants against certain metabolic diseases (Argov-Argaman et al., 2012; Kaur et al., 2013). Hemicellulose is a heterogeneous polysaccharide composed of 5- and 6-carbon sugars, including xylose, arabinose, mannose, galactose, and glucose, linked through β-1,4 glycosidic bonds. Like cellulose, it contributes to the production of volatile fatty acids in the rumen.

Additionally, it has positive effects on rumen health by supporting the development of rumen microorganisms and papillae in weaned animals (Ishler et al., 1996; Phakachoed et al., 2012; Atalay et al., 2021;). Lignin is a crucial component of the cell wall, playing a significant role in providing plant rigidity, protecting the plant against microbial attacks, and facilitating the transport of nutrients and water to the plant (Austin & Ballaré,2010; Rencoret et al., 2011). The NDF content of a feed material provides predictions regarding the dry matter intake capacity of ruminants based on their live weight. Furthermore, NDF is a fraction that has a higher effect on rumen fill and chewing time compared to ADF and crude cellulose (Mertens, 1997; Atalay et al., 2021).

1.2. ADF

ADF is another fiber fraction found in feeds and represents the least digestible fiber components of roughages (Saha et al., 2010). ADF is the residue that remains after treatment with an acid detergent solution. This fraction contains difficult-to-digest components such as cellulose, lignin, and silica found in plant cell walls; however, hemicellulose is not included in ADF. Therefore, as the ADF value in feed increases, the digestible energy level of the feed generally decreases (Ishler et al. 1996; Saha et al. 2010). Cellulose, one of these fractions, is a homogeneous glucose polymer composed of glucose molecules linked by β-1,4 glycosidic bonds. Cellulose plays a role in the production of acetic acid, butyric acid, and propionic acid, also known as volatile fatty acids, in the rumen through microbial digestion (Tekce & Gül, 2014; Atalay et al., 2021). At the same time, cellulose helps maintain rumen pH under optimum conditions by increasing saliva production and assists in protecting ruminants against certain metabolic diseases (Argov-Argaman et al., 2012; Kaur et al., 2013). Lignin is a crucial component of the cell wall, playing a significant role in providing plant rigidity, protecting the plant against microbial attacks, and facilitating the transport of nutrients and water to the plant (Austin & Ballaré, 2010; Rencoret et al., 2011). The ADF value of a feed provides insight into the amount of digestible dry matter that can be obtained from it. In this way, it serves as an important auxiliary parameter in calculating digestible dry matter intake and digestible energy levels in ruminants (Atalay et al., 2021). When ADF in the ration falls below the required level, various nutritional problems may arise. For example, when the ADF ratio of the ration falls below the minimum requirement, it is recommended to add 44 g of sodium bicarbonate or 20 g of magnesium oxide for each 1-unit decrease. When the ADF level in a ration given to animals is 14%, and the minimum value is 19%, 220 g sodium bicarbonate or 100 g magnesium oxide should be added to prevent milk fat loss (Millen et al., 2016).

2. ADF AND NDF RATIOS IN DAIRY CATTLE RATIONS

The NDF value in ruminant rations should be 25-33% (NRC, 2001). When the NDF ratio in ruminant rations is between 16-25% on a dry matter basis, it causes a decrease in saliva amount in ruminants, rumen acidosis due to decreased rumen pH as a result of excessive rumen fermentation, damage to rumen papillae, and also a decrease in feed utilization (Tekce & Gül, 2014). The total NDF ratio in the ration should be at least 25%, with at least 76% of this NDF derived from roughages; thus, the NDF ratio from roughage sources should comprise at least 19% of the diet (Wu 2018). When the NDF ratio exceeds 32% on a dry matter basis, feed intake in ruminants is limited by rumen capacity, causing the bacterial density in the rumen environment to shift toward cellulolytic bacteria (Khafipour et al. 2009). Among the feeds used in animal nutrition, the NDF ratio of alfalfa is 46.7%, while wheat straw has the highest NDF ratio at 84.9%. When feeds containing high levels of NDF are used in the ration, digestion time is prolonged. (Van Soest, 1994). This situation causes the rumen to remain full for a longer period, which increases the feeling of satiety and reduces feed intake (Van Soest, 1994).

The ideal ADF value in ruminant rations should be 17-21% (NRC, 2001). When the ADF ratio exceeds the ideal level desired in ruminant rations, feed consumption decreases, depending on the energy density. Therefore, the desired production level cannot be achieved in animals (Tekce & Gül, 2014).

3. IMPORTANCE OF NDF AND ADF IN DAIRY COW NUTRITION

The fiber fraction in dairy cow nutrition plays a critical role not only in maintaining general health but also in ensuring the regular maintenance of rumen functions and the continuity of physiological processes in the rumen (Mirzaei-Aghsaghali & Maheri-Sis, 2011). Although the fiber content of the ration is generally expressed as NDF and ADF, by looking at the NDF value of a feed, information can be obtained about how much dry matter an animal can consume relative to its live weight, and with the ADF value, information can be obtained about the amount of digestible energy in addition to the amount of digestible dry matter (Banakar et al., 2018; Atalay et al., 2021).

The NDF level of the ration is taken into consideration in estimating the fiber content in ruminant rations (Biricik & Gençoğlu, 2010). Although standard NDF levels are considered when preparing dairy cattle rations in the United States, only the NDF level is considered sufficient to evaluate the physical structure of feeds (NRC, 2001). The physical properties of feeds, especially particle size and the concept of physically effective NDF (peNDF), which affects the animal's chewing behavior, are accepted as a standard considered in ration formulation today (Biricik & Gençoğlu, 2010). Physically effective NDF is related to the properties of the fiber. Feed particle size stimulates saliva secretion by increasing the frequency and intensity of chewing movements. In this way, rumen pH is balanced, the acetate-to-propionate ratio increases, and milk fat production increases; it also contributes to the prevention of diseases such as rumen acidosis and laminitis (Nørgaard, 1993; Beauchemin & Rode, 1997; Mertens, 1997). Studies on cows with high milk yield show that for optimum chewing activity, continuity in rumen fermentation, good level of milk fat percentage, and dry matter consumption, the rations of these animals should consist of roughages with adequate particle size and optimum NDF content (Krause & Oetzel, 2006; Golder & Lean, 2024). When the NDF ratio in dairy cow rations is low, milk fat synthesis decreases due to the decrease in acetate/propionate ratio as a result of decreased ruminal pH and saliva production due to decreased chewing activity (Tekce & Gül, 2014). Several studies have reported that an inadequate NDF ratio in dairy cow rations reduces milk yield, milk fat, and the ratio of other milk components by 4% (Moon et al., 2002; Zebeli et al., 2008; Kendall et al., 2009).

The ADF level that should be present in dairy cattle rations is important for both animal health and economic efficiency. Therefore, determining the optimum ADF level in ruminant rations is of great importance for an effective feeding program (Tekce & Gül, 2014). ADF in ruminant feeds is a crucial measure that indicates feed energy. If the ADF ratio is higher than recommended, the feed becomes weak in terms of energy, and the animal consumes less feed. This causes a decrease in yield. If the ADF ratio is low, the digestion balance in the rumen may be disrupted. In this case, health problems such as rumen acidosis, abomasal displacement, laminitis, a decrease in milk fat ratio, and a decrease in body condition may occur (Avellaneda et al., 2009; Yang & Beauchemin, 2009; Tekce & Gül, 2014). Erdman (1988) reported in a study on dairy cows that ration ADF concentration affected the ruminal pH level, but there was no linear relationship between ruminal pH and milk fat content.

4. NDF AND ADF ANALYSIS IN FEEDS

The detergent fiber system, developed by Van Soest in 1960 to determine the amount of plant fiber that directly affects yield in ruminant animals and to separate fiber components, was developed. As a result of the analyses conducted in this system, two basic fiber fractions are measured. Following these measurements, the amounts of NDF (neutral detergent fiber, comprising hemicellulose, cellulose, and lignin) and ADF (acid detergent fiber, comprising cellulose and lignin) in the feed can be determined (Yavuz, 2005).

4.1. NDF Analysis

NDF is a method commonly used to chemically separate cell walls from cell contents (Yavuz, 2005). Sodium lauryl sulfate added to a neutral detergent (pH= 7) solution dissolves proteins, EDTA dissolves pectin, and tri ethylene glycol dissolves other non-fiber substances. Additionally, starch becomes soluble with the help of the amylase enzyme. Thus, these substances found in cell contents are removed, and hemicellulose, cellulose, and lignin that constitute the cell wall remain. As a result of this separation process, molecules such as protein, nitrogen, and minerals that are bound to the cell wall remain together with the cell wall structure. This process is called neutral detergent fiber (Van Soest, 1994). The points to be considered when performing NDF analysis are given below in order.

One of the most important considerations is the use of amylase enzyme or sodium lauryl sulfate in the solution, taking into account the chemical structure of the sample to be analyzed for NDF (Yavuz, 2005).

Another point to be considered is adjusting the acid level of the solution. The acid level should be measured with a pH meter one day after the solution is prepared. If the substances added to the solution were measured, the pH range should be between 6.95 and 7.05. At the same time, neutrality should be achieved in the medium by adding base or acid to the medium, depending on whether the medium is acidic or basic. It should not be forgotten that the solubility levels of cellulose, hemicellulose, and lignin can be affected by the medium's pH level, which can be acidic, basic, or neutral (Van Soest, 1994; Yavuz, 2005). Additionally, substances such as starch, animal keratin and silica, iron, and aluminum compounds, which are part of soil minerals, are among insoluble substances, and mineral components can be determined by ash determination after NDF, and correction can be made by subtracting the ash amount from NDF (Yavuz, 2005).

When analyzing products containing starch, a heat-resistant amylase enzyme should be used to ensure the breakdown of starch and its dissolution in the solution. Otherwise, it should not be forgotten that the filter pores will be clogged during the filtration process for the sample in the solution, which may cause changes in the analysis results (Van Soest et al., 1991).

NDF Analysis can be performed by following the steps below:

Take 2 grams from the sample and place it in a beaker. Add 2 mL of decalin (decahydronaphthalene), 0.5 g of sodium sulfite, and 100 mL of NDF solution on top.

After boiling the mixture for 1 hour in a reflux condenser device, filter it through a Gooch crucible and wash first with hot distilled water, then with acetone.

The crucible is dried at 105°C for 8 hours, cooled in a desiccator, and then weighed.

(This weight: a = crucible + NDF + inorganic matter)

After the crucible is placed in an ash furnace at 500-550°C and burned, only inorganic matter remains. It is cooled in a desiccator and weighed again (b = crucible + inorganic matter).

The calculation of the result is performed with the following formula:

$\%NDF = \frac{a-b}{sample\ amount\ (g)} * 100$ is performed as follows (Yalçın, 2020).

4.2. ADF Analysis

The structure of ADF is primarily composed of cellulose and lignin, with a small amount of ash content. The ADF method is an analytical procedure developed to remove hemicelluloses and obtain a residue with low nitrogen content for lignin measurement (Van Soest, 1994).

In ADF analysis, when the ADF solution is used in conjunction with sulfuric acid and cetyltrimethylammonium bromide (CTAB) detergent, it renders the substances found in cell contents, as well as hemicelluloses and proteins present in the cell wall structure, soluble. The remaining insoluble materials consist primarily of cellulose, along with lignin, cutin, indigestible nitrogen, and silica. Several important considerations must be observed in ADF analysis (Yavuz, 2005; Canbolat, 2019). These are as follows:

The normality of sulfuric acid must be maintained between 0.995 and 1.005 when preparing the ADF solution.

The boiling duration for the prepared sample in ADF analysis must be 60±5 minutes, and this time limit must not be exceeded.

If the acid is not adequately removed with hot water following the boiling process, the residual acid during the drying stage will cause the sample to burn and acquire a brown coloration. In such cases, it may be necessary to repeat the analysis.

The temperature of the distilled water used for the washing procedure must not fall below 95°C. Otherwise, specific soluble proteins, particularly pectin, cannot be removed entirely, which may affect the analytical results (Canbolat, 2019).

ADF analysis can be performed by following the steps outlined below:

Two grams of feed sample is taken and placed in a lignin beaker. Two milliliters of decalin (decahydronaphthalene) and 100 mL of ADF solution are added.

The mixture is boiled for one hour in a reflux apparatus.

Subsequently, the mixture is filtered through a Gooch crucible and washed first with hot distilled water, then with acetone.

The crucibles are dried in a drying oven at 105°C for 8 hours. After cooling in a desiccator, weighing is performed (a = crucible + ADF + inorganic matter, g).

The crucibles are placed in a muffle furnace and incinerated at 500-550°C. Since ADF is combusted, only inorganic matter remains. The crucible, cooled in a desiccator, is weighed again (b = crucible + inorganic matter, g).

The ADF percentage is calculated using the following formula: $\%ADF = \frac{a-b}{sample\ amount\ (g)} * 100$ is performed as follows (Yalçın, 2020).

5. CONCLUSION

Roughages hold a significant position in ruminant nutrition due to their cost-effectiveness and their beneficial effects on maintaining general health in ruminant animals, sustaining rumination function, and positively influencing milk fat content. Roughages contain substantial amounts of fiber, with the fiber components being NDF and ADF. While the NDF value in a feed provides insight into the amount of dry matter an animal can consume relative to its body weight, the ADF level in the feed assists in calculating the digestible energy level in addition to the amount of digestible dry matter in a feed.

The presence of NDF at recommended levels in dairy cow rations helps maintain rumen pH under optimal conditions by stimulating chewing activity in ruminant animals, thereby increasing salivary secretion. This contributes to minimizing metabolic diseases that may occur in animals and maintaining milk fat percentage at desired levels. Maintaining ADF levels within recommended limits in dairy cow rations provides benefits from both animal health and economic perspectives.

However, exceeding ADF levels in the ration can reduce the energy density of feeds, leading to decreased feed intake and resulting in metabolic diseases, reductions in milk yield and milk fat levels, and undesirable weight changes in animals. These studies demonstrate that NDF and ADF levels in dairy cow rations are important for maintaining regular rumination, preserving rumen microbial balance, and supporting milk yield and its components, thereby contributing to a better understanding of the significance of these fiber fractions in ruminant rations.

Conflict of Interest

The authors declare no conflict of interest.

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