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Comparison of serum biochemical parameters in ketotic and healthy Siirt Colored Mohair goats during early lactation to identify potential Biomarkers of lactation ketosis

Comparación de parámetros bioquímicos séricos en cabras de mohair de color Siirt con cetosis y sanas durante la lactancia temprana para identificar posibles biomarcadores de cetosis de lactancia

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ABSTRACT

This study aimed to compare serum biochemical parameters between ketotic and healthy Siirt colored mohair goats during early lactation, to diagnose subclinical lactation ketosis and identify potential biomarkers. A total of 77 female goats, aged 2 to 5 years and within 30 days postpartum, were evaluated under similar management conditions. The animals were classified into two groups based on serum β–hydroxybutyric acid levels: subclinical lactational ketosis (n = 37) and health controls (n = 40). β–hydroxybutyric acid levels were significantly elevated in the ketosis group (0.891 ± 0.0141 mmol·L^{-1}) compared to the control group (0.595 ± 0.0159 mmol·L^{-1}, $P<0.001$), confirming its diagnostic value. Other serum parameters did not show significant differences between the groups ($P>0.05$). On the other hand, effect size analysis revealed that glucose level decreased in does with subclinical lactational ketosis while cholesterol increased (large effect size). The study concluded that most liver and metabolic indicators remained within normal ranges, while glucose and cholesterol levels changed due to subclinical lactational ketosis. These data indicate that feeding based on pasture under extensive conditions may be insufficient to meet the energy requirements of does in lactation and emphasize the importance of early biochemical screening during lactation for effective management of metabolic disorders during early lactation stage in goats. Therefore, it is recommended the further studies to expand the knowledge of the effect of lactational ketosis on metabolic changes in goats.

Key words: Lactational ketosis; colored Mohair goats; β–hydroxybutyric acid; serum biochemical parameters; early lactation

RESUMEN

Este estudio tuvo como objetivo comparar los parámetros bioquímicos séricos entre cabras mohair de color Siirt cetósicas y sanas durante la lactancia temprana, con el fin de diagnosticar la cetosis subclínica de la lactancia e identificar posibles biomarcadores. Se evaluaron 77 cabras hembras, entre 2 y 5 años de edad y dentro de los 30 días posparto, bajo condiciones de manejo similares. Los animales se clasificaron en dos grupos según los niveles séricos de ácido β–hidroxibutírico: cetosis subclínica de la lactancia (n = 37) y controles sanos (n = 40). Los niveles de ácido β–hidroxibutírico fueron significativamente más altos en el grupo con cetosis ($0{,}891 \pm 0{,}0141$ mmol·L^{-1}) en comparación con el grupo control ($0{,}595 \pm 0{,}0159$ mmol·L^{-1}, $P<0{,}001$), lo que confirma su valor diagnóstico. Los demás parámetros séricos no mostraron diferencias significativas entre los grupos ($P>0{,}05$). Por otro lado, el análisis del tamaño del efecto reveló que el nivel de glucosa disminuyó en las cabras con cetosis subclínica de la lactancia, mientras que el colesterol aumentó (tamaño del efecto grande). El estudio concluyó que la mayoría de los indicadores hepáticos y metabólicos se mantuvieron dentro de los rangos normales, mientras que los niveles de glucosa y colesterol cambiaron debido a la cetosis subclínica de la lactancia. Estos datos indican que la alimentación basada en pastoreo bajo condiciones extensivas puede ser insuficiente para satisfacer los requerimientos energéticos de las cabras durante la lactancia, y enfatizan la importancia de la detección bioquímica temprano durante la lactancia para el manejo eficaz de los trastornos metabólicos en esta etapa inicial en las cabras. Por lo tanto, se recomienda realizar estudios adicionales para ampliar el conocimiento sobre el efecto de la cetosis de la lactancia en los cambios metabólicos en cabras.

Palabras clave: Cetosis de la lactancia; cabras Mohair de color; ácido β–hidroxibutírico; parámetros bioquímicos séricos; lactancia temprana

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INTRODUCTION

Animal health plays a critical role in ensuring animal welfare and the sustainability of livestock production. In this context, the early diagnosis of diseases not only enhances the effectiveness of treatment but also helps prevent economic losses [1].

Lactation ketosis is a metabolic disorder that primarily occurs during the lactation period because of negative energy balance (NEB), which arises due to inadequate nutritional intake. This condition is associated with the inability of ruminants to meet the energy requirements necessary for both milk production and vital physiological functions through dietary intake [2].

Ketosis may develop because of nutritional mismanagement, such as consuming feeds with insufficient energy content, selecting inappropriate grain types, or using low–quality roughage. Although it predominantly occurs during the lactation period, similar metabolic disturbances can also be observed during non–lactating stages under comparable nutritional deficiencies [3, 4].

During this period, when milk production increases rapidly but feed intake remains insufficient, the mobilization of body fat reserves intensifies in order to meet the animal's elevated energy demands. As a result, the levels of ketone bodies in the bloodstream rise. Among these ketone bodies, β–hydroxybutyrate (β–HBA) is particularly prominent and is widely recognized as a key biochemical indicator of the disease. Additionally, hypoglycemia is a typical clinical feature of lactation ketosis, generally characterized by a reduction in blood glucose concentrations [5, 6].

Clinical signs of lactation ketosis include anorexia, reduced milk yield, weight loss, and a general state of depression. However, in its subclinical form, overt clinical symptoms may be absent. In such cases, subclinical ketosis can only be identified through biochemical measurements, as the condition is not detectable by physical examination alone [7].

Therefore, the evaluation of blood parameters plays a crucial role in the diagnosis and monitoring of the disease [6]. Prior to the appearance of clinical symptoms, blood biochemical analyses are among the most reliable and widely used diagnostic tools for detecting subclinical conditions [8].

Since relying solely on clinical signs may be insufficient for identifying ketotic animals, a variety of biochemical parameters are commonly used for assessment. These include glucose, β–HBA, non–esterified fatty acids (NEFAs), liver enzymes, protein metabolism indicators, electrolytes, and renal function markers [9].

In goats (*Capra hircus*) with ketosis, glucose (GLUC) levels decrease significantly due to the high demands of lactation and a limited capacity for gluconeogenesis. β–HBA concentrations exceed diagnostic thresholds of 0.8 mmol·L^{-1} for subclinical and 1.6 mmol·L^{-1} for clinical ketosis [10, 11, 12]. NEFA levels increase substantially due to adipose tissue mobilization compensating for energy deficits [13, 14]. Hepatic enzymes Aspartate Aminotransferase (AST) and Alanine Aminotransferase (ALT) increase, indicating hepatocellular stress from an increased gluconeogenic burden [15]. Protein levels show mild decreases, while calcium concentrations drop significantly, contributing to the risk of hypocalcemia [16]. β–HBA and glucose represent highly sensitive diagnostic markers for ketosis detection and monitoring [14].

Lactation ketosis is a severe metabolic disorder that can result in production losses, fertility disorders, and even death [7, 17]. Since clinical symptoms may not always be evident, evaluating blood biochemical parameters is indispensable for diagnosis and early intervention. The parameters assessed in this study, including direct bilirubin (DBILC), GLUC, β–HBA, AST, and ALT are of critical importance in diagnosing ketosis. Particularly in the identification of subclinical forms, monitoring these indicators enables disease control before progression occurs. Therefore, regular monitoring of the biochemical profile in herd management will enhance both animal welfare and production efficiency [18].

This study aims to compare serum biochemical parameters between ketotic and healthy Siirt colored mohair goats during the early lactation period postpartum, to diagnose lactation ketosis and identify potential biomarkers for disease diagnosis.

MATERIALS AND METHODS

The experimental procedures of this study were approved by the Local Animal Care and Ethics Committee of Siirt University (Decision No: 2025/07/62)

In the study, Siirt colored Mohair goats, a native breed specific to the Siirt province, were used as the animal material. A total of 77 female goats (does), aged between 2 and 5 years, within the first 30 days (d) postpartum, and maintained under similar husbandry and feeding conditions, were included in the study. Goats were raised and fed under extensive conditions only based on natural pasture vegetation (mainly Poaceae and Fabaceae species) during the lactation period. All goats reached to the water *ad libitum*.

Blood samples were collected from the animals in the morning hours, before feeding, from the jugular vein into sterile vacuum tubes. The obtained blood samples were immediately centrifuged (Nüve, NF–200, Türkiye) at 3000× g for 20 min to separate the serum, which was then stored at -20°C (Regal cd62210, Türkiye) until biochemical analyses were performed.

Blood β–HBA levels of the goats were measured using a commercial hand–held meter previously confirmed by Turgut *et al.* [19] (Centrivet, Acon, UK). Based on β–HBA values, the animals were divided into two groups as follow:

Subclinical ketosis group: animals with β–HBA ≥ 0.8–1.6 mmol·L^{-1} and **healthy group**: animals with β–HBA < 0.8 mmol·L^{-1}.

In animals from both groups, the following serum biochemical parameters were analyzed: DBILC, GGT, ALT, AST, TBILC, TP, ALP, GLUC, CHOL, TRIG, ALB, BUN, and CRE (Beckman Coulter Chemistry Analyzer AU5800 Germany). All biochemical analyses were performed using automated biochemistry analyzers by the manufacturer's protocols.

Statistical analysis

The data obtained were statistically analyzed. For parameters showing a normal distribution, an independent sample *t*–test was applied; for parameters not showing a normal distribution, the Mann–Whitney U test or the independent sample *t*–test was used. All statistical analyses were performed using Minitab® 21 statistical software. The significance level was accepted as $P<0.05$. G*Power (v3.1.9.7) was used to calculate effect size (Cohen's d) of pairwise comparisons. Pairwise classification was accepted as low (<0.50), medium (0.51–0.79) and large (>0.80) effect.

RESULTS AND DISCUSSION

In this study, a comparative biochemical analysis was performed on subclinical lactation ketosis (48.1%) and healthy (51.9%) Siirt colored Mohair goats. No clinical cases were observed in the study. Numerical differences were observed between groups in terms of liver function indicators.

β–HBA is the primary ketone body accepted as the gold standard in ketosis diagnosis and represents the most reliable indicator of metabolic status resulting from negative energy balance [14, 20, 21, 22]. Symptoms of ketosis in goats include depression, loss of appetite, and decreased milk yield [23, 24]. In this study, the β–HBA concentration was determined to be 0.89 $mmol \cdot L^{-1}$ in subclinical ketotic goats and 0.59 $mmol \cdot L^{-1}$ in the control group ($P<0.001$). While lactational ketosis is considered a rare condition in goats, blood β–HBA concentration in sheep and goats typically increase during late pregnancy [7, 25].

Conversely, the current study detected a high rate of lactation ketosis in pasture–fed Siirt colored Mohair goats, contrary to expectations. In the examined herd, lactation ketosis was detected in 37 out of 77 animals (48.1%), while 40 animals (51.9%) were evaluated as healthy. β–HBA levels were evaluated as the primary indicator of ketosis diagnosis. β–HBA concentration was measured as 0.892 ± 0.014 $mmol \cdot L^{-1}$ in the lactation ketosis group and 0.595 ± 0.016 $mmol \cdot L^{-1}$ in the healthy group, and this difference was found to be statistically highly significant as it expected ($P<0.001$; TABLE I).

DBILC levels were measured as 0.027 ± 0.006 $mg \cdot dL^{-1}$ in the lactation ketosis group and 0.020 ± 0.003 $mg \cdot dL^{-1}$ in the healthy group ($P>0.05$; TABLE I). There was no significant difference in DBILC levels between groups ($P>0.05$). Similarly, TBILC concentrations were determined as 0.247 ± 0.005 $mg \cdot dL^{-1}$ in the lactation ketosis group and $mg \cdot dL^{-1}$ in the control group without any significant change ($P>0.05$; TABLE I). This could be attributed to high variability within the control group, potentially caused by undiagnosed subclinical hepatic dysfunction or analytical error, as similarly noted by González *et al.* [26]. Small variations in bilirubin levels have been associated with liver stress and metabolic adaptation in early lactation [27, 28].

When liver enzyme activities were examined, GGT levels were determined as 43.324 ± 2.377 $U \cdot L^{-1}$ in the lactation ketosis group and 42.675 ± 2.483 $U \cdot L^{-1}$ in the healthy group ($P>0.05$). ALT activity was measured as 19.432 ± 0.775 $U \cdot L^{-1}$ in the lactation ketosis group and 19.20 ± 0.7563 $U \cdot L^{-1}$ in the control group ($P>0.05$). AST levels were determined to be 96 ± 3.310 $U \cdot L^{-1}$ in the lactation ketosis group and 92.35 ± 3.978 $U \cdot L^{-1}$ in the healthy group ($P>0.05$). ALP activity was detected as 1079.35 ± 216.594 $U \cdot L^{-1}$ in the lactation ketosis group and 777.590 ± 178.247 $U \cdot L^{-1}$ in the control group ($P>0.05$; TABLE I). No statistically significant difference was detected in liver enzyme activities (ALT, AST, GGT and ALP) between groups ($P>0.05$). This finding indicates that the ketotic goats in the present study have not yet developed severe hepatic damage.

Significant effects can be observed in the plasma levels of AST, ALT, and GGT indices in ketotic animals, indicating that liver damage may occur in these animals [29]. When liver cells are damaged, ALT and AST are released into the blood from the cells [29]. While relatively greater increases in ALT and AST activity indicate hepatocellular damage, greater increases in ALP and GGT activity indicate cholestasis [30]. These normal enzyme values in does with subclinical lactational ketosis suggest that this may result from the disease being in its early stage or mild ketonemia in these goats, as well as indicating that there may be variations in fat metabolism and susceptibility to liver damage among different ruminant species [7].

TP concentrations were measured as 73.943 ± 1.0056 $g \cdot L^{-1}$ in the lactation ketosis group and 74.977 ± 0.8669 $g \cdot L^{-1}$ in the healthy group ($P>0.05$). ALB levels were determined as 30.514 ± 0.3738 $g \cdot L^{-1}$ in the lactation ketosis group and 30.382 ± 0.4622 $g \cdot L^{-1}$ in the control group ($P>0.05$).

BUN concentrations were detected as 48.116 ± 1.1636 $mg \cdot dL^{-1}$ in the lactation ketosis group and 46.974 ± 1.17956 $mg \cdot dL^{-1}$ in the healthy group ($P>0.05$). CRE levels were measured as 0.485 ± 0.0112 $mg \cdot dL^{-1}$ in the lactation ketosis group and 0.503 ± 0.0093 $mg \cdot dL^{-1}$ in the control group ($P>0.05$; TABLE I).

These findings indicate that protein metabolism and kidney functions in does with subclinical lactational ketosis in this study have not yet deteriorated. This condition supports that does are still in the early stage of the disease [31] and chronic metabolic stress has not yet affected these organ systems. Although an increasing trend was observed in ALP activity in the lactational ketosis group (1079.35 vs 777.59 $U \cdot L^{-1}$), it did not reach statistical significance ($P>0.05$).

On the other hand, CHOL levels were measured as 61.324 ± 2.1824 $mg \cdot dL^{-1}$ in the lactation ketosis group and 56.37 ± 1.7312 $mg \cdot dL^{-1}$ in the control group ($P>0.05$). A slight increase in cholesterol levels was observed in does with subclinical lactational ketosis. Large effect size (2.51) indicates that serum CHOL level may increase in does with subclinical lactational ketosis. Increases in serum CHOL levels were also reported in subclinical pregnancy toxemia (SPT) in Romanov ewes during late pregnancy when NEB occurs [22]. Similar to previous findings in SPT ewes, NEB also occurs during early lactation stages in ruminant species. Therefore, an increase in CHOL level may be an early indicator of increased fat mobilization and changes in liver metabolism [29, 32].

Biochemical changes in ketotic goats are among the most important findings [32, 33]. Among metabolic parameters, GLUC concentrations were determined as 30.784 ± 1.913 $mg \cdot dL^{-1}$ in the lactation ketosis group and 34.6 ± 1.2834 $mg \cdot dL^{-1}$ in the healthy group ($P>0.05$). This condition reflects the negative energy balance underlying the pathogenesis of ketosis. Furthermore, large effect size (2.34) of serum GLUC comparison confirms negative energy balance in does with subclinical lactational ketosis. In a study conducted by Marutsova and Binev [7], a difference was detected between groups in terms of glucose values. In addition, decreases in GLUC level were reported in SPT ewes due to NEB.

TABLE I
Comparison of serum biochemical parameters between Siirt colored Mohair goats with lactational ketosis and healthy counterparts during early lactation

Variable	Groups	N	Mean	SE Mean	Minimum	Median	Maximum	*P*–Value	Cohen's d
DBILC (mg·dL^{-1})	Lactational Ketosis	37	0.027	0.0062	0	0.02	0.23	0.809	0.26
	Healthy	39	0.020	0.0025	0	0.02	0.06		
TBILC (mg·dL^{-1})	Lactational Ketosis	37	0.247	0.0052	0.17	0.25	0.31	0.374	0.22
	Healthy	39	0.240	0.0050	0.17	0.24	27		
GGT (U·L^{-1})	Lactational ketosis	37	43.324	2.3770	21	43	82	0.851	0.04
	Healthy	40	42.675	2.4836	20	42	86		
ALT (U·L^{-1})	Lactational Ketosis	37	19.432	0.7745	11	19	29	0.831	0.03
	Healthy	40	19.200	0.7563	10	18	30		
AST (U·L^{-1})	Lactational ketosis	37	96.000	3.3102	58	96	136	0.487	0.16
	Healthy	40	92.350	3.9779	21	95	139		
ALP (U·L^{-1})	Lactational Ketosis	37	1079.350	216.5940	19	72	3813	0.236	0.24
	Healthy	39	777.590	178.2470	12	57	3628		
TP (g·L^{-1})	Lactational Ketosis	37	73.943	1.0056	61.30	73	84.40	0.436	0.17
	Healthy	40	74.977	0.8669	62	74.85	85		
ALB (g·L^{-1})	Lactational Ketosis	37	30.514	0.3738	24.90	30.50	36	0.828	0.05
	Healthy	40	30.382	0.4622	23.70	30.75	37		
BUN (mg·dL^{-1})	Lactational Ketosis	37	48.116	1.1636	35.50	47.10	68	0.493	0.15
	Healthy	39	46.974	1.17956	33.60	46.50	66		
CRE (mg·dL^{-1})	Lactational Ketosis	37	0.485	0.0112	0.33	0.47	0.63	0.219	0.36
	Healthy	39	0.503	0.0093	0.42	0.50	0.62		
GLUC (mg·dL^{-1})	Lactational Ketosis	37	30.784	1.9133	1	30	50	0.097	2.34
	Healthy	40	34.600	1.2834	9	35.50	53		
CHOL (mg·dL^{-1})	Lactational Ketosis	37	61.324	2.1824	40	58	94	0.077	2.51
	Healthy	40	56.370	1.7312	34	55.50	77		
TRIG (mg·dL^{-1})	Lactational Ketosis	37	19.946	1.7194	11	18	71	0.271	0.05
	Healthy	39	20.462	0.9794	10	19	39		
β–HBA (mmol·L^{-1})	Lactational Ketosis	37	0.891	0.0141	0.80	0.90	1.10	0.001	3.2
	Healthy	40	0.595	0.0159	0.40	0.60	0.70		

Similarly, in this study, serum GLUC level was decreased in does with lactational ketosis [34]. Therefore, this may be due to NEB in lactational ketosis.

Ketosis is characterized by the excessive accumulation of ketones in the blood, urine, and milk due to the incomplete metabolic breakdown of adipose tissue in the body [10, 29]. This condition occurs before or after parturition as a result of the goat's inability to consume sufficient feed to meet its needs [5, 30, 35, 36]. Similarly, in a study conducted by Marutsova and Binev [7], a difference was detected between groups in terms of glucose values. There was no significant difference in TRIG concentrations between groups (P>0.05). TRIG concentrations were detected as 19.946±1.7194 mg·dL^{-1} in the lactation ketosis group and 20.462±0.9794 mg·dL^{-1} in the healthy group (P>0.05). There was no significant difference in triglyceride concentrations between groups (P>0.05) (FIG. 1).

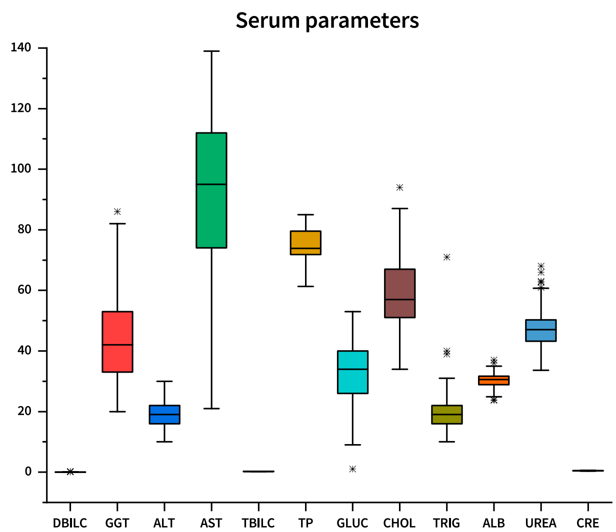

FIGURE 1. Boxplot showing serum parameters in all Siirt colored mohair goats during early Lactation (n=77)

CONCLUSION

The present study demonstrated that subclinical lactation ketosis is a common metabolic disorder in Siirt colored Mohair goats during the early lactation period, particularly under extensive pasture–based feeding conditions. Among the evaluated biochemical parameters, elevated serum β–HBA concentrations emerged as the most reliable indicator for the detection of subclinical ketosis. At the same time, slight reductions in glucose and mild increases in cholesterol levels may reflect early metabolic adaptations to negative energy balance. The absence of significant alterations in hepatic and renal biomarkers suggests that the disorder was detected in its early stage before organ dysfunction occurred. These findings underscore the importance of routine biochemical monitoring, especially of β–HBA and glucose levels, for the early diagnosis and prevention of lactation ketosis in this breed, thereby contributing to improved health management and productivity.

Conflicts of interest

None of the authors have any financial or personal conflicts of interest that could inappropriately influence or bias the content of the article.

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