Adaptive changes in blood biochemical profile of dairy goats during the period of transition

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SUMMARY

The purpose of this study was to assess the metabolic profile of clinically healthy dairy goats during the period of transition, reared in the Brazilian Semi-arid region of the State of Pernambuco. Ninety-four crossbreed multiparous pregnant goats, raised under an intensive system, were monitored and sampled in this research. Blood specimens were collected on the 30th, 20th and 10th day ante-partum, at parturition and on the 10th, 20th and 30th day post-partum. β-hydroxybutyric acid (βHB), non-esterified fatty acids (NEFA), glucose, fructosamine, cholesterol, triglycerides, total protein, albumin, globulin, urea, creatinine, aspartate-aminotransferase (AST), gamma glutamyl transferase (GGT), creatine kinase (CK), amylase, insulin, cortisol, free T3, free T4, total and ionized calcium, phosphorus, potassium, sodium and chloride were measured. The data was analyzed by the analysis of variance at the level of 5% of probability. Cholesterol, CK, free T3, free T4, ionized calcium, phosphorus, sodium and potassium did not present physiological adaptations. At parturition, the highest concentrations of NEFA, glucose and cortisol and lowest concentrations of total calcium and albumin were observed (P<0.05). The highest concentrations of insulin, creatinine and triglycerides were noted during late pregnancy, whereas the highest concentrations of βHB, fructosamine and globulin during early lactation (P<0.05). AST, GGT and amylase showed the high activity during lactation (P<0.05). These results could be used as an aid tool for early detection of blood changes due to metabolic disorders during the transitional period and thus enabling an early therapeutic intervention.

Keywords: blood metabolites, gestation, lactation, metabolic adaptation, metabolic profile, peri-partum, small ruminants.

Introduction

The period of transition, included 3 weeks before and 3 weeks after parturition, is considered critical due to the fact this phase is marked by several metabolic changes and adaptations to the new physiological status of the animal [2]. In this period, there is a greater possibility of losses under the imbalance between demand and supply of nutrients, generated by the high nutritional requirement due to the greater development of the fetuses and the mammary gland [13]. Most females, if handled properly, can adapt to these changes without detrimental effects to their health. However, when females come into this period of important metabolic challenges without receiving proper care, the possibilities of developing metabolic and/or nutritional disorders become higher as verified by Souto et al. [71].

These metabolic changes and adaptations modify the concentration of blood indicators that are related to the development of the metabolic profile of female [4, 56].
Thus, blood biochemical parameters are the most important indicator used in the determination of the energy, protein, enzymatic, hormonal and mineral profiles, as well as assessing nutritional status, milk production and animal health [4].

Deeper knowledge of the physiological adaptations that occur in the female’s organism during the transitional period allows the identification of early pathological metabolic changes, through performing one or a set of variables of different metabolic profiles in dairy cattle and ewes (2, 36, 37). However, biochemical attributes during different metabolism statuses have not been reporting routinely in goats [4]. In light of the above mentioned, the objective of this study was to evaluate the adaptive changes of the biochemical profile (energy, protein, enzymatic, hormonal and mineral profiles) of healthy dairy goats during the transitional period, raised in the Semi-arid region of the State of Pernambuco.

Material and methods

ETHICAL COMMITTEE

The research was approved by the Animal Ethics Committee (CEUA - Comissão de Ética no Uso de Animais) of the Universidade Federal Rural de Pernambuco under license nº 070/2016 CEPE/UFRPE, according to the Brazilian School for Animal Experimentation (COBEA – Colégio Brasileiro de experimentação animal) and the National Institute of Health Guide for the Care and Use of Laboratory Animals.

Animals and experimental protocol: The experimental protocol was carried out in dairy goat farms, located in the Semi-arid region of the State of Pernambuco, Brazil. Ninety-four crossbreed multiparous pregnant dairy goats (about 3 kg/day/goat of milk yield) were monitored in this research. Nine farms were subjected to intensive system by adopting a feed that is comprised of sugarcane bagasse (Saccharum sp.) with forage cactus (Opuntia tuna (L.) Mill) and concentrated feed that is comprised of sugarcane bagasse (Saccharum sp.), fresh water and mineral salt were available in all the farms and the diet was prepared to cover nutritional requirements during the pregnancy and lactation periods. Fresh water and mineral salt were available ad libitum.

Experimental assessments of all the goats were carried out on the 30th, 20th and 10th day ante-partum (dap), at parturition and on the 10th, 20th and 30th day post-partum (dpp). All the animals systematically were vaccinated and dewormed according to protocol adopted in each farm. The goats were observed clinically [20], being considered healthy and the large majority of the animals had been carrying twin pregnancy. The body condition score (BCS) remained constant in 3.5, on a scale of 1-5, throughout the study [69]. Ultrasonography was performed to diagnose, monitor gestation and as the selection criteria for goats in herds from the last month of gestation (Ultrasonic GE - Logiq 100 Pro, Milwaukee, USA).

Sampling and measurement

Blood specimens were taken by jugular venipuncture, with 25x8mm needles, into sterile vacuum tubes. One tube contained sodium fluoride and K3 EDTA (Vacuette® FC Mix tube, Greiner Bio-One, São Paulo, Brazil), as anticoagulants for glucose analysis, while the other tube did not include anticoagulant for biochemical and mineral analysis. The samples were conditioned in an isothermal box with ice and sent to process about 15 minutes. In the laboratory, blood specimens were centrifuged (Centrifuga Fanem Ltda, Baby I, Mod. 206, Brazil) at 3600 rpm for 10 min, and the plasma and serum were removed, placed in eppendorf, and stored in an ultra-low temperature freezer (Ultralow freezer NuAire Inc., USA) at -80°C until required analysis.

Blood specimen measurements were subject to metabolic profile by standard biochemical procedures. Glucose (Glicose Liquiform, Labtest Diagnóstica S.A., Brazil) was analyzed in plasma specimens by GOD-Trinder method, whereas serum concentrations were carried out for fructosamine by nitroblue tetrazolium (NBT) reduction method (Frutosamina Labtest Diagnóstica S.A., Brazil), β-hydroxybutyric acid (Tris buffer 100 nmol pH 8.5 method, βHB/Rambut RANDOX Laboratories Ltd., UK), non-esterified fatty acids (NEFA colorimetric method - RANDOX Laboratories Ltd.), cholesterol and triglycerides by Trinder reaction method (Labtest Diagnóstica S.A., Brazil); urea by enzymatic-colorimetric method and creatinine by Jaffe’s reaction determination (Ureia CE and Creatininina enzimática, Labtest Diagnóstica S.A., Brazil). Total protein (TP) and albumin were conducted by biuret and brom cresol green methods, respectively (Proteina total and Albumina, Labtest Diagnóstica S.A., Brazil). Globulin content was also calculated to determine the difference between TP and albumin. When it comes to the enzymatic profile, its serum activities were subjected to aspartate aminotransferase (AST/GOT Liquiform, Labtest Diagnóstica S.A., Brazil) by U.V. kinetic (IFCC) method, Gamma glutamyltransferase (Gamma GT, Labtest Diagnóstica S.A., Brazil) by methodology of Szasz modified, creatine kinase (CK- NAC, Labtest Diagnóstica S.A., Brazil) by IFCC standard (International Federation of Clinical Chemistry and Laboratory Medicine) and amylase by CNPG, method (Amlase, Labtest Diagnóstica S.A., Brazil). All findings were supported by traditional biochemical analysis using semi-automatic analyzer (Bioplus 2000, Bioplus laboratory products Ltda, Brazil) at 37°C with commercial kits. The hormones cortisol, insulin, free T3 and free T4, were subjected by chemiluminescent immunoassay (Chemiluminescent Beckman Counter, Inc.) using commercial kits (Acess Immunoassay Systems - Beckam Counter*).

The intra-assay coefficients of variation were calculated using an in-house control serum assayed 10 times: βHB (at 0.4 mmol/L, CV=10.0%), NEFA (at 0.2 mmol/L, CV=5.7%), glucose (at 2.9 mmol/L, CV=5.5%), fructosamine (at 227.9 μmol/L, CV=7.7%), triglycerides (at 0.3 mmol/L, CV=2.2%),
cholersterol (at 2.4 mmol/L, CV=16.6%), TP (at 76.7 g/L, CV=7.8%), albumin (at 25.0 g/L, CV=8.2%), urea (at 8.9 mmol/L, CV=16.5%), creatinine (at 67.1 μmol/L, CV=7.2%), AST (at 78.1 U/L, CV=10.3%), CK-NAC (at 75.3 U/L, CV=8.5%), GGT (at 49.7 U/L, CV=9.4%) and amylase (at 144.8 U/L, CV=12.7%).

Serum concentrations of mineral profiles: total calcium by O-cresolphthalein complex method (Cálculo Liquiform, Labtest Diagnóstica S.A., Brazil), phosphorus by Daly & Ertingshausen modified method (Fósforo UV Liquiform, Labtest Diagnóstica S.A., Brazil), and chloride by thiocyanate method (Cloretos, Labtest Diagnóstica S.A., Brazil) were also analyzed by a semi-automatic biochemical analyzer with commercial kits. Ionized Ca²⁺, Na⁺ and K⁺ ion concentrations were determined by an electrolyte analyzer (Roche Mod. 9180, Electrolyte Analyzer).

The intra-assay coefficients of variation were calculated using an in-house control serum assayed 10 times: total calcium (at 1.9 mmol/L, CV=5.4%), chloride (at 109.5 mmol/L, CV=13.6%), phosphorus (at 1.9 mmol/L, CV=6.3%), ionized Ca⁺⁺ (at 1.1 mmol/L, CV=6.4%), sodium (at 151.6 mmol/L, CV=6.9%) and potassium (at 4.6 mmol/L, CV=6.2%).

STATISTICAL ANALYSIS

All statistical analyses were performed using a generalized linear model procedure of SAS Institute Inc. [63] at p-values<0.05. The data were described by means and standard error and they were tested for normal distribution (Kolmogorov-Smirnov test). Therefore, when those have not attended to the premises of normality and homogeneity, they were submitted to logarithmic transformation (Log X+1) or by the square root [RQ (X+1/2)]. Afterwards, they were submitted to analysis of variance (F Test). If the significance was found in the F test and the means were compared by the Student-Newman-Keuls test for the least significant difference (LS) [60].

Results

The results of blood biochemical parameters are set out in Table 1. Among the variables, choleserol, urea, CK, free T3 and free T4, ionized calcium, phosphorus, sodium and potassium had no metabolic adaptation during the transitional period on the dynamics of their blood concentrations (P>0.05).

ENERGY METABOLISM INDICATORS

Higher concentrations of βHB were observed at the beginning of lactation (P<.0001) in relation to parturition and the end of pregnancy. There was a gradual increase of NEFA concentrations at the end of gestation, reaching a peak at parturition (0.5±0.38 mmol/L; P<.0001), and then a subsequently gradual decrease of its concentration during lactation.

Regarding glycemia, its elevation was verified at parturition (P=0.0079). Fructosamine showed higher concentrations during early lactation in relation to late pregnancy (P<.0001). Higher concentrations of triglycerides were observed during late pregnancy in relation to parturition and lactation (P<.0001).

PROTEIN METABOLISM INDICATORS

The TP and globulin variables presented similar evolution during the studied period, in which it was possible to observe higher mean values of both at the beginning of lactation in relation to the end of gestation and at parturition (P<.0001). The concentration of albumin decreased before parturition (P=0.0010) and subsequently back to previous concentrations from 10th post-partum.

A significant creatinine decrease after parturition was observed (P<.0001) and subsequent stability of the values during lactation. However, mean concentrations were lower than that observed in the gestation and parturition periods. When it comes to the creatinine variable, a positive linear effects as a function of time during end of gestation and a negative linear effects as the lactation time were observed (P<.0001).

ENZYME PROFILE

The AST and amylase enzymes showed higher activity during lactation in relation to pregnancy (P=0.0083; P=0.0049, respectively). As for GGT, there was an increase in serum activity from the 20th day of lactation (P<.0001).

HORMONAL PROFILE

A decrease in the mean values of insulin was observed in the assessment times during the end of gestation, as well as a lower mean value at parturition (15.6±19.21 pmol/L; P=0.0002), and subsequent stability of this variable was noted during lactation. Nevertheless, an increase was observed in cortisol only at parturition (P=0.0081).

MINERAL METABOLISM INDICATORS

A decrease of total calcium concentration was observed (P<0.0001) at parturition, when the lowest mean concentration was recorded (1.8±0.24 mmol/L). Thus, a subsequent increase of mean values was observed in early lactation with the similar concentrations during gestation. There was a decrease in concentration of chloride after parturition, remaining lower during lactation (P=0.0001).

Discussion

The elevation of the βHB concentration in early lactation is due to the high energy requirement in organisms such as cattle with a high milk yield [21]. However, despite this increased concentration of βHB observed in this study, mean
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<th>Triglycerides (mmol/L)</th>
<th>24.4±0.72&lt;sup&gt;ab&lt;/sup&gt;</th>
<th>23.0±0.65&lt;sup&gt;a&lt;/sup&gt;</th>
<th>23.0±0.55&lt;sup&gt;b&lt;/sup&gt;</th>
<th>23.0±0.63&lt;sup&gt;b&lt;/sup&gt;</th>
<th>22.0±0.69&lt;sup&gt;a&lt;/sup&gt;</th>
<th>23.0±0.76&lt;sup&gt;a&lt;/sup&gt;</th>
<th>24.0±0.71&lt;sup&gt;b&lt;/sup&gt;</th>
<th>0.1928&lt;sup&gt;bc&lt;/sup&gt;</th>
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<td>Total calcium (mmol/L)</td>
<td>3.1±0.18&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3.2±0.16&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>0.0122&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>Ionized calcium (mmol/L)</td>
<td>1.1±0.10&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>0.0004&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>Phosphorus (mmol/L)</td>
<td>2.1±0.72&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>0.0001&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>Sodium (mmol/L)</td>
<td>146.4±6.72&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>Potassium (mmol/L)</td>
<td>4.5±0.42&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>Chloride (mmol/L)</td>
<td>111.3±5.63&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>0.0001&lt;sup&gt;bc&lt;/sup&gt;</td>
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NEFA: non-esterified fatty acids; βHB: Beta-hydroxybutyrate; dap: Total protein; AST: Aspartate aminotransferase; GGT: Gamma glutamyl-transferase; CK: Creatine Kinase day ante-partum; dpp: day post-partum; Different letters on the same line represent significant difference amongst the sampling times (p<0.05)

Table I: Mean value, standard deviation (x±SD) and level of significance (P) of blood metabolites of healthy dairy goats (n=94) during the transitional period in the Semi-arid region of the State of Pernambuco.
values of this variable were within the reference interval for the species (≤0.8 mmol/L) [55].

Higher concentrations of βHB during early lactation were also reported by Rios et al. [52] and Sadjadian et al. [57] in the healthy dairy goats. This elevation is considered an adaptive mechanism of the female due to the high energetic demand for milk synthesis and does not characterize a metabolic disorder. Several tissues such as the heart, skeletal muscle, kidney, non-fetal uterine tissues and the mammary gland are responsible for using ketone bodies as a source of energy thus allowing βHB concentrations not to exceed the physiological barrier [55]. On the contrary, Barbosa et al. [9] observed high βHB concentration at parturition with a gradual decrease up to the 8th week of lactation in Alpine goats with different degrees of body condition score and related this finding the use of this metabolite by the mammary gland for the milk fat synthesis. Previous studies reported different βHB evolution in ewes and dairy cow that showed the highest concentrations are recorded in the moments that precede the parturition and post-partum respectively [40, 45, 53, 67, 83].

The increase of NEFA concentration in pre-partum as well as its peak at parturition is due to the high energy demand in the final third of gestation, rapid growth of fetuses and the mammary gland development [9]. The magnitude of the metabolic challenge during the peri-partum period due to the higher energetic demand causes a greater release of NEFA into the bloodstream due to the lipolysis rate that overlaps with the lipogenesis. Part of this metabolite is used as a source of energy by peripheral tissues and another part is metabolized in the liver, being completely oxidized for energy production or partially oxidized to produce ketone bodies or esterified and stored as triglycerides [9, 40]. The NEFA concentrations obtained during this study have not exceed values considered normal for the species, being to those reported by other authors in clinically healthy goats [17, 35, 54]. This results have demonstrated the ability of adaptive mechanisms in order to adjust to the demand situation without developing metabolic disorders in different species of ruminants [9, 42, 57, 62, 76].

The evolution of glucose concentration during late pregnancy and early lactation was similar observed by other studies in Saanen goats in the peri-partum period [35, 42]. An increase of glucose concentration at parturition is due to the high concentration of glucocorticoid hormones such as cortisol, which promotes an increase in hepatic glycogenolysis and gluconeogenesis from glucose precursors [42, 57]. Moreover, the decrease in the responsiveness of peripheral tissues to insulin, at the end of gestation, contributes to the increase of blood glucose concentration since these tissues save their use [5]. A previous study has reported a decrease in glycemia in the first weeks of lactation, especially in high producing dairy goats, related to high demand for milk lactose synthesis [42, 43, 57, 58]. Other studies also reported similar glycemia in dairy cows [83] and in sheep [2, 62]. Moreover, a recent study has reported that the regulation of glucose homeostasis changes at different physiological stages, and that an additional elevation of βHB beyond the metabolic adaptation after parturition might change glucose concentration in early-lactation dairy cows [83].

The highest concentrations of fructosamine were observed in the initial phase of lactation, and this response may be related to elevated glucose at parturition [70]. This increase can be attributed to the latter increased of glucose during the parturition due to the blood fructosamine concentration is related to glycemia and to the synthesis and elimination of the protein compounds, formed by the non-enzymatic reaction between the glucose and the amine group of proteins [25, 62]. However, if albumin blood concentrations are stable, the concentration of fructosamine is linked to the mean blood glucose concentration in the last two weeks [21, 25, 70].

Considering the few fructosamine concentrations studies in healthy goat reported in the literature, the mean overall values of fructosamine in this study were within the reference interval proposed by different studies with dairy cows [19, 66, 72]. However, these results are different from those found by Silva et al. [67] and Soares et al. [70] working with sheep, which did not observe significant difference for this variable during the observed assessment times, whereas Filipovic et al. [25] showed a significant decrease at 10 days post-partum when compared to the last 10 days of gestation, being related to the substantial decrease in albumin concentrations that was also recorded by the authors in this same period.

Moreover, the higher concentrations post-partum in relation to pregnancy was also observed by Ceballos et al. [15]. They have reported that this increase in the concentration of this indicator would only be reflected two weeks after the supplementation, which agrees with an increase in the level of post-partum fructosamine as a consequence of the beginning of the supplementation in the preparatory period. However, other studies have reported a decrease in the concentration of post-partum fructosamine in cows that were not prepared in the preparation [16, 66].

The decrease in the concentration of triglycerides in the last days of gestation and in the beginning of lactation is a reflection of the increase in milk production, lower availability of free fatty acids, lipolysis to obtain energy and the greater supply of circulating triglycerides to the mammary gland to meet the milk fat synthesis. According to Mundim et al. [48] second dairy Saanen goat present significantly lower concentrations of triglycerides compared to the first and third lactations, which are more likely to develop energy imbalance, since about two thirds of the circulating triglycerides are used for the synthesis of milk fat. Lower concentrations of triglycerides at parturition and lactation when compared to pre-partum were also reported by Celi et al. [17] and Sadjadian et al. [57] in goats and by Balikci et al. [7] and Moreira et al. [47] in crossbred dairy cows.

Stability in peri-partum cholesterol concentration values was also reported by Sotillo et al. [56] in goats and Moreira et al. [47] in dairy cows. On the other hand, Bamerny [8] and Sadjadian et al. [46] observed decreased serum cholesterol in the last weeks of gestation in goats, as well as Ceballos et al. [15] and Kessler et al. [34] from third last week before parturition to the first week post-partum in dairy cows. The mean values obtained for this variable were similar to those reported by Sotillo et al. [73] in healthy goats during different productive periods and by Barbosa et al. [9] in goats at the beginning of lactation.

Lower concentrations of TP and globulins observed during late pregnancy and on the day of parturition, then the migration of globulins directed at colostrum synthesis [5]. Elzein et al. [24] and Piccione et al. [51] observed a similar evolution of these protein concentrations that showed a decrease in its concentration at the end of gestation and at parturition and the return to normal values post-partum in dairy goat and cows, respectively. Moreover, Mohammadi et al. [46] have reported that the ability to synthesize milk constituents begins about three to four weeks before parturition and this drainage of globulins into the mammary glands can be considered the primary factor for serum TP reduction. The mean values obtained for the TP and globulin variables were similar to those reported by Zabaleta et al. [82] and Mundim et al. [48] in goats, respectively.

The average values obtained for albumin over the studied assessment times were similar to those reported by Cajuereiro [12] in goats. The decrease in albumin concentration is related to when the date of parturition approaches, as well as other factors such as a fetal increased demand for this metabolite due to the exponential growth that it presents during late gestation [14, 20, 57]. Another factor that accounts for the decrease in values of TP and albumin at the end of gestation is the increase in the plasma volume that occurs during pregnancy and is related to the increase of estrogen concentrations [6, 14]. However, a previous study with dairy cows has reported a small increase of albumin concentration at parturition. This slight increase could be due to higher albumin synthesis by liver or to a decrease of plasma volume masked by hypoglobulinemia due to the fact that a substantial and progressive increase in plasma volume occurs during pregnancy, followed by its decrease 6-24h after parturition [51].

Higher creatinine concentrations during the late gestation period when compared to early lactation were also reported in goats [24], dairy cows [52], and sheep [3, 62]. Changes in the evolution of this variable are related to the maternal mobilization of protein for the development of the fetal musculature and the elimination of the fetus organic residues. Therefore, this residue elimination is performed by the dam through the placenta during pregnancy and after parturition is gradually assumed by the offspring [10, 52]. However, Waziri et al. [80] observed stable evolution of this variable in goats at the end of gestation. The mean creatinine value obtained in this study was similar to that observed by Opara et al. [49] and Elzein et al. [24], but remained below the values reported by Kaneko et al. [33].

The observed urea concentrations in this study were similar to those reported by Mundim et al. [48], yet they are differed from the results of Rios et al. [54] who observed higher values and Waziri et al. [80] who observed lower values. The observed evolution for the urea variable ratifies the non-occurrence of disorders in protein metabolism, considering that the observed decrease in albumin occurred due to the fetal demand and its development and not due to protein deficiency in the diet. Urea responds more quickly in relation to changes in protein intake of the diet and its blood concentration directly reflects the amount of protein ingested through the diet [81].

Higher serum AST activity during lactation in relation to pre-partum was also reported by Sadjadian et al. [57] in goats. Periods of high energy demand, such as lactation, leads to increased gluconeogenesis which may be responsible for causing an increase in the serum activity of this enzyme, as a consequence of the increase in hepatic metabolism [31, 38, 74]. AST activity is an indicator of liver function in periparturient animals, having similar AST activity in Saanen goats [46] and dairy cattle [29, 64]. Despite the elevation, the AST serum activity remained below the normal values for the specie cited by Sadjadian et al. [57], and in accordance with the values obtained by Elzein et al. [24]. However, EL-Sherif & Assad [23] observed an increase in the activity of this enzyme in sheep during gestation and maintenance of high concentrations during lactation. This evolution was attributed to an increase of energy demand and consequently from gluconeogenesis due to fetal development during pregnancy and milk yield during lactation.

The serum amylase activity showed values above those reported by Mundim et al. [48] and Cajuereiro [12] in dairy goats at different stages of lactation and in the period of transition, respectively. Despite the few studies related to dairy goat during peri-partum, this higher activity is due to the high carbohydrate consumption by the animals, thus stimulating the synthesis of amylase, because it is a calcium-dependent metalloenzyme that acts on the small intestine by hydrolysing glucose polymers and producing maltose and dextrin [12, 18, 33, 71].

The evolution of the CK enzyme in this study was higher than observed by Tharwat et al. [78] in goats, although who reported a similar declined of its activity at two weeks before parturition but returned to normal during other points of examination during transition period.

The decrease in the blood concentrations of insulin observed near parturition represented a fall of 35%, then the negative linear effect as a function of the time of gestation and the parturition time observed ratified this result. This
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finding is in accordance with the results reported by Juárez-Reyes et al. [32] who observed a 38% decrease in serum insulin concentrations in healthy goats from the beginning of gestation to the time of parturition. Moreover, the decrease in feed intake during late pregnancy and at parturition leads to a decrease in the availability of glucogeneogenesis precursors. This process reduces the serum concentrations of propionate and glucose which are stimulating agents for the release of insulin from the pancreas causing decrease of serum concentrations of this hormone [12].

Mean values of insulin remained lower than those obtained by Magistrelli & Rosi [42] in dairy goats in the peri-partum. Moreover, in dairy cows, the maintenance of lower insulin concentrations during lactation when compared to pre-partum is related to the nutrient requirement by the mammary gland during this period, as well as the goats used in this study were multiparous [27]. According to Magistrelli & Rosi et al. [42] primiparous goats, which are still immature, limit the mobilization of body reserves for lactation and use this mechanism to conserve nutrients for their own body growth, thus these animals may not present a decrease in insulin concentrations during lactation. Therefore, this difference in values was probably due to the use of different methods to determine this variable. However, the evolution of this variable was similar in both studies, in which lower values were recorded at parturition and during lactation in relation to the pre-partum. This evolution is associated with the increase of NEFA in the same period which reflects the adaptive mechanisms of the female on the energy metabolism to supply the increase in the energy demand of the fetal development [17, 32, 35].

The mean values of serum cortisol obtained were relatively similar than those reported by Tharwat et al. [78] in goats who observed a peak of concentration at parturition due to the placental transfer from fetus to the dam. During the late stage of pregnancy, there is an increase in the ACTH section from the fetal pituitary, which stimulates the rapid growth of the fetal adrenals, leading to a rise in the concentration of serum cortisol. The increased cortisol enters the maternal circulation and induces parturition by activating the production of prostaglandin F2α [75].

Moreover, Magistrelli & Rosi [42] also observed a similar evolution of cortisol during the transitional period of primiparous and multiparous dairy goats, finding a higher concentration of this hormone near parturition. However, these authors obtained higher mean values than those observed in this study, probably due to the different methodology applied. Serum concentrations of cortisol increased during late pregnancy, more precisely at parturition due to this hormone acts as a signal of parturition and when there is a greater release of the glucocorticoid [2]. This increase is responsible for the elevation of glycemia, since the release of this hormone into the blood stimulates both hepatic glycogenolysis and gluconeogenesis from endogenous precursors [22, 74].

Despite the thyroid hormones T3 and T4 in their free forms showed no significant variation in mean concentrations throughout the experimental assessment times, their evolution together with NEFA and βHB ratifies the efficacy of the adaptive mechanisms of these animals which may meet the energy needs without resulting the development of metabolic imbalances. In contrast to the results of this study, Celi et al. [17] reported lower concentrations of free T3 and free T4 in the last weeks of gestation in goats when compared to parturition and early lactation. These authors attributed this finding to a competitive role of the fetus, resulting an increased thyroid activity with a great affinity for circulating iodine than the female, resulting in a decrease in maternal hormones.

Suganya & Gomathy [75] reported a similar decline of serum T3 and T4 concentrations from 30 days prior to parturition, and lowest on the day of parturition followed by an increase till day 15 post-partum. This evolution could be attributed to the inhibitory effect of glucocorticoids on TSH or to be a self defence mechanism to reduce metabolic demand when catabolic functions are high [11, 44]. The increase in the concentrations of thyroid hormones during the post-partum period could be due to the influence of estrogen on the development of mammary gland [6, 26]. It is worth noting the lack of work in the literature by measuring free T3 and free T4 in the goat species.

The concentration of total calcium in the present study was in agreement with the results of Azab & Abdel-Maksoud [6] and Iriadam [31] in goats. They showed that total calcium concentrations decreased in late gestation, the lowest value was at parturition and the values remained low for the first weeks of lactation. The observed decrease in calcium concentration at late gestation could be attributed to increased demand for calcium for mineralization of fetal skeleton [6, 52].

In the present study serum chloride concentrations remained slightly above the values reported by Samardzija et al. [59] in meat and dairy goats and Skrzypczak et al. [68] in cows. Moreover, the decrease in serum chloride concentrations during lactation has also been described by Antunovic et al. [4] and Skrzypczak et al. [68]. These authors recorded the lowest concentration of this mineral on the 40th day and 120th of lactation in sheep and dairy cows respectively, being the reason for this occurrence attributed to the increased secretion of this variable in milk.

In this study, no adaptive changes were observed in the phosphorus, sodium and potassium variables during the transitional period. Waziri et al. [80] also did not observe alterations of these variables in dairy goats. The results of serum phosphorus concentrations remained slightly above the values reported by Azab & Abdel-Maksoud [6] in dairy goat in different physiological stages. However, Bamerny [8] reported a marked increase in phosphorus in the last two weeks of gestation, which continued to increase until

reaching the maximum value in the third week of lactation. The decrease in sodium in the last week of gestation and potassium on the day of parturition and first week post-partum was also observed by others studies with goats [6,8]. These changes may occur due to their loss through colostrum, as well as the loss of large amounts of fluid during partum [8, 39].

Conclusion

Healthy goats undergo homeorhetic metabolic adaptation, mainly between 10 days before and 10 days after parturition, is characterized by some changes in the blood concentrations of the metabolic profile. These biochemical changes were seen in blood concentrations of NEFA, glucose, cortisol, total calcium and albumin at parturition, whereas insulin, creatinine and triglycerides during late pregnancy and βHB, fructosamine, globulin, AST, GGT and amylase during early lactation. All biochemical variables in this study could be used as physiologic parameters for dairy goats during the periparturient period. Management programs during this period may usefully, as an aid in the early diagnosis of metabolic disorders.

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References

17. - CELI P., DI TRANA A., CLAPS S.: Effects of perinatal nutrition on lactation performance, metabolic and


76. - SUNDRUM A.: Metabolic disorders in the transition period indicate that the dairy cows’ ability to adapt is overstressed. *Animals*, 2015, 5, 978-1020.


