Journal of the Selva Andina Animal Science
ISSN: 2311-3766
ISSN: 2311-2581
editor.animalscience@sars.org.bo
Selva Andina Research Society
Bolivia

Cayo-Rojas, Faustina; Mamani-Linares, Lindón Willy
Indicators of energy metabolism in llamas (*Lama glama*) in the prepartum, postpartum and lactation transition period
Journal of the Selva Andina Animal Science, vol. 11, no. 2, 2024, pp. 65-79
Selva Andina Research Society
Bolivia

DOI: https://doi.org/10.36610/j.jsaas.2024.110200065x

JOURNAL OF THE Selva Andina Animal Science
Official Journal of the Selva Andina Research Society.

Review Article

ISSN 2311-3766 (print edition)
JSAAS
ISSN 2311-2581 (online edition)

Indicators of energy metabolism in llamas (*Lama glama*) in the prepartium, postpartum and lactation transition period

Indicadores del metabolismo energético en llamas (*Lama glama*) en el período de transición preparto, posparto y lactancia

Cayo-Rojas Faustina[1*], Mamani-Linares Lindón Willy[2]

Article Data

[1] Public University of El Alto.
Veterinary Medicine and Zootechnics.
Between Sucre Avenue A and Juan Pablo II Avenue s/n Zona Villa Esperanza.
Phone: +591-2844177 – 2845787.
El Alto, La Paz, Plurinational State of Bolivia.

[2] Public University of El Alto.
Postgraduate Unit.
Agricultural, Livestock and Natural Resources Sciences Area.
Between Sucre A Av. and Juan Pablo II Av. s/n Zona Villa Esperanza.
El Alto, La Paz.
Phone: +591-2844177 – 2845787
Plurinational State of Bolivia.

***Contact address:**

Public University of El Alto.
Veterinary Medicine and Zootechnics.
Between Sucre Avenue A and Juan Pablo II Avenue s/n Zona Villa Esperanza.
Phone: +591-2844177 – 2845787.
Cell phone: +591 73095766
El Alto, La Paz, Plurinational State of Bolivia.

Faustina Cayo Rojas
E-mail address: cayorf31076@gmail.com

Keywords:

Negative energy balance,
non-esterified fatty acids,
beta-hydroxybutyrate,
prepartum,
postpartum,
Lama glama.

***J. Selva Andina Anim. Sci.* 2024; 11(2):65-79.**
Article ID: 139/JSAAS/2024

Article history

Received May, 2024.
Returned August, 2024.
Accepted September, 2024.
Available online October, 2024.

Edited by: Selva Andina Research Society

Abstract

Energy metabolism indicators allow determining the nutritional and metabolic condition and the energy imbalance that may be the cause of low fertility rates in llamas grazing on native pastures. In llamas, gestation is long, only one calf is born per year and the fertility rate is low. Therefore, measures must be taken to prevent miscarriages and give the offspring the best possible start in life. During the prepartum, postpartum and lactation transition period the decrease in dry matter intake coincides with the increase in nutrient demand due to the onset of lactation, which can lead to a negative energy balance, the enormous metabolic challenges during the transition period are related to the negative energy balance as a result of the mobilization of the body's energy reserves by increasing the concentration of non-esterified fatty acids and beta-hydroxybutyrate in the blood plasma. Camelids have higher blood glucose concentrations, lower plasma ketone body concentrations than domestic ruminants, a weak response to insulin and reduced cellular glucose uptake. The imbalance in metabolic adaptation mechanisms during the transition and lactation period interferes with body homeostasis, also predisposing to the development of ketosis. In addition, early postpartum is associated with a prolonged period of postpartum anestrus, delayed ovulation and poor reproductive outcomes.

Resumen

Los indicadores del metabolismo energético permiten determinar la condición nutricional, metabólica y el desequilibrio energético que puede ser la causa de las bajas tasas de fertilidad en llamas pastoreadas sobre pasturas nativas. En llamas, la gestación es larga, sólo nace una cría por año y la tasa de fertilidad es baja. Por lo tanto, se deben tomar medidas para prevenir abortos espontáneos y ofrecer a las crías el mejor comienzo de vida posible. Durante el período de transición preparto, posparto y lactancia la disminución de la ingesta de materia seca coincide con el aumento de la demanda de nutrientes debido a la llegada de la lactancia, que puede conducir a un balance energético negativo, los enormes desafíos metabólicos durante el periodo de transición están relacionados con el balance energético negativo como resultado de la movilización de las reservas energéticas del cuerpo, al aumentar la concentración

Palabras clave:

Balance energético negativo,
ácidos grasos no esterificados,
beta-hidroxibutirato,
preparto,
posparto,
Lama glama.

de ácidos grasos no esterificados y beta-hidroxibutirato en el plasma sanguíneo. Los camélidos tienen mayores concentraciones de glucosa en sangre, concentraciones más bajas de cuerpos cetónicos plasmáticos que rumiantes domésticos, una débil respuesta a la insulina y reducción de la absorción celular de glucosa. El desequilibrio en los mecanismos de adaptación metabólica durante el período de transición y lactancia interfieren en la homeostasis corporal, también predisponen a la presentación de cetosis. Además, el posparto temprano está relacionado con un período prolongado de anestro posparto, retraso de la ovulación y malos resultados reproductivos.

Introduction

South American camelids (SAC) have fulfilled a key role in the culture, economy and food security of Andean countries, and their contribution to the subsistence of low-income farmers is important[1]. Thus, improving breeding systems represents the best strategy to avoid poverty[2]. This is due to the ability of alpacas and llamas to produce fiber and meat under extreme geographic and climatic conditions[3].

In camelid production, nutrient deficiency and imbalance in metabolic adaptation mechanisms can cause sub-fertility syndrome (less than 50 %). Several authors approve that one of the main obstacles for this species lies in the low fertility rates, both in alpacas and llamas, which usually do not exceed 60 %[4]. And an embryonic mortality rate of 45-56 % has been determined in herds in Peru[5-7].

Early embryonic demise is estimated to be the most common form of reproductive loss in SAC, affecting 10-15 % in the first 60 days of pregnancy. Under these conditions, it can occur up to 60-80 % in the first 90 days of gestation[8].

Dairy cows at the end of gestation and beginning of lactation have a negative energy balance (NEB), related with a decrease in dry matter (DM) intake and an increase in energy demand[9,10]. In the peripartum period, a marked metabolic change occurs, from a gestational state (low demand) to a lactation state (high demand), associated with a growth in the rate of lipolysis and alterations in insulin action in peripheral tissues[11].

Dietary insufficiency causes mobilization of adipose reserves, characterized by an increase in non-esterified fatty acids (NEFA) in blood (more than 0.6 mmol L^{-1}) and a slight increase in beta-hydroxybutyrate (BHB) in blood, up to approximately (more than 0.09 to 0.18 mmol L^{-1}) in camelids[12,13].

NEB is strongly related with the duration of the postpartum an ovulatory period, through the attenuation of luteinizing hormone (LH) and low levels of blood glucose, insulin and insulin-like growth factor 1 (IGF-1), which in set limit the production of estrogens by dominant follicles[14]. Cows with high plasmatic concentrations of NEFA in the transition period postpartum, they have a higher risk of hyperglycemia and insulin resistance (IR) during the period of prepartum and postpartum transition[15].

There are many reports in the literature on the relationships between NEB and fertility, almost all of them related to beef cattle production systems, dairy farming on pasture, grazing plus supplementation and confined, with feeding totally mixed rations, we did not find in the literature reports that link NEB with indicators of energy metabolism in llamas (total protein, urea or NUS, creatinine, glucose, IR, triacylglycerols (TG), cholesterol, NEFA and BHB), under a production system based on native pastures or grazing plus supplementation in the Andean Altiplano.

The nutritional status of the female during the prepartum, postpartum and lactation transition period is very important, nutritional balances or imbalances during these periods can lead to phenotypic and metabolic changes in development of the individual[15,16]. Therefore, the objective of this review was to assemble national and international scientific literature on advances in this knowledge acquired on metabolism indicators energy of llamas, in the prepartum, postpartum and breastfeeding transition period.

Development

Llama production systems are traditional, completely non- specialized and based on extensive grazing in native grasslands, composed mainly of grasses of low nutritional quality[2]. Which it affects the productive performance of camelids, another factor that affects productivity is reproduction. In the pre-partum, delivery and lactogenesis animals undergo a NEB that occurs when the energy needed for metabolism-homeostasis is greater than the energy supplied through nutrient intake[17]. Dietary insufficiency causes mobilization of adipose reserves, characterized by an increase in NEFA and BHB in camelids blood[13]. Energy imbalance in ruminants can cause a sub-fertility syndrome, low conception rate, increased embryonic mortality and delayed uterine involution[17,18]. All these antecedents indicate that the nutritional status of the female during the pre-partum, post-partum and lactation transition period is quite important[16].

Pre-birth transition period. The fetal development of domestic camelids shows exponential growth around the seventh month of gestation[19]. Thus, the high nutritional demand for fetal growth coincides with the critical period of the pre-birth transition period of altiplano (August to October), with nutrient deficiency[20], it is causing an energy imbalance in ruminants[17,18].

The dairy cow endures tremendous physiological challenges during the transition period, which is the most critical period[21], leading to NEB associated with decreased DM intake and increased energy demand[9,10], impaired immunity, alterations in hormonal activity, nutrient distribution, to help nourish the growing fetus, and support the start of a new lactation[21].

Energy supplementation (with cracked corn kernels) administered three weeks before calving to grazing cows increased milk production and reduced ovarian restart, consistent with improved energy balance, body condition score (BCS), and higher insulin levels during the early postpartum period. supplemental feed may not improve pregnancy rates, an increase in the percentage of calves alive at weaning and weaning weight would improve net returns during the cow-calf phase[22].

Postpartum transition period. Apparently, in SAC the dietary restriction could be associated with the physiological and productive state of the animal[23]. It has been described in llamas subjected to chronic nutritional restriction, which had small dominant follicles, corpus luteum, and less progesterone secretion[24]. In addition, dietary changes in cows cause an immediate and rapid stimulation in metabolism[25]. DM intake is the main component of energy balance, which affects fertility in cows[18].

During the calving season, and without the presence of males, females can remain sexually receptive for periods of up to 36 days, with a brief anestrus of no more than 48 h[26]. When males and females are kept separate, and come together at any time (once a month), both are sexually active throughout the year, and females can give birth in different months[5,26,27]. Thus, to achieve high levels of milk production, in the early postpartum period, their body reserves must be mobilized, which, in turn, are related to energy intake in the dry period (2 months before delivery). Fat reserves are mainly used for lactation and maintenance, and reproductive processes receive a lower priority[14], in relationship with another physiological states of maintenance, lactation and growth when available nutritional resources are limited[28]. Therefore, ensuring good nutritional status during this period is an important objective to optimize postpartum in females[29].

Lactation period. Food availability affects both mother and offspring. The year of birth (dry years vs. rainy years) of the offspring considerably affected live weight (LW) at birth, at weaning, implying that the environment has a marked influence on the development of biomass body weight of the offspring and the pre-and postpartum BCS of llamas over time[30]. In primiparous cows that have a lower BCS during the early postpartum period, cows produce less milk than multiparous cows[31], milk production affects the weaning weight of the offspring.

An important element that increases the survival rate of alpaca offspring is birth weight (higher birth weight, it has lower risk of perinatal complications and less need for bottle feeding). Offspring from mothers who received mineral supplements have higher birth weights[32]. Likewise, weaning weight is higher for calves born to cows that grazed on irrigated pasture in relationship to cows fed with hay after animalbirth[22]. On the other hand, nutritional deficiency associated with breastfeeding is considered the main factor, that is affecting the duration of postpartum anestrus in cattle[33,34].

Blood indicators of energy balance. During the transition period (prepartum and postpartum) the decrease in intake, or consumption of DM coincides with the increase in nutrient demand, due to the beginning of lactation, this can lead to a NEB and enormous metabolic challenges, which leads to the mobilization of fat, such incidents would increase the levels of NEFA and BHB in the plasma[35], as well as alter the blood levels of other indicators: glucose, cholesterol, urea, albumin, aspartate-aminotransferase and glutamate-dehydrogenase[15].

Metabolites in blood.

Total protein or proteinemia. Wittwer[36] indicates that total protein corresponds to all the proteins present in a serum sample (albumins + globulins). In llamas, the influence of the season (dry or rainy) on serum biochemistry is evident: alanine transaminase, total protein, albumin, increased in summer, while, urea and bilirubin increased in winter[37].

Llamas develop hypoproteinemia[38] (total proteins: 55.9 g L^{-1}, reference limits: 58-69.3 g L^{-1}) and hypoalbuminemia[39] (albumin: 28.1 g L^{-1}, reference limits: 33.9-40.5 g L^{-1}). According to Tallacagua-Terrazas & Mamani-Tola[40] in the determination of total protein, it was detected that the values are low (43.2 g L^{-1}), in relationship to the data obtained by Copa & Condori[41], in llamas of baby teeth and two teeth, this it is probably due to the physiological state, because they use more proteins for tissue and body growth.

Non-protein nitrogenous metabolites. Among the non-protein nitrogenous compounds of the body, urea, creatinine, uric acid and ammonia are cited for their clinical interest, the first two being of greatest interest[36]. Likewise, Norambuena et al.[20,24], shown increased NEB and plasma urea concentrations in previous studies carried out in llamas, alpacas and vicuñas. Apparently, camelids use in a greater extent protein as a substrate for energy production and gluconeogenesis, with urea recycling being more efficient[19].

Blood urea nitrogen (BUN). Urea is a terminal product of protein metabolism, synthesized in the liver from ammonia and the transamination of transport amino acids and those absorbed in the intestine. In ruminants, the formation and use of ammonia in the rumen is of greater importance; it depends on the protein/energy ratio of the diet. In ruminants it is an indicator of the ruminal synchrony of degradable proteins with energy[36].

The plasma concentration of urea in camelids is 3.2-12.8 mmol L^{-1} in llamas, 3.9-10.2 mmol L^{-1} in alpacas. Urea decrease levels are infrequent, although it can occur in association with serious liver diseases or protein malnutrition[42].

In llamas, high concentrations of plasma urea were observed when they consumed foods with low gross protein content (6.2 %), it reveals different metabolic adaptations of proteins and/or nitrogen, something not observed in true ruminants such as sheep and goats. These characteristics may contribute to explaining the lower metabolic rates in llamas compared to real ruminant[43]. Tallacagua-Terrazas & Mamani-Tola[40] informed urea values of 90 mg dL^{-1} in llamas, these parameters are high for the species[44].

The BUN is directly influenced by the amount of crude protein (CP) in the diet[45,46], another important aspect is also the energy content of the feed[47]. In alpacas, ranges of 13.53-20.54 mg dL^{-1} and values from 11.61 to 20.18 mg dL^{-1} in sheep were reported. It was concluded that, although there is a direct relationship between BUN and the levels of CP in the diet in both species (alpacas and sheep), the rates of increase are different between them[45]. Tallacagua-Terrazas & Mamani-Tola[40] informed BUN levels of 42.03 mg dL^{-1} for llamas, these values are similar for alpacas, Dixon et al.[48] showed values of 44 mg dL^{-1} in alpacas (reference interval 13 to 28 mg dL^{-1}), these values are high in llamas and alpacas in relationship to sheep and cattle. It should be considered that the nutritional needs for maintenance of adult animals are lower than for animal in growth stage[49], and, therefore, urea recycling of an adult animal will be lower than in growing animals, thus increasing BUN levels. In this case, recycled urea can be an important source of nitrogen to sustain microbial fermentation and, therefore, guarantee efficient digestion and the utilization of low protein content feeds[50].

The mean plasma urea nitrogen (BUN) concentration for all animals in the first week of postpartum was significantly higher than the mean for the other three weeks. Moreover, decrease in temperature, that occurred with a change from summer to autumn, it appeared to coincide with an increase in BUN levels[51].

Creatinine. Metabolite generated in the muscles from phosphocreatine as a source of energy. Its production in each individual is constant and it is eliminated by the kidney through glomerular filtration without tubular reabsorption, so it is a measure of the degree of glomerular filtration. Indicator of renal function[36].

The plasma concentration of creatinine in mammals is 15 to 150 μmol L^{-1}, in camelids as llamas, it is 79.5-247. 5 μmol L^{-1} and 54-177 μmol L^{-1} in alpacas[42]. In young growing animals, the plasma concentration is encountered highest values[40].

Other cases of azotemia in SAC were described following acute renal failure because of poisoning Chamorro et al.[52] Dixon et al.[48], reported creatinine increase of 176.8 μmol L^{-1} (reference interval, 80-150 μmol L^{-1}) in alpaca calves. Clinical chemistry in alpacas revealed increased creatinine, urea, calcium and potassium. These results are similar to those described by Jankovsky et al.[53]. In addition, kidney changes were escorted by azotemia, hyperphosphatemia and also hypocalcemia[54]. Biochemical parameters did not report changes in serum creatinine[44] with an overall mean serum creatinine level of 92 μmol L^{-1} in llamas grazed on native pastures[24]. While creatinine concentration in all categories of llamas was higher than in alpacas[39].

Carbohydrates. Wittwer[36] arguments that carbohydrates or glucides are the main energy source of animal cellula. Most frequent alterations in carbohydrate metabolism in cattle are ketosis type I (hypoglycemia or hyperketonemia), II (diabetic or hyperinsulinic) and dietary (butyric or dietary).

Glucose or glycemia. Camelids have higher blood glucose concentrations than domestic ruminants, and they have a weak insulin response and slow cellular uptake of glucose. Feed-restricted camelids have reduced glucose clearance, and sick camelids may be even more glucose intolerant. While ruminants with fatty liver and ketosis have concurrent hypoglycemia, camelids often have hyperglycemia[55]. Therefore, glucose administration must be carefully controlled in anorexic camelids.

Glycemia in mammals fluctuates between 2.14 to 7 mmol L^{-1}, being lower in ruminants, (2.5-4.1 mmol L^{-1})[36]. Plasma glucose concentration is 4.3 to 9.9 mmol L^{-1} in llamas and 5.1 to 9.1 mmol L-1 in alpacas[42].

Fowler & Bravo[56] described that normal concentrations range from 4.3 to 9.9 mmol L^{-1}. This range is twice that of cattle and sheep (2.5 and 3.9 mmol L-1) at several stages of gestation. The higher blood glucose concentrations compared to other ruminants may be due to IR or the inability of camelids to switch their metabolism from fat to carbohydrates[57]. According to Burton et al.[58] glucose concentrations ranged from 6.6 to 12.7 mmol L^{-1} for mothers, with the highest concentration occurring at the time of parturition. However, it is not possible to determine whether the glucose peak occurred before parturition or peaked on the day of parturition.

Insulin resistance (IR). It is known by a state of reduced sensitivity of target cells to respond to physiological concentrations of insulin[59]. In dairy cows, periparturient ketosis can be categorized by hyperglycemia and hyperinsulinemia, probably due to IR[60], and it is classified as type II ketosis due to its similarities with type I diabetes mellitus[61]. Barboza et al.[15] informed prepartum hyperglycemia (>4.1 mmol L^{-1}) in cattle, that were the main risk factors for IR in the transition period. Studies have proposed that IR is a homeostatic adaptation of the dairy cow to prioritize the mammary gland and promote gluconeogenesis and lipolysis[11].

The imbalance in the metabolic adaptation mechanisms during the transition period and early lactation interferes body homeostasis, and also it predisposes to the presentation of ketosis. Ketosis is classified into type I and II, due to a shortage of precursors or a blockage in the gluconeogenic capacity to meet energy demand, respectively[61]. Type I ketosis happens between the third and sixth week of lactation, because of the high energy demand, accompanied by hypoglycemia, hypoinsulinemia and high circulating concentrations of ketone bodies. On the other hand, type II ketosis occurs around calving due to NEB and the mobilization of adipose tissue, obese cows are the most susceptible due to the greater depression in DM consumption in the peripartum period. Acetonemia or subclinical ketosis happens in cows with BHB values > 1.2 mmol L^{-1}; cows with clinical ketosis present BHB values > 3.0 mmol L^{-1} in all animals with type II ketosis[36].

Lipids and ketone bodies. According to Wittwer[36] lipids found in plasma are cholesterol and triacylglycerols (triglycerides), which form part of lipoproteins, in addition to NEFAs and ketone bodies (acetone, acetoacetate and BHB).

Triacylglycerol or triacylglycerolemia. This is a constituent of adipose tissue formed by glycerol bound to three fatty acids and as such is the main source of energy for the body. It is an indicator of suspected primary and secondary alterations in lipid metabolism[36].

The plasma concentration of TG in camelids is 0-0.27 mmol L^{-1} in llamas and 0.12-0.51 mmol L^{-1} in alpacas[42]. On the other hand, McKenzie et al.[38] reported a plasma concentration of TG of 0.53 mmol

L^{-1} in llamas and alpacas, with a reference range of 0.09 to 0.63 mmol L^{-1}.

Plasma TG concentrations (mmol L^{-1}) are generally of similar magnitude in llamas, sheep and goats, and they are not affected by the diet supplied[43]. Husakova et al.[62] reported higher concentrations of TG, cholesterol, vitamins and some minerals in alpacas in the group of animals that received supplementation in the winter feed.

Pregnant and non-pregnant alpacas have similar plasma TG concentrations (0.3 vs. 0.4 mmol L^{-1}) with a general range of (0.1-0.5 mmol L^{-1})[23]. The high liver TG, in turn, these are associated with an increase in the interval - first ovulation (open days) and reduced fertility[63].

Cholesterol or cholesterolemia. It can be of external or internal origin, the latter is predominating in herbivores, mostly synthesized by the liver, and in adipose tissue in ruminants, from acetyl-CoA, which is then esterified. It is found in animals as a component of the cell membrane and precursor of steroid hormones. Cholesterol is an indicator of supposed primary or secondary alterations in lipid metabolism. Cholesterolemia in mammals fluctuates between 1.5 and 6.5 mmol L^{-1}, It is being higher after food intake and in older animals. Hypocholesterolemia and hypoadrenocorticism are appreciated in diets with scarse energy or fiber in ruminants[36].

Prepartum cows had inferior cholesterol concentrations (±27 %) than lactating cows, in relationship with low DM intake in primiparous cows[36]. backwards[31], cholesterol concentration increased during the early postpartum period in both primiparous and multiparous categories, although multiparous cows had higher cholesterol around day 60 after early postpartum than primiparous cows, calves had considerably higher cholesterol than the older group, it can be explained by the fact that most of the sampled calves had breast milk as the main part of their nutrition[62].

Plasma cholesterol concentration in camelids is 0.34-2.3 mmol L^{-1} in llamas and 0.24-2.15 mmol L^{-1} in alpacas[39]. Pregnant and non-pregnant alpacas have similar plasma cholesterol concentration (1 vs. 0.9 mmol L^{-1})[23].

Non-esterified fatty acids (NEFA). These are long-chain free fatty acids (>12 C), that usually derive from the degradation of TG in adipose tissue, liver and mammary gland. These are conveyed in the plasma, for having as their final destination their β-oxidation, or the neosynthesis of TG. The degree of fat mobilization, mainly in ruminants are an indicator of an energy deficiency. The most frequently described condition that presents an increase of NEFA in the plasma is the increase in its mobilization in response to a negative energy balance. Its greatest clinical use is in ruminants in order to evaluate the nutritional balance of cows in the transition period[36].

Plasmatic NEFA concentration in mammals oscillates between 0.1 and 0.5 mmol L^{-1}, It is being higher after prolonged fasting[36]. They are raised in cases of hepatic lipolysis[42]. Strieder Barboza et al.[15] report NEFA values >0.40 mmol L^{-1} in dairy cows, because of to excessive lipomobilization.

The plasmatic concentration of NEFA in camelids is (<0.6 mmol L^{-1})[42], with a range of (0.1- 0.7 mmol L^{-1})[62]. Similarly, Norambuena et al.[20,24] indicated that BEN increased plasmatic NEFA concentrations in previous studies conducted on llamas, alpacas, and vicuñas. Biochemical analysis of llama and alpaca plasma exposed raised NEFA concentrations (0.30 mEq L^{-1})[34]. Norambuena et al.[20] moreover stated an increase in NEFA blood (more than 0.6 mmol L^{-1}) in camelids. The values described in this study were lower than those cited above. Likewise, Putman et al.[64] cited that NEFA levels appear to be high after two days of drying off or after finishing lactation. Pregnant and non-pregnant alpacas have comparable NEFA concentrations (0.6 vs. 0.8 m-mol L^{-1}), it is indicating that the energy metabolic state does not explain the differences found in their reproductive success[31].

NEFA levels gradually decline over time (days postpartum)[65], it is accompanied by a reduction in the mobilization of reserve tissues. Also, Alforma et al.[66] indicated that NEFA levels diminished as the postpartum period progressed in cows. No rise in postpartum of NEFA were observed in llamas[43].

Ketone bodies or ketonemia. These are three intermediate products of energy metabolism, it is produced by β-oxidation of fatty acids in hepatocytes when acetyl-CoA is transformed into BHB, acetoacetate and acetone. The quantity of BHB and acetoacetate in the hepatocyte is the same. It is mainly used in ruminants as an indicator of energy deficiency. The unit for BHB 1 mg dL^{-1} x 0.096 = 1 mmol L^{-1}, it is present in cases of mobilization of fat reserves compared to a NEB[40]. Camelids have lower concentrations of plasmatic ketone bodies than domestic ruminants[39]. BHB concentrations in llamas seem to reflect hepatic ketogenesis, and therefore, an altered metabolic state of the animal, unlike true ruminants, where BHB is greatly influenced by foregut fermentation[43].

In alpacas, NEFA values of (0.24 mmol L-1) are exposed[42]. Norambuena et al.[20,24] report that NEFA increased plasmatic BHB concentrations in llamas, alpacas and vicuñas. Norambuena et al.[23], also it reported a slight increase in BHB (up from 0.1 to 0.19 mmol L^{-1}) in camelids, the values reported in this study were lower than those cited above. Biochemical analysis of llama and alpaca plasma revealed elevations of plasma BHB levels (1.17 mg dL^{-1})[38]. The increase in BHB, although, it is not as closely correlated with CC as reported by Reist et al.[67], it could also be a reflection of low energy in the postpartum diet[68], BHB levels remained higher for longer after parturition, probably due to a different composition of the diet or a lower amount of DM intake. According to Norambuena et al.[20] BHB values were higher than expected under nutritional energy balance, indicating a lipolytic and ketogenic metabolic response, respectively, in domestic camelids.

Negative energy balance, ketosis and their risk factors. Feed intake offers the essential energy for reproduction in camelids[69]. According to Norambuena et al.[23], energy restriction levels in feed have different consequences such as: low energy restriction (30 %) of maintenance energy requirements for 28 days in llamas did not affect LW, BCS and metabolic parameters that may indicate NEB. However, moderate energy restriction at 40 % for 21 days in alpacas affected BCS, LW and corpus luteum diameter.

Primary ketosis or pregnancy toxemia occurs in ruminants due to NEB, this is causing lipid mobilization, fatty liver and ketosis. However, camelids are slightly different in their digestive and metabolic systems: glycemia is higher and ketones are lower in relationship to true ruminants. It is an infrequent trait in camelids compared to small ruminants. In contrast, severely debilitated females, abortion or parturition induction should be considered to alleviate the syndrome. Insufficient energy intake during or at the end of pregnancy is often responsible for increased body fat mobilization, fatty liver, and ketonemia. It is indirect evidence of a lipid disorder, and affected camelids occasionally can die[70].

Conclusion

Based on the available technical-scientific information, it can be concluded that: If during the transition period prepartum, postpartum and lactation, maintenance requirements are not fulfilled, this can lead to NEB and enormous metabolic challenges, it lead to fat mobilization, such incidences produce changes of indicator levels of energy metabolism in llamas like: total protein, urea or BUN, glucose, TG, cholesterol, NEFA and BHB.

SAC suffer from BEN during the dry season, it can increase plasma concentrations of NEFA, BHB and NUS have been reported in previous studies in llamas, alpacas and vicuñas. Elevated BUN values were reported in llamas and alpacas. This may cause abortions and contribute to low fertility rates in the herds. Furthermore, BHB concentrations in llamas seem to reflect hepatic ketogenesis and, therefore, metabolic alteration of the animal.

Plasma glucose levels were similar between llama and alpaca species. Studies have proposed that IR is a homeostatic adaptation to prioritize the mammary gland and promote gluconeogenesis and lipolysis.

Plasmatic TG concentrations are commonly comparable in order of magnitude in llamas, sheep, and goats and are not affected by diet. Hypocholesterolemia is appreciated in diets with low energy or fiber intake in ruminants.

This review agrees to indicate that more researches are needed to evaluate NEB (NEFA, BHB) in pregnant llamas in different seasons of the year and transition periods (prepartum and postpartum) to improve reproductive performance and maximize productivity in South American camelid production systems.

Source of financing

The study was funded with own resources of the authors.

Conflicts of interest

The manuscript was elaborated and reviewed by the authors, who declare that there is no conflict of interest that could risk the validity of the results presented.

Acknowledgments

The authors thank to Área Ciencias Agrícolas, Pecuarias y RRNN de la UPEA, La Paz, Estado Plu-rinacional de Bolivia for the support provided during the development of the research work.

Ethical considerations

The research fulfilled with the ethical standards of the information process.

Authors' contribution to the article

The authors realize information gathering and bibliographic compilation, as well as the review and writing of the final review.

Research limitations

The authors indicate that there were no limitations in this review.

Cited literature

1. Wurzinger M, Delgado J, Nürnberg M, Valle Zárate A, Stemmer A, Ugarte G, et al. Growth curves and genetic parameters for growth traits in Bolivi an llamas. Livest Prod Sci 2005;95(1-2):73-81. DOI: https://doi.org/10.1016/j.livprodsci.2004.12.015

2. Popova T, Limachi J, Tejeda L, Mollinedo P, Peñarrieta JM. Fatty acid composition in llama meat from bolivian markets, observation from three different markets. Rev Bol Quím 2020;37(2):64-73. DOI: https://doi.org/10.34098/2078-3949.37.2.1
3. Miranda-de la Lama GC, Villarroel M. Behavioural biology of South American domestic camelids: An overview from a welfare perspective. Small Rumin Res 2023;220:106918. DOI: https://doi.org/10.1016/j.smallrumres.2023.106918
4. Choque Sánchez DS, Ayala Vargas C. Comparación de tres métodos de diagnóstico de preñez en llamas (*Lama glama*) de la estación experimental Choquenaira. Apthapi 2017;3(1):1-10.
5. Fernández-Baca S, Hansel W, Novoa C. Embryonic mortality in the alpaca. Biol Reprod 1970;3(2):243-51. DOI: https://doi.org/10.1093/biolreprod/3.2.243
6. Bravo PW, Sumar J, Riera SG. Factors that determine fertility in alpacas. In: Proceedings of the International Convention on SAC, Cusco, Perú; 1985. p. 4.
7. Ratto M, Cervantes M, Norambuena MC, Silva M, Miragaya M, Huanca W. Effect of location and stage of development of dominant follicle on ovulation and embryo survival rates in alpacas. Anim Reprod Sci 2011;127(1-2):100-5. DOI: https://doi.org/10.1016/j.anireprosci.2011.07.003
8. Vaughan JL, Tibary A. Reproduction in female South American camelids: A Review and clinical observations. Small Rumin Res 2006;61(2-3):259-81. DOI: https://doi.org/10.1016/j.smallrumres.2005.07.015
9. Ospina PA, Nydam DV, Stokol T, Overton TR. Associations of elevated nonesterified fatty acids and beta-hydroxybutyrate concentrations with early lactation reproductive performance and milk production in transition dairy cattle in the northeastern United States. J Dairy Sci 2010;93(4):1596-603. DOI: https://doi.org/10.3168/jds.2009-2852
10. Ospina PA, Nydam DV, Stokol T, Overton TR. Evaluation of nonesterified fatty acids and beta-hydroxybutyrate in transition dairy cattle in the northeastern United States: Critical thresholds for prediction of clinical diseases. J Dairy Sci 2010;93(2):546-54. DOI: https://doi.org/10.3168/jds.2009-2277
11. Zachut M, Honig H, Striem S, Zick Y, Boura-Halfon S, Moallem U. Periparturient dairy cows do not exhibit hepatic insulin resistance, yet adipose-specific insulin resistance occurs in cows prone to high weight loss. J Dairy Sci 2013; 96(9):5656-69. DOI: https://doi.org/10.3168/jds. 2012-6142
12. Tornquist SJ, Cebra CK, Van Saun RJ, Smith BB, Mattoon JS. Metabolic changes and induction of hepatic lipidosis during feed restriction in llamas. Am J Vet Res 2001;62(7):1081-7. DOI: https://doi.org/10.2460/ajvr.2001.62.1081
13. Van Saun R, Cebra C. Nutritional diseases. In: Cebra C, Anderson DE, Tibary A, Van Saun RJ, Johnson LRW, editors. Alpaca and Llama Care. Medicine, Surgery, Reproduction, Nutrition, and Herd Health. Philadelphia: Elsevier Inc.; 2014. p. 124-39. DOI: https://doi.org/10.1016/B978-1-4377-2352-6.00013-4

14. Butler WR. Energy balance relationships with follicular development, ovulation and fertility in postpartum dairy cows. Livest Prod Sci 2003;83(2-3):211-8. DOI: https://doi.org/10.1016/S0301-6226(03)00112-X
15. Strieder Barboza C, Cucunubo LG, Smulders JP, Wittwer F, Noro M. Indicadores energéticos de vacas lecheras a pastoreo en período de transición y lactancia temprana con alta o moderada condición corporal preparto. Rev Cient 2014;24(1):73-82.
16. Meyer K, Zhang L. Fetal programming of cardiac function and disease. Reprod Sci 2007;14(3):209-16. DOI: https://doi.org/10.1177/1933719107302324
17. Diskin MG, Mackey DR, Roche JF, Sreenan JM. Effects of nutrition and metabolic status on circulating hormones and ovarian follicle development in cattle. Anim Reprod Sci 2003;78(3-4):345-70. https://doi.org/10.1016/s0378-4320(03)00099-X
18. Patton J, Kenny DA, McNamara S, Mee JF, O´Mara FP, Diskin MG, et al. Relationship among milk production, energy balance, plasma analytes, and reproduction in Holstein-Frisian Cows. J Dairy Sci 2007;90(2):649-58. DOI: https://doi.org/10.3168/jds.S0022-0302(07)71547-3
19. San Martín F, Van Saun RJ. Feeding management systems. In: Cebra C, Anderson DE, Tibary A, Van Saun RJ, Johnson LRW, editors. Alpaca and Llama Care. Medicine, Surgery, Reproduction, Nutrition, and Herd Health. Philadelphia: Elsevier Inc.; 2014. p. 91-100. DOI: https://doi.org/10.1016/B978-1-4377-2352-6.00011-0
20. Norambuena C, Mussa K, Hernández F, Alfaro J, Velasco M. Energy balance of pregnant vicuñas (*Vicugna vicugna*) in the Chilean High Andes. Austral J Vet Sci 2019;51(1):33-6. DOI: https://dx.doi.org/10.4067/S0719-81322019000100106
21. Huzzey JM, von Keyserlingk MAG, Weary DM. Changes in feeding, drinking, and standing behavior of dairy cows during the transition period. J Dairy Sci 2005;88(7):2454-61. DOI: https://doi.org/10.3168/jds.S0022-0302(05)72923-4
22. Stalker LA, Adams DC, Klopfenstein TJ, Feuz DM, Funston RN. Effects of pre- and postpartum nutrition on reproduction in spring calving cows and calf feedlot performance. J Anim Sci 2006;84(9):2582-9. DOI: https://doi.org/10.2527/jas.2005-640
23. Norambuena C, Hernandez F, Alfaro J, Silva G, Topp S, Ratto M. Effect of different levels of energy diet restriction on energy balance, leptin and cl development, vascularization, and function in South American Camelids. Front Vet Sci 2020;7:598147. DOI: https://doi.org/10.3389/fvets.2020.598147
24. Norambuena MC, Silva M, Urra F, Ulloa-Leal C, Fernández A, Adamas GP, et al. Effects of nutritional restriction on metabolic, endocrine, and ovarian function in llamas (*Lama glama*). Anim Reprod Sci 2013;138(3-4):252-60. DOI: https://doi.org/10.1016/j.anireprosci.2013.01.019
25. Cavestany D, Viñoles C, Crowe MA, La Manna A, Mendoza A. Effect of prepartum diet on postpartum ovarian activity in Holstein cows in a pasture-based dairy system. Anim Reprod Sci 2009;

114(1-3):1-13. DOI: https://doi.org/10.1016/j.anireprosci.2008.08.007

26. San-Martin M, Copaira M, Zúñiga J, Rodreguez R, Bustinza G, Acosta L. Aspects of reproduction in the alpaca. J Reprod Fertil 1968;16(3):395-9. DOI: https://doi.org/10.1530/jrf.0.0160395
27. Mamani-Mondragón CV. Susceptibility of the corpus luteum to prostaglandin F2α action in alpacas induced to ovulate with seminal plasma [tesis licenciatura]. [Lima]: Universidad Mayor de San Marcos; 2014 [citado 16 de septiembre de 2023]. Recuperado a partir de: https://hdl.handle.net/20.500.12672/3947
28. Van Saun RJ. Effect of nutrition on reproduction in llamas and alpacas. Theriogenology 2008;70(3):508-14. DOI: https://doi.org/10.1016/j.theriogenology.2008.04.025
29. Ayres H, Ferreira RM, Torres-Júnior JRS, Demétrio CGB, Sá Filho MF, Gimenes LU, et al. Inferences of body energy reserves on conception rate of suckled Zebu beef cows subjected to timed artificial insemination followed by natural mating. Theriogenology 2014;82(4):529-36. DOI: https://doi.org/10.1016/j.theriogenology.2014.04.026
30. García W, Leyva V. Índices genéticos estimados para peso corporal en llamas. Rev Investig Vet Perú 2007;18(1):11-7. DOI: https://doi.org/10.15381/rivep.v18i1.1269
31. Cavestany D, Blanc JE, Kulcsar M, Uriarte G, Chilibroste P, Meikle A, et al. Studies of the transition cow under a pasture-based milk production system: metabolic profiles. J Vet Med A Physiol Pathol Clin 2005;52(1):1-7. DOI: https://doi.org/10.1111/j.1439-0442.2004.00679.x
32. Kapustka J, Budzyńska M. Reproductive losses and their causes in alpacas a survey-based study. Animals 2022;12(21):3030. DOI: https://doi.org/10.3390/ani12213030
33. D'Occhio MJ, Baruselli PS, Campanile G. Influence of nutrition, body condition, and metabolic status on reproduction in female beef cattle: A review. Theriogenology 2019;125:277-84. DOI: https://doi.org/10.1016/j.theriogenology.2018.11.010
34. Fontes PLP, Oosthuizen N, Ciriaco FM, Sanford CD, Canal LB, Cooke RF, et al. Effects of nutrient restriction on the metabolic profile of *Bos indicus*-influenced and *B. taurus* suckled beef cows. Animal 2021;15(3):100166. DOI: https://doi.org/10.1016/j.animal.2020.100166
35. McArt JA, Nydam DV, Oetzel GR, Overton TR, Ospina PA. Elevated non-esterified fatty acids and β-hydroxybutyrate and their association with transition dairy cow performance. Vet J 2013;198(3):560-70. DOI: https://www.doi.org/10.1016/j.tvjl.2013.08.011
36. Wittwer FG, editor. Manual de patología clínica veterinaria. 3ra ed [Internet]. Valdivia: Ediciones Universidad Austral de Chile; 2021 [citado 22 de abril de 2023]. Recuperado a partir de: https://www.google.com.bo/books/edition/Manual_de_patolog%C3%ADa_cl%C3%ADnica_veterinari/nQM0EAAAQBAJ?hl=es&gbpv=1
37. Zaki MG, Baraka TA, Elkhiat MA, Younis MR, Tayeb FAEF. Determination of hematobiochemical and fore stomach fluid constituents of llama (*Lama glama*) living in Egypt. Trop Anim Health

Prod 2023;55(6):403. DOI: https://doi.org/10.1007/s11250-023-03820-z

38. McKenzie EC, Guerra JC, Middleton JR, Kim DY, Williams F 3rd, Garcia TM, et al. Black oil sunflower seed ingestion associated with renal azotemia, gastroesophageal ulceration, and a high mortality rate in four alpacas and two llamas. J Am Vet Med Assoc 2021;259(4):406-14. DOI: https://doi.org/10.2460/javma.259.4.406

39. Hengrave Burri I, Tschudi P, Martig J, Liesegang A, Meylan M. Neuweltkameliden in der Schweiz. II. Referenzwerte für hämatologische und blutchemische Parameter. Schweiz Arch Tierheilk 2005; 147(8):335-43. DOI: https://doi.org/10.1024/0036-7281.147.8.335

40. Tallacagua-Terrazas R, Mamani-Tola R. Determinación de los parámetros bioquímicos sanguíneos y hematología, en Llamas (*Lama glama*) en el Altiplano Central, La Paz. Apthapi 2017;3(3):693-701.

41. Copa S, Condori R. Parámetros bioquímicos sanguíneos en llamas (*Lama glama*) alimentadas en praderas nativas tholar pajonal en Choquecota Oruro, Bolivia. Rev Inv Cs Agro y Vet 2020;4(10):15-25. DOI: https://doi.org/10.33996/revistaalfa.v4i10.68

42. Foster A, Bidewell C, Barnett J, Sayers R. Haematology and biochemistry in alpacas and llamas. In Practice 2009;31(6):276-81. DOI: https://doi.org/10.1136/inpract.31.6.276

43. Kiani A, Alstrup L, Nielsen MO. Differential metabolic and endocrine adaptations in llamas, sheep, and goats fed high- and low-protein grass-based diets. Domest Anim Endocrinol 2015;53:9-16. DOI: https://doi.org10.1016/j.domaniend.2015.03.006

44. Fumuso FG, Carretero MI, Chaves MG, Arraztoa CC, Veiga MF, Schapira A, et al. Neurological disorder in a male llama originated by an abscedative myositis. Trends Med 2020;20:1-3. DOI: DOI: https://doi.org/10.15761/TiM.1000225

45. Huamán M, Olazábal-Loaiza J, San Martín F. Proteína cruda de la dieta y nitrógeno ureico sanguíneo en alpacas y ovejas. Rev Investig Vet Perú 2023;34(1):e24617. DOI: https://doi.org/10.15381/rivep.v34i1.24617

46. Tshuma T, Fosgate GT, Hamman R, Holm DE. Effect of different levels of dietary nitrogen supplementation on the relative blood urea nitrogen concentration of beef cows. Trop Anim Health Prod 2019;51(7):1883-91. DOI: https://doi.org/10.1007/s11250-019-01883-5

47. Calsamiglia S, Ferret A, Reynolds CK, Kristensen NB, van Vuuren AM. Strategies for optimizing nitrogen use by ruminants. Animal 2010;4(7):1184-96. DOI: https://doi.org/10.1017/S1751731110000911

48. Dixon CE, Kelley D, Froehlich JM, Gruntman A, Oura T, Mazan MR, et al. Therapeutic plasma exchange to mitigate flunixin meglumine overdose in a cria. J Vet Emerg Crit Care (San Antonio) 2021;31(4):521-4. DOI: https://doi.org/10.1111/vec.13071

49. Van Saun RJ. Nutrient requirements of South American camelids: a factorial approach. Small Rumin Res 2006;61(2-3):165-86. DOI: https://doi.org/10.1016/j.smallrumres.2005.07.006

50.Reynolds CK, Kristensen NB. Nitrogen recycling through the gut and the nitrogen economy of ruminants: an asynchronous symbiosis. J Anim Sci 2008;86 Suppl 14:E293-305. DOI: https://doi.org/10.2527/jas.2007-0475

51.Blanche D, Vaughan J, Maloney S, Milton J. Feeding Alpacas to Enhance reproduction and fleece quality. Australia: Rural Industries Research and Development Corporation; 2011.

52.Chamorro MF, Passler T, Joiner K, Poppenga RH, Bayne J, Walz PH. Acute renal failure in 2 adult llamas after exposure to Oak trees (*Quercus* spp.). Can Vet J 2013;548(1):61-4.

53.Jankovsky JM, Newman SJ. Pathology in Practice. Vitamin D toxicosis in an alpaca cria. J Am Vet Med Assoc 2017;251(5):531-4. DOI: https://doi.org/10.2460/javma.251.5.531

54.Wagener MG, Ganter M. Body condition scoring bei neuweltkamelen. Der Praktische Tierarzt 2020;101(7):684-96. DOI: https://doi.org/10.2376/0032-681X-2020

55.Tornquist SJ, Van Saun RJ, Smith BB, Cebra CK, Snyder SP. Hepatic lipidosis in llamas and alpacas: 31 cases (1991-1997). J Am Vet Med Assoc 1999;214(9):1368-72. DOI: https://doi.org/10.2460/javma.1999.214.09.1368

56.Fowler ME, Bravo PW. Feeding and Nutrition. In: Fowler ME, Bravo PW, editors. Medicine and Surgery of Camelids [Internet]. Singapore: Wiley-Blackwell; 2010. p. 17-58. DOI: https://doi.org/10.1002/9781118785706.ch2

57.Cebra CK, Tornquist SJ, Van Saun RJ, Smith BB. Glucose tolerance testing in llamas and alpacas. Am J Vet Res 2001;62(5):682-6. DOI: https://doi.org/10.2460/ajvr.2001.62.682

58.Burton S, Robinson TF, Roeder BL, Johnston NP, Latorre EV, Reyes SV, et al. Body condition and blood metabolite characterization of alpaca (*Lama pacos*) three months prepartum and offspring three months postpartum. Small Rumin Res 2003;48(2):69-76. DOI: https://doi.org/10.1016/S0921-4488(02)00257-2

59.Bobowiec R, Kierska M, Kosior-Korzecka U. Insulin sensitivity in high-producing lactating cows. Medycyna Wet 2011;67(3):181-5.

60.Holtenius P. Hormonal regulation related to the development of fatty liver and ketosis. Acta Vet Scand 1993;89(Suppl.):55-60.

61.Holtenius P, Holtenius K. New aspects of ketone bodies in energy metabolism of dairy cows: a review. Zentralbl Veterinarmed A 1996;43(10):579-87. DOI: https://doi.org/10.1111/j.1439-0442.1996.tb00491.x

62.Husakova T, Pavlata L, Pechova A, Hauptmanova K, Pitropovska E, Tichy L. Reference values for biochemical parameters in blood serum of young and adult alpacas (*Vicugna pacos*). Animal 2014;8(9):1448-55. DOI: https://doi.org/10.1017/S1751731114001256

63.Jorritsma R, Jorritsma H, Schukken YH, Wentink GH. Relationships between fatty liver and fertility and some periparturient diseases in commercial Dutch dairy herds. Theriogenology 2000;54(7):1065-74. https://doi.org/10.1016/S0093-691x(00)00415-5

64.Putman AK, Brown JL, Gandy JC, Wisnieski L, Sordillo LM. Changes in biomarkers of nutrient metabolism, inflammation, and oxidative stress in dairy cows during the transition into the early dry period. J Dairy Sci 2018;101(10):350-59. DOI: https://doi.org/10.3168/jds.2018-14591

65. Ponter AA, Douar C, Mialot J-P, Benoit-Valiergue H, Grimard B. Effect of underfeeding postpartum Charolais beef cows on composition of plasma non-esterified fatty acids. Animal Science 2000;71(2):243-52. DOI: https://doi.org/10.1017/s1357729800055077

66. Alforma AMP, Pereira GR, da Rocha MK, Teixeira ODS, de Oliveira MCM, Lima JA, et al. Influence of weaning management at 30, 75 and 180 days of age on non-esterified fatty acids and reproductive performance in beef cows. J Anim Physiol Anim Nutr (Berl) 2023;107(2):407-17. DOI: https://doi.org/10.1111/jpn.13736

67. Reist MD, Erdin D, von Euw D, Tschuemperlin K, Leuenberger Y, Chilliard Y, et al. Estimation of energy balance at the individual and herd level using blood and milk traits in high-yielding dairy cows. J Dairy Sci 2022;85(12):3314-27. DOI: https://doi.org/10.3168/jds.S0022-0302(02)74420-2

68. Nikkhah A, Alimirzaei M. Management updates on prepartal stress effects on transition cow and calf health. World Vet J 2023;13(2):250-7. DOI: https://doi.org/10.54203/scil.2023.wvj27

69. Pritchard CE, Palme R, Langkilde T. Glucocorticoid and triiodothyronine concentrations do not correlate with behavior in vicuñas (*Vicugna vicugna*). Gen Comp Endocrinol 2020;286:113299. DOI: https://doi.org/10.1016/j.ygcen.2019.113299

70. Sylla L, Crociati M. Pregnancy toxemia and lipid mobilization syndrome in two alpaca (*Vicugna pacos*) at 6 and 10 months of gestation. Large Anim Rev 2020;26(6):317-20.