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UNIVERSIDADE ESTADUAL PAULISTA "JULIO DE MESQUITA FILHO"
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CÂMPUS DE JABOTICABAL

PROTEIN AND ENERGY REQUIREMENTS FOR MAINTENANCE AND GROWTH IN DAIRY GOATS: A META-ANALYSIS

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TÍTULO: PROTEIN AND ENERGY REQUIREMENTS FOR MAINTENANCE AND GROWTH IN DAIRY GOATS: A META-ANALYSIS

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BIOGRAPHY

ANAIANE PEREIRA SOUZA was born in September 22, 1988, in Miguel Calmon, Bahia, Brasil. From 2006 to 2010, she did her undergraduate study in Animal Science at Universidade Federal da Paraíba, Areia, Paraíba, Brasil. During her undergrad, she completed an internship at Universidade Técnica de Lisboa, Lisboa, Portugal, from September 2008 to February 2009. She became graduate student at Universidade Federal da Paraíba and concluded her Master’s degree in Animal Science in February 2013. She focused on nutritional requirements for indigenous goats under supervision of Dr. Ariosvaldo Nunes de Medeiros. In 2013, she began her doctoral degree at Universidade Estadual Paulista, Jaboticabal, São Paulo, Brasil, and she worked on a meta-analysis of nutritional requirements for dairy goats under supervision of Dr. Izabelle Auxiliadora Molina de Almeida Teixeira. She also completed a graduate internship at The Ohio State University, Columbus, Ohio, USA, from January 2015 to December 2015 under supervision of Dr. Normand St-Pierre.

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SUMMARY

PROTEIN AND ENERGY REQUIREMENTS FOR MAINTENANCE AND GROWTH IN DAIRY GOATS: A META-ANALYSIS

ABSTRACT - A database of seven comparative slaughter studies of Saanen goats was gathered to predict the protein and energy requirements for maintenance and growth of dairy goats. For the evaluation of energy utilization by dairy goats we used 238 Saanen goats subjected to three levels of intake. The experimental design provided different levels of metabolizable energy intake (MEI) and body weight (BW), allowing the development of regression equations to predict the net energy requirements for maintenance (NE_M). The nonlinear relationship between MEI and heat production was used to estimate the NE_M and the requirements of ME for maintenance (ME_M). The efficiency of energy utilization for maintenance (k_m) was calculated as the relationship between NE_M and ME_M. The slope between retained energy (RE) and metabolizable energy intake above maintenance (MEI_G) was adopted as the efficiency of utilization of ME for growth (k_g). The efficiency of utilization of energy for protein and fat deposition (k_p and k_f, respectively) were calculated using a multiple regression on MEI_G (model intercept equal to 0) on the RE as protein (RE_p) and RE as fat (RE_f). For the development of linear and non-linear equations we used MIXED and NLMIXED procedures in SAS considering sex (castrated male, intact male, and female, *n* = 80, 98, and 60, respectively) as fixed effect and block nested in study and sex as random effect. The NE_M was affected by sex where castrated males and intact males have similar requirements (75 kcal/kg$^{0.75}$ empty BW); on the other hand, females presented a lower value (64 kcal/kg$^{0.75}$ empty BW). The k_m did not differ between sexes (0.62). The k_g was different between sexes (0.32 for castrated males, 0.26 for intact males, and 0.31 for females) but the k_p (0.21) and k_f (0.80) were similar between sexes. For the evaluation of the net protein requirements for maintenance (NP_M) of dairy goats we used 185 Saanen goats subjected to three levels of intake. The equations were analyzed using MIXED procedure of SAS, sex was considered as fixed effect and block nested in study and sex as random effect. The NP_M was assumed to be the intercept of the linear regression of the N retained (g/kg$^{0.75}$ BW) on the total N intake (g/kg$^{0.75}$ BW) multiplied by 6.25. The NP_M was similar between sexes. Using the comparative slaughter technique, the daily estimated NP_M was 1.23 g/kg$^{0.75}$ BW; lower than the one using N balance method (3.18 g/kg$^{0.75}$ BW) for dairy growing goats and previous reports by the current feeding systems. For estimating the net requirements of protein (NP_G) and energy (NE_G) for growth we used only animals fed ad libitum (n = 238). The allometric equation included the fixed effects of sex (castrated male, male and female, *n* = 73, 94, and 71, respectively) and the random effect of study. The net requirements for growth were estimated as the first partial derivative of allometric equations in relation to empty BW. The estimated parameters were obtained using the MIXED procedure of SAS. Sex affects the NP_G, where female goats showed lower NP_G than male goats (castrated males and intact males). The NE_G of castrated males was greater than intact males, and lower than females.

Keywords: allometry, comparative slaughter, nutritional requirements, Saanen

EXIGÊNCIAS DE PROTEÍNA E ENERGIA PARA MANTENÇA E CRESCIMENTO DE CAPRINOS LEITEIROS: UMA METANÁLISE

RESUMO - Um banco de dados de sete estudos de abate comparativo utilizando caprinos Saanen foi construído para predizer as exigências de proteína e energia para mantença e crescimento de caprinos leiteiros. Para a avaliação da utilização de energia por caprinos leiteiros foram utilizados 238 caprinos Saanen submetidos a três níveis alimentação. O delineamento experimental proporcionou variação no consumo de energia metabolizável (CEM) e peso corporal (PC), permitindo o desenvolvimento de equações de regressão para predição das exigências líquidas de energia para mantença (EL_M). A relação não linear entre CEM e produção de calor foi utilizada para estimativa das exigências de EL_M e as exigências de energia metabolizável para mantença (EM_M), a eficiência de uso de energia para mantença (k_m) foi calculada como a relação entre EL_M e EM_M. O coeficiente de inclinação entre a energia retida (ER) em relação ao consumo de energia metabolizável acima da mantença (CEM_G) foi adotado como a eficiência de utilização de EM para crescimento (k_g). A eficiência de utilização de EM para retenção de proteína (k_p) e gordura (k_f) foram calculadas utilizando uma regressão múltipla do CEM_G (modelo com intercepto igual a 0) na ER como proteína e na ER como gordura. Para o desenvolvimento das equações lineares foi utilizado o PROC MIXED e para as não lineares o PROC NLINMIXED do software SAS considerando a classe sexual (macho castrado, macho inteiro e fêmea; 80, 98, e 60, respectivamente) como efeito fixo e bloco aninhado a estudo e a classe sexual como efeito aleatório. Classe sexual afetou a EL_M, de modo que machos castrados e machos inteiros não diferiram e apresentaram exigências superiores (75 kcal/kg^{0,75} PC vazio) aos valores obtidos para fêmeas (64 kcal/kg^{0,75} PC vazio) utilizando o método do abate comparativo. Os valores de k_m não diferiram entre classes sexuais (0,62). Os valores de k_g foram diferentes entre classes sexuais (0,32 para machos castrados, 0,26 para machos inteiros, e 0,31 para fêmeas) e k_p (0,21) e k_f (0,80) foram semelhantes entre classes sexuais. Para avaliação das exigências líquidas de proteína para mantença (PL_M) de caprinos leiteiros foram utilizados 185 caprinos Saanen submetidos a três níveis de alimentação. As equações foram analisadas usando o PROC MIXED do SAS, a classe sexual foi considerada como efeito fixo e bloco aninhado a estudo e classe sexual foi considerado efeito aleatório. A PL_M foi assumida como o intercepto da regressão linear entre o N retido (g/kg^{0,75} PC) em relação ao N ingerido (g/kg^{0,75} de PC) multiplicado por 6,25. A PL_M foi semelhante entre sexos. Usando a técnica de abate comparativo a PL_M foi 1,23 g/kg^{0,75} PC foi inferior à estimada usando balanço de N (3,18 g/kg^{0,75} PC) para caprinos leiteiros em crescimento e recomendações dos atuais sistemas de alimentação. Para as exigências líquidas de proteína e energia para crescimento (PL_G e EL_G respectivamente) foram utilizados apenas animais alimentados ad libitum (n = 238). Os parâmetros foram estimados usando o PROC MIXED do SAS. O modelo incluiu o efeito fixo de classe sexual (macho castrado, macho inteiro e fêmea; 73, 94 e 71, respectivamente) e o efeito aleatório de estudo. As exigências líquidas para crescimento foram estimadas como a primeira derivada parcial das equações alométricas em relação ao PC vazio. Houve efeito de classe sexual nas exigências líquidas de proteína (PL_G) e energia (EL_G) para crescimento, em que para PL_G, machos inteiros e machos castrados não diferiram, no entanto apresentaram valores superiores aos valores obtidos para fêmeas. Em relação aos valores de EL_G, machos castrados apresentaram valores superiores aos valores de machos inteiros e inferiores aos valores de fêmeas.

Palavras-chave: abate comparativo, alometria, exigências nutricionais, Saanen

LIST OF ABBREVIATIONS

ADG	Average daily gain
AL	Ad libitum
BW	Body weight
CP	Crude protein
DE	Digestible energy
DMI	Dry matter intake
EBW	Empty body weight
EWG	Empty weight gain
GE	Gross energy
GH	Growth hormone
HP	Heat production
k_f	Efficiency of energy retained as fat
k_g	Efficiency of energy utilization for growth
k_m	Efficiency of ME utilization for maintenance
k_p	Efficiency of energy retained as protein
LCI	Lower confidence limit
ME	Metabolizable energy
ME_G	Metabolizable energy requirement for growth
MEI	Metabolizable energy intake
MEI_G	Metabolizable energy intake above maintenance
ME_M	Metabolizable energy requirement for maintenance
ML	Maintenance level
MP_G	Metabolizable protein requirement for growth
MR	Moderate feed restrition
N	Nitrogen
NE_G	Net energy requirement for growth
NE_M	Net energy requirement for maintenance
NP_G	Net protein requirement for growth
NP_M	Net protein requirement for maintenance
Q	Metabolizability
RE	Retained energy
RE_f	Energy retained as fat
RE_p	Energy retained as protein
SD	Standard deviation
SEM	Standard error of mean
UCI	Upper confidence limit
σ^2_e	Estimated residual variance
σ^2_s	Estimated study variance
$\sigma^2_{b:s}$	Estimated block nested in study variance

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DISSERTATION STRUCTURE

Chapter 1 is a literature review, about protein and energy requirements for maintenance and growth, covering the main concepts, factors that influence, and the methods used to predict these requirements. It was written following the guidelines of the Graduate Program in Animal Science of Unesp, Jaboticabal Campus.

Chapter 2 describes the energy requirements and efficiency of energy utilization by dairy goats. This chapter was also written following the guidelines of the Journal of Dairy Science except by the letter style, spaces between lines, and position of tables. The paper authors are A. P. Souza, N. R. St-Pierre, M. H. R. M. Fernandes, A. K. Almeida, J. A. C. Vargas, K. T. Resende and I. A. M. A. Teixeira.

Chapter 3 is a technical note about the protein requirements for maintenance in growing dairy goats. This chapter was also written following the guidelines of the Journal of Dairy Science except by the letter style, spaces between lines, and position of tables. The authors are A. P. Souza, N. R. St-Pierre, M. H. R. M. Fernandes, A. K. Almeida, J. A. C. Vargas, K. T. Resende and I. A. M. A. Teixeira.

Chapter 4 describes the protein and energy requirements for growth of dairy goats. This chapter was modified from the paper published in the Journal of Dairy Science in 2017 (doi/10.3168/jds.2016-11895). The paper authors are A. P. Souza, N. R. St-Pierre, M. H. R. M. Fernandes, A. K. Almeida, J. A. C. Vargas, K. T. Resende and I. A. M. A. Teixeira.

Chapter 5 describes the main implications of this study, written following the guidelines of the Graduate Program in Animal Science of Unesp, Jaboticabal Campus.

CHAPTER 1. GENERAL CONSIDERATIONS

INTRODUCTION

Goats are rustic animals existing in distinct regions of the world, which have been historically used for many purposes such as milk, meat, fiber and skin production (DUBEUF et al., 2004). The goat's milk production in the world has risen by about 60% in the last 20 years (FAOSTAT, 2015). Making the correct choice of the goat's breed and providing a diet adequately formulated to supply the nutrients and energy for optimal production are essential steps for meeting the demand of goat dairy products, thereby improving the efficiency of the production system. In this sense, the Saanen breed is one of the best breeds used in dairy production, because, on average, they produce a greater amount of milk compared to other dairy breeds (RIBEIRO, 1997).

Knowledge about the protein and energy requirements of the dairy goats and about the composition of the feedstuffs used, are the basis for providing a balanced diet in the production system. The importance of an adequate supplying of protein lies in its function as it pertains to animal production and the high costs of the sources of protein for diets. Additionally, animals that are either underfed or overfed in energy may exhibit reproductive problems throughout their lives (RUKKWAMSUK et al., 1999; FENWICK et al., 2008).

The knowledge about body composition is important for estimating the nutritional requirements because they are associated (NRC, 2007). One of the factors that may affect the body composition is the sex of an animal (GEAY, 1984; HERRING et al., 2013). The effects of sexual hormones on the deposition of muscle and adipose tissue have been studied in cattle where differences in body composition between sexes, and, consequently, differences between protein and energy requirements for maintenance and growth were found (ARC, 1980; NRC, 2007). However, the effect of the sex of an individual on the requirements for maintenance and growth remains poorly quantified in goats.

This review will discuss the main factors related to protein and energy requirements for maintenance and growth in dairy goats. Furthermore, it will discuss the main methods used to predict those requirements.

PROTEIN AND ENERGY REQUIREMENTS FOR MAINTENANCE

Protein and energy requirements are frequently estimated by the factorial approach (NRC, 2007). The requirements for maintenance describe the nutrient quantities, or energy, for the basic functions in the body (AFRC, 1998). The losses of nitrogen in urine, feces, and skin are associated with the concept of nitrogen required for maintenance, since this considers the sum of the losses that occur in the body for the basal functions (AFRC, 1998). On the other hand, the energy requirements for maintenance have been defined as the amount of the feed energy intake that will not result in net loss or gain of energy from tissues of the animal body (NRC, 2007, NRC 2016).

The body composition also may affect the requirements for maintenance because the metabolic activity differs between tissues that constitute the body. The expenditure of energy by muscular tissues and organs will be different from the expenditure in adipose tissues, for example (GILL et. al, 1989).

Protein requirements for maintenance

Factors related to the animal as well as diets may affect the protein requirements for maintenance (CANNAS et al., 2008). The metabolic fecal crude protein includes crude protein (CP), such as enzymes and epithelial cells in the true endogenous losses (AFRC, 1998; NRC, 2007). Urinary CP includes costs associated with protein turnover, and those costs are usually lower than the fecal CP. Protein included in dermal losses, such as scurf and fiber, are also described as requirements for maintenance (AFRC, 1998; NRC, 2007).

The effect of sex is not reported in the protein requirements for maintenance by the current feeding systems (AFRC, 1998; CSIRO, 2007; NRC, 2007). Due to a lack of information about the protein requirements for maintenance, the current feeding systems still consider similar requirements to those reported for sheep and cattle. In a meta-analytical study, SALAH et al (2014) showed that the net protein required for maintenance (NP_M) in sheep was greater than the value found in goats (3.36 g/kg$^{0.75}$ BW vs 2.38 g/kg$^{0.75}$ BW). In the same study, they reported that the protein requirements for animals in warm climates are different from the values reported by the current feeding systems (AFRC, 1998; CSIRO, 2007; NRC, 2007).

Energy requirements for maintenance

The factors that affect the metabolizable energy requirement for maintenance (ME_M) are associated with animal characteristics, as well as the diets used in each situation (AFRC, 1993). Functions comprising the energetic costs for maintenance include body temperature regulation, essential metabolic processes, and physical activity (NRC, 2016). Among factors related to the animal, the effect of sex has been discussed and the current feeding systems for ruminants have reported that intact males have 15% greater requirements than females (ARC, 1980; CSIRO, 1990; NRC, 2000; NRC, 2007; BR-CORTE, 2016; NRC, 2016). The differences between sexes are associated with differences in body composition and the stage of maturity at a given BW (NRC, 2000).

As reported in the NE_G, it is preferred to express the requirements for maintenance in net terms than based on digestible energy (DE), total digestible nutrients (TDN), or metabolizable energy (ME). However, it requires predicting the efficiency of the utilization of energy.

In a meta-analysis using animals in warm climates, Salah et al. (2014) reported a value of ME_M of 105 kcal/kg$^{0.75}$ BW for goats. The reports by the current feeding systems are greater, when NRC (2007) and AFRC (1998) reported 128 and 117 kcal/kg$^{0.75}$ BW of ME_M, respectively. Independent studies conducted in goats have found that sex did not affect the energy requirements for maintenance (ASH & NORTON, 1987; BOMPADRE et al., 2014; ALMEIDA, et al., 2015a, FIGUEIREDO, et al., 2016b).

METHODS TO ESTIMATE THE PROTEIN AND ENERGY REQUIREMENTS

Different methods have been used to estimate the protein requirements in ruminant nutrition such as N balance and the comparative slaughter technique (ARC, 1980). In the N balance method, the maintenance requirements are estimated based on the losses of N in feces and urine, measuring them during a metabolism trial. The N balance is considered a better conceptual representation of the protein requirements for maintenance (ALMEIDA, et al., 2015b), however, this is based on a short period of experiment; consequently, this may be affected by any condition during this specific period (FORBES, 1973; HEGSTED, 1976). Due to limitations reported for the N balance method, the comparative slaughter technique, first developed for estimating energy requirements (LOFGREEN & GARRET, 1968), has been also adopted to determinate the protein requirements for maintenance (CHIZZOTTI et al., 2008.; ALMEIDA, et al., 2015b). In the comparative slaughter technique, the body composition of animals submitted to different levels of intake is evaluated; the procedures measure both protein intake and retained protein. In both methods, a regression of the retained N in the daily gain on N intake is used to calculate the net N requirement for maintenance. The intercept of the regression equation is assumed to be the endogenous and metabolic losses of N, which multiplied by the factor 6.25, is defined as the NP_M (ARC, 1980).

Basically, three methods have been used to measure the energy requirements: feeding trials, the comparative slaughter technique, and calorimetric methods. Using the feeding trials, it is the energy requirements for maintenance that are estimated by the quantity of feed needed to maintain BW that is determined. In the comparative slaughter technique, included in The California System, it is possible to obtain the energy requirements in net terms (LOFGREEN & GARRET, 1968), the differences in the body composition of animals fed in different levels of energy is obtained, and the heat production (HP) is calculated based on the retained energy (RE). The efficiency of energy utilization for maintenance (k_m) is obtained using the simple ratio between net energy for maintenance (NE_M) and the metabolizable energy for maintenance (ME_M), and the efficiency of energy utilization for growth (k_g) is estimated as the slope of the linear regression between RE and MEI above maintenance. The comparative slaughter technique presents the measurement of the body composition but lacks complexity and the costs of measurements (NRC, 2000); in this sense, the number of animals is limited. The calorimetric method has traditionally been used to estimate the energy requirements for maintenance, where the method is conducted in respiration chambers to measure gas exchange, fasting heat production and energy loss via urine and methane with animals fed at maintenance level (SALAH et al., 2014).

PROTEIN AND ENERGY REQUIREMENTS FOR GROWTH

The simplest definition of growth means getting bigger. In one individual animal we could refer to cell growth, tissue growth, or organ growth, but this discussion would be restricted to the physical aspects of growth (LAWRENCE, et al., 2012). The main interest when we study dairy animals lies in the growth of specific parts of the body such as bone, muscle, fat, or the development of the mammary gland, because these ones will be associated with the reproductive and productive lives of the animals (PETERS, 1983; LAWRENCE, et al., 2012). In this sense, we will develop the concept of growth related to body composition to evaluate, herein, in the field of nutritional requirements.

The net protein and net energy requirements for growth (NP_G and NE_G, respectively) can be more accurately defined based on the deposition of different tissues in the body (NRC, 2000). One of the factors that may affect the deposition of the different tissues, and consequently the nutritional requirements, is the genotype, since different breeds, for example, have different body composition mainly for presenting different weights at maturity (NRC, 2007; WEBSTER, 1986). Beyond the species or breeds, the body composition, and consequently the protein and energy requirements, may be affected by the physiological stage and sex of the animal in which the growth rate of bones, muscles, and adipose tissues are affected by different hormones during life (GEAY, 1984; LAWRENCE et al., 2012). Indeed differences in sexes also represent differences in maturity weight in dairy goats because of the distinct deposition of fat and protein in males and females, where females reach maturity earlier than males (ALMEIDA et al., 2016). Younger animals tend to present more protein and minerals in their bodies; on the other hand the deposition of fat increases with aging (OWENS et al., 1993; LAWRENCE et al., 2012).

Over the years, tissue growth and body composition have been studied in different species. BRODY (1945) detailed aspects related to bioenergetics and growth in ruminants. Different methods for determine body composition were also revised by BLAXTER (1989). Different researchers have verified that the animal grows to its adult weight following a sigmoid curve for cumulative growth (LAWRENCE, et al., 2012). In an attempt to model these variables, the model proposed that best describes the postnatal growth was the allometric model. Allometry, by definition, designates the changes in relative dimensions of parts of an organism that are correlated with changes in overall size (GAYON, 2000). The allometric equation usually takes the form of a two-parameter power function:

$$Y = a X^b$$

where Y is a biological variable of special interest, X is a measure of body size, and a and b are fitted parameters known as the allometric coefficient and allometric exponent, respectively (PETERS, 1983).

The concept of allometry has been adopted since 1968 in the comparative slaughter technique to predict NE_G (LOFGREEN & GARRET, 1968). This concept is adopted for understanding the requirements of an animal based on the specifics constituents (fat or protein).

Most investigators, however, work with logarithmic transformations of their data, so the mentioned equation is commonly expressed in the mathematical equivalent form as:

$$\log Y = \log a + b \log X$$

Traditional practice is to fit a straight line to logged values, usually by the method of ordinary least squares, and then to back-transform the resulting equation from logarithmic to arithmetic scale to obtain estimates for the parameters *a* and *b* (ZAR, 1968; SMITH, 1993). After that, the errors are multiplicative. The multiplicative error model assumes that the measures differ by equal proportion, and this is in line with the multiplicative nature of biological processes (KERKHOFF & ENQUIST, 2009). In this sense, the logarithmic transformation remains as an important and advantageous tool in allometry.

Protein requirements for growth

The current feeding systems for goats (NRC, 2007) and for cattle (NRC, 2000; NRC, 2016; BR-CORTE, 2016) have expressed the protein requirements in terms of metabolizable protein (MP) rather than crude protein (CP). The adoption of MP is basically explained by two reasons: there is now more information about the MP system which allows at more accurate prediction, and also because the CP system is based on an invalid assumption that the feedstuffs have an equal extent of protein degradation in the rumen (NRC, 2016). Net terms are also adopted to express the protein requirements for representing the absorption and incorporation of protein in the body (NRC, 2016). Net protein required is determined based on the retention of the protein in the body, and this will directly represent the amount of protein that an animal needs for archiving a specific average daily gain. The problems related to net proteins are the necessity of understanding the efficiency of utilization of the protein intake that will be affected either by the animals, or by the characteristics of each ingredient, or even by the combination of the ingredients in the diets (NRC, 2016).

The effect of sex on the body protein was verified in cattle, in which males present greater lean content than females at a similar body weight (BW; BERG & BUTTERFIELD, 1976; SEIDMAN et al., 1982; GEAY, 1984). On the other hand, studies with goats did not report differences in body protein between sexes (ALMEIDA et al., 2015b; FIGUEIREDO et al., 2016b), and consequently in the protein requirements. The current feeding systems for goats do not make a distinction in regards to the effect of sex on the protein requirements. The NRC (2007) reported that the MP estimated for growth (MP_G) in dairy goats is 290 g/kg BW gain, irrespective of sex. In the AFRC (1998) the NP_G ranged from 126 to 154 g/kg BW gain in goats weighing between 5 and 45 kg BW, evaluating mainly data from castrated goats.

Energy requirements for growth

The NE_G is defined based on the content of the tissue deposited using the comparative slaughter, which energy is a function of the proportion of fat and protein in the body (GARRET et al., 1980). The energy requirements are preferred expressed in net terms rather than based on digestible energy (DE), total digestible nutrients (TDN), or metabolizable energy (ME). However, this requires predicting the efficiency of energy use, and there are still few serial slaughter studies to allow this estimation (SAHLU et al., 2004; NRC, 2007).

Sex is a factor that determines the composition of growth, where hormonal regulations can establish biological limits for protein and fat deposition (BYERS, 1982). In response to changes in absorbed nutrients, the hormonal regulations in females results in a greater increase of fat in their body, and consequently, a greater amount of energy than in males (CHIZZOTTI et al., 2008; ALMEIDA et al., 2015a). This is possibly because of the earlier fat deposition in the abdominal tissues of females, which is an innate preparation of the female for future pregnancy (BERG & BUTTERFIELD, 1976). Sexual hormones are involved in the control of many mechanisms, and testosterone is one of the hormones that affect the secretion of growth hormone (GH); and it is also synergistic with estrogen for enhancing deposition of lean tissue (OWENS et al., 1993). The importance of GH in modulating lipid metabolism by decreasing glucose transportation and lipogenesis was detailed by LOUVEAU & GONDRET (2004).

The NE_G estimated by AFRC (1998) ranges from 2.2 to 4.1 Mcal/kg EBW gain, but there is no distinction between sexes in their estimation. The AFRC (1998) used studies mainly with castrated males, by the comparative slaughter technique. The NRC (2007) also does not incorporate a sex effect on the energy requirements for growth. In NRC (2007), the requirements are expressed in ME units (ME_G; 5.5 Mcal/kg BW gain). Variation in diet and body composition components has been reported to affect the partial efficiency of energy use for gain in lambs (k_g; GALVANI et al., 2014; ALMEIDA et al., 2015a).

META-ANALYSIS IN ANIMAL SCIENCE

The research in ruminant nutrition has markedly increased in the last years. In particular, there is a notable increase in the number of publications, which enhanced the number of experimental data available (ST-PIERRE, 2007). The aggregation of the information of several experiments may increase the possibility to get a better understanding of nutritional processes in the animal, allowing for the conclusion about animal responses in a broader application range than individual experiments (ST-PIERRE, 2001). Despite this, controlled and non-controlled factors, such as the basal plane of nutrition, vary from study to study, thus eventually requiring a quantitative summarization technique (SAUVANT et al., 2008). At this point, the meta-analysis can be proposed as a quantitatively summarization technique to attend this objective, which isolates the study effect.

In this context, the meta-analysis stands out as a statistical procedure to obtain reliable results regarding the values of protein and energy requirements in dairy goats. The development of a meta-analysis is done in several stages. The first defines the objectives and identifies the previous selection criteria for including variables in the database, the characterization of the variables as discrete or continuous, and definitions of the effects as fixed and random should also be taken into consideration (ST-PIERRE, 2007; ST-PIERRE, 2011). The objectives and reasons for using meta-analysis as a statistical procedure in animal studies were detailed by LOVATTO et al. (2007) and by SAUVANT et al. (2008). These researchers pointed out five important objectives of using meta-analysis: to obtain new results; to synthetize results; to improve the power of an analysis; to provide a better representation across studies; and even to generate new hypotheses.

Over the past few decades, multiple comparative slaughter studies were conducted at Universidade Estadual Paulista to quantify the effect of sex on protein and energy requirements for maintenance and growth in dairy goats (GOMES, 2011; BOMPADRE et al., 2014; MEDEIROS et al., 2014; ALMEIDA et al., 2015a,b; FERREIRA et al., 2015; FIGUEIREDO et al., 2016a,b). A meta-analysis of the individual records from these studies will be presented in the next chapters.

OBJECTIVE

The main objective of the research described in this dissertation is to predict protein and energy requirements for maintenance and growth in dairy goats of different sexes over a wide range of body weight.

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CHAPTER 5. IMPLICATIONS

The knowledge about protein and energy requirements is essential to formulate diets and we focused on evaluating the effect of sex on the protein and energy requirements for growing dairy goats. The main contribution of the results obtained in this study is that sex affects the estimative of protein and energy requirements of dairy goats. Beyond the knowledge about nutritional requirements, it is important to highlight also that we found some relevant aspects about methodologies used herein.

Regarding the protein and energy requirements for growth, we found differences between sexes at similar BW, and we also found that those could be canceled out if we take into account the mature weight of the different sexes. For adopting the net requirements to formulate diets is crucial the knowledge about the efficiency of energy or protein use, which is affected by feed factors as well as animal factors. We evaluated animal factors and found that sex affects the efficiency of energy use for growth, considering that the animals received similar diets in this study, this area should be more investigated in future studies.

Regarding net energy requirements for maintenance, is very interesting the fact that values obtained herein were similar to those reported to other ruminants. We infer that the net energy requirement for maintenance between species are not as distinct as we presumed before, and in future models, those values could be evaluated between species.

There is a huge difference between methods of prediction of the protein requirements for maintenance (i.e., comparative slaughter technique and N balance). It is known that N balance conveys some limitations that tend to overestimate the protein requirements. Our findings suggest that for many years, probably, we have been feeding animals with more protein than they really need. The use of more accurate protein requirements in diets can improve animal performance as well as to reduce problems of N losses in water and soil quality.

Other contribution of this study relates to the methodologies used herein. This was the first dissertation in our graduate program using a large dataset to evaluate nutritional requirements of dairy goats. We verified clearly one of the great advantages of using meta-analysis in the topic evaluated; we had a statistic power that allowed us to verify differences in protein requirements for growth as well as differences in energy requirements for maintenance across sexes, which were not found in previous independent studies. Besides, we provided a summary of those requirements to Saanen goats of different sexes with BW ranging from 5 to 45 kg (Table 1).

Other statistical approaches used in this work contributed to the improvement of scientific field. We used allometric equations (nonlinear equation) to estimate requirements for growth. Contrary to the general concept, the log transformation in allometric equations used for estimating requirements for growth in our situation was still more appropriate based on the residual pattern than the use of nonlinear models in statistical programs.

Additionally, we highlighted one important aspect that is not usually taken into account and should be adopted in animal nutrition that is the evaluation of uncertainty. We cannot feed adequately dairy herds if we do not understand a dimension of the variation between animals. We investigated those aspects in protein and energy requirements using Monte Carlo method, and we understand that it could be adopted in other variables related to ruminant nutrition and in the field routine. We pointed out that in dairy herds, it is not necessarily the best choice to feed animals according to the mean value of those nutritional requirements and the uncertainty can contribute to build applicable stochastic models.

All in all, related to the contribution in the field of protein and energy requirements of dairy goats, it is still necessary to evaluate the relationship between feed and animal factors to better understand the efficiencies of use and to develop more robust models.

We expected that our findings might contribute to improve the accuracy of nutritional recommendations that can bring economic and environmental advantages in this production system.