SEMINA
Ciências Agrárias

DOI: 10.5433/1679-0359.2023v44n1p19

Economic valuations for technical indicators in sheep production

Valoração econômica para indicadores técnicos na produção de ovinos

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Highlights

Ewe weight at lambing and litter size influenced the weight of born lambs.
Kilos born, ewe age, lamb survival and daily gain affected kilos of lambs weaned.
Each additional year of the ewe at lambing increased the profit by US$ 3.78 ewe^{-1}.
FAMACHA© score 1 increased profit by US$ 1.09 (breeding) or US$ 1.71 (lambing).

Abstract

The objectives of this work were to identify and model the interrelationships among zootechnical indicators manifested in sheep production from an intensive system in Brazil and to ascertain the impact of these indicators on the economic and productive outcomes from management operations. To this end, two multiple regression models were developed to determine which indicators had influence, and in what proportion, on the quantity of kilograms of lambs sold in the system. In order to determine the effects of the FAMACHA© scores on ewes during breeding and lambing, as related to the production quantity in kilograms of weaned sheep, two analyses of one-factor variance were designed, in which the absolute (AEV) and relative (REV) economic values were assigned to zootechnical indicators. This approach was taken in order to verify which indices have the greatest effects on profit and, consequently, should be prioritized in the selection criteria. The primary indicators were found to be the prolificacy, ewe weight at lambing, ewe

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Received: Sept. 21, 2022 Approved: Jan. 20, 2023

age at lambing, average daily gain, offspring survival and the FAMACHA© score of the ewe at birth and at lambing; their significance (P<0.05) determined the number of kilograms of lambs produced in the system. The indicator with the highest AEV and REV was the age of the ewe at lambing, with US$ 3.78 year^{-1} ewe^{-1} and 54.09%, respectively. FAMACHA© score 1 provided the highest return to the system, with an absolute economic value of US$ 1.09 ewe^{-1} at breeding and US$ 1.71 ewe^{-1} at lambing. Scores 4 and 5 caused damage to both breeding and lambing, with -US$ 1.15 ewe^{-1} and -US$ 1.44 ewe^{-1} for score 4, and -US$ 1.24 ewe^{-1} and -US$ 1.76 ewe^{-1} for score 5 at breeding and at lambing, respectively. The findings indicated that the producer can manipulate the flock culling rate to increase the age of the dams in order to guarantee a greater productivity of sheep. Another indication would be to apply selection criteria to ensure an increase in the number of superior animals present in the system, especially animals that are resilient to worms. This strategy can facilitate increased profits without the need to significantly increase expenditure on inputs.
Key words: FAMACHA©. Lamb. Production cost. Profit.

Resumo

Os objetivos deste trabalho foram de identificar e modelar as inter-relações entre indicadores zootécnicos utilizados na produção de ovinos, em um sistema intensivo no Brasil, e verificar o impacto desses indicadores nos resultados econômicos e produtivos da propriedade. Para tanto, foram desenvolvidos dois modelos de regressão múltipla para determinar quais indicadores influenciaram, e em que proporção, a quantidade de quilogramas de cordeiros vendidos no sistema. A fim de determinar os efeitos dos graus FAMACHA© das ovelhas durante a monta e parto, em relação à quantidade de produção em quilogramas de cordeiros desmamados, foram realizadas duas análises de variância de um fator, nas quais valores econômicos absoluto (VEA) e relativo (VER) foram atribuídos aos indicadores zootécnicos. Essa abordagem foi feita com o objetivo de verificar quais índices têm maiores efeitos no lucro e, consequentemente, devem ser priorizados nos critérios de seleção. Os principais indicadores foram a prolificidade, peso da ovelha ao parto, idade da ovelha ao parto, ganho médio diário, sobrevivência da prole e grau FAMACHA© da ovelha ao nascimento e ao parto; sua significância (P<0,05) determinou o número de quilogramas de cordeiros produzidos no sistema. O indicador com maior VEA e VER foi a idade da ovelha ao parto, com US$ 3,78 ano^{-1} ovelha^{-1} e 54,09%, respectivamente. O grau FAMACHA© 1 proporcionou o maior retorno ao sistema, com valor econômico absoluto de US$ 1,09 ovelha^{-1} na monta e US$ 1,71 ovelha^{-1} no parto. Os graus 4 e 5 causaram prejuízos tanto à monta quanto ao parto, com -US$ 1,15 ovelha^{-1} e -US$ 1,44 ovelha^{-1} para o grau 4, e -US$ 1,24 ovelha^{-1} e -US$ 1,76 ovelha^{-1} para o grau 5 na monta e no parto, respectivamente. Os resultados indicaram que o produtor pode manipular a taxa de descarte do rebanho para aumentar a idade das matrizes a fim de garantir uma maior produtividade das ovelhas. Outra indicação seria a aplicação de critérios de seleção para garantir o aumento do número de animais superiores presentes no sistema, principalmente animais resistentes a helmintoses. Essa estratégia pode facilitar o aumento dos lucros sem a necessidade de aumentar significativamente os gastos com insumos.
Palavras-chave: Cordeiro. Custos de produção. FAMACHA©. Lucro.

Introduction

The zootechnical indicators are qualitative or quantitative production data that indicate the performance of any productive activity that permit decision making. Through the management of these indicators, it is possible to infer the effects arising from each applied creative practice; however, for this to be realized it is necessary that the properties have detailed information about the different characteristics of the animals, including productive, reproductive, sanitary, and genetic aspects (Bohan et al., 2019). With this approach, it is possible to evaluate several elements of the system in an associated and precise way; moreover, information obtained by the correlated evaluation of zootechnical indicators is more consistent than if interpreted in isolation (Pacheco et al., 2014).

In the scope of sanitary aspects, one of the most relevant factors that must be considered in a sheep production system is the FAMACHA© score of the ewes. The FAMACHA© score corresponds to a method developed to diagnose anemia in sheep and goats, and it has been used as a strategy for selective treatment in regions where the main parasite corresponds to Haemonchus contortus. Based on standard FAMACHA© cards, the color of the ocular mucosa is evaluated on a scale of five colors that represent different ranges of hematocrits, as follows: FAMACHA© 1, > 28%; FAMACHA© 2, 27-23%; FAMACHA© 3, 22-18%; FAMACHA© 4, 17-13%; and FAMACHA© 5, < 12%. The relevance of FAMACHA© is based on perspectives that the method can retard the resistance of parasites to anthelmintic drugs, since it only allows the treatment of animals with high parasite load (FAMACHA© 3, 4 and 5) (Van Wyk & Bath, 2002). The growing resistance of endoparasites to anthelmintic drugs is a raising concern in sheep production systems because it can significantly impact on productive and reproductive aspects of sheep (Fthenakis et al., 2015).

The economic values of zootechnical indicators are defined as partial derivatives of the profit function (which describes the relationship between profit and biological, economic and productive parameters in a production system) and calculated for each characteristic (Wolfová et al., 2009). While traditional economic analyzes indicate the feasibility and identify the most critical aspects of production systems, the valuation of zootechnical indicators points to estimates of the impacts on the profitability of each criterion, allowing the comparison of the relative importance of each one and prioritizing the approach of production indices with greater impact on profit. Thus, the association between the two analyzes facilitates the identification and optimization of indicator values that maximize the economic result of the system.

In the current body of relevant literature, there are studies applying the economic valuation of zootechnical indicators to several species, including sheep (Tolone et al., 2011; Wolfová et al., 2011; Gebre et al., 2012; Krupová et al., 2013; Bohan et al., 2019); however, in Brazil, research in this regard is scarce. Lôbo et al. (2011) determined economic values of different productive characteristics of sheep in a pasture-based production system in the Brazilian semiarid region. Raineri et al. (2015b) verified the composition and elasticity of lamb production costs. No studies were found in Brazilian conditions that have attributed economic value to zootechnical indicators in intensive sheep production systems.

The proposal of most works of this nature is to contribute to the profitability of the activity through genetic improvement, addressing mainly the genetic component of the characteristics studied, but disregarding attributes resulting mainly from environmental effects. The variation in results between these studies also demonstrates that economic values are sensitive to the particularities of each system, and sheep production systems are quite heterogeneous.

The hypothesis and relevance of this study are based on a perspective that is not limited to genetic components, but rather focuses on zootechnical indicators observed in the field, which express both genetic and environmental effects; therefore, the results will not only allow inferences regarding the selection of traits, but will also offer indications about productive practices that should be prioritized to optimize the technical and economic efficiency of the system. The objective of this work was to analyze an intensive and semi-confined sheep production system in Brazil to determine the relationship between the zootechnical indicators and the economic results of the activity. Furthermore, with the use of modeling, the objective was to estimate the effect of certain zootechnical indicators on the productivity and economy of the production system in order to attribute absolute and relative economic values to the characteristics of the animals.

Materials and Methods

Characterization of the production system

The data used came from the zootechnical records of the Goat and Sheep Production Sector of the Capim Branco Experimental Farm, at the Federal University of Uberlândia. Zootechnical information from the operational periods between 2016 and 2021 was evaluated, especially with regard to the production of lambs for slaughter. The offspring were kept in feedlots from birth until weaning, at which time the males were sold, and part of the females were retained for replacement; the surpluses were also sold.

The system was intensive and semi-confined with the presence of Dorper, Santa Ines, White Dorper and crossbred varieties among them. The dams were distributed into collective pens of approximately 20 m² during the end of gestation until weaning. Ewes in maintenance, breeding and early gestation, and replacement ewe lambs were separated into paddocks with areas of 800 m² each, with cultivation of *Urochloa brizantha* cv. Marandu grass.

Ewes in maintenance, breeding and early gestation, and replacement ewe lambs consumed only pasture with mineral salt *ad libitum.* The feedlot diet for the other categories (ewes in late gestation and ewes in lactation period) was based on concentrated foods (ground corn, soybean meal, urea and mineral salt) and roughage (corn silage). The ration had a concentrate: roughage ratio of 40:60 on a dry matter (DM) basis. The concentrate had 605 g kg^{-1} ground corn, 360 g kg^{-1} soybean meal, 25 g kg^{-1} mineral salt and 10 g kg^{-1} urea, offering 897.0 g kg^{-1} DM, 245.0 g kg^{-1} of crude protein (CP), 31.4 g kg^{-1} of ether extract (EE), 248.0 g kg^{-1} of neutral detergent fiber (NDF), 73.0 g kg^{-1} of acid detergent fiber (ADF), and 818.8 g kg^{-1} of total digestible nutrients (TDN). The corn silage presented 340.0 g kg^{-1} DM, 65.0 g kg^{-1} CP, 24.0 g kg^{-1} EE, 566.0 g kg^{-1} NDF, 336.0 g kg^{-1} ADF, and 631.7 g kg^{-1} TDN. All diets were balanced according to the National Research Council [NRC] (2007). Ewes in late gestation and lactation were supplemented daily with 20 g kg^{-1} of protein salt. All animals received water *ad libitum.*

Regarding health management of the flock, coprocultures were periodically performed and indicated that historically *Haemonchus* sp. corresponded from 75 to 100% of the present parasites. Other occasionally recorded parasites included *Trichostrongylus* sp., *Oesophagostomum* sp. and *Cooperia* spp. Since *Haemonchus* sp. was the most prevalent parasite in the system, the FAMACHA© score was applied to selectively treat the animals for helmintosis. All animals were assessed every 15 days, and their FAMACHA© scores were individually recorded. Animals with FAMACHA© scores 4 and 5 received antiparasitic treatment, as well as those with FAMACHA© score 3 that presented body condition score lower than or equal to 2.5 points.

Description of the cost calculation model

The cost calculation model developed by Raineri et al. (2015a) was used as a basis for calculating the cost of production, profit, and attribution of economic values to the system's zootechnical indicators, which follows the precepts of Economic Theory and encompasses all necessary cost items. The model was structured into an electronic spreadsheet, where the input variables were the quantities and prices of inputs used in the system, as well as their zootechnical indicators (Table 1).

The cost allocation structure considered variable costs (food, sanitary, and reproductive management items), fixed operational costs (labor, energy and fuel, depreciation, and maintenance) and income of the factors (remuneration on fixed and working capital, and opportunity cost of land) (Raineri et al., 2015a). The annual costs were calculated on prices and interest rates referring to January 2022.

The economic indicators calculated and generated by the model were the cost of production and profit related to the activity in US$ per kg of live lamb sold. The calculation of the system's profit was based on equation (1), where:

$$P = \frac{\sum RKL + \sum RC - \sum FC - \sum VC - \sum IF}{KLS} \qquad (1)$$

P = system profit (US$/kg), RKL = revenue from sales of kilograms of lamb (US$), RC = revenue from culled animals (US$), FC = fixed costs (US$), VC = variables costs (US$), IF = Income of the factors (US$), KLS = Number of kilograms of live lambs sold (kg).

Table 1
Input values for model variables

Variables	Mean	Variables	Mean
Number of ewes	92	Twin lambing rate (%)	36.99
Number of rams	2	Triplet lambing rate (%)	2.40
Lambs available per year	109	Quadruplet lambing rate (%)	0.34
Body condition score at lambing	3.24	Survival rate (%) (60 days)	84.20
FAMACHA© score at lambing	1.86	Mortality rate (%) (60 days)	15.80
Average daily gain (g day^{-1})	311	Fertility rate (%)	90.00
Ewe age at lambing (years)	2.28	Ram body weight (kg)	78.96
Kilograms weaned (kg $birth^{-1}$)	26.10	Lambing interval (months)	11.00
Kilograms born (kg $birth^{-1}$)	5.47	Lambings per year	1.09
Weaning weight (kg $lamb^{-1}$)	15.80	Ewe cull rate (% $year^{-1}$)	25.00
Ewe weight at lambing (kg)	60.20	Ram cull rate (% $year^{-1}$)	17.00
Birth weight (kg $lamb^{-1}$)	3.85	Age at first lambing (months)	15.56
Prolificacy rate (%)	143.00	Age at weaning (days)	60
Single lambing rate (%)	60.27	Replacement ewes kept (per year)	23

Statistical analysis

Statistical analyzes were generated to model the interrelationships among the zootechnical indicators in order to translate the impact of each variable on the others and to make the simulations performed in the model more realistic and biologically accurate. All analyzes were performed using the statistical software R-studio version 4.1.2.

The zootechnical indicators analyzed were: i) FAMACHA® score of ewes at breeding and lambing, ii) Average daily gain of lambs, iii) Ewe's age at lambing, iv) Number of kilograms of lambs born and weaned per ewe per parturition, v) Ewe weight at lambing, vi) Prolificacy, and vii) Pre-weaning lamb survival.

Two multiple regression models were created to verify which zootechnical indicators had influence and their proportions on the dependent variables of kilograms of lambs born per parturition and kilograms of lambs weaned per parturition. The observations were constituted by the information obtained for each ewe lambed.

The Shapiro-Wilk and Kolmogorov-Smirnov tests were used to verify the normality of residuals, and the Durbin-Watson test was used to assess the autocorrelation of the variables under study. As the assumptions were not violated, a development of multiple regression models was initiated. For the diagnosis of multicollinearity, the VIF (Variance Inflation Factor) of the variables was evaluated, so that only those that presented VIF < 10 remained in the model.

For the analysis of the significance of the parameters, the t-statistic was used, and the verification of the significance of the zootechnical indicators on the dependent variables was carried out by the F-statistic through the partial F test. All analyzes were performed at a significance level of 5%, i.e., only the indicators that presented a P-value lower than 0.05 remained in the models. To determine the suitability of the models, the coefficient of determination (R^2) was estimated.

In the model generated for the variable kilograms of lambs born per parturition, the explanatory variables were ewe weight at parturition and prolificacy by using equation (2) to formulate the evaluated response:

$$Y_{ij} = \alpha + \beta_1 X_1 + \beta_2 X_2 + e_{ij} \quad (2)$$

where: Y_{ij} = number of kilograms of lambs born per birth; α = intercept; $\beta_{1,2}$= regression coefficients linked to independent variables; X_1 = ewe weight at parturition; X_2= prolificacy and e_{ij} = random error.

In the model of kilograms of lambs weaned per parturition, the explanatory variables were: kilograms of lambs born, ewe's age at lambing, offspring survival and average daily gain (equation 3).

$$Y_{ij} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + e_{ij} \quad (3)$$

where: Y_{ij} = Number of kilograms of lambs weaned per parturition; α = intercept; $\beta_{1,2,3,4}$ = regression coefficients linked to independent variables; X_1= Kilograms of lambs born; X_2= ewe´s age at parturition; X_3= Offspring survival; X_4= Average daily gain; and e_{ij} = Random error.

In order to evaluate the individual effect of each FAMACHA© score of the ewes on the number of kilograms of lambs weaned per parturition, 2 one-way analyzes of variance were performed; one was to identify the impact of the FAMACHA© score at breeding and the other at lambing. As the animals were submitted to the same conditions of management, nutrition, reproduction, and environment, the only sources of variation considered were the individual variation of experimental units and treatments.

The treatments evaluated corresponded to the FAMACHA© score of the ewes during the breeding season and at parturition. To obtain the FAMACHA© score, the color of the ocular conjunctiva was observed and compared with a color scale present on a standard card, which ranged from 1 to 5, in which: 1 = red; 2 = red-pink; 3 = pink; 4 = pink-white; 5 = white (Van Wyk & Bath, 2002). Thus, the response variable "kilos weaned" for lambs was submitted to tests of normality (Shapiro-Wilk and Kolmogorov-Smirnov tests) and homogeneity of variance of treatments (Bartlett's test). As both assumptions were met, the following mathematical model was used (Equation 4):

$$Y_{ij} = \mu + H_i + e_{ij} \quad (4)$$

In which Y_{ij} represents the observation in the FAMACHA© score at lambing or parturition i and in repetition j; μ represents overall mean; H_i represents the fixed effect of FAMACHA© score at breeding or lambing i, and e_{ij} was the random error.

The comparison of variance estimates between treatments was performed using the F test, followed by Duncan's average comparison test when statistical differences were verified between the FAMACHA© scores.

Attribution of economic values to zootechnical indicators

The estimations of the economic values of the zootechnical indicators were carried out through simulations of changes in each indicator in order to quantify their effects on profit. The economic model used was complemented in order to consider the equations of interrelationships between the zootechnical indicators calculated in the previous step so that the valuation was able to capture the effects of changing one indicator on others.

In order to perform a critical ranking of the economic relevance of the different zootechnical indicators in the system, the absolute and relative economic values for each variable were calculated. To calculate both, the profit per kilo of lamb sold was used as a basis. The absolute value was represented in US$/marginal unit of the indicator/sheep and was determined according to the methodology described by Wolfová et al. (2009), through Equation (5):

$$AEV_c = \frac{P_h - P_l}{HIV_C - VIL_l} \quad (5)$$

where AEV_c = Absolute economic value of indicator c; HIV_C and VIL_l = Value of indicator c when raised and lowered by 0.05, respectively; and P_h and P_l = Result of the profit function for the high and low values, respectively, of the indicator c.

The relative value of each indicator was estimated by its percentage in relation to the sum of the economic values of all the characteristics, according to Equation (6):

$$REV_c = \frac{AEV_c}{\sum AEV_n} \quad (6)$$

where REV_c = Relative economic value of indicator c; and AEV_c = Absolute economic value of indicator c; and $\sum AEV_n$ is the sum of the AEVs of all indicators.

For the categorical indicators (FAMACHA© score), a method based on an underlying normal distribution was used (Wolfová et al., 2009). The frequencies in the individual classes were entered as parameters, and from these frequencies an average value was calculated (flock average score). Thus, based on the original frequencies, the distribution of each parameter was shifted up and down by 5%. The resulting new frequencies of the individual classes were used to calculate new average values of the indicator and the corresponding new profit, both to increase and to decrease the indicator. These values were inserted into equations (5, 6) to calculate absolute and relative economic values.

Results and Discussion

Table 2 contains the estimates obtained by the multiple regression model to determine the number of kilograms of lambs born. The intercepts, ewe weight at lambing and prolificacy, were statistically significant, and the model presented a coefficient of determination (R^2) of 74.11%, indicating that it can be considered adequate to estimate the independent variable. Thus, from the results it was possible to calculate the number of kilograms of lambs born by equation (7).

$$KLB = -0.38740 + 0.01303\,PM + 2.242555\,LS \quad (7)$$

where: KLB = Number of kilograms of lambs born per lambing (kg); PM = Ewe weight at lambing (kg); LS = Prolificacy (head).

Table 2

Zootechnical indicators, estimates, standard error, and P-value of the variables included in the multiple regression model for the number of kilograms of lambs born per parturition

Coefficients (units)	Estimated	SE	P-value
Intercept	-0.38740	0.10123	<0.001
Ewe weight at lambing (kg)	0.01303	0.00018	<0.001
Prolificacy (head)	2.42555	0.20551	<0.001
n	118		
R^2	74.11%		

n: Number of observations; R^2: determination coefficient; SE: standard error.

Based on the estimates generated by the model, for each extra unit of weight of the ewes at lambing, there was an increase of 0.01 kg in the kilograms of lambs born per parturition. This result may be associated with the nutrition of ewes during pregnancy, since fetal growth and birth weight are mainly regulated by maternal nutrition, parental genotype, and environment (Parraguez et al., 2020). Possible dietary restrictions to the mother during pregnancy can lead to reduced availability of nutrients to the embryo and fetus during the phases of development in the uterus, preventing the potential genetic growth of the offspring (Sinclair et al., 2016).

In addition to the weight of the mother at lambing, for each additional lamb born per litter, the quantity of kilos born increased by 2.24 kg. The prolificacy refers to the number of lambs born per lambing per ewe, or litter size. According to Rego et al. (2014), the greater the number of fetuses present in the maternal uterus so the greater is the nutritional demand as the uterine physical space becomes limited to fetal growth with greater intrauterine competition for nutrients. The birth weight of lambs is negatively influenced; however, even with lower individual birth weights, the total weight of lambs born per ewe increases according to prolificacy, if sanitary and nutritional conditions are met for ample productivity of the dams (Brien et al., 2014).

Regarding the multiple regression model generated for the variable kilograms of weaned lambs, the variables kilograms of lambs born per litter, age of the ewe at lambing, offspring survival, and average daily gain (ADG) showed statistical significance. Table 3 shows the generated estimates. The R^2 obtained was 92.96%, which can be considered a great predictor of residuals in the generated model. Equation (8) was used to calculate the number of kilograms of weaned lambs.

$$KLW = -0.6946 + 1.31765\,KLB + 0.46032\,AE + 2.13251\,S + 0.05018\,ADG \quad (8)$$

where KLW = kilograms of weaned lambs (kg); KLB = kilograms of lambs born per lambing (kg); AE = Ewe's age at lambing (years); S = Survival (head); ADG = Average daily gain (g $lamb^{-1}$ day^{-1}).

Table 3
Zootechnical indicators, estimates, standard error, and p-value obtained by the multiple regression model for the variable kilograms of lambs weaned per parturition

Coefficients	Estimated	SE	*P*-value
Intercept	-0.6946	0.20611	0.008
Kilos of lambs born per litter (kg)	1.31765	0.19382	<0.001
Ewe's age at lambing (years)	0.46032	0.23150	0.012
Lamb survival (head)	2.13251	0.57035	0.002
Average daily gain (g day^{-1})	0.05018	3.13428	<0.001
n	88		
R^2	92.96%		

n: Number of observations; R^2: determination coefficient; SE: standard error.

It is possible to observe that for each additional kilo of lambs born per litter, there was an increase of 1.32 in the total amount of kilos of lambs weaned per litter. This result is related to a higher pre-weaning survival rate provided by the birth weight of the offspring, since lambs with higher birth weights have lower mortality rates (Ridler et al., 2022), which contributes to an increase in the number of animals that arrive alive at weaning and, consequently, a greater number of kilos of weaned lambs.

Another indicator defined in the model was the ewe's age. The one-year increase in this variable resulted in an increase of 0.46 kilograms of lambs weaned per litter. According to Farrell et al. (2019), the reproductive performance of ewes is directly affected by age with a peak at five years old; a younger flock results in lower lambing rates and lower numbers of weaned lambs.

In addition to the age of the mother at lambing, the survival of the offspring also had an impact on the number of kilograms of lambs weaned per litter, with each additional lamb arriving at the point of weaning having an increase of 2.13 in the total amount of kilograms weaned. This result can be associated with the fact that the nature of this indicator is directly related to the number of kilograms of animals available in the system; a lower pre-weaning survival rate will result in a decrease in the number of lambs that will be sold for slaughter.

The last indicator inserted in the regression model was the ADG of the offspring, with each extra gram of gain per day implying 0.05 g more of weaned lambs. In a study carried out by Teklebrhan et al. (2014), a positive association was observed between ADG and weaning weight, in which animals that had ADG of 103.1 g day^{-1} had an average weaning weight of 15.4 kg, and lambs that had ADG of 122.4 g day^{-1} managed to wean at 17.6 kg.

Considering the FAMACHA© score of the ewes during breeding season and at the time of lambing, the results obtained by the analysis of variance are shown in Table 4. It was possible to observe that there was a significant effect ($P<0.05$) between the FAMACHA© score of the dams and the number of kilograms of lambs weaned in both verified periods.

During breeding, the dams that presented FAMACHA© score 1 were those that obtained the highest number of kilograms of weaned lambs, with an average of 22.13 kg for the animals in this group. In addition, it is possible to observe that as the FAMACHA© score increased, so the evaluated response in weaning weight of lambs decreased, with groups 4 and 5 having the lowest averages (14.00 and 14.29 kg, respectively). This result can be associated with the energy requirement level of the ewes and, consequently, their body condition score. According to Fthenakis et al. (2015), the increase in energy supply to ewes can increase the ovulation rate and the number of lambs born per ewe, and animals with low body condition scores have reduced fertility, estrus delay, and a decrease in the number of oocytes released. Thus, energy deprivation during the pre-breeding period directly affects reproductive performance in intensive and extensive production systems and promotes a series of negative effects to the system. In this sense, it is possible to understand the impact of worms on sheep reproduction, since parasitism by gastrointestinal helminths is the most serious form of draining energy from healthy sheep (Fthenakis et al., 2015). Gastrointestinal nematodes can reduce the availability of nutrients to the host by reducing voluntary feed intake and by reducing the efficiency of absorption of ingested nutrients, which contributes to a decrease in the energy available to sheep infected by such organisms (Fthenakis et al., 2015). Calvete et al. (2020) obtained higher numbers of lambs born per ewe and survival rates in animals that were dewormed before the start of the breeding season. It is therefore evident that parasitism can affect the reproductive efficiency of ewes during the breeding season, which is in agreement with the result found in this work.

Table 4
Effect of the FAMACHA© score of ewes at breeding and lambing on the weight of weaned lambs (mean ± standard error)

FAMACHA© score	Weight of weaned lambs (kg)	
	Breeding	Lambing
1	22.13±1.35a	22.91±0.85a
2	17.48±1.25b	17.33±1.27b
3	16.10±1.47bc	14.96±0.96c
4	14.00±1.59c	9.74±0.68d
5	14.29±1.65c	8.01±0.71e
OA	19.63	20.10
n	77	102
CV	34.67	30.89
P-value	0.004	<0.001

OA: Overall average; n: Sample number; CV: Coefficient of variation (%); Means followed by different lowercase letters in the same column differ by Duncan's test (P<0.05).

Several papers have assessed the heritability of genetic components related to parasite resistance. Medrado et al. (2021) observed that the heritability of FAMACHA© scores can reach 0.32. In the same sense, Hayward (2022) verified heritability of 0.51 for FAMACHA© scores and of 0.29 for faecal egg count. These results contribute to argue the importance of selecting animals that are resilient and resistant to parasitic infections, considering that the traits present moderate heritability. This would allow farmers to keep superior animals in their flocks, resulting in better productive performance.

Regarding the FAMACHA© scores of the ewes at lambing, there was a statistical difference between all the groups evaluated, where animals presenting score 1 had the highest average of weaning weights of offspring, with 22.91 kg, and score 5 the lowest average with only 8.01 kg. Several authors have reported the impact of worms in sheep affected by parasites, with negative effects being observed in the ewe and their offspring. The main factors are: lower milk production, higher mortality of the offspring and of the dam, reduced lamb performance, lower ADG and lighter births (Papadopoulos et al., 2013; Fthenakis et al., 2015). This is in agreement with the findings in this study, because ewes with higher a FAMACHA© score at lambing are more affected by parasitic infections and therefore have a reduced number of kilograms of lambs born.

After determining and estimating the impact of each zootechnical indicator on the number of kilograms of lambs available in the system, it was possible to assign an economic value to the variables under study in order to rank them and determine which criteria have the greatest impact on the company's operational profit (Table 5).

Prolificacy showed absolute and relative economic values of US\$ 0.31 lamb^{-1} ewe^{-1} and 4.39%, respectively. For the Merinolandshaf, Rommey, Sumavska and Romanov breeds, Wolfová et al (2011) obtained absolute economic values of US\$ 0.62 lamb^{-1} ewe^{-1}, US\$ 1.01 lamb^{-1} ewe^{-1}, US\$ 0.44 lamb^{-1} ewe^{-1} and US\$ 0.44 lamb^{-1} ewe^{-1}, respectively. In reviewing the impact of the prolificacy rate on the system, it is necessary to evaluate this indicator together with the survival rate. The possible positive economic impact of higher prolificacy rates tends to be reduced by decreased survival rates in these situations, which evokes a drop in the number of lambs sold for slaughter. In this study, the survival rate of lambs was 84.20% (Table 1), a value considered low for the species; this indicator may have contributed to reducing the impact of prolificacy on the system. This result is in agreement with the results obtained by Wolfová et al. (2011), where animals of the Romanov breed had the highest rate of prolificacy, but with the lowest rate of offspring survival, making prolificacy the indicator with the lowest economic impact for this breed.

Table 5
Zootechnical indicators and their absolute (in US$ marginal unit of the indicator^{-1} sheep^{-1}) and relative (%) economic values

Indicators	Absolute economic value	Relative economic value
Prolificacy (head)	0.31	4.39
Ewe weight at lambing (kg)	0.06	0.79
Ewe age at lambing (years)	3.78	54.09
Survival (head)	0.23	3.35
Average daily gain (kg)	0.35	5.06
Weight of lambs born per litter (kg)	0.70	9.98
FAMACHA© at breeding		
Score 1	1.09	29.08
Score 2	0.28	7.42
Score 3	0.00	0.00
Score 4	-1.15	30.54
Score 5	-1.24	32.96
FAMACHA© at lambing		
Score 1	1.71	24.54
Score 2	1.13	16.16
Score 3	-0.93	13.31
Score 4	-1.44	25.30
Score 5	-1.76	20.68

The weight of the ewe at lambing had an absolute economic value of US$ 0.06 kg^{-1} ewe^{-1} and a relative economic value of 0.79%. Lôbo et al. (2011) and Gebre et al. (2012) obtained economic values of -US$ 0.27 kg^{-1} ewe^{-1} and - US$ 0.99 kg^{-1} ewe^{-1} respectively, for this indicator because there was a higher expenditure on inputs related to animal feed. The justification of these authors is similar, being based on the fact that to increase the weights of ewes, larger amounts of food supply or exchange of inputs used are demanded, generating more expenses to the system. Notably, these authors did not take into account the interrelationships between the zootechnical indicators, as was done in this work; therefore, they did not quantify the impact of the ewe weight at lambing on other variables present in the production systems, such as the number of kilograms of lambs born per parturition in the system. Also, the above-mentioned works presented higher expenses from inputs and did not verify the financial return that this indicator can promote to the system through improvements in other zootechnical indicators.

Considering the age of the ewes at lambing, this was the indicator with the highest absolute and relative values, with US$ 3.78 year^{-1} ewe^{-1} and 54.09%, respectively. This result is a consequence of the low average age of the dams, since they have not yet reached peak production, which occurs around the fifth year of life. Ewes with higher parity orders have the potential to achieve higher offspring prolificacy and survival rates, shorter calving intervals, and wean more kilograms of lambs per calving (Areb et al., 2021). According to Wolfová et al. (2011), an absolute economic value of US$ 4.85 year^{-1} ewe^{-1} was obtained for Romney sheep. Similarly, Krupová et al. (2013) found an absolute value of US$ 17.81 year^{-1} ewe^{-1} for the productive life of the dams in a flock with an average age of 3.59 years, indicating that in younger flocks there is a greater tendency for the age of the ewes to have more impact on profit because there is still potential for these animals to expand their production. This argument can be reinforced by the result obtained by Gebre et al. (2012), where in a flock with an average age of 7.34 years, the absolute value of the productive life of the animals corresponded to -US$ 1.25 day^{-1} ewe^{-1}.

Given this, the age of the ewe was the indicator with the highest relative economic value, so it is necessary that this index be prioritized to obtain better system performance. The flock currently has an average age of 2.28 years with a culling rate of 25% of ewes annually. If the culling rate were lowered to 10%, the average age of the sheep would increase to 2.74 years. Thus, in order to increase the values of this indicator in the system, it is essential to review the culling and replacement rates because they directly influence the age of the animals.

In addition, a higher rate of culling generates a need for a higher rate of ewe replacement, if the flock is to be kept stable. This reduces the number of ewe lambs that could be sold for breeding, as they will be retained in the production system and, consequently, the profit would be reduced. This information is in agreement with that obtained by Farrell et al. (2020), who observed that in a situation with a 20% culling rate, the average age of the flock corresponded to 4.15 years with an annual production of 2805 weaned lambs. Raising the culling rate to 30% decreased the average age of the flock to 3.64 years, and resulted in 2748 lambs weaned, which meant 57 fewer lambs.

For the survival rate, absolute and relative economic values of US$ 0.23 lamb^{-1} ewe^{-1} and 3.35%, respectively, were obtained. Tolone et al. (2011) found that a 1% increase in the flock survival rate provided an absolute value of US$ 1.08 ewe^{-1}. Wolfová et al. (2009) observed that the survival rate had an impact of US$ 0.01 ewe^{-1} on the system's profit.

The ADG presented US$ 0.35 kg-1 ewe-1 of absolute economic value and a 5.06% of the relative value. Gebre et al. (2012) obtained an absolute economic value of US$ 1.74 kg^{-1} ewe^{-1} for this indicator, while Wolfová et al. (2011) found US$ 17.07 kg^{-1} ewe^{-1} for animals of the Romanov breed. In this work, lambs were sold immediately after weaning at 60 days of age, which can be associated with the result obtained by Bohan et al. (2019), where each additional day that the lambs remained in the system generated an increase in production costs of US$ 8.69 lamb^{-1} and a reduction of US$ 0.67 lamb^{-1} in profit. With a higher average gain, the animals are able to reach the selling weight faster and stay in the system for less time, which reduces production costs and increases profit.

For the number of kilograms of lambs born per litter, the absolute economic value and relative economic value of US$ 0.70 and 9.98%, respectively, were identified. Birth weight and kilograms of lambs born per litter are two closely related indicators, where both are dependent on the ewe's prolificacy rate, maternal nutrition and lambing order (Ridler et al., 2022). Wolfová et al. (2011) found that birth weight had an absolute economic value of US$ 3.81 kg^{-1} ewe^{-1} and a relative economic value of 1.17% for Merinolandschaf sheep. According to Boujenane and Diallo (2017), birth weight has a direct genetic correlation with the average pre-weaning daily gain of 0.54±0.23. Given this, the selection of lambs with higher birth weight can be an interesting consideration for sheep producers, since these animals will present higher ADG and, consequently, will produce higher amounts of kilos for commercialization in less time by the fact that this reduces costs and increases the profit of the system.

Results regarding the economic valuation of FAMACHA© scores of ewes at breeding and lambing are also shown in Table 5. System profit increased as FAMACHA© score decreased. At the time of breeding, for each additional score 1 ewe in the flock, the profit increased by US$ 1.09, while for each additional score 5 ewe, the profit was reduced by US$ 1.24. Similarly, the FAMACHA© score of the ewes at lambing also influenced the system's profit, where scores 1 and 2 presented positive economic values of US$ 1.71 ewe^{-1} and US$ 1.13 ewe^{-1}, in contrast, scores 3, 4 and 5 had negative values of US$ 0.93 ewe^{-1}, US$ 1.44 ewe^{-1} and US$ 1.76 ewe^{-1}, respectively, for each score per ewe.

For the FAMACHA© score of ewes at lambing, it was possible to notice that worms have a considerable impact on the system as this indicator had an effect on the number of kilograms of weaned lambs (Table 4). The increase in the FAMACHA© score of the animals is an indication of anemia from the effect of worms, where the higher the score, the more affected the animals are. In addition to the loss in productive and reproductive efficiency of the animals, the occurrence of worms still implies greater expenses with anthelmintic treatments and, consequently, causes higher costs with inputs and reduces profit. No studies were found in the literature that measured the impact of the FAMACHA© score of ewes on the profit of sheep operations.

Animals with high parasite loads have reduced available energy, and the food consumed will not provide ample use of nutrients, a fact that weakens the ewes and eventually promotes deleterious effects to the ewes and their offspring (Fthenakis et al., 2015). In addition, affected females with high parasite loads have a higher occurrence of diseases, such as mastitis, pregnancy toxemia and diarrhea (Papadopoulos et al., 2013), which introduces a greater probability of death for both the offspring and the dam. Bohan et al. (2019) found economic values of -US$ 0.28 for each ewe presenting postpartum mastitis with a -US$ 0.38 per diarrhea score and a -US$ 0.09 per 50 eggs g-1 for fecal egg count. Thus, to ensure greater animal health and the prevalence of more resistant sheep in the flock, it is important to select animals that are resilient to parasitic infections, since this is a characteristic that can have high heritability. Cloete et al. (2016) found heritability estimates of 0.38 ± 0.13 for FAMACHA© score, in addition to a genetic correlation of -0.82 ± 0.23 between FAMACHA© score and body condition score.

Moreover, it is important to reinforce the need to carry out strategic deworming in animals that present FAMACHA© scores 3, 4 and 5, especially in the lambing period, to attempt to reverse the negative effects that worms can have on the profitability of sheep production systems.

Further to everything that has been presented in this body of work, it is important to emphasize that it is possible to increase the values of the zootechnical indicators found in production systems without the need to increase quantities or costs of the production inputs used. This can be attained by means of selection of superior ewes and rams, keeping more productive animals in the system and culling unproductive or less productive individuals that would lead to the production of inferior lambs (Raineri et al., 2015b).

Conclusion

In summary, the zootechnical indicators that influenced the number of kilograms of lambs available in the system were prolificacy, ewe's weight at lambing, maternal FAMACHA© score at breeding and lambing, ewe's age at lambing, offspring survival, and ADG of lambs. The age of the ewes at lambing was the indicator that presented the highest absolute and relative economic values. Given this, it is recommended that the rates of culling and replacement of the flock be reviewed so that the profit of the system is increased through greater productivity of the ewes and commercialization of lambs.

The FAMACHA© score of the ewes at breeding and lambing had a significant impact on the productivity and profitability of the system; therefore, it is advisable to develop a good strategy to carry out selections of animals based on historical records of FAMACHA© score to identify animals that are resilient and resistant to parasitic infections. Doing so promotes better health for the ewes and their offspring and ensures greater economic and productive return.

The selection of animals by the association between the indicators of birth weight and ADG can also be a viable alternative to increase the productivity of the system, since lambs with higher birth weight have a greater potential for daily gain and so remain in the system for a shorter time. This makes it is possible to reduce the age at sale of these animals and concomitantly the costs of the producer, which increases the profitability of the production.

More studies are needed to identify the impacts arising from other zootechnical indicators on the productivity and economy of the system, such as the effects of the FAMACHA© score of the ewes on the fertility and pregnancy rates in the system. Little attention has been given these details in corresponding literature.

Acknowledgment

The authors thank the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for the scientific initiation scholarship granted through public notice nº10/2021 PIBIC - FAPEMIG.

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