FULL ARTICLE

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Relationship between FAMACHA© scores and zootechnical indicators of a sheep production system

Relação entre os graus FAMACHA© e indicadores zootécnicos de um sistema de produção de ovinos

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ABSTRACT

In Brazil, lamb producers face challenges raising their animals because of high anthelmintic resistance and loss of productivity due to parasites. It is well known that parasitic infections can reduce the performance of sheep. However, until the publication of this work, no research was found that quantified the effects that anemia reflected by FAMACHA© scores can exert on other zootechnical indicators in a lamb production system. The objective of this study was to use the FAMACHA© scores to quantify the impacts of anemia in ewes at breeding and lambing on the productive and reproductive performance of a meat sheep flock. The variables evaluated were i) FAMACHA© score of ewes at breeding and lambing, ii) body condition score of ewes at breeding and at lambing, iii) average daily gain of lambs until weaning, iv) ewe's age, v) birth weights per individual lamb and litter, vi) weaning weight, vii) ewe's weight, viii) litter size and ix) pre-weaning survival. The treatments evaluated corresponded to the FAMACHA© score of the ewes during breeding and lambing. Quantitative responses were submitted to analyses of variance and compared by Duncan's test. In contrast, qualitative or discrete responses were evaluated by the Kruskal & Wallis test and compared to Dunn's test. The Wilcoxon test was performed to compare the FAMACHA© scores of ewes at breeding and lambing. All statistical analyzes were performed using the R-Studio software version 4.2.0 at a 5% significance level. The FAMACHA© score of breeding ewes was related to the body condition score at breeding, ewe weight, pre-weaning survival, ewe age, litter size, and birth weight. Furthermore, the FAMACHA© score of ewes at lambing was related to the body condition score at lambing, ewe weight, pre-weaning survival, birth weight per lamb and litter, pre-weaning average daily gain, weaning weight, and age of the ewe. There was no significant difference between the test times of the FAMACHA© scores of the ewes, indicating that an ewe will present a similar score at both stages. It was concluded that ewes with FAMACHA© scores of 4 and 5 and their offspring showed the worst productive and reproductive performances. Conversely, the ewes with FAMACHA© 1 obtained the opposite result, demonstrating better technical performance.

Keywords: Body condition score. Haemonchosis. Litter size. Performance. Worms.

RESUMO

No Brasil, produtores de cordeiros enfrentam desafios na criação de seus animais devido à alta resistência anti-helmíntica e perda de produtividade devido a parasitoses. Sabe-se que as infecções parasitárias podem reduzir o desempenho de matrizes ovinas, contudo, até a elaboração desse trabalho não foram encontradas pesquisas que mensuraram os efeitos que a anemia refletida pelos graus FAMACHA© podem exercer sobre outros indicadores zootécnicos em um sistema de produção de cordeiros. Sendo assim, o objetivo desse estudo foi quantificar os impactos das verminoses em matrizes ovinas, representadas pelo grau FAMACHA©, durante a estação de monta e a parição, no desempenho produtivo e reprodutivo de um rebanho ovino de corte. As variáveis avaliadas foram: i) grau FAMACHA© das matrizes à monta e ao parto, ii) escore de condição corporal das matrizes à monta e ao parto, iii) ganho médio diário até o desmame, iv) idade da matriz, v) pesos dos cordeiros ao nascer individual e por parto, vi) peso ao desmame, vii) peso da matriz, viii) prolificidade e ix) sobrevivência pré-desmame. Os tratamentos avaliados corresponderam ao grau FAMACHA© das matrizes durante a monta e parto. As respostas quantitativas foram submetidas à análise de variância e comparadas pelo teste de Duncan, já as respostas qualitativas ou discretas foram avaliadas pelo teste de Kruskal & Wallis e comparadas pelo teste de Dunn. Realizou-se o teste de Wilcoxon para comparar os graus FAMACHA© das matrizes nos momentos de monta e parto.

Todas as análises estatísticas foram realizadas no software R-Studio versão 4.2.0 ao nível de 5% de significância. O grau FAMACHA© das matrizes à monta foi relativo ao escore de condição corporal à monta, peso da matriz, sobrevivência pré-desmame, idade da matriz, prolificidade e peso ao nascer coletivo por parto. Já o grau FAMACHA© das matrizes ao parto foi relativo ao escore de condição corporal ao parto, peso da matriz, sobrevivência pré-desmame, pesos ao nascer individual e coletivo por parto, ganho médio diário pré-desmame, peso ao desmame e idade da matriz. Não houve diferença significativa entre os momentos dos graus FAMACHA© das matrizes, indicando que uma ovelha manterá um grau FAMACHA© similar em ambas as fases. Conclui-se que ovelhas com graus FAMACHA© 4 e 5, assim como suas crias, apresentaram os piores desempenhos produtivos e reprodutivos. Em contrapartida, as matrizes com FAMACHA© 1 obtiveram o resultado oposto, mostrando indicadores zootécnicos com valores mais eficientes ao sistema de produção.
Palavras-chave: Escore de condição corporal. Hemoncose. Prolificidade. Desempenho. Verminoses.

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Introduction

The biggest health challenge in raising sheep on pasture is infections caused by gastrointestinal nematodes, mainly due to the prevalence of *Haemonchus* spp. and *Trichostrongylus* spp. in countries with a tropical or subtropical climate (Mavrot et al., 2015). The growing resistance of these parasites to anthelmintic drugs has raised concerns in lamb production systems because they can significantly impact sheep's productive and reproductive aspects (Fthenakis et al., 2015).

In this sense, Brazil is in an unfavorable situation, and it is one of the countries with the highest rate of anthelmintic resistance in the world because a large part of the sheep flock is raised on pasture (Salgado & Santos, 2016). Thus, lamb producers need help with pasture management. In addition to pasture quality, they must pay attention to performance losses caused by parasitic infections (Salgado et al., 2017). Animals compromised by gastrointestinal nematodes have reduced nutrient utilization and, consequently, have lower productive performance and loss of fat reserves (Méndez-Ortíz et al., 2019). As a result of these factors, ewes in poor body condition during the breeding season may show reduced fertility, prolificacy, and cycling rates, delayed estrus, and higher embryonic mortality in the early stages of pregnancy (Kenyon et al., 2014).

In an attempt to control the advance of anthelmintic resistance and selectively treat the animals, the FAMACHA© method was developed. The FAMACHA© score system was designed to estimate degrees of anemia in sheep, and it has been used as a form of selective treatment in regions where the main parasite is *Haemonchus contortus*. Based on this method, the color of the ocular mucosa is evaluated on a scale of five colors that represent different ranges of hematocrits, as follows: F1, > 28%; F2, 27-23%; F3, 22%-18%; F4, 17%-13%; and F5, < 12% (van Wyk & Bath, 2002).

In the body of literature, some works evaluated sheep's productive and reproductive performances affected by parasites (Fthenakis et al., 2015; Issakowicz et al., 2016). However, until the time of writing this article, no studies were found that compared the performance of sheep and the difference in the FAMACHA© scores that they presented. Likewise, no studies are available that quantify the effects that FAMACHA© scores can have on other zootechnical indicators in a lamb production system. Therefore, this study aimed to quantify the impacts of worms in ewes, represented by the FAMACHA© score during breeding and lambing, on the productive and reproductive performance of a semi-confined sheep flock under tropical conditions.

Materials and Methods

Definition of the production system

The data used came from the zootechnical records of the Goat and Sheep Production Sector at the Capim Branco Experimental Farm belonging to the Federal University of Uberlândia (latitude: 18°30'25"S, longitude: 47°50'50"W and altitude: 863 meters). The information was collected during the routine flock management between 2019 and 2021 by employees with technical qualifications for the animals' sanitary, productive, and reproductive control.

The local climate is tropical, with a dry period in the winter and rainfall distributed during the summer. The production system was intensive and semi-confined, using crosses between Dorper, White Dorper, and Santa Inês breeds. The ewes were allocated in collective pens of approximately 20 m^2 from late gestation until weaning. In contrast, ewes in maintenance, breeding, or early pregnancy and the replacement ewe lambs were separated in paddocks with an area of 800 m^2 cultivated with Maranda grass (*Urochloa brizantha*).

The diet of the confined animals was based on concentrated and bulky foods (corn silage and elephant grass), and those on paddocks consumed pasture. All categories received mineral salt and protein salt supplementations and water *ad libitum*. Lambs were weaned at 60 days of age and had access to creep feeding throughout this period. From 20 days onwards, a controlled suckling was started to further encourage the consumption of solid food by the offspring.

Reproduction took place by inducing heat through hormonal protocols, which began controlled breeding seasons. Since the ewes belonged to breeds with low reproductive seasonality, the breeding seasons in the flock aimed at distributing births throughout the year. Pregnancy diagnoses by ultrasound were performed 30 days after the end of the breeding seasons when pregnant and non-pregnant females were separated. Ewe lambs were submitted to this process from 7 months old and mature ewes soon after the weaning of their offspring.

Sanitary management of the flock

Regarding the sanitary management of the flock, coprocultures were performed periodically, indicating that historically *Haemonchus* sp. corresponded to 75 to 100% of the 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 treat animals for helminths selectively. The technicians who worked in the production system individually evaluated all the animals every 14 days and recorded information about their health. The points observed were: FAMACHA© score, body condition score, body weight, presence of cough, condition of the mucous membranes, and occurrence of diarrhea in the ewes of the flock.

Based on these assessments, animals with FAMACHA© 4 and 5 were grouped into separate lots and confined to receive antiparasitic treatment. For ewes with a score of FAMACHA© 3, their body condition score was observed, and individuals with a score lower than or equal to 2.5 were confined to receive treatment. Those that were above this value returned to the main flock. In addition to medication, the confined animals received reinforced nutrition with the supplementation of energy-protein concentrate, corn silage, fresh grass, and protein mineral salt.

Animals were treated with anthelmintics containing the following active principles: Nitroxinil (1 mL for each 50 kg of body weight), 1% Moxidectin (1 mL for each 50 kg of body weight), and Levamisole hydrochloride (1 mL per 10 kg of body weight). The determination of the medicine and the frequency of its administration to the animals (single dose or two doses with an interval of 15 days) were based on the physiological state of the animal (growth, gestation, maintenance, or lactation) and according to the recommendations of a veterinarian associated with the property. In addition, an energetic vitamin supplement was offered along with the application of iron (5 mL per animal) and vitamins B12 (3 mL per animal) and K (5 mL per animal) for 3 interspersed days, which followed recommendations for use from the product's package inserts.

Ewes that persisted in the clinical symptoms of diarrhea and anemia (FAMACHA© scores 4 and 5) after the treatment were culled after weaning their lambs. Thus, cullings took place after the experimental period. Likewise, if the animal did not show improvement after completing the treatment and supplementation, it was sent to the veterinary hospital belonging to the Federal University of Uberlândia, where it received proper care. When the animals were considered healed and able by the veterinary team, they were sent back to the production system.

Characteristics evaluated and data collection

The relationship between the FAMACHA© score of ewes at breeding and lambing and other zootechnical indicators of the flock was observed. Thus, the evaluated variables were: i) FAMACHA© score of the ewes at breeding and at lambing, ii) body condition score of the ewes at breeding and at lambing, iii) average daily gain of the lambs until weaning, iv) ewe's age at breeding and lambing, v) birth weights per individual lamb and litter, vi) lamb weight at weaning, vii) ewe's weight, viii) litter size, ix) pre-weaning survival. Table 1 contains the corresponding response variables about the explanatory variables.

Before the beginning of the breeding season, the animals were identified, and information regarding the general condition of the animals was recorded, such as the body condition score and FAMACHA© score. After lambing, the ewes and their lambs were left alone for four hours to ensure maternal-offspring bonding. Then, when it was observed

Table 1 – Explanatory and response variables evaluated in this study.

Explanatory variables	Response variables
Ewe's FAMACHA© score at breeding	Pre-weaning survival (%)
	Litter size (per head)
	Ewe's age (months)
	Ewe's body condition score at breeding
	Individual lamb birth weight (kg)
	Ewe's weight at lambing (kg)
	Litter birth weight (kg)
Ewe's FAMACHA© score at lambing	Pre-weaning survival (%)
	Average daily gain of lambs (kg/day)
	Ewe's age (months)
	Body condition score at lambing
	Individual lamb birth weight (kg)
	Ewe's weight at lambing (kg)
	Weaning weight of lambs (kg)
	Litter birth weight (kg)

that the lamb was suckling, they were identified, tagged, and weighed using a suspended scale with a precision of 5 g, obtaining the birth weight of the animal. At the same time, the dams were weighed using a mechanical scale with a capacity of 500 kg and accuracy of 100 g, and their body condition score and FAMACHA© score were evaluated.

The scale used to measure the body condition score of the ewes at breeding and lambing ranged from 1 to 5, according to Souza et al. (2011), through palpation of the animal's lumbar region, where the spinous apophyses, transverse apophyses of the lumbar vertebrae and muscle and fat coverings in the area were evaluated, where: BCS1 = very thin; BCS2 = thin; BCS3 = medium; BCS4 = fat; BCS5 = obese. To estimate 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).

The weaning weight and average daily gain of lambs were collected at 60 days when the lambs were weaned. Litter size refers to the number of lambs born per mother, whereas litter birth weight is the sum of the individual birth weights of all lambs born in the same litter. Pre-weaning survival had characteristics of a binary variable, i.e., it was observed whether the animal managed to survive (= 100%) or not (= 0%) until weaning. About the age of the ewe, this indicator was obtained based on the individual identification forms of the flock, which contain the date of birth of the animals, their respective ages at the time of breeding and lambing, and lamb death records.

Statistical analyzes

The ewes were evaluated at the beginning of the breeding season and lambing. The evaluated treatments corresponded to the FAMACHA© score presented by the ewes during these two periods. To meet a larger sample size and make the statistical analyses more meaningful and assertive, the ewes that presented FAMACHA© scores 4 and 5 were included in a single set. The distribution of the sample number by the experimental group is shown in Table 2.

Table 2 – The sample size for each evaluated treatment.

FAMACHA© score	Breeding	Lambing
1	69	97
2	29	23
3	20	16
4 and 5	15	23

First, the quantitative responses of average daily gain of the lambs until weaning, ewe's age at lambing, birth weights per individual lamb and litter, lamb weaning weight, and ewe's weight at lambing were submitted to normality tests (Shapiro-Wilk test), and homogeneity of treatment variances (Bartlett's test). As none of the variables violated the aforementioned assumptions, they were subjected to an analysis of variance. Since the animals were subjected to the same handling, nutrition, reproduction, and environmental conditions, the only sources of variation considered were the individual variation of experimental units and treatments. The mathematical model used for the analysis of variance was (Equation 1):

$$Yij = + Hi + eij \quad (1)$$

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

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

For qualitative or discrete responses (body condition score, pre-weaning survival, and litter size), the Kruskal & Wallis test was used, followed by the Dunn multiple comparisons test to verify differences between the FAMACHA© scores.

Then, the Wilcoxon test was used to verify if there was a difference between the FAMACHA© scores of the ewe in the two breeding stages: the beginning of the breeding season and at lambing.

All statistical analyses were carried out using the statistical software R-Studio version 4.2.0. (R Core Team, 2020). The Shapiro-Wilk, Bartlett, Kruskal & Wallis, Dunn, and Wilcoxon tests were performed with the Rstatix package (Kassambara, 2021). Analysis of variance and Duncan's

mean comparison test were performed using the ExpDes.pt package (Ferreira et al., 2014). All procedures were performed at a 5% significance level, i.e., a statistical difference was considered when the P-value obtained was less than 0.05.

Results and Discussion

FAMACHA© score of ewes at breeding

Table 3 shows the results referring to the analysis of variance carried out to determine the implications arising from the FAMACHA© score of the ewes at the time of breeding on the zootechnical indicators, body condition score of the ewe at breeding, litter size, pre-weaning survival, birth weight per lamb and litter, dam's weight and age at lambing.

Ewe body condition score at breeding (BCB) was related to FAMACHA© score at breeding (P < 0.001); animals with FAMACHA© 1 had a body condition score of 3.59 ± 0.08 (mean ± standard error), and ewes with FAMACHA© 4 and 5 had a BCS of 1.73 ± 0.18. The body condition score indicates the animal's ability to accumulate energy reserves (fat deposits). Thus, the response obtained may be associated with the fact that parasitism by gastrointestinal helminths is the most significant form of energy drain in healthy sheep (Fthenakis et al., 2015). As gastrointestinal nematodes have the potential to reduce the availability of nutrients to the host by decreasing the efficiency of the absorption process of these compounds, also as a result of anorexia (Rojo-Vázquez et al., 2012), it is possible that parasitism contributed to the occurrence of deprivation of available energy in infected ewes and, consequently, there was a decrease in the body condition score of the ewes with the highest FAMACHA© scores. Rosalinski-Moraes et al. (2012) obtained a negative correlation between FAMACHA© and body condition scores of -0.32, indicating that an increase in one variable resulted in a decrease in the other.

It is important to emphasize that ewes' body condition score can be related to their feeding status, productivity level, weight, and reproductive efficiency (Santos et al., 2022). This argument can be reinforced by the fact that animals with FAMACHA© 1 had the highest body condition score and weight at lambing (EWB), with an average of 58.30 ± 1.39 kg, while ewes having FAMACHA© 4 and 5 had weight at lambing of only 42.94 ± 2.31 kg and the worst body condition score; therefore, maintaining the body condition score at levels of 2.5 to 3.5 is essential to ensure greater performance for the animals (Kenyon et al., 2014).

Litter size (LTS) also showed statistical relationships between FAMACHA© scores (P < 0.001). The ewes that presented score 1 had the greater litter size among the evaluated groups, with an average of 1.72 ± 0.07 lambs per litter. This observation may be related to ewes with FAMACHA© 1 having the highest body condition score since animals with higher energy reserves demonstrate increased fertility rates and increase the number of oocytes released (Kenyon et al., 2014). Therefore, draining energy during the breeding period can directly affect the reproductive performance of ewes and be a differential for the property's profitability because reductions in prolificacy rates decrease the number of sold lambs. This indicates that sheep breeders should evaluate the FAMACHA© of their ewes during the preparation for breeding season to guarantee a higher rate of prolificacy in their flock.

Regarding pre-weaning survival (SWB), it was possible to observe that ewes with FAMACHA© scores 4 and 5 had only 50.70 ± 7.53% of their offspring alive until the weaning date (P = 0.032). This result may be associated with a possible change in the development of the placenta because this organ is formed in the first two-thirds of pregnancy, and debilitated animals have less capacity to facilitate placental functions (López-Mazz et al., 2018). In addition, according to Vonnahme (2012), the chance of survival of a lamb can be correlated with the development of vascularization at the beginning of the placental growth stage and the utero-fetal blood flow. Therefore, as the ewes that presented FAMACHA© 5 had the worst body condition

Table 3 – Relationship between FAMACHA© score of ewes at breeding and other zootechnical indicators in the studied flock (mean ± standard error).

Variables	FAMACHA© score at breeding					CV
	1	2	3	4 and 5	P	
BCB	3.59 ± 0.08 A	3.00 ± 0.07 B	2.60 ± 0.15 B	1.73 ± 0.18 C	<0.001	27.83
LTS	1.72 ± 0.07 A	1.34 ± 0.09 B	1.27 ± 0.07 B	1.20 ± 0.11 B	<0.001	29.06
SWB	78.,26 ± 5.00 A	89.66 ± 5.80 A	75.00 ± 9.90 A	50.70 ± 7.53 B	0.032	25.30
BWB	3.57 ± 0.15	3.66 ± 0.15	3.46 ± 0.32	3.44 ± 0.45	0.823	20.05
LWB	5.48 ± 0.27 A	4.42 ± 0.32 B	3.72 ± 0.33 C	3.05 ± 0.35 D	<0.001	28.81
EWB	58.30 ± 1.39 A	53.24 ± 1.46 B	48.42 ± 1.84 C	42.94 ± 2.31 C	0.002	17.56
EAB	34.65 ± 2.46 A	23.10 ± 2.98 AB	28.52 ± 3.69 AB	18.10 ± 2.36 B	0.019	28.58

BCB: ewe's body condition score at breeding (score); LTS: litter size (head); SWB: lamb pre-weaning survival (%); BWB: birth weight per lamb (kg); LWB: Birth weight per litter (kg); EWB: ewe's weight at breeding (kg); EAB: ewe's age at breeding (months); P: P-value; CV: coefficient of variation (%). Capital letters differ from each other in the lines at the 5% level of significance.

score and birth weight, it is possible that the association between probable anemia and poor placental development affected the chance of pre-weaning survival of the lambs.

No statistical differences (P = 0.823) were observed between the lamb's birth weight (BWB) as a function of the different FAMACHA© scores of the dams. These data can be explained by the development of lambs occurring mainly in the final third of pregnancy. Therefore, the FAMACHA© score of animals at the beginning of the breeding season may not be as effective in influencing the individual birth weight of animals.

However, when the birth weight per litter (LWB) is considered, it is possible to verify that there was statistical significance (P < 0.001) between the evaluated treatments, where ewes from the FAMACHA© 1 group obtained the highest average of kilograms of lambs born per litter (5.48 ± 0.27 kg). When assessing the birth weight per litter, it is necessary to consider the prolificacy rate of the ewes, since the greater the number of fetuses present in the uterus, so the demand for nutrients increases, which causes greater intrauterine competition and negatively influences the birth weight of the lambs (Rego Neto et al., 2014). Despite this, even with lower individual birth weight, the total weight of lambs born per ewe increases as prolificacy increases provided that ewes' sanitary and nutritional needs during the gestational period are met (Murphy et al., 2020). Because the ewes from the FAMACHA© 1 group had the largest litter size, this result probably contributed to the higher collective birth weight of lambs conceived by ewes with FAMACHA© 1 in the breeding season. Mavrogianni et al. (2011) recorded more elevated numbers of lambs born per dam and higher survival rates in animals that were dewormed before the start of the breeding season.

For the ewe's age at breeding (EAB), there were statistical differences between the evaluated treatments (P = 0.019), which showed that the animals with FAMACHA© 4 and 5 had the lowest average age (18.10 ± 2.36 months). This result may be associated with the fact that these ewes are possibly individuals that have just left the first lactation and are returning to the breeding period for re-conception. Thus, it is likely that they were in weakened conditions due to the high energy demand from the lactation period added to growth, and therefore more susceptible to parasitic infections and more likely to suffer from anemia. According to Chay-Canul et al. (2016), ewes that become pregnant at a very young age experience metabolic challenges because the growth and lactation phases overlap, which can increase the nutritional and energy demand of these animals by up to 70%. Given this, the need to separate first-pregnancy ewes from the other ewes on the property is evident since they are more sensitive and demand greater nutritional support.

It is important to note that ewe lambs were exposed to the rams from 7 months of age; if they became pregnant at that age, they would be 12 months old at the first lambing and spend another 2 months in the lactation period, totaling 14 months. In the FAMACHA© 4 and 5 group, the dams were 18.10 ± 2.36 months old, indicating that these ewes were inactive for 4 months on the property. This result is associated with this group's low breeding body condition score since animals with inadequate scores may have delayed estrus, reducing the flock's fertility rate (Kenyon et al., 2014).

Based on the results shown in Table 3, it is necessary to emphasize the importance of observing and treating animals with a FAMACHA© score above 3 since reproductive and productive losses related to these ewes and their lambs were observed. Given this, it may be of value for sheep breeders to use the FAMACHA© score to determine which animals can breed and which will be destined to receive anthelmintic treatments or nutritional and vitamin supplements to ensure greater health and performance in the flock. Animals bred with FAMACHA© 4 and 5 have lower litter sizes, and their lambs have lower viability (higher mortality), which indicates losses to the farmer who will sell these animals.

FAMACHA© score of ewes at lambing

In addition to the implications of the FAMACHA© score at breeding, the consequences of the FAMACHA© score at lambing were also analyzed. Its effects on ewe body condition score at lambing, pre-weaning survival, birth weight per lamb, birth weight per litter, lamb average daily gain, lamb weaning weight, and dam's age and weight at lambing are shown in Table 4.

Ewe's body condition score (BCL) and ewe's body weight (EWL) at lambing were related to the FAMACHA© score at lambing (P < 0.001). Ewes with FAMACHA© 1 at lambing had a mean body condition score and weight of 3.56 ± 0.06 and 58.63 ± 1.01 kg, respectively, while the ewes with FAMACHA© 4 and 5 at lambing had a body condition score of 1.46 ± 0.13 and weighed 46.62 ± 1.99 kg. The same response behavior of these variables was observed in Table 3 when the evaluated treatments were related to the FAMACHA© score of ewes at breeding. The results reinforce that as the FAMACHA© score of the ewes increases, energy losses due to parasitism increase, and consequently, there is a more significant detriment to the health and productivity of compromised animals since there is a decrease in the body condition score and body weight of the ewe.

Table 4 – Relationship between FAMACHA© score of ewes at lambing and other zootechnical indicators in the studied flock (mean ± standard error).

Variables	FAMACHA© score at lambing					CV
	1	2	3	4 and 5	P	
BCL	3.56 ± 0.06 A	3.00 ± 0.15 B	2.44 ± 0.13 B	1.46 ± 0.13 C	<0.001	29.21
SWL	98.97 ± 1.00 A	91.30 ± 6.06 AB	75.00 ± 11.20 B	17.45 ± 8.15 C	<0.001	26.16
BWL	415 ± 0.10 A	3.71 ± 0.21 AB	3.26 ± 0.20 B	1.94 ± 0.15 C	<0.001	23.52
LWL	6.10 ± 0.19 A	5.39 ± 0.47 B	4.03 ± 0.41 C	2.99 ± 0.38 D	<0.001	22.23
ADG	0.224 ± 0.01 A	0.201 ± 0.01 A	0.212 ± 0.02 A	0.130 ± 0.01 B	0.034	25.64
LWW	16.64 ± 0.45 A	14.73 ± 0.74 A	14.40 ± 1.04 A	9.48 ± 1.11 B	0.002	24.98
EAL	29.29 ± 1.98 B	40.42 ± 4.49 A	31.67 ± 3.94 AB	17.97 ± 2.50 C	0.023	29.75
EWL	58.63 ± 1.01 A	54.61 ± 1.88 AB	54.10 ± 2.29 AB	46.62 ± 1.99 C	<0.001	16.87

BCL: ewe's body condition score at lambing (note); SWL: pre-weaning survival (%); BWL: birth weight per lamb (kg); LWL: birth weight per litter (kg); ADG: lamb average daily gain (kg/day); LWW: lamb weaning weight (kg); EAL: ewe's age at lambing (months); EWL: ewe's weight at lambing (kg); P: P-value; CV: coefficient of variation (%). Capital letters differ from each other in the lines at the 5% level of significance.

Regarding pre-weaning survival (SWL), 98.97 ± 1.00% of the lambs born from ewes with FAMACHA© 1 at lambing were alive at the weaning date; in contrast, only 17.45 ± 8.15% of the offspring of FAMACHA© 5 ewes managed to reach 60 days (P < 0.001). Two reasons can explain these results.

The first is based on the fact that parasitism reduces milk production in infected animals, contributing to a higher pre-weaning mortality rate (Brozos et al., 2011). In a study by Cruz-Rojo et al. (2012), ewes with a high parasite load had milk production decreased by 18% compared to healthy animals.

The second explanation would be the existing correlation between the pre-weaning survival rate and the individual birth weight of the lambs (BWL). Lambs born from ewes from the FAMACHA© 1 group had the highest individual birth weight (4, 15 ± 0.10 kg) and obtained the highest percentage of survivors until weaning (98.97 ± 1.00%). According to Pettigrew et al. (2018), lambs with birth weights between 3.0 and 5.5 kg have an 85% higher survival rate than animals outside this range. Intrinsically, it is important to emphasize that lower birth weight is directly associated with the energy and body condition of the ewes because lighter ewes tend to have a lower body condition score and a body weight that limits fetal growth in the final third of pregnancy.

The birth weights per lamb and litter showed differences in the FAMACHA© score of the ewes at lambing (P < 0.001). Ewes that had FAMACHA© 1 at lambing were able to generate 6.10 ± 0.19 kg of lambs per litter, while ewes with FAMACHA© 4 and 5 lambed only 2.99 ± 0.38 kg. These results can be linked to the metabolic demand of the ewes during the final third of pregnancy since, in this period, the lambs develop rapidly and acquire approximately 75-80% of their birth weight. Intrinsically, the energy needs of pregnant ewes also increase during this phase, making it essential to meet the protein requirements for the production of colostrum in the mammary glands (Fthenakis et al., 2012). However, when ewes are infected with high parasitic loads, there is a greater demand for energy due to histiophagy (Fthenakis et al., 2015). Thus, the result of these metabolic problems from parasitic infections can be seen in the birth weight of the offspring. Osaer et al. (1999) found that lambs born to dams with high parasite loads had lower birth weights than those from healthy animals.

As to the pre-weaning average daily gain of lambs (ADG), lambs born from dams with FAMACHA© scores 4 and 5 showed the worst increases, with only 0.130 ± 0.001 kg/day (P = 0.034). This result can be associated with the low birth weight of the lambs (1.94 ± 0.15 kg). According to Guedes et al. (2015), animals with lower birth weights demonstrate worse performance, need more days to reach the ideal weight for slaughter, have worse feed conversion, and reduced weight gain. Likewise, parasites directly influence the absorption of nutrients in animals (Fthenakis et al., 2015), i.e., they may have impaired the mother-fetus nutrient partition during pregnancy and, consequently, delayed pre-and postnatal development of the lambs.

Regarding weaning weight (LWW), it was observed that the lambs of ewes with FAMACHA© 1 at lambing were weaned 75.52% (16.64 ± 0.45 kg) heavier than lambs born from ewes that had FAMACHA© scores 4 and 5 at lambing (9.48 ± 1.11 kg) (P = 0.002). The weaning weight is dependent on birth weight and pre-weaning average daily gain. Thus, the association between the lowest birth weight and the worst pre-weaning average daily gain observed in the FAMACHA© 4 and 5 group contributed to the fact that these lambs had the worst weight at weaning among the evaluated treatments (9.48 ± 1.11 kg).

Considering the average age of the ewes at lambing (EAL), the animals in FAMACHA© groups 4 and 5 were the youngest (17.97 ± 2.50 months). The younger the ewes are, the greater their growth rate and requirements. This, combined with the condition of gestation, makes these animals more susceptible to worms. According to Najarnezhad et al.

(2016), ewes in their first pregnancies have a higher energy expenditure due to the changes caused in the body for the fetus's viability (es) to occur. Therefore, they may be more debilitated and susceptible to parasitic infections caused by anemia. Furthermore, it is possible to relate the age of the ewe with the survival rate of the lambs because as the age of the ewe at lambing decreases, survival decreases. This association may be linked to the fact that there is a higher incidence of dystocia in ewes at a younger age since there is a disproportion between the size of the ewe and its lamb (Jacobson et al., 2020). Likewise, the ewes in FAMACHA© 4 and 5 group had the lowest weight at lambing, which is a zootechnical indicator with a positive correlation with the size of the pelvic dimensions, a fact that causes a greater chance of mortality for the lamb (Jacobson et al., 2020).

As the average age at lambing the ewes with FAMACHA© 4 and 5 was 17.97 ± 2.50 months, the ewes belonging to this group became pregnant on average at 12.97 months. This result indicates a deficit in the reproductive management of these ewes since they were exposed to the rams from 7 months of age. Therefore, they remained on average for almost 6 months in the breeding period. This fact is probably associated with a low body condition score at breeding and the allocation of these animals to pasture, so there is more significant parasitic contamination and a decrease in the use of consumed nutrients, increasing the age at first lambing. An interesting strategy for the farmer would be to apply the flushing feeding management, which consists of increasing the energy density of the diet offered in the pre-breeding period to improve the ewes' body condition score and increase fertility and prolificacy rates.

It is important to point out that when evaluating different zootechnical indicators of the same production system, it is necessary to conduct a joint analysis of them because several interrelationships between them must be addressed. In addition, based on the information discussed and available in Table 4, there is a need to redouble care with ewes that have FAMACHA© scores 4 and 5 at lambing since not only do the ewes suffer from production, health, and performance issues but so do their offspring.

Variation of the FAMACHA© score of the ewes from breeding to lambing

The Wilcoxon test performed indicated that there was no significant difference between the FAMACHA© scores of the ewes at breeding and lambing (P = 0.3218), meaning that the animals have high probabilities of presenting the identical FAMACHA© scores at breeding and lambing, even after anthelmintic treatment. These results reinforce the need to monitor the FAMACHA© score of ewes when preparing for the breeding period since, as shown in Tables 3 and 4, ewes with FAMACHA© scores 4 and 5 presented weight loss, lower body condition score, worse reproductive performance, higher chance of offspring mortality and reduced weaning weight of their lambs. Notably, if a ewe enters the breeding season weakened, she will probably spend most of her pregnancy in critical health conditions, which will cause deleterious effects for her and her lambs.

Taking into account that all the ewes that presented FAMACHA© 4 and 5 were treated, it is possible to emphasize that these are susceptible animals to haemonchosis since they were dewormed at the beginning of the breeding season and still presented FAMACHA© 4 and 5 at lambing. This result could reflect the high metabolic demand for viability of the fetus in the final third of pregnancy (Kenyon et al., 2014). The greater susceptibility of ewes to parasites in the peripartum period is due to an interaction of several factors resulting from hormonal changes and nutritional needs (Amarante, 2015). There is a metabolic priority in the use of nutrients for the maintenance and survival of the offspring to the detriment of the female's immune response, which becomes more susceptible to gastrointestinal parasitosis and other diseases (Pereira et al., 2020). For this work, data on egg count per gram of feces are not available, so it is impossible to quantify the effectiveness of the anthelmintic treatment in reducing the parasite load of the animals.

The tendency to maintain the FAMACHA© score during pregnancy reinforces the importance of selecting animals resistant to worms in sheep production systems. As the FAMACHA© score has heritability values in the range of 0.32 to 0.46 (Medrado et al., 2021; Santos et al., 2021), it would be of value for sheep farmers to use data records about the FAMACHA© score of the animals as a selection criterion. The present work demonstrated that, in addition to health damage, ewes with FAMACHA© 4 and 5 results in the production of lambs with inferior performance; therefore, culling these individuals and keeping superior animals can be the driver to increase the flock's performance and make a significant improvement in zootechnical indicators.

Conclusions

The FAMACHA© score of ewes at breeding is associated with the pre-weaning survival rate, litter size, ewe's age at breeding, body condition score at breeding, ewe's weight at lambing, and birth weight per litter. The FAMACHA© score of ewes at lambing is related to the pre-weaning survival rate, ewe's age at lambing, ewe's body condition score at lambing, ewe's weight at lambing, birth weight per lamb and litter, and lamb weaning weight. Ewes with

FAMACHA© scores 4 and 5 and their offspring had the worst productive and reproductive performances. Conversely, ewes with FAMACHA© 1 demonstrated the opposite result, showing zootechnical indicators compatible with improved production efficiency.

More studies are needed to continue advancing our understanding of the various deleterious effects that parasites can exert on sheep production systems, e.g., to verify if there is a difference in the pregnancy and fertility rates of ewes with different FAMACHA© scores. This result would be of great value to further measure the impact of worms on sheep performance and to recommend adequate control strategies.

Conflict of Interest

None of the authors have financial or personal relationships that could inappropriately influence or bias the paper's content.

Ethics Statement

This study was conducted using a historical database derived from records of the Small Ruminant Production Sector at the Federal University of Uberlândia. According to the national Brazilian Law No. 11,794/2008, which establishes procedures for the scientific use of animals, zootechnical practices related to livestock farming are not considered research activities. This exempts the present study from the need to be evaluated by an Ethics Committee for Animal Use. Besides, all results are original and the authors declare no competing interests.

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