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Reproductive performance of hair sheep under different body conditions and feeding levels

Abstract – The objective of this work was to evaluate the effect of the interaction between feeding level (FL) and body condition score (BCS) on the reproductive parameters of Pelibuey hair sheep (*Ovis aries*). The experimental units (64 ewes) were randomly assigned to one of four treatments: low feeding level and low body condition score; high feeding level and low body condition score; low feeding level and high body condition score; and high feeding level and high body condition score. The effect of sheep body condition score was significant on the pregnancy and lambing rates. The effect of feeding level was significant on the ovulation, estrus returning, pregnancy, and prolificacy rates. The interaction effect between BCS and FL was significant on the ovulation, estrus returning, pregnancy, lambing, and prolificacy rates. The reproductive function is more sensitive to the better nutrition effects in sheep with a low body condition score.

Index terms: *Ovis aries*, flushing, ovulation rate, prolificacy.

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Desempenho reprodutivo de ovelhas de pelo em diferentes condições corporais e níveis de alimentação

Resumo – O objetivo deste trabalho foi avaliar o efeito da interação entre nível de alimentação (FL) e escore de condição corporal (BCS) sobre os parâmetros reprodutivos de ovelhas de pelo Pelibuey (*Ovis aries*). As unidades experimentais (64 ovelhas) foram distribuídas aleatoriamente a um dos quatro tratamentos: baixo nível de alimentação e baixo escore de condição corporal; alto nível de alimentação e baixo escore nas condições corporais; baixo nível de alimentação e alto escore nas condições corporais; e alto nível de alimentação e alto escore nas condições corporais. O efeito do escore de condição corporal de ovelhas foi significativo sobre as taxas de prenhez e parto. O efeito do nível de alimentação foi significativo sobre as taxas de ovulação, retorno do estro, prenhez e prolificidade. O efeito da interação entre escore de condição corporal e nível de alimentação foi significativo sobre as taxas de ovulação, retorno do estro, prenhez, parto e prolificidade. A função reprodutiva é mais sensível aos melhores efeitos nutricionais em ovelhas com baixo escore de condição corporal.

Termos para indexação: *Ovis aries*, flushing, taxa de ovulação, prolificidade.

Introduction

Sheep farm productivity is improved by increasing twin births, which can be achieved by introducing prolific breeds into the flock, or by performing ovary stimulation with gonadotrophin hormones. In addition, the manipulation of body condition score, live weight, and metabolic status by nutrition strategies, and short-term nutrition supplementation (Fernández-Foren et al., 2019) are effective ways to improve sheep reproductive performance. Accordingly, fertility rates in ewes are improved, when body condition scores range from 2.5 to 4.0 (Cam et al., 2018).

Nutritional strategies to improve animal reproduction should be designed to target specific reproductive events at a very specific time (Delgadillo & Martin, 2015), such as folliculogenesis and ovulation. The most common approach is to increase the supplementation level above that for the maintenance recommendations (Khaiseb et al., 2022), but other approaches explored the effect of switching between high- (with supplementation) and low-feeding (without supplementation) regimes, before and after mating (Rhind et al., 1989), from 5 to 80 days (Viñoles et al., 2005; Macías-Cruz et al., 2017). However, there is a lack of studies evaluating the interaction between body condition score and different levels of supplementation. In addition, the above mentioned researches have mostly used ewes from wool breeds as experimental units, while others have mentioned that the reproductive performance of hair sheep breeds such as Katahdin x Pelibuey is not compromised by undernourishment (Macías-Cruz et al., 2017).

The objective of this work was to evaluate the interaction effect between feeding levels and body condition scores on the reproductive parameters of hair sheep.

Materials and Methods

This work was carried out to observe the standards for use and care of research animals at Colegio de Postgraduados, Campus Montecillo, Texcoco, Mexico, according to the Mexican standards Normas Oficiales Mexicanas NOM-024-ZOO-1995 and NOM-033-ZOO-1995 (Mexico, 1998).

The experiment was performed at the Sheep and Goat Reproductive Laboratory of the Colegio de Postgraduados, Campus Montecillo, Texcoco, Mexico (98°53'W, 19°29'N, at 2,250 m of altitude), during the reproductive season for sheep (from August/2020 to February/2021; short days).

A preliminary study was carried out for 45 days with 64 Pelibuey ewes with 3.5±1.3-year-old animals and 40.7±7.1 kg mean weight. The ewes were assigned to one of two feeding groups (Figure 1) for 60% or 120% of the recommended daily allowance by the NRC (1985), as follows: wheat straw, 3%; calcium carbonate, 1%; corn gluten, 4%; molasses, 8.5%; oat hay, 3.5%; canola meal, 9%; sorghum, 47%; soybean hulls, 13%; urea, 0.5%; wheat bran, 9.5%; minerals, 1%; protein, 14.76%; metabolizable energy, 2.71 Mcal kg^{-1}; and fiber, 11.7%), to achieve the required body conditions score of 2.5 to 3.0 (LoBCS) and >3.5 (3.5–4.0; HiBCS), on a scale of 1.0 to 5.0 (Russel et al., 1969). At the end of the preliminary study, an experiment was carried out to study the interaction effect of body condition scores with feeding levels. The ewes were assigned to one of four treatments, as follows: ewes with low body condition score (LoBCS) and low feeding level (LoFL) [LoBCS×LoFL, n=16]; ewes with LoBCS and high FL (HiFL) [LoBCS×HiFL, n=15]; ewes with high BCS (HiBCS) and LoFL [HiBCS×LoFL, n=14]; and ewes with HiBCS and HiFL [HiBCS×HiFL, n=19] (Figure 1). This experiment lasted 21 days; it began 14 days prior to mating, and it ended seven days after mating.

An intramuscular injection of prostaglandin PGF2α (Dinoprost 5 mg per sheep) was given to all ewes at the days 45 and 56 of the experiment, to synchronize the estrus cycle (Figure 1). Estrus detection was carried out every four hours after the second injection of prostaglandin, and rams wore apron to prevent copulation and a harness to mark the ewes in heat. An ewe was declared in heat when she stood to be mounted by a ram. The ewes were mated by one of twelve rams of proven fertility at 12 and 24 hours after heat detection.

The response variables were estrus rate, ovulation rate (OR), number of ewes returning to estrus, pregnancy rate, lambing rate, and prolificacy. The ewes returning to estrus were detected with rams wearing an apron from the day 10 to the day 25 after mating. The OR was measured by counting the number of *corpus luteum* in each ewe, with a laparoscope, at 11 days after mating. The pregnancy diagnoses were performed by ultrasonography at 45 days post-mating, with the aid of a transrectal transducer connected to an ultrasound equipment (Aloka SSD 500, Aloka Co. LTD., Tokio, Japan).

Chi-square analysis was applied to the variables expressed as percentages. Generalized linear models

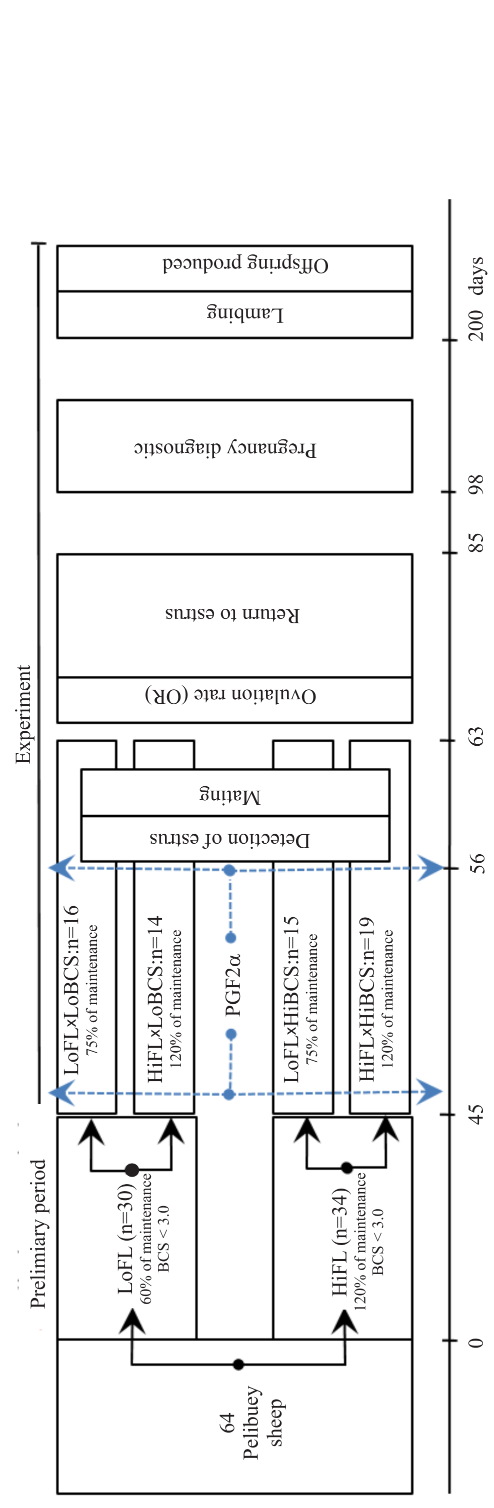

Figure 1. Experimental groups and research activities: LoFL×LoBCS, low feeding level and low body condition score; HiFL×LoBCS, high feeding level and low body condition score; LoFL×HiBCS, low feeding level and high body condition score; HiFL×HiBCS, high feeding level and high body condition score, from August/2020 to February/2021 (short day length), in Montecillo, Texcoco, Mexico.

(GLM) provided in the computational program SAS (SAS Institute Inc., Cary, NC, USA) were used for the numeric variables, and the Tukey's test was used to determine significant differences, at 5% probability.

The statistical model used to evaluate the studied variables was a completely randomized linear model arranged in a 2 x 2 completely balanced design (Steel & Torrie, 1990) described as follows:

$$Y_{ijk} = \mu + BCS_j + FL_k + (BCS \times FL)_{jk} + \varepsilon_{ijk},$$

where: Y_{ijk} is the response variable in the i^{th} replicate of the j^{th} level of body condition, and of the k^{th} feeding level; μ is the mean; BCS_j is the effect of j^{th} body condition score, and j represents Lo (low) or Hi (high); FL_k is the effect of the k^{th} feeding level, and k represents Lo (low) or Hi (high); $(BCS \times FL)_{jk}$ is the effect of BCS×FL interaction between levels j and k; and ε_{ijk} is the observational error, where $\varepsilon_{ijk} \sim N(0, \sigma^2)$.

Results and Discussion

The percentage of ewes that showed estrus after the second injection of PGF2α was 89.06%, and there were no differences ($p<0.05$) between treatments (Table 1). The ovulation rate mean ranged from 1.80±0.16 to 2.43±0.16 *corpus luteum* per sheep. The effect of body condition was not significant, but ewes under low feeding level had a lower ovulation rate than those under the high feeding level. In addition, the interaction effect was significant. The ewes in

Table 1. Ovulation rate of Pelibuey hair ewes (*Ovis aries*) in accordance with the feeding level and body conditions score (BCS) before and after breeding, from August/2020 to February/2021 (short day length), in Montecillo, Texcoco, Mexico(1).

BCS	Feeding level(2)		Mean±SE
	Low (75%)	High (120%)	
Low (≤3.0)	(14/16) 1.73±0.23a	(14/14) 2.50±0.24b	2.12±0.16A
High (≥3.5)	(15/15) 1.87±0.23ab	(14/19) 2.37±0.20b	2.13±0.50A
Mean±SE	1.80±0.16A	2.43±0.16B	

(1)Means followed by equal lowercase and uppercase letters in the rows and columns do not differ, by Tukey's test, at 5% probability. (2)Feeding levels in relation to the NRC (1985) recommendations: low = 75%; high = 120%. Body condition scores: low ≤ 3.0; high ≥ 3.5. SE, standard error. Terms of the proportions in parentheses indicate the number of ewes that showed estrus.

the LoFL×LoBCS group showed a lower ovulation rate than those in the HiFL groups. According to results, the ewes with low body condition scores are more susceptible to the short-term nutrition effect than ewes with high body condition scores. The low ovulation rate observed in the group LoFL×LoBCS might be explained by a nutrition-mediated reduction of the number of recruited follicles, as well as by a lower supply of gonadotropin hormones and follicular sensitivity to gonadotropins (Luo et al., 2016).

The growth of the ovarian follicles to achieve the ovulatory stage depends on the access to gonadotropins, nutrients, and growth factors. There is evidence that ewes with high ovulation rate have a greater receptor expression and responsivity to gonadotropins – follicle-stimulating hormone (FSH) and luteinizing hormone (LH) – than ewes with low ovulation rate (Goyal et al., 2017). Coincidently, it is known that a greater supply of nutrients increases the expression of gonadotropin receptors (Guo et al., 2019) and ovulation rate in ewes (Khaiseb et al., 2022), which explains the greater ovulation rate obtained in the HiFL group than ewes in the LoFL group. However, nutritional restriction reduces ovulation rate (Rhind et al., 1989) by limiting the release of the gonadotropin-releasing hormone (GnRH) and, subsequently, the release of gonadotropins (Matsuyama & Kimura, 2015). It is currently well known that kisspeptin is a mediator of GnRH release, and that feed restriction and fasting disrupt the kisspeptin expression and synthesis, leading to a shutdown of gonadotropins releasing pathway (Polkowska et al., 2015; Merkley et al., 2020).

There are several metabolic signals that the hypothalamus translates to decode the nutritional status of the animal, to allow or to block the induced release of GnRH by kisspeptin, such as the variations of blood concentrations of insulin and leptin. Starvation and food restriction cause the decrease of blood concentrations of these hormones and disrupt the secretion of gonadotropins in ewes (Viñoles et al., 2005; Abo El-Maaty & Abd El-Gawad, 2014). These hormones are known to regulate kisspeptin neurons by a direct stimulation, or by suppressing the production of orexigenic (appetite-stimulating) neuropeptides, such as the neuropeptide Y (Daniel et al., 2013; De Bond & Smith, 2014).

An acute and dynamic effect of nutrition on ovulation rate can be achieved by a short period (5 to 14 days) of supplementation before mating (Khaiseb et al., 2022). However, others have fail to observe any changes in ovulation rate by supplementing thin ewes for six days (Viñoles et al., 2010); obviously, there is an implication of time; however, it is worth to mention that the thin ewes used by Viñoles and colleagues were fed at a maintenance ratio, and those used in the present study were undernourished, which implies that previous nutritional status dictates the type of response to supplementation. The results of the present study indicate that the reproductive system of previously undernourished ewes is very sensitive to positive nutritional inputs, which is evidenced by a similar ovulation rate observed between groups of well-nourished ewes. In addition to previous nutritional status, it has been reported that the effect of nutritional input depends on the breed of ewes, since the feeding of ewes with 50% of maintenance ratio for up to 30 days did not affect ovulation rate homogeneously among three different ewe breeds, which might be explained by body fat reserve mobilization to cope undernutrition in fat tail ewes (Abo El-Maaty & Abd El-Gawad, 2014). A similar conclusion can by drawn from the present study because ovulation rate of well-nourished ewes was not affected by a short exposure to a low feeding regimen.

The average estrus return rate ranged from 7.14 to 23.81%, the effect of feeding level was significant

Table 2. Estrus return rate of Pelibuey hair ewes (*Ovis aries*) according to the feeding levels and body conditions score (BCS) before and after breeding, from August/2020 to February/2021 (short day length), in Montecillo, Texcoco, Mexico[1].

BCS	Feeding level[2]		Mean
	Low (75%)	High (120%)	
Low (≤3.0)	(2/14) 14.28a	(2/14) 14.28a	14.28A
High (≥3.5)	(5/15) 33.33b	(0/14) 0.00a	16.66A
Mean	23.81A	7.14B	

[1]Means followed by equal lowercase and uppercase letters in the rows and columns do not differ, by Tukey's test, at 5% probability. [2]Feeding levels in relation to the NRC (1985) recommendations: low = 75%; high = 120%. Body condition scores: low ≤ 3.0; high ≥ 3.5. SE, standard error. Terms of the proportions in parentheses indicate the number of ewes that return to estrus.

(p<0.05), and the body condition score was not significant (Table 2). The largest return rate was observed in the group of ewes that received the low feeding regimen. The interaction effect was also significant (p<0.05). The highest return rate was observed in the LoFL×HiBCS group. In addition, low pregnancy (Table 3) and low lambing rate (Table 4) were also recorded in this group. The highest prolificacy was registered in ewes under the HiFL. The interaction effect was also significant. The lowest prolificacy was observed in the group LoFL×LoBCS (Table 5). The results indicate that, contrarily to pregnancy rate, the number of lambs that a thin ewe would produce is reduced when they are subjected to a low feeding regimen for a short period of time, before and after mating. In addition, it can be speculated if fertilization failure and/or embryo death increases in underfed ewes with a high body condition score. In agreement with the results of the present study, others have also reported a lower pregnancy rate in undernourished than in well-fed ewes (Rhind et al., 1989). The results also show that a short period of supplementation (high feeding regimen) is sufficient to improve the reproductive performance of ewes with low body condition scores.

The growth and dominance capability of ovarian follicle, and the number of recovered blastocyst are low in ewes fed with 50% of the maintenance diet (Sosa et al., 2010; Fernández-Foren et al., 2019). In addition, a higher production of uterine prostaglandins have been reported in ewes offered 50% of the maintenance ratio (Lozano et al., 2003). All together indicates that oocyte competence, uterine environment and embryo survival is compromised in undernourished ewes, which explains the reduced pregnancy rate observed in the group LoFL×HiBCS. Surprisingly, the low feeding regimen did not compromise the pregnancy rate in ewes with a low body condition score, others have also reported similar results (Macías-Cruz et al., 2017). It can be speculated that the LoFL regimen was not sufficient to influence the pregnancy rate, or that the sheep organism has adapted to a low-nourishment environment. It is also worth noting that a high nutritional regimen was not detrimental to the pregnancy rate as previously reported in other researches (Parr et al.,

Table 3. Pregnancy rate of Pelibuey hair ewes (*Ovis aries*) in accordance with the feeding levels and body conditions score (BCS) before and after breeding, from August/2020 to February/2021 (short day length), in Montecillo, Texcoco, Mexico(1).

BCS	Feeding level(2)		Mean
	Low (75%)	High (120%)	
Low (Lo) (≤3.0)	(12/16) 75.00a	(12/14) 85.71a	80.36A
High (Hi) (≥3.5)	(9/15) 60.00b	(14/19) 73.68ab	66.84B
Mean	67.50A	79.69A	

(1)Means followed by equal lowercase and uppercase letters in the rows and columns do not differ, by Tukey's test, at 5% probability. (2)Feeding levels in relation to the NRC (1985) recommendations: low = 75%; high = 120%. Body condition scores: low ≤ 3.0; high ≥ 3.5. SE, standard error. Terms of the proportions in parentheses indicate the number of pregnant ewes.

Table 4. Lambing rate of Pelibuey hair ewes (*Ovis aries*) in accordance with the feeding levels and body conditions score (BCS) before and after breeding, from August/2020 to February/2021 (short day length), in Montecillo, Texcoco, Mexico(1).

BCS	Feeding level(2)		Mean
	Low (75%)	High (120%)	
Low (≤3.0)	(11/16) 68.75a	(12/14) 85.71b	77.46A
High (≥3.5)	(9/15) 60.00a	(14/19) 73.68ab	66.84B
Mean	64.38A	79.69B	

(1)Means followed by equal lowercase and uppercase letters in the rows and columns do not differ, by Tukey's test, at 5% probability. SE, standard error. (2)Feeding levels in relation to the NRC (1985) recommendations: low = 75%; high = 120%. Body condition scores: low ≤ 3.0; high ≥ 3.5. Terms of the proportions in parentheses indicate the number of ewe lambings.

Table 5. Prolificacy of Pelibuey hair ewes (*Ovis aries*) in accordance with the feeding levels and body conditions score (BCS) before and after breeding, from August/2020 to February/2021 (short day length), in Montecillo, Texcoco, Mexico(1).

BCS	Feeding level(2)		Mean
	Low (75%)	High (120%)	
Low (≤3.0)	1.52±0.2a	2.25±0.2b	1.89±0.1A
High (≥3.5)	2.00±0.2b	2.27±0.2b	2.14±0.1A
Mean	1.77±0.1A	2.26±0.1B	

(1)Means followed by equal lowercase and uppercase letters in the rows and columns do not differ, by Tukey's test, at 5% probability. (2)Feeding levels in relation to the NRC (1985) recommendations: low = 75%; high = 120%. Body condition scores: low ≤ 3.0; high ≥ 3.5. SE, standard error.

1987). According to Parr and colleagues, providing nutrients above the recommendations after mating results in higher clearance of blood progesterone, which reduces the number of pregnancies in ewes. However, a reduction of the pregnancy rate in well-fed ewes was not observed in the present study, probably because the high feeding regimen was provided before mating to allow of sufficient time for ewes to adapt.

Conclusions

1. The effect of Pelibuey sheep (*Ovis aries*) body condition score is significant for pregnancy rate and lambing rate.
2. The effect of feeding level is significant for the rates of the following parameters: ovulation, estrus returning, pregnancy, and prolificacy.
3. The interaction effect is significant for the rates of ovulation, estrus returning, pregnancy, lambing, and prolificacy.
4. The reproductive function of sheep with a low body condition score is more sensitive to the better nutrition effects than that of sheep with high body condition score.

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