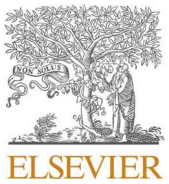
Small Ruminant Research 217 (2022) 106841



Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres



Short communication



Social communication advances the onset of puberty and increase body weight in female goats reared as a group

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ARTICLE INFO

Keywords:
Caprine
Doeling goats
Social isolation
First ovulation
Social stress

ABSTRACT

In small ruminant females, goats, and sheep, sensorial stimuli that emit (seeing, smelling, touching, hearing) have a marked influence on reproduction. The aim of this study was to determine if the females reared as a social group advance the onset of puberty and gained more body weight than females reared under social isolation. Females were isolated from males from weaning at 40 days of age and were split into two groups. In the first, females ($n = 10$) were placed together in a pen, while in the second ($n = 10$), each female was placed individually in a pen. The first ovulation, indicative of puberty's onset, was denoted by the plasma progesterone (≥ 1 ng/mL) acquired from at least two consecutive blood samples collected weekly. The onset of puberty in females reared as a social group was at 342.2 ± 4.5 days of age, and in females reared in social isolation was at 360.8 ± 3.6 days. Body weight at the beginning of puberty in the social group was higher (28.7 ± 0.4 kg) than in those females reared under social isolation (24.5 ± 0.5 kg) ($P < 0.5$). In addition, at the end of the study, on day 379, the social group recorded a higher body weight (29.5 ± 1.8 kg) than those in social isolation (25.0 ± 0.5 kg) ($P < 0.05$). We conclude that female goats reared as a social group advanced the onset of puberty and gained more body weight compared to females reared under social isolation.

1. Introduction

In mammalian species, the onset of puberty occurs at different ages and may be hastened or delayed. For example, in small ruminants such as goat and sheep females, the onset of puberty is due to the activation of the hypothalamus-pituitary-gonadal axis (Foster et al., 1985; Ebling, 2005). However, photoperiod (Ebling and Foster, 1988; Bronson, 2009), the season of birth (Delgadillo et al., 2007), sexually active male presence (Chasles et al., 2018), and social environment (Hemsworth et al., 1982; Ebling, 2005) can be involved in such activation.

Regarding the season of birth, for females born from January to May, the ovulatory activity begins in September and December of the same year. In contrast, the females born in October, this activity begins in October of the following year (Delgadillo et al., 2007), when pre-pubertal females have reached an adequate body weight (Chentouf et al., 2011). In fact, adult females with seasonal reproductive activity initiate their sexual activity when they perceive long days of spring and summer followed by the short days of autumn (Ebling and Foster, 1988). Therefore, in pre-pubertal females, goats and sheep, puberty begin similarly to when the reproductive season begins in adult females (Papachristoforou et al., 2000; Duarte et al., 2008).

Groups of female goats, who are in direct or indirect contact with the male, face an advancement in the onset of puberty (Espinoza-Flores et al., 2020). In contrast, animals reared in social isolation delay the initiation of sexual activities (Kercmar et al., 2014). In females that are kept in social isolation during rearing, plasma cortisol levels are increased due to activation of the hypothalamic-pituitary-adrenal axis (Hawkley et al., 2012; Kannan et al., 2021). The high cortisol concentrations inhibit the LH and FSH secretion (Narayan and Parisella, 2017) due to decreased activity of the hypothalamic-pituitary-gonadal axis by suppressing GnRH, inhibiting follicular development (Macfarlane et al., 2000). Therefore, social isolation for a long time can delays the onset of

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https://doi.org/10.1016/j.smallrumres.2022.106841
Received 29 August 2022; Received in revised form 9 October 2022; Accepted 11 October 2022
Available online 13 October 2022
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puberty due to the lack in the activation of the hypothalamic-pituitary-gonadal axis (Kercmar et al., 2014).

Social animals such as goats (Miranda-de la Lama and Mattiello, 2010), sheep (Dwyer, 2009), pigs (Hemsworth et al., 1982), and cattle (Boissy et al., 1998), live in a group and form a society. Social interactions between two or more individuals within a group modify that group's behavioral and reproductive responses (Bronson, 1985). Besides, a social group has the purpose of participating in group cohesion by providing advantages such as access to a sexual encounter or efficient consumption of forage (Hemsworth, 1983; Costa et al., 2016). In the present study, we hypothesized that prolonged social isolation in females cause stress and delay the onset of puberty and affects body weight. Therefore, the objectives of this study were to determine whether the females reared as a social group advance the onset of puberty and whether these females gained more body weight than females reared under social isolation.

2. Material and methods

2.1. General conditions

Procedures performed in this study were in accordance with the protocol of the Law for the Protection and Dignified Treatment of Animals for the State of Coahuila de Zaragoza, number 332 (Congreso del Estado Independiente, 2013), which provides technical specifications for the production, care, and use of experimental animals. In this study the females always had contact with people.

The study was carried out in the Chihuahuan Desert in Torreon, State of Coahuila, Mexico (latitude 25°23′N; longitude 104°47′W). The natural photoperiod varies from 13 h and 44 min of light/day at the summer solstice to 10 h and 33 min of light/day at the winter solstice. Torreon has a semi-arid climate, according to the classification of Köppen: BS_0 hw, characterized by having an extreme climate. Data show that in the warm season, the average maximum temperature is 35 °C and a minimum of 22 °C, and in the cold season, the average minimum temperature is 8 °C, and the maximum is 22 °C (Weather Spark, 2022). In this study, Creole female goats (*Capra hircus*) were used. In this region, the breeding season in females isolated from males is from September to January (Duarte et al., 2008).

2.2. Female rearing conditions

Twenty local goat kids with the date of birth on December 18 ± 1 day were used. The mothers were housed as a group. Goat kids were suckled by their mother, and always had physical contact with persons during their rearing. Goat kids were weaned at 40 days of age with a body weight (BW) of 7.4 ± 0.3 kg (mean ± SEM), and were isolated from males. Then females were randomly assigned into two groups. In the first group, females were reared as a social group ($n = 10$) and placed in a pen (5 × 8 m). Thus, females had total physical contact among them. In the second group, females ($n = 10$) were reared under social isolation, without visual and tactile contact. Each female was placed individually in a pen (1.5 × 2 m); thus, females had no physical contact, the wall that separated one pen from the other was of solid wood, all females always had contact with people. Although each female was able to hearing and smelling the female of the next pen because the two walls were made of wooden trellises. The two groups of females were separated by 250 m to avoid any interference between female groups. Females were fed ad libitum with hay alfalfa (21 % crude protein, 1.95 Mcal/kg of metabolizable energy (ME)) and with 200 g of commercial concentrate (18 % crude protein, 2.05 Mcal/kg of ME) to fulfill their nutritional requirements (110 g of crude protein, 2.86 of ME, 795 g of TND, 4 g of calcium, and 2.8 g of phosphorus) (National Research Council, 1981). In addition, water and mineral salts (12 % phosphorus and 11 % calcium) were supplied ad libitum.

2.3. Blood samples and progesterone assay

Blood samples were taken weekly from the jugular vein by venipuncture from the 31st of July 2019 to the 1st of January 2020. Each sample was put in a 5 mL tube containing 30 μL of sodium heparin (5000 IU/mL) as an anticoagulant. Blood samples were centrifuged at 3500 × *g* for 30 min, and plasma was stored in 1.5 mL centrifuge tubes at − 15 °C until the determination of hormone concentrations. Plasma progesterone concentrations were determined by Enzyme-Linked Immunosorbent Assay (ELISA, EIA-1561, DRG International, Inc., USA). The assay's sensitivity was 0.045 ng/mL, and the inter-and intra-assay coefficients of variation were 7.3 % and 7.7 %, respectively.

2.4. Variables assessed

The criterion indicated that a female attained puberty when their first ovulation occurred. It was detected when plasma progesterone concentration was ≥ 1 ng/mL in at least two consecutive blood samples (Delgadillo et al., 2007). In addition, the swelling and reddening of the vulva as indicative of heat was recorded weekly. Body weight was measured weekly. For this purpose, females were weighted on a portable platform scale with a capacity from 100 kg (accuracy ± 0.10 g).

2.5. Statistical analysis

A longitudinal design was used to determine the cumulative percentage of females that reached puberty. The Kaplan-Meier procedure was used to estimate the survival time function and determine the days when the first ovulation occurred. The non-parametric Log Rank test was used (Kaplan and Meier, 1958) to evaluate the equality of distributions for survival time in the two groups of females. In addition, the means (± standard error of the mean) for survival time at the onset of puberty were calculated according to the Kaplan-Meier procedure. Body weight was analyzed with a completely randomized model with repeated measures using the methodology of the generalized estimating equations (GEE). The model included the group of females, day of measurement, and the interaction day of measurement × group of females; the female was the effect subject. For the selection of the best model and the correlation structure with the best fit, an extension of the Akaike information criterion called quasi-likelihood was used under the criterion of the corrected independence model (QICC). The swelling of the vulva was compared between the two groups using the Mann-Whitney U test. The statistical analyses were carried out using the package SPSS version 22.0 (IBM Corp. Released, 2013). The level of statistical significance was set at $P \leq 0.05$.

3. Results and discussion

Fig. 1 shows the cumulative percentage of females that attained puberty for females reared as a social group and for females reared in social isolation. The distributions of the onset of puberty differed significantly between the two groups of females (Log Rank, $X^2 = 4.3, 1$; $P < 0.05$). The results show that the females reared as a social group began ovulations on September 25th on day 281 and ended on November 27th on day 344. During this period, all females ovulated. While the goats reared under social isolation began to ovulate on October 23rd on day 309 and ended on December 25th on day 372 (Fig. 2). The means (± SEM) at the onset of puberty for females reared as a social group was at 342.2 ± 4.5 days after birth, whereas for females reared in social isolation, the puberty started at 360.8 ± 3.6 days.

Body weight was similar between the two groups of females in the first measurement on July 31st on day 225; the social group recorded 21.6 ± 1.0 kg and the isolated group 21.0 ± 0.4 kg ($P > 0.05$; Table 1 and Fig. 2). The results showed no significant effect of the female group for body weight ($P > 0.05$). However, the week of measurement, the interaction between the week of measurement and the group of females

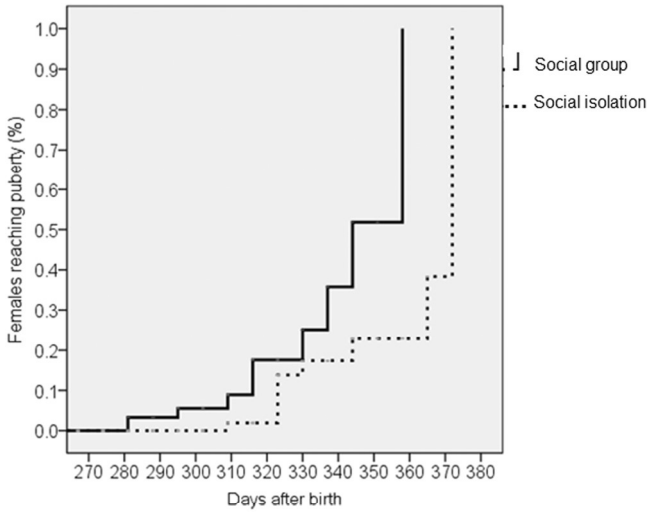


Fig. 1. Cumulative percentage of females born in December reaching puberty. Ten females were reared as a social group and were placed in a pen (J), and 10 females were reared in social isolation. Each female was placed individually in a pen (...). Females were isolated from males. The females reared as a social group advanced the onset of puberty.

differed significantly ($P < 0.001$). The results of the present study show that females reared as a social group began puberty with a body weight of 28.7 ± 0.4 kg, while females reared in social isolation was 24.5 ± 0.5 kg (Table 1). Our results agree with previous studies that indicate that body weight positively influences the onset of puberty in female goats (Sakurai et al., 2004).

Regarding the first measurement on July 31st on day 225 after birth, the social group increased body weight on August 21st on day 246 ($P < 0.001$), while the isolated group was on August 28th on day 253 ($P < 0.001$). From August 28th on day 253 until October 16th on day 302, both groups of females registered similar variations in body weight ($P > 0.05$). However, from day 295, the social group registered 3.3 kg more than the isolated group, although the differences were not significant ($P > 0.05$). In addition, during the last three weeks of measurement from the days 358–379, the social group recorded 4 kg more than the isolated group ($P < 0.05$) (Fig. 2).

The results of the present study support our hypothesis that prolonged social isolation in females cause stress and delay the onset of puberty and affects body weight. Our results show that females kept as a social group is more efficient in the forage intake because increased body weight and advance the onset of puberty, as reported in previous studies (Moallem et al., 2010; Costa et al., 2016).

On the other hand, the reason for the delayed onset of puberty in females reared in social isolation could have been probably due to the increased levels of cortisol because the females were individually separated from weaning and experienced social stress (Hawkley et al., 2012). Another possible explanation is that those females did not experience all the sensory cues from their mates, such as seeing and smelling each other. Although, this group always had contact with humans, such as during feeding, water supply, bed cleaning, blood sampling, and body weight recording. In contrast, our results show that the females reared as a social group, sensory signals mentioned above among females were totally expressed and participated in the activation of the hypothalamus-pituitary-gonadal axis (Bronson, 1985; Costa et al., 2016). Regarding to the swollen vulvas, the results of this study did not detect significant difference between the two groups of females ($P > 0.05$). This response is due to that the females were cyclical. In addition, females reared in social isolation did not show estrous behavior compared with females in group (0 % and 80 %, respectively; $P < 0.05$). Therefore, it is likely that females reared as a social group, in the absence of male goats, exhibited stereotyped behaviors of estrus among themselves, such as female-female mounting, lateral approaches, ano-genital sniffing, head butting, and tail fanning (Sherer and Katz, 2006; Haulenbeek and Katz, 2011).

Regarding body weight in our experimental females, the results show that females reared as a social group gained more body weight from the first week of August until the end of the study in January of the following year. Our findings agree with previous reports indicating that animals housed in a social group increase their body weight gain (de Paula Vieira et al., 2010). Although body weight did not differ significantly between the two groups of females at the first measurement on July 31st, both groups increased this variable from autumn to winter when the study ended. In our experimental females, it is worth remembering that feeding was provided ad libitum as reported in previous studies (Foster and Olster, 1985; Moallem et al., 2010). Because our results show that females reared as a social group began puberty with a body weight of

Table 1
Body weight (mean ± SEM) at the onset of puberty in female goats reared as a group and female goats reared individually in pens. Females were isolated from male goats. Body weight was recorded weekly from days 225–379 when the study ended.

Females reared	*n*	Body weight at weaning (kg)	Body weight on July 31st on day 225 (kg)	Body weight at onset of puberty (kg)
Group	10	7.2 ± 0.9	21.6 ± 1.0	28.7 ± 0.4[a]
Individual	10	7.6 ± 0.4	21.0 ± 0.4	24.5 ± 0.5[b]

Means with different superscripts in the same column are significantly different ($P < 0.05$).

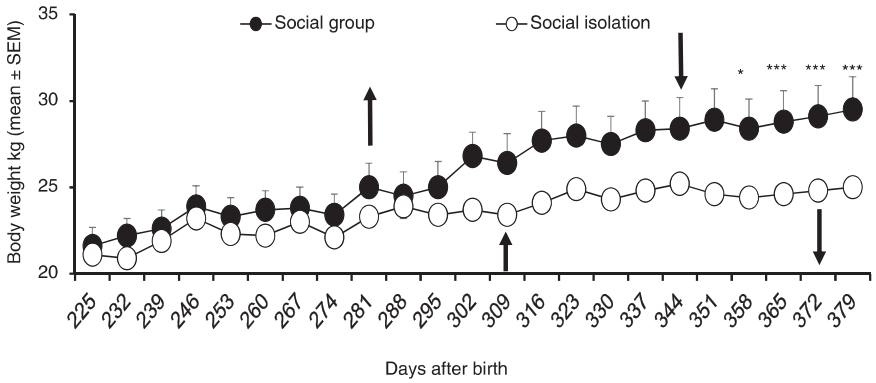


Fig. 2. Body weight (mean ± SEM) of females born in December reaching puberty. Ten females were reared as a social group and were placed in a pen (•), and 10 females were reared in social isolation. Each female was placed individually in a pen (○). Females were isolated from males. The arrows (↑↓) indicate the beginning and end of the onset of puberty. * ($P < 0.05$), ***($P < 0.001$).

28.7 ± 0.4 kg, while females reared in social restriction was 24.5 ± 0.5 kg. The results of this study confirm that females with adequate body weight advance the onset of puberty (Sakurai et al., 2004). Furthermore, body weight at the onset of puberty in our females reared in group without the presence of males shows agreement with the body weight of 27.0 ± 1.0 kg recorded in females placed in a group where there were male goats close to them (Delgadillo et al., 2007). Ours results are similar to females exposed to photo-stimulated males, grazed and supplemented with similar registered weights (26 ± 1.0 kg) (Espinoza-Flores et al., 2020). In addition, the body weight of adult female goats in this region is approximately 42 kg (Fernández et al., 2022). Therefore, in the present study, the onset of puberty occurred when females in social isolation and as social group registered 59 % and 67 % of the body weight of adult females, respectively. Therefore, our results, like previous studies, show considerable differences in relation to the ideal percentage of body weight of the adult female to reach puberty in pre-pubertal females (Chentouf et al., 2011). Our results show the importance of social contact during the rearing of groups of animals because it improves animal welfare. While social isolation causes negative disturbance to physiology and behavior, reducing animal productivity and reproductive performance (Neethirajan et al., 2021).

4. Conclusion

We conclude that female goats reared as a social group advanced the onset of puberty and gained more body weight compared to females reared under social isolation. However, prolonged social isolation should be avoided, although sometimes is necessary to separate animals due to aggression or by illness. Other factors also must be considered that affect the wellbeing and health as the negative effect of climate change that alters animal production.

Funding

This research did not receive support from any specific grant-funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Ilda G. Fernández: Conceptualization, Validation, Visualization of the experiment, Writing – review & editing the manuscript. **Luis Sifuentes:** Validation, Visualization of the experiment, Writing – review & editing the manuscript. **Gerardo Duarte**: Validation, Visualization of the experiment, Writing – review & editing the manuscript. Raúl Ulloa-Arvizu: Formal analyses, Writing – review & editing the manuscript. **María Jesús Palomo Peiró:** Writing – review & editing the manuscript. All authors read and approved the final manuscript.

Conflict of Interest Statement

No potencial conflict of interest was reported by the authors.

Acknowledgements

The authors thank all members of the Centro de Investigación en Reproducción Caprina of the Universidad Autónoma Agraria Antonio Narro, for your help to carry out this study. They thank Clara Murcia Mejía and José Gerardo Perera Marín of the Facultad de Medicina Veterinaria y Zootecnia, Universidad Nacional Autónoma de México by hormonal determinations. The authors thank Jesús Palomo Reyna for taking care of the females.

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