



HAL
open science

The reproductive response to the male effect of 7- or 10-month-old female goats is improved when photostimulated males are used

L. A Zarazaga, M. C Gatica, H. Hernandez, Matthieu Keller, Philippe Chemineau, J. A Delgadillo, J. L Guzmán

► To cite this version:

L. A Zarazaga, M. C Gatica, H. Hernandez, Matthieu Keller, Philippe Chemineau, et al.. The reproductive response to the male effect of 7- or 10-month-old female goats is improved when photostimulated males are used. *Animal*, 2019, 13 (8), pp.1658-1665. 10.1017/S1751731118003397. hal-02347389

HAL Id: hal-02347389

<https://hal.science/hal-02347389>

Submitted on 5 Nov 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - ShareAlike 4.0 International License

The reproductive response to the male effect of 7- or 10-month-old female goats is improved when photostimulated males are used

L. A. Zarazaga^{1†}, M. C. Gatica², H. Hernández³, M. Keller⁴, P. Chemineau⁴, J. A. Delgadillo³ and J. L. Guzmán¹

¹Departamento de Ciencias Agroforestales, Universidad de Huelva, Campus de Excelencia Internacional Agroalimentario, ceiA3, Carretera Huelva-Palos de la Frontera s/n, 21819 Palos de la Frontera, Huelva, Spain; ²Universidad Arturo Prat, Avenida Arturo Prat, 2120 Iquique, Chile; ³Centro de Investigación en Reproducción Caprina, Departamento de Ciencias Médico Veterinarias, Universidad Autónoma Agraria Antonio Narro, Periférico Raúl López Sánchez y Carretera a Santa Fe, 27054 Torreón, Coahuila, Mexico; ⁴Physiologie de la Reproduction et des Comportements, CNRS, IFCE, INRA, Université Tours, Agreenium, 37380 Nouzilly, France

(Received 19 June 2018; Accepted 27 November 2018)

The exposure of adult, female, Mediterranean goats during anoestrus to males with induced sexual activity via photostimulation, induces a very high percentage of ovulations. The present work examines the ability of photostimulated bucks to improve the male effect-induced reproductive response of young does over that induced by non-stimulated bucks. A 2 × 2 factorial experiment was designed, consisting of doe age and buck photoperiod treatments. During seasonal anoestrus, 41 does aged 7 (n = 19) or 10 (n = 22) months were subjected to the male effect on 10 April; half of each group was exposed to males rendered sexually active by prior exposure to 3 months of long days (16 h of light/day) from 31 October (PHOTO bucks), and half to males maintained under the natural photoperiod (CONTROL bucks). Oestrous activity was recorded daily by direct visual observation of the marks left by male-worn marking harnesses over the 32 days following the bringing of the sexes together (introduction). Doe body weight and body condition were determined weekly. Ovulation was detected by measuring plasma progesterone concentrations twice per week over the 3 weeks after introduction. The ovulation rate was assessed by transrectal ultrasonography. Fecundity, fertility, prolificacy and productivity were also determined. The interaction doe age × buck photoperiod treatment had no effect on any outcome. The percentage of females showing ovulation or oestrus was higher in the does exposed to PHOTO bucks (85% v. 43% for those exposed to CONTROL bucks) they also showed higher fertility (75% v. 43%) and productivity (1.05 ± 0.17 v. 0.57 ± 0.16 kids born per doe serviced) (all P values at least P < 0.05). The 10-month-old group showed higher percentage of females showing ovulation, oestrus, fertility and productivity than the 7-month-old does after the male effect (females showing ovulation: 82% v. 42%; showing oestrus: 73% v. 42%; fertility: 73% v. 42% and productivity: 1.09 ± 0.17 v. 0.47 ± 0.14 goat kids born per doe serviced; respectively, all P values at least P < 0.05). The present results show that the use of photostimulated males improves the reproductive performance of 7- and 10-month-old does, and may contribute towards increasing their productivity and lifetime reproductive performance.

Keywords: male effect, puberty, fertility, fecundity, productivity

Implications

On Mediterranean goat farms, the use of the male effect in spring is a common practice. Spring is when normal male reproductive activity is diminished, but it can be induced by subjecting them to three months of long days. Mating female goats aged 7 to 10 months in spring is difficult; apart from the season being unfavourable, they have not yet entered puberty. The present results show that does aged 7 or

10 months enter puberty sooner, and thus return better reproductive results, if exposed to photostimulated males than non-treated males.

Introduction

Puberty in female goats may be defined as the time at which oestrus is first detected by a male, followed by cyclical ovarian activity (Greyling, 2000). In seasonal breeders such as sheep and goats, puberty is reached during the breeding season. The interval between weaning and the onset of reproductive

† E-mail: zarazaga@uhu.es

activity is thus an unproductive period for stock-raisers, and reducing its length, that is, allowing does to be mated at an earlier age, would likely increase their lifetime productive performance and reduce flock production costs.

A number of environmental factors influence the onset of puberty in does, including the photoperiod and season of birth (kids experience different photoperiodic stimuli depending on the time of year when they are born; age at puberty therefore differs according to the season of birth), body weight (BW), body condition (BC), and the male effect (Delgadillo *et al.*, 2007; Zarazaga *et al.*, 2009; Gallego-Calvo *et al.*, 2015). Summer/autumn-born does cannot be mated during the ensuing breeding season since they will either not have reached puberty, or barely reached it with just the minimum BW required (Kenyon *et al.*, 2012). Such does can only be mated in the following year when they are 1 or 1.5 years old (Papachristoforou *et al.*, 2000; Delgadillo *et al.*, 2007; Zarazaga *et al.*, 2009).

Numerous studies have reported a close association between body growth, nutritional status and the timing of puberty (Frisch and Revelle, 1970; Frisch *et al.*, 1977; Gallego-Calvo *et al.*, 2015). Several lines of evidence suggest that, in mammals, a critical BW (Frisch and Revelle, 1970) or critical BC (Frisch *et al.*, 1977) must be reached if puberty is to be attained at the expected time. Gallego-Calvo *et al.* (2015) suggest that upon reaching this critical BW, the BC becomes a determining factor in the onset of puberty.

The induction of the male effect in adult does is a common practice in extensive and semi-extensive goat-raising systems in Mediterranean countries. However, the degree of sexual activity displayed by males in spring – when the male effect is required, but when they show the least sexual interest – could influence the response of females (Flores *et al.*, 2000; Delgadillo *et al.*, 2001 and 2014). In Mediterranean and subtropical latitudes, bucks rendered sexually active by exposure to long days appear to induce the sexual activity of seasonally anoestrous does better than bucks kept under the natural photoperiod (Zarazaga *et al.*, 2010 and 2018; Chasles *et al.*, 2016). This raises the question of whether photostimulated males are also able to stimulate puberty in young females. In sheep, Kenyon *et al.* (2012) demonstrated that when 8-month-old ewe lambs were exposed to teaser rams, a greater proportion displayed oestrous. Moreover, Chasles *et al.* (2017) and Espinoza-Flores *et al.* (2018) recently showed that, in goats, exposure to sexually active males advances puberty in females over that seen in those isolated from males.

On the basis of these results, it was hypothesized that, at Mediterranean latitudes, the male effect induced by photostimulated bucks might induce puberty in young does, perhaps independent of doe age.

Material and methods

Study conditions

All procedures were performed by trained personnel in strict accordance with Spanish guidelines for the protection of

experimental animals (RD 53/2013), and in agreement with European Union Directive 86/609. The study was conducted at the University of Huelva experimental farm (latitude 37° 20'N and longitude 6° 54'W), which meets the requirements of the European Community Commission for Scientific Procedure Establishments (2010/63). Methods were similar to those used in similar works of our research group (Gallego-Calvo *et al.*, 2015; Gallego-Calvo *et al.*, 2018).

Experimental design

The experiment was a 2 × 2 factorial design, consisting of a doe age and buck photoperiod treatments. The does used ($n=41$) were divided into two age groups before exposure to the males (introduction): (1) 7-month-old group ($n=19$; age 221 ± 0.42 days at introduction (born on 1 September ± 0.42 days); BW 23.5 ± 0.40 kg; BC score 2.95 ± 0.04), and (2) 10-month-old group ($n=22$; age at introduction 292 ± 0.92 days (born on 22 June ± 0.92 days); BW 28.9 ± 0.40 kg; BC score 3.08 ± 0.04). These groups were then subdivided, exposing half to photostimulated bucks (PHOTO bucks) ($n=9$ for the 7-month olds and 11 for the 10-month olds), and half to unstimulated bucks (CONTROL bucks) ($n=10$ for the 7-month olds and 11 for the 10-month olds).

The animals of each experimental age group were kept together in separate pens until the introduction of the males when the four subgroups were established. Feeding was adjusted weekly in relation to the BW to ensure a weight gain of 75 g per day, in accordance with the Institut National de la Recherche Agronomique standards (Morand-Fehr and Sauvant, 1988). All animals were fed concentrate, a commercial mixture of maize (26.3%), beans (20%), oats (14.1%), cotton-seed (13.7%), peas (13.4%), lupin (7.3%), barley (0.2%), wheat (0.2%), sunflower seeds (0.2%), a mineral–vitamin complement (4.6%) and barley straw. The nutritional values of the concentrate was 0.93 milk fodder units (UFL) and 76 g digestible protein per kilogram of dry matter (DM), while that of the barley straw was 0.37 UFL and 25 g of digestible protein per kilogram of DM. Concentrate was offered once a day and distributed individually; barley straw was administered *ad libitum*. All animals had free access to water and mineral blocks containing trace elements and vitamins.

Preparation of the males

At the latitude where the work was performed, male sexual rest lasts from January to February, to June to July (Zarazaga *et al.*, 2009). Four young entire males (1.5 years old) were exposed to 3 months of long days (16 h of light per day) (PHOTO bucks) from 31 October, and thereafter to natural photoperiodic conditions. These long days were achieved by providing extra light beyond the natural daylength (at least 300 lux at the animals' eye level, from 0600 to 0800 h and from 1900 to 2200 h), employing fluorescent lights. The PHOTO males were located in an open barn with access to an uncovered area. During the extra light periods and night the access to the uncovered area was closed. This treatment stimulates testosterone secretion and sexual behaviour in

bucks during March and April, that is, the natural sexual rest period when control males are sexually inactive (Zarazaga *et al.*, 2010). Another four young entire males (1.5 years old) completely isolated from the PHOTO bucks (located in another open barn), were exposed to natural photoperiodic conditions during the whole experimental period (CONTROL bucks).

Determination of buck plasma testosterone concentrations
Blood was sampled weekly at 0900 h, from 31 October until 12 May. Plasma testosterone concentrations were determined using a commercial enzyme-linked immunoassay (ELISA) kit (Demeditec Diagnostics, Kiel-Wellsee, Germany). The sensitivity of the assay was 0.1 ng/ml. Intra- and inter-assay coefficients of variation for sample pools of 0.2 and 6.0 ng/ml were 1.6%, 2.3%, and 4.5% and 2.3%, respectively.

One week before introducing the bucks to the does, the sexual behaviour of the bucks was assessed by observing genital sniffing, nudging and mounting attempts over a 5 min period when the bucks were exposed to females (not those in experimental groups) in oestrus. The bucks within each photoperiod treatment group showed similar sexual behaviour; they were therefore randomly allocated to the appropriate doe subgroups.

The male effect

On 10 April, 69 days after the end of the photoperiod treatment, the males, equipped with marking harnesses, were introduced to the does (two per subgroup) and maintained with them for the following 32 days (until 12 May) to induce the male effect. All four experimental groups was located in open barns completely isolated from the other ones.

Variables recorded for the does

BW and body condition (BC). The BW and BC of all the does were recorded weekly. The BC was scored by lumbar palpation (always by the same handler) based on a scale of 0 = emaciated to 5 = very fat, with increments of 0.25 (Hervey *et al.*, 1991).

Detection of oestrous behaviour, ovulation and ovulation rate. Oestrous activity was recorded every day by direct visual observation of the marks left by male-worn marking harnesses (Walkden-Brown *et al.*, 1993). The interval between introduction and first oestrous behaviour was calculated for each female.

To monitor the ovarian cyclicity of the does before their introduction to the males (day 0; 10 April), blood samples were collected once per week over 3 consecutive weeks and the plasma progesterone concentration determined. The does were deemed to be anoestrous if all plasma samples showed plasma progesterone concentrations of ≤ 1.0 ng/ml (Chemineau *et al.*, 1992). To monitor the ovarian response after introduction, the plasma progesterone concentration was determined twice per week. Does with plasma progesterone concentrations of ≥ 1.0 ng/ml for at least two

consecutive samples were deemed to have ovulated (Chemineau *et al.*, 1992). The date of onset of the ovarian response was defined as that of the first sample with a progesterone concentration of ≥ 1.0 ng/ml. Blood samples were collected by jugular venipuncture in tubes containing 10 μ l heparin, and plasma obtained by centrifugation at $3500 \times g$ for 30 min. This was stored at -20°C until analysis. Plasma progesterone was determined using a commercial ELISA kit (Ridgeway Science Ltd, Gloucester, UK) in accordance with the manufacturer's instructions. The sensitivity of the assay was 0.28 ng/ml. Intra- and inter-assay CV for sample pools of 0.5 and 1 ng/ml were 7.1%, 6.5%, and 7.9% and 9.1%, respectively.

The ovulation rate was assessed by the number of corpora lutea observed by transrectal ultrasonography conducted 6 to 8 days after the detection of oestrus. The procedure was performed using an Aloka SSD-500 (Ecotron, Madrid, Spain) apparatus connected to a 7.5 MHz linear probe.

Fecundity, fertility and productivity. Fecundity (percentage of pregnant does/does mounted by the males) was determined via transrectal ultrasonography on day 45 after mounting (Schrick *et al.*, 1993). Fertility (percentage of does kidding per doe serviced), prolificacy (number of kids born per doe kidding) and productivity (number of kids born per doe serviced) were also determined (Caravaca *et al.*, 1999).

Statistical analyses

Data are presented as means \pm standard error. The weekly values for BW, BC, the testosterone concentration and the twice-weekly values for the progesterone concentration, were examined by ANOVA with time as a repeated measure, with doe age and buck photoperiod treatment as the main factors. The Tukey test was used to detect differences between groups and between weeks. The difference in testosterone concentration each week between the CONTROL and PHOTO bucks was analysed by one-way ANOVA.

The variables expressed as percentages (global and daily percentages of females showing ovulatory activity via the progesterone concentration, oestrous, ovulation, fecundity, fertility and females kidding) were analysed using the multinomial logistic regression.

The ovulation rate and prolificacy were compared using the Mann–Whitney *U* test. Productivity, and the interval between introduction and the date of females showing oestrus with ovulation were compared by ANOVA, contemplating doe age and buck photoperiod treatment as fixed effects. Significance was set at $P < 0.05$. All analyses were performed using the STATA14 package (STATA14; StataCorp, 2015).

Results

BW and body condition scores

Body weight (BW) and BC both increased over the experimental period in both main doe groups ($P < 0.01$; Figure 1); however, the BW and BC were higher in the 10-month-old

does ($P < 0.01$). Buck photoperiod treatment had no effect on BW or BC, nor did the interaction *doe age* × *buck photoperiod treatment* ($P > 0.05$). Neither did the interaction *doe age* × *buck photoperiod treatment* × *time* have any effect on BW or BC ($P > 0.05$).

At the first ovulation, and at the first oestrus with ovulation, BW was higher in the older does, independent of the type of male to which they were exposed ($P < 0.05$).

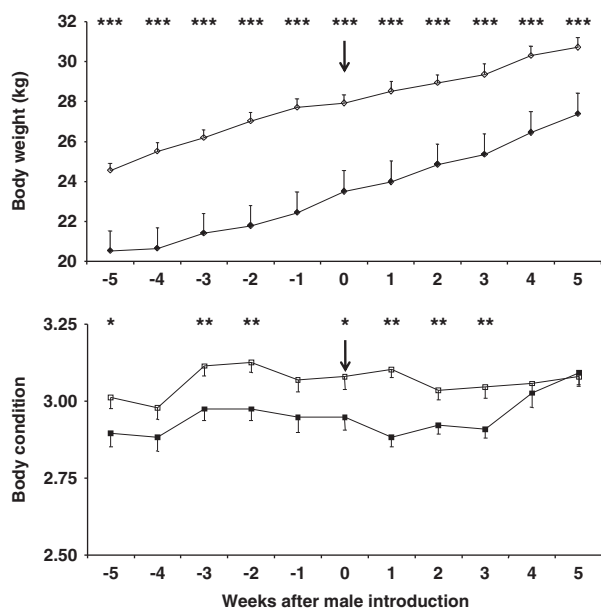


Figure 1 Change in body weight (top) and body condition score (bottom) in 7-month-old (filled symbols) and 10-month-old (blank symbols) female goats. The arrow indicates the moment when the sexes were introduced to one another. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ in the same week.

However, no differences were seen in terms of BC between the age groups independent of the type of male present ($P > 0.05$) (Table 1). No differences were seen in terms of BW in does exposed to CONTROL or PHOTO bucks, independent of doe age ($P > 0.05$). In contrast BC was higher in the does exposed to CONTROL bucks, independent of doe age ($P < 0.05$) (Table 1).

Reproductive response to the male effect

The interaction *doe age* × *buck photoperiod treatment* had no effect on any of the reproductive variables studied. The percentage of females showing ovulation via the elevation of the progesterone concentration, and oestrus with ovulation, was higher in the 10-month-old than in the 7-month-old does as a whole, independent of the type of male to which they were exposed (82% v. 42%, respectively; $P < 0.01$). Irrespective of their age, the percentage of females showing ovulation or oestrus of the does exposed to PHOTO bucks was greater than that shown by those exposed to CONTROL bucks (85% v. 43% for the PHOTO and CONTROL male-exposed does, respectively; $P < 0.01$) (Table 1).

The fertility of the 10-month-old does was greater than that of the 7-month-old does as a whole, independent of the type of male to which they were exposed (73% v. 42%, respectively; $P < 0.05$). Irrespective of their age, the fertility of the females exposed to the PHOTO bucks was greater than that shown by those exposed to the CONTROL bucks (75% v. 43% for the PHOTO and CONTROL male-exposed does, respectively; $P < 0.05$) (Table 1).

The productivity of the 10-month-old does was greater than that of the 7-month-old does as a whole, independent of the type of male to which they were exposed (1.09 ± 0.17

Table 1 Percentage of females showing ovulation or oestrus, BW and body condition, at those moments, intervals from male introduction to ovulation or oestrus, ovulation rate of the first oestrus, fecundity, fertility, prolificacy and productivity, in 7- and 10-month-old does exposed to photostimulated bucks (PHOTO) and to unstimulated bucks (CONTROL)

	7-month-old does (n=19)		10-month-old does (n=22)		Statistical significance	
	CONTROL (10)	PHOTO (9)	CONTROL (11)	PHOTO (11)	Doe age	Buck photoperiod treatment
Females showing ovulation or oestrus (%)	20	67	64	100	*	*
BW at ovulation (kg)	26.5 ± 0.0	26.3 ± 1.2	29.8 ± 0.8	29.2 ± 0.4	*	NS
Body condition score at ovulation	2.88 ± 0.13	3.00 ± 0.00	3.14 ± 0.05	2.95 ± 0.03	NS	*
Interval 'introduction-ovulation' (days)	15.0 ± 0.0	16.5 ± 0.7	14.3 ± 1.1	14.6 ± 0.8	NS	NS
BW at oestrus (kg)	25.0 ± 0.0	26.0 ± 1.3	30.1 ± 1.0	29.0 ± 0.4	*	NS
Body condition score at oestrus	3.00 ± 0.00	3.00 ± 0.00	3.14 ± 0.05	3.00 ± 0.03	NS	*
Interval 'introduction-oestrus' (days)	10.0 ± 0.0	12.5 ± 1.1	10.4 ± 1.1	10.4 ± 0.8	NS	NS
Ovulation rate	1.00 ± 0.00	1.00 ± 0.00	1.43 ± 0.20	1.27 ± 0.14	NS	NS
Fecundity (%)	100	100	100	82	NS	NS
Fertility (%)	20	67	64	82	*	*
Prolificacy	1.00 ± 0.00	1.17 ± 0.17	1.43 ± 0.20	1.56 ± 0.18	NS	NS
Productivity	0.20 ± 0.13	0.78 ± 0.17	0.91 ± 0.10	1.27 ± 0.15	*	*

Fecundity = percentage of pregnant female goats/female goats mounted by the males, determined via transrectal ultrasonography on day 45 after mounting.

Fertility = percentage of female goats kidding per female goat serviced.

Prolificacy = number of kids born per female goat kidding.

Productivity = number of kids born per female goat serviced.

* $P < 0.05$.

The interaction *doe age* × *buck photoperiod treatment* had no significant (NS) effect on any variable ($P > 0.05$).

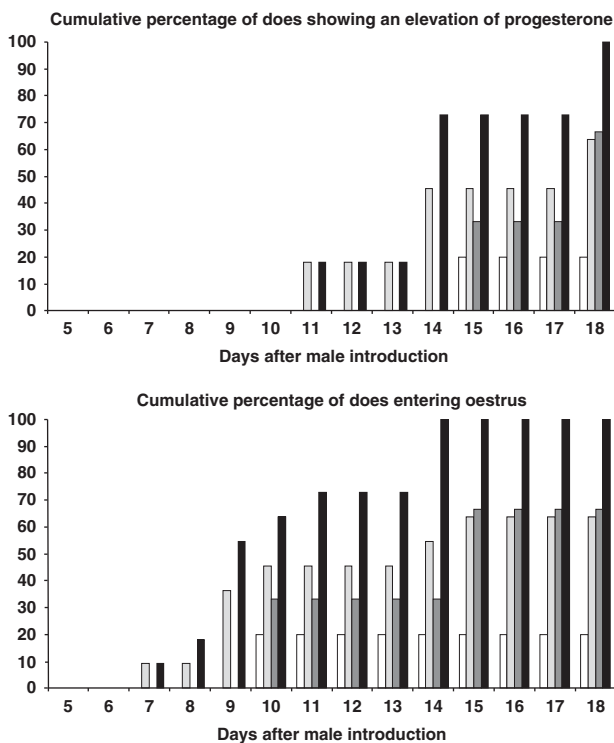


Figure 2 Top: Cumulative percentage (%) female goats showing a progesterone concentration of ≥ 1 ng/ml or bottom: female goats showing oestrous of 7-month old after exposure to bucks exposed to natural changes in day length over the whole experiment (CONTROL bucks (□), and to bucks submitted to a period of 3 months of long days, and then to the natural photoperiod (PHOTO bucks, ◻); and 10-month-old female goats after exposure to CONTROL bucks (▣), and to PHOTO bucks (■).

kids born per doe serviced v. 0.47 ± 0.14 goat kids born per doe serviced; $P < 0.05$). Irrespective of their age, the productivity of the females exposed to the PHOTO bucks was greater than that shown by those exposed to the CONTROL bucks (1.05 ± 0.17 goat kids born per doe serviced v. 0.57 ± 0.16 goat kids born per doe serviced, respectively; $P < 0.05$) (Table 1).

The other variables such as the intervals 'introduction-first ovulation' and 'introduction-first oestrus', the ovulation rate at first oestrus, fecundity and prolificacy, were not influenced by either doe age or buck photoperiod treatment, or their interaction.

The interval between introduction and the first increase in the progesterone concentration, or the first detected oestrous, was not influenced by doe age ($P > 0.05$), nor by buck photoperiod treatment ($P > 0.05$), nor by the interaction between them ($P > 0.05$). The interval 'introduction-first observed oestrous' was shorter than the interval 'introduction-first elevation of the progesterone concentration' (10.9 ± 0.5 days v. 15.0 ± 0.5 days, respectively; $P < 0.001$).

From day 14 after introduction, the percentage of does showing elevated progesterone was higher among the 10-month-old than the 7-month-old animals, independent of the type of male to which they were exposed ($P < 0.05$) (Figure 2). From day 18 after introduction, the percentage of

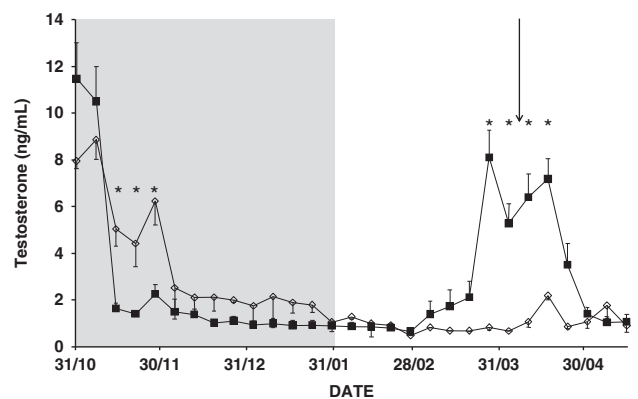


Figure 3 Mean change in plasma testosterone concentration (ng/ml) in bucks submitted to a period of 3 months of long days (grey area), and then to the natural photoperiod (PHOTO bucks, ■) or to natural changes in day length over the whole experiment (CONTROL bucks, ◇). * $P < 0.05$ in the same week. The arrow indicates the moment when the sexes were introduced to one another.

does showing elevated progesterone was higher among those exposed to the PHOTO males than among those exposed to the CONTROL males ($P < 0.05$) (Figure 2). From day 11 after introduction, the percentage of does showing oestrus was higher among the 10-month olds than in the 7-month olds as a whole, independent of the type of male to which they were exposed ($P < 0.05$) (Figure 2). Finally, from day 14 after introduction, the percentage of does showing oestrus was higher among those exposed to the PHOTO bucks than among those exposed to the CONTROL bucks ($P < 0.05$) (Figure 2). The interaction *doe age* \times *buck photoperiod treatment* had no effect on any of the above variables ($P > 0.05$).

Testosterone concentrations

Time, and the interaction *time* \times *buck photoperiod treatment*, were found to influence testosterone concentrations ($P < 0.01$; Figure 3). The concentration decreased rapidly after the start of the photoperiod treatment ($P < 0.05$), but began to increase 7 weeks after its end, and did so for about 4 weeks. In contrast, the CONTROL bucks showed very low testosterone concentrations at the end of November and thereafter ($P < 0.05$; Figure 3). Neither doe age, nor the interaction *doe age* \times *buck photoperiod treatment*, nor the interaction *time* \times *doe age* \times *buck photoperiod treatment*, had any effect on the testosterone concentration ($P > 0.05$).

Discussion

The present results show that doe age and the sexual activity of males are important factors to bear in mind when seeking the maximum response to the male effect in spring. Better reproductive responses and performances were observed in the 10-month-old does, and in those exposed to PHOTO bucks. These results support the hypothesis that photo-stimulated males can induce an intense reproductive response, and increase reproductive performance, even in very young does.

Autumn-born does of the Spanish Blanca Andaluza (Gallego-Calvo *et al.*, 2015), Payoya (Zarazaga *et al.*, 2009) and Murciano-Granadina (Pérez-Fuentes *et al.*, 1999) breeds usually enter puberty in the following breeding season (i.e. the next autumn). The mean onset of puberty in Blanca Andaluza does is at 317.2 ± 5.1 days after birth, with BW and BC having a clear influence on the exact time (Gallego-Calvo *et al.*, 2015). Autumn- and winter-born Payoya does show their first oestrous at 257 and 348 days of age, respectively (Zarazaga *et al.*, 2009), whereas Murciano-Granadina does ovulate at 154.4 ± 4.2 days of age (Pérez-Fuentes *et al.*, 1999). In the present work, the male effect was used to induce puberty at 292 and 221 days of age for the 10- and 7-month-old does, respectively. The results indicate that inducing the male effect with photostimulated males brings about earlier puberty in does. This was true even for the present 7-month-old does, which entered their first oestrous with a mean BW of 25.8 ± 1.0 kg and a mean BC score of 3.00 ± 0.00 . According to previous results for Blanca Andaluza does born in November, these values are appropriate for the onset of breeding activity (Gallego-Calvo *et al.*, 2015). In the latter experiment, oestrous activity first began earlier in does with a BC of around 3.00 points and a BW of >24.0 kg. November- and February-born Payoya does showed their first oestrous after reaching a BW of 28.7 ± 0.6 kg plus a BC score of 2.73 ± 0.04 and 23.3 ± 0.5 kg plus a BC score of 2.64 ± 0.05 , respectively. These figures indicate that all the does in the present work had reached an adequate developmental condition for onset of puberty and, perhaps, to respond to the male effect.

The percentage of 10-month-old does that ovulated and entered oestrous was higher than for the 7-month-old does. These results were expected since the former does were older and had a greater BW; therefore, closer to the threshold for the onset of puberty. Gordon (1975) indicated that puberty in farm animals requires a critical BW be reached. For goats, Smith (1980) reported this to be 60% to 75% of the mature BW. For Blanca Andaluza does, the critical BW for initiating puberty is ~60% of the mature BW (Gallego-Calvo *et al.*, 2015). In the present experiment, the 7-month-old does showed their first oestrous at 25.8 ± 1.0 kg, while the 10-month-old does did so at 29.5 ± 0.5 kg, that is, at around 55% and 63% of their mature BW, respectively. The slightly higher BW of the 10-month-old does might explain their greater reproductive response; the hypothalamic–pituitary–ovarian axis in these animals might be better developed, leading to a higher frequency of LH pulses during the prepubertal period resulting in earlier onset of puberty (Foster *et al.*, 1975). Moreover, during the prepubertal period, the preovulatory gonadotrophin surge system is able to function, but it remains inactive in the absence of sustained high physiological levels of oestradiol (Foster *et al.*, 1985). As a consequence, the reduced sensitivity of the axis to oestradiol originates a high-frequency rhythm of gonadotropin-releasing hormone and a sustained rise in basal LH secretion as the frequency of LH pulses increases. The first follicular phase then begins, leading to the first LH surge and ovulation (Foster and Jackson, 2006).

The does in contact with the PHOTO bucks showed a better percentage of females showing ovulation or oestrus irrespective of doe age. This is likely due to the intense sexual behaviour and strong odour of these bucks. The stimulatory effect of long days on the capacity of bucks to induce a male effect has been extensively documented at temperate latitudes (Chasles *et al.*, 2016), under Mediterranean conditions (Zarazaga *et al.*, 2010) and under subtropical conditions (Flores *et al.*, 2000). However, this is the first indication that it can stimulate a reproductive response in such young does. It might be argued that, rather than this being an effect of exposure to these PHOTO bucks, doe BW or BC might be responsible. However, the design of the present experiment means this possibility can be ruled out. First, there were no differences in BW at the first progesterone elevation point, or first oestrus, between the females exposed to the PHOTO or CONTROL bucks – and yet the reproductive response of the PHOTO buck-exposed females was stronger. In addition, the BC of the does exposed to the CONTROL bucks was actually slightly higher than that of their PHOTO buck counterparts, which in any event also surpassed the ~2.50 points required (Gallego-Calvo *et al.*, 2015).

The positive reproductive response of the does exposed to PHOTO bucks was confirmed by their higher fertility and productivity results. When exposed to these males, the 10-month-old does produced one kid per doe more than did the 7-month-olds exposed to CONTROL bucks. These results confirm previous findings (Zarazaga *et al.*, 2017 and 2018). The reason for the lack of any difference between any groups (i.e. with respect to doe age or buck photoperiod treatment) in terms of fecundity can be explained in that this variable is calculated from the number of females that become pregnant compared to those that showed signs of oestrus. In general, all the does that entered their first oestrous became pregnant, indicating that all were in optimum reproductive condition (the males too). The main question is thus the percentage of induction into puberty achievable by the male effect, rather than fecundity once that induction has been achieved.

The intervals 'introduction-oestrous' or 'introduction-first elevation of the progesterone concentration', were not modified by doe age, buck photoperiod treatment or their interaction. However, the interval 'introduction-first oestrous behaviour' was shorter than the interval 'introduction-first elevation of progesterone concentration'. This result may largely be explained by the procedure used to estimate the interval to the first elevation of the progesterone concentration, that is, when the progesterone concentration reached ≥ 1 ng/ml. This occurs when the corpora lutea are fully functional, some days after the start of oestrous behaviour (Zarazaga *et al.*, 1996). The present does therefore showed a typical response to the male effect – a short ovarian cycle unaccompanied by oestrus, followed by a first oestrous accompanied by ovulation about 10 days after teasing (Chemineau, 1983). However, in the present work, no short elevation of progesterone concentrations was seen to occur, probably because the twice weekly frequency of determination was insufficient to detect it.

Finally, the distribution of the daily percentage of females showing oestrous differed to that reported in other studies (Flores *et al.*, 2000; Véliz *et al.*, 2002); the latter authors observed oestrous in the 1st week after introduction. However, the latter authors' experiments were performed at subtropical latitudes and the does were all adults. Certainly, Véliz *et al.* (2009) observed the distribution of females showing oestrous following the male effect to differ between multiparous and nuliparous females.

Conclusions

The present results show that, at Mediterranean latitudes, the reproductive response induced by photostimulated bucks is stronger in both 10- and 7-month-old does, than that induced by untreated bucks. Although the present PHOTO bucks advanced the onset of puberty in does of both ages, increasing their productivity, the 10-month-old does exposed to PHOTO bucks produced one kid more per doe serviced than did the 7-month-old does exposed to CONTROL bucks. Mating summer/autumn-born does with photostimulated bucks would appear to be a practical means of increasing their reproductive/productive performance.

Acknowledgements

This study was funded by Grant AGL2016-75848-R from MINECO-AEI-FEDER (Spain). Thanks are also owed to CEI CamBio for their support.

Declaration of conflicts of interest

None of the authors of this paper has any financial or personal relationship with any other person or organisation that might inappropriately influence or bias the content of the paper.

Ethics statement

All procedures were performed by trained personnel in strict accordance with Spanish guidelines for the protection of experimental animals (RD 53/2013), and in agreement with European Union Directive 86/609.

Software and data repository resources

None of the data were deposited in an official repository.

References

Caravaca FP, Castel Genís JM, Guzmán JL, Delgado M, Mena Y, Alcalde MJ and González P 1999. Bases de la Producción Animal. Don Folio, Córdoba, Spain.

Chasles M, Chesneau D, Moussu Ch, Delgadillo JA, Chemineau P and Keller M 2016. Sexually active bucks are efficient to stimulate female ovulatory activity during the anestrus season also under temperate latitudes. *Animal Reproduction Science* 168, 86–91.

Chasles M, Chesneau D, Moussu C, Delgadillo JA, Chemineau P and Keller M 2017. Advancement of puberty in autumn-born goat kids by exposure to sexually active. *Reproduction in Domestic Animals* 52 (Suppl. 3), 58.

Chemineau P 1983. Effect on oestrus and ovulation of exposing creole goats to the male at three times of the year. *Journal of Reproduction and Fertility* 67, 65–72.

Chemineau P, Daveau A, Maurice F and Delgadillo JA 1992. Seasonality of estrus and ovulation is not modified by subjecting female Alpine goats to a tropical photoperiod. *Small Ruminant Research* 8, 299–312.

Delgadillo JA, Carrillo E, Morán J, Duarte G, Chemineau P, Malpoux B and Mora J 2001. Induction of sexual activity of male creole goats in subtropical northern Mexico using long days and melatonin. *Journal of Animal Science* 79, 2245–2252.

Delgadillo JA, De Santiago-Miramontes MA and Carrillo E 2007. Season of birth modifies puberty in female and male goats raised under subtropical conditions. *Animal* 1, 858–864.

Delgadillo JA, Flores JA, Duarte G, Vielma J, Hernández H, Bedos M, Fitz-Rodríguez G, Fernández IG, López-Sebastián A, Gómez-Brunet A, Santiago-Moreno J, Zarazaga LA, Keller M and Chemineau P 2014. Out-of-season control of reproduction in subtropical goats without exogenous hormonal treatments. *Small Ruminant Research* 121, 7–11.

Espinoza-Flores LA, Hernández H, Andrade-Esparza JD, Ramírez S, Zarazaga LA, Chemineau P, Keller M and Delgadillo JA 2018. Nutritional supplementation and exposure to sexually active bucks advance puberty in spring-born goat kids. *Reproduction in Domestic Animals* 53 (Suppl. 2), 131.

Flores JA, Véliz FG, Pérez-Villanueva JA, Martínez de la Escalera G, Chemineau P, Poindron P, Malpoux B and Delgadillo A. 2000. Male reproductive condition is the limiting factor of efficiency in the male effect during seasonal anestrus in female goats. *Biology of Reproduction* 62, 1409–1414.

Foster DL and Jackson LM 2006. Puberty in sheep. In *Physiology of reproduction* (ed. JD Neill), pp. 2127–2176. Elsevier Academic Press, San Diego, CA, USA.

Foster DL, Lemons JA, Jaffe RB and Niswender GD 1975. Sequential patterns of circulating luteinizing hormone and follicle-stimulating hormone in female sheep from early postnatal life through the first estrous cycles. *Endocrinology* 97, 985–994.

Foster DL, Yellon SM and Olster DH 1985. Internal and external determinants of the timing of puberty in the female. *Journal of Reproduction and Fertility* 75, 327–344.

Frisch RE, Hegsted DM and Yoshinaga K 1977. Carcass components at first estrous of rats on high-fat and low-fat diets: body water, protein and fat. *Proceedings of the National Academy of Science of the United States of America* 74, 379–383.

Frisch RE and Revelle R 1970. Height and weight at menarche and hypothesis of critical body weights and adolescent events. *Science* 169, 397–399.

Gallego-Calvo L, Gatica MC, Celi I, Guzmán JL and Zarazaga LA 2015. Body condition score is a critical factor determining the onset of puberty in Blanca Andaluza female goat kids. *Animal Production Science* 55, 1179–1183.

Gallego-Calvo L, Gatica MC, Guzmán JL and Zarazaga LA 2018. Reproductive responses to sexually active buck of does treated with melatonin when body weight/body condition is increasing or decreasing. *Animal Reproduction Science* 190, 75–84.

Gordon I 1975. *Controlled breeding in farm animals*. Pergamon Press Ltd, Headington Hill Hall, Oxford, England.

Greyling JPC 2000. Reproduction traits in the Boer goat doe. *Small Ruminant Research* 36, 171–177.

Hervieu J, Morand-Fehr P, Schmidely Ph, Fedele V and Delfa R 1991. Mesures anatomiques permettant d'expliquer les variations des notes sternales, lombaires et caudales utilisées pour estimer l'état corporel des chèvres laitières. *Options Méditerranéennes* 13, 43–56.

Kenyon PR, Viñoles C and Morris ST 2012. Effect of teasing by the ram on the onset of puberty in Romney ewe lambs. *New Zealand Journal of Agricultural Research* 55, 283–291.

Morand-Fehr P and Sauvant D 1988. Alimentation des caprins. In *Alimentation des Bovins, Ovins et Caprins* (ed. R Jarrige), pp. 281–304. INRA, Paris, France.

Papachristoforou C, Koumas A and Photiou C 2000. Seasonal effects on puberty and reproductive characteristics of females sheep and Damascus goats born in autumn or in February. *Small Ruminant Research* 38, 9–15.

Pérez-Fuentes AA, Lleó-Casanova B and Pérez-Picazo T 1999. Concentraciones de progesterona hemática durante la gestación en la cabra Murciana-Granadina. *Medicina Veterinaria* 16, 478–485.

Schrick FN, Surface RA, Pritchard JY, Dailey RA, Townsend EC and Inskeep EK 1993. Ovarian structures during the estrous cycle and early pregnancy in ewes. *Biology of Reproduction* 49, 1133–1140.

Smith MC 1980. Caprine reproduction. In *Current therapy in theriogenology diagnosis, treatment and prevention of reproductive diseases in animals* (ed. DA Morrow), pp. 971–1004. WB Saunders Company, Philadelphia, PA, USA.

StataCorp 2015. *Stata 14 base reference manual*. Stata Press, College Station, TX, USA.

Véliz FG, Meza-Herrera CA, De Santiago-Miramontes MA, Arellano-Rodríguez G, Leyva C, Rivas-Muñoz R and Mellado M 2009. Effect of parity and progesterone priming on induction of reproductive function in Saanen goats by buck exposure. *Livestock Science* 125, 261–265.

Véliz FG, Moreno S, Duarte G, Vielma J, Chemineau P, Poindron P, Malpoux B and Delgadillo JA 2002. Male effect in seasonally anovulatory lactating goats depends on the presence of sexually active bucks, but not estrous females. *Animal Reproduction Science* 72, 197–207.

Walkden-Brown SW, Restall BJ and Henniawati 1993. The male effect in the Australian cashmere goat. 2. Enhancement with buck nutrition and use of oestrous female. *Animal Reproduction Science* 32, 69–84.

Zarazaga LA, Gatica MC, Celi I, Guzmán JL and Malpoux B 2010. Effect of artificial long days and/or melatonin treatment on the sexual activity of Mediterranean bucks. *Small Ruminant Research* 93, 110–118.

Zarazaga LA, Gatica MC, Hernández H, Gallego-Calvo L, Delgadillo JA and Guzmán JL 2017. The isolation of females from males to promote a later male effect is unnecessary if the bucks used are sexually active. *Theriogenology* 95, 42–47.

Zarazaga LA, Gatica MC, Gallego-Calvo L and Guzmán JL 2018. When using photostimulated bucks to induce the male effect in female goats living at Mediterranean latitudes, a male: female ratio of 1:20 is optimum. *Journal of Applied Animal Research* 46, 883–887.

Zarazaga LA, Guzmán JL, Domínguez C, Pérez MC, Prieto R and Sánchez J 2009. Nutrition level and season of birth do not modify puberty of Payoya goat kids. *Animal* 3, 79–86.

Zarazaga LA, Malpoux B and Chemineau P 1996. Characteristics of the plasma melatonin rhythm are not modified by steroids during the estrous cycle in Ile-de-France ewes. *Journal of Pineal Research* 23, 114–120.