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# Effective Seasonal Breeding Strategies to Improve Goat Reproduction Rates

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**Abstract** This study aims to explore seasonal breeding strategies to enhance goat reproduction rates, particularly effective measures for the non-breeding season. By adjusting photoperiods and applying the "male effect," sexual activity in goats can be stimulated, achieving estrus synchronization. Additionally, using dairy cow feed residues as nutritional supplements in a circular economy approach significantly enhances goat reproductive performance. The study also examines the efficacy of hormone treatments, including hCG and kisspeptin analogs, in improving ovulation rates and embryo implantation. Findings indicate that effectively leveraging environmental cues in combination with nutritional and hormonal treatments can improve reproductive efficiency in goats, contributing to year-round stable production and promoting the sustainable development of the goat farming industry.

**Keywords** Goat reproduction; Seasonal breeding; Photoperiod regulation; Male effect; Circular economy

## 1 Introduction

Goat reproduction is a critical aspect of livestock management, particularly in regions where goats are a primary source of meat, milk, and other dairy products. Goats are typically seasonal breeders, with their reproductive cycles influenced by environmental factors such as photoperiod and nutrition (Delgadillo, 2011; Khan et al., 2019). This seasonality can lead to fluctuations in the availability of goat products, impacting market supply and producer income (Bustamante-Andrade et al., 2021). The economic importance of goats is significant, especially in arid and semi-arid regions where they are often more resilient than other livestock (Machado-Ramos et al., 2023). Enhancing reproductive efficiency in goats can lead to more stable production cycles, thereby improving the economic stability of goat farming communities.

Managing goat reproduction presents several challenges, primarily due to their seasonal breeding patterns. The reliance on natural breeding seasons can result in periods of low productivity, which is problematic for meeting market demands year-round (Jiang, 2024). Additionally, the genetic diversity and varying reproductive potentials among different goat breeds complicate the optimization of breeding programs (Notter, 2012). Environmental factors such as photoperiod and nutrition play a significant role in reproductive efficiency, necessitating tailored management strategies to address these variables (Souza-Fabjan et al., 2021). Furthermore, traditional hormonal treatments used to control and synchronize breeding cycles have ethical and environmental drawbacks, prompting the need for alternative methods (Abecia et al., 2011; Decourt et al., 2019).

This study reviews the use of environmental and social cues, such as photoperiod manipulation and "male effects," to induce and synchronize the estrus cycle of goats, evaluates the potential of integrating circular economy principles, such as using cow feed residues to improve goat reproductive performance, and examines the efficacy of exogenous hormones and alternative biotechnology methods, such as using kispeptin analogs to promote off-season breeding. This study aims to explore and evaluate sustainable and economically feasible breeding techniques to improve the reproductive rate of goats.

## 2 Understanding Goat Reproductive Cycles

### 2.1 Seasonality and breeding cycles in goats

Goats are inherently seasonal breeders, with their reproductive cycles influenced by various environmental and physiological factors. In temperate regions, goats typically exhibit seasonal breeding patterns, with the breeding season occurring in the fall and winter months. This seasonality is primarily driven by changes in photoperiod, which is the length of day versus night (Fatet et al., 2011). In contrast, goats in tropical regions may breed year-round, although food availability can significantly impact their reproductive cycles, often leading to prolonged anoestrous and anovulatory periods during times of scarcity (O'Sullivan et al., 2019). The degree of seasonality can also vary between breeds, with some displaying more pronounced seasonal breeding behaviors than others.

### 2.2 Influence of photoperiod and climate on reproduction

Photoperiod is a critical environmental cue that regulates the reproductive cycles of goats. Changes in daylight length signal the onset of the breeding season, with shorter days typically triggering reproductive activity (Zarazaga et al., 2021). This photoperiodic response is particularly evident in temperate regions, where the breeding season aligns with shorter day lengths in the fall and winter. In subtropical and tropical regions, while photoperiod still plays a role, other factors such as climate and food availability can also influence reproductive cycles (Khan et al., 2019). For instance, photoperiodic treatments have been used to stimulate sexual activity in bucks during the non-breeding season, thereby inducing and synchronizing estrous behavior in does through the 'male effect' (Chasles et al., 2019).

### 2.3 Impact of seasonal breeding on production efficiency

Seasonal breeding in goats has significant implications for production efficiency. The seasonality of reproduction leads to corresponding fluctuations in the production of milk, cheese, and meat, which can result in variable incomes for producers (Delgadillo, 2011). To mitigate these fluctuations and stabilize production throughout the year, various breeding management strategies have been developed (Hameed et al., 2020). These include hormonal treatments to synchronize estrus and ovulation, as well as photoperiodic treatments combined with the 'male effect' to induce out-of-season breeding (Delgadillo et al., 2014). Additionally, targeted nutritional supplementation, such as using dairy cow feed leftovers, has been shown to enhance reproductive performance in goats during the anestrous season, thereby improving overall production efficiency (Table 1) (Machado-Ramos et al., 2023). By understanding and manipulating the factors that influence goat reproductive cycles, producers can achieve more consistent and efficient production outcomes (Habeeb and Kutzler, 2021).

## 3 Seasonal Breeding Strategies

### 3.1 Synchronization of estrus cycles

Hormonal treatments are widely used to synchronize estrus cycles in goats, facilitating out-of-season breeding and improving reproductive efficiency. These treatments typically involve the use of progesterone analogs combined with gonadotropins such as pregnant mare serum gonadotropin (PMSG) or human chorionic gonadotropin (hCG) to induce ovulation and synchronize estrus (Fatet et al., 2011). For instance, the use of PMSG and prostaglandin (PGF2α) has shown high estrus response rates and improved conception and kidding rates in goats (Table 2) (Wondim et al., 2022). Additionally, kisspeptin analogs like C6 have emerged as promising alternatives to PMSG, offering longer-lasting effects and enhanced activity (Decourt et al., 2014).

Natural methods of synchronization, such as photoperiodic treatments and the male effect, are gaining popularity due to their hormone-free approach. Photoperiodic treatments manipulate the light exposure to mimic seasonal changes, thereby inducing estrus and ovulation. The male effect involves the sudden introduction of a male to a group of anestrous females, which triggers neuroendocrine changes leading to estrus and ovulation. These methods, while effective, often result in lower fertility rates compared to hormonal treatments (Luo et al., 2019).

Table 1 Frequencies and means ± standard error for estrus responses, ovulations (%), total number of corpuses luteum (n), ovulation rate (units), luteal tissue volume ($mm^3$), type of ovulation (%), and pregnancy rate (d36, %) from multiparous crossbred/rangeland goats (*n* = 38) (i.e., extensive system) receiving (SG, *n* = 19) or not (NSG, *n* = 19) a nutritional supplementation of feed leftovers from a dairy cow enterprise (i.e., intensive system) in Northern Mexico [1] (Adopted from Machado-Ramos et al., 2023)

| Variables | Groups | |
|---|---|---|
| | SG | NSG |
| Estrus induction (%) | 16/19 (84.21) | 13/19 (68.42) |
| Latency to estrus (h) | 99.75 ± 8.7 | 101.54 ± 12.3 |
| Estrus duration (h) | 32.25 ± 3.2 | 31.38 ± 4.0 |
| Goats ovulating, *n* (%) | 15/19 (78.94) [a] | 9/19 (47.36) [b] |
| Total number of corpora luteum, (*n*) | 27 [a] | 14 [b] |
| Ovulation rate (*n*) | 1.42 ± 0.23 [a] | 0.73 ± 0.21 [b] |
| Luteal tissue volume ($mm^3$) | 657 ± 100 | 424 ± 89 |
| Type of ovulation: | | |
| -Single, *n* (%) | 4/15 (26.67) | 4/9 (44.44) |
| -Double, *n* (%) | 9/15 (60.00) [a] | 4/9 (44.44) [b] |
| -Triple, *n* (%) | 2/15 (13.33) | 1/9 (11.11) |
| -Multiple, *n* (%) | 11/15 (73.33) [a] | 5/9 (55.55) [b] |
| Pregnancy rate, d36, *n* (%) | 13/19 (68.42) [a] | 7/19 (36.84) [b] |

Note: [1] The SG was supplemented from day −5 to +15 in relation to the mating period; d0 = onset of the experimental out-of-season breeding (i.e., 28 March to 7 April). SG = supplemented group; NS = non-supplemented group. [a,b] Response variables with different superscript between columns within row differ ($p \leq 0.05$) (Adopted from Machado-Ramos et al., 2023)

Table 2 Conception rate (%), kidding rate (%), litter size (LSM±SE), and birth weight (LSM±SE) of Abergele goats synchronized with the PMSG and PGF2α protocols (Adopted from Wondim et al., 2022)

| Protocol | *N* | Mating (%) | Conception (%) | Kidding (%) | Litter size (LSM±SE) | Birth weight (LSM±SE) |
|---|---|---|---|---|---|---|
| Treatments | | | | | *** | * |
| PMSG | 24 | 15 (62.5) | 9 (37.5) | 6 (66.6) | 1.5 ± 0.20 | 1.8 ± 0.04 |
| PGF2*α* | 44 | 44 (100) | 29 (65.9) | 25 (86.2) | 1.0 ± 0.03 | 2.1 ± 0.04 |
| Overall | | 81.25 | 51.7 | 76.4 | 1.1 ± 0.05 | 2.0 ± 0.03 |
| CV | | | | | 24 | 10 |

Note: Here, PMSG = pregnant mare serum gonadotropin hormone, PGF2*α* = prostaglandin f2*α*, *N* = total population, LSM = least square means, and SE = standard error, * = $p < 0.05$, *** = $p < 0.001$ (Adopted from Wondim et al., 2022)

### 3.2 Nutritional management for reproductive health

Nutritional management plays a crucial role in enhancing reproductive health and performance in goats. Supplementation with energy-rich feeds, such as maize, has been shown to increase the number of follicles, follicle growth rate, and ovulation rate in anestrous goats (Nogueira et al., 2016). Nutritional supplements can also elevate plasma concentrations of metabolic hormones like insulin, leptin, and IGF-1, which are associated with improved follicular development and reduced rates of follicular atresia. Proper nutritional management ensures that goats maintain optimal body condition, which is essential for successful breeding and high fertility rates.

### 3.3 Genetic selection for seasonal breeding adaptability

Genetic selection is a powerful tool for improving seasonal breeding adaptability in goats. By selecting for traits such as litter size, ovulation rate, and breeding season length, breeders can enhance the reproductive efficiency of their herds (Ehrhardt et al., 2019). Crossbreeding with divergent breeds can rapidly reset genetic potentials for these traits, followed by within-breed selection to optimize reproductive performance (Notter, 2012). Although heritabilities for reproductive traits are generally low, strategic genetic selection can lead to significant improvements in seasonal breeding adaptability.

### 3.4 Use of artificial insemination in seasonal breeding

Artificial insemination (AI) is a critical component of modern goat breeding programs, allowing for the dissemination of superior genetic material and improving reproductive efficiency. AI, when combined with estrus synchronization protocols, facilitates out-of-season breeding and the grouping of kidding periods (Grizelj, 2022). The use of fresh or frozen semen in AI has been increasingly adopted, and advancements in fixed-time AI protocols have further enhanced its effectiveness (Bustamante-Andrade et al., 2021). Additionally, the integration of AI with other reproductive technologies, such as embryo transfer (ET), can significantly accelerate genetic progress and improve reproductive outcomes.

## 4 Environmental and Management Factors Affecting Reproduction Rates

### 4.1 Role of housing and climate control

Housing and climate control play a crucial role in the reproductive efficiency of goats. The photoperiod, or the length of day and night, is a significant environmental factor influencing the reproductive cycles of goats. In subtropical regions, manipulating the photoperiod can stimulate sexual activity in bucks during the non-breeding season, which in turn can induce and synchronize estrous behavior in does through the 'male effect' (Delgadillo, 2011). Additionally, providing appropriate housing that protects goats from extreme weather conditions and ensures a stable environment can help maintain consistent reproductive performance throughout the year (Figure 1) (Khan et al., 2019; Grizelj, 2022).

Figure 1 Interior and exterior of sheep house

### 4.2 Stress reduction and welfare practices

Stress reduction and welfare practices are essential for improving reproductive rates in goats. Stress can negatively impact the reproductive hormones and overall health of goats, leading to reduced fertility and prolificacy. Implementing welfare practices such as proper nutrition, adequate space, and minimizing handling stress can enhance reproductive outcomes. Nutritional supplementation, for instance, has been shown to improve the sexual response of bucks and their ability to stimulate reproduction in does, especially under semi-extensive management systems (Delgadillo et al., 2020). Ensuring that goats are well-nourished and free from stress can lead to higher pregnancy rates and better reproductive performance (Simões et al., 2021).

### 4.3 Disease management and vaccination strategies

Effective disease management and vaccination strategies are critical for maintaining the health and reproductive efficiency of goat herds. Health management aims to control or eradicate economic and zoonotic diseases, ensuring animal health and welfare, food safety, and low environmental impacts. Vaccination programs and regular health check-ups can prevent the spread of infectious diseases that may impair reproductive performance. Additionally, the use of exogenous hormones, such as human chorionic gonadotropin (hCG), has been shown to enhance luteogenesis and embryo implantation in goats, thereby improving reproductive outcomes during the non-breeding season (Bustamante-Andrade et al., 2021). Implementing comprehensive disease management and vaccination strategies can significantly contribute to the overall reproductive success of goat herds (Decourt et al., 2019; Souza-Fabjan et al., 2021).

## 5 Case Study

### 5.1 Background and selection of study area

The study was conducted in the arid lands of Northern Mexico, a region characterized by its challenging climatic conditions and extensive rangeland management systems for goats. This area was selected due to its significant population of dairy cattle managed under intensive production systems, which produce a substantial amount of feed leftovers. These feed leftovers retain high nutritional value and present an opportunity to enhance the reproductive performance of goats managed under marginal-extensive schemes (Figure 2) (Machado-Ramos et al., 2023).

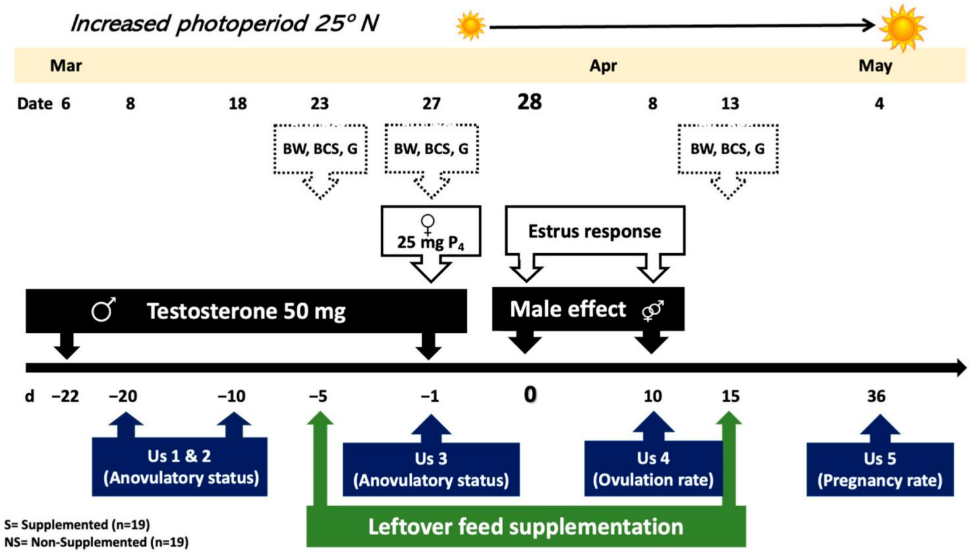


Figure 2 Schematic representation of the experimental protocol in of multiparous crossbred/rangeland goats (*n* = 38) (i.e., extensive system) receiving (S) or not (NS) a nutritional supplementation of feed leftovers from a dairy cow enterprise (i.e., intensive system) in Northern Mexico (Adopted from Machado-Ramos et al., 2023)

### 5.2 Seasonal breeding practices employed

To address the issue of reproductive seasonality in goats, several innovative breeding practices were employed. One approach involved the use of photoperiodic treatments to stimulate the sexual activity of bucks during the non-breeding season. These sexually active male goats were then used to induce and synchronize the estrous behavior and ovulatory activity of anestrous females through the 'male effect'. Additionally, a circular economy approach was implemented, where leftover feed from dairy cows was used as a targeted supplementation strategy for anestrous goats. This supplementation aimed to improve the reproductive outcomes of rangeland-managed goats during the deep-anestrous season. Furthermore, hormonal treatments, such as the administration of human chorionic gonadotropin (hCG), were used to enhance luteal function and embryo implantation in goats subjected to fixed-time artificial insemination protocols (Bustamante-Andrade et al., 2021).

### 5.3 Outcomes and observations

The implementation of these seasonal breeding practices yielded promising results. The use of photoperiodic treatments combined with the 'male effect' successfully controlled the reproductive activity of local goats, leading to synchronized estrous behavior and ovulatory activity in anestrous females (Delgadillo, 2011). The targeted supplementation with dairy cow feed leftovers significantly improved reproductive outcomes, with higher ovulation rates, multiple ovulations, and pregnancy rates observed in the supplemented group compared to the non-supplemented group. The administration of hCG also enhanced reproductive outcomes, with higher fecundity rates, corpus luteum areas, and embryo implantation efficiency observed in goats treated with higher doses of hCG.

### 5.4 Lessons learned and recommendations for broader application

The case study highlights the effectiveness of integrating environmental and nutritional strategies to improve goat reproduction rates. The use of photoperiodic treatments and the 'male effect' demonstrated the potential to control and synchronize reproductive activity in goats, which can be particularly beneficial in regions with pronounced seasonal variations. The circular economy approach of utilizing dairy cow feed leftovers as a supplementation strategy not only improved reproductive performance but also promoted sustainability by reducing feed waste. Hormonal treatments, such as hCG administration, further enhanced reproductive outcomes, suggesting that a combination of these practices can be highly effective in managing goat reproduction during the non-breeding season.

For broader application, it is recommended to tailor these strategies to the specific environmental, economic, and social characteristics of the local breeding systems. Producers should consider the feasibility and cost-effectiveness of implementing photoperiodic treatments, targeted supplementation, and hormonal protocols in their operations. Additionally, further research and extension services should focus on optimizing these practices and providing training to farmers to ensure successful adoption and sustained improvements in goat reproduction rates.

## 6 Impact of Seasonal Breeding on Productivity and Profitability

### 6.1 Comparison of seasonal vs. year-round breeding

Seasonal breeding in goats, particularly in subtropical and temperate regions, is influenced by environmental factors such as photoperiod and nutritional availability. Goats in these regions exhibit varying degrees of reproductive seasonality, which can significantly impact productivity. For instance, some breeds show large seasonal variations in their breeding cycles, while others maintain moderate seasonality or year-round sexual activity (Delgadillo, 2011). This seasonality affects the production of milk, cheese, and meat, leading to fluctuations in producer incomes. Implementing strategies to control reproductive cycles, such as photoperiodic treatments and the 'male effect,' can help stabilize production throughout the year.

In contrast, year-round breeding can be achieved through hormonal treatments or nutritional management. For example, the use of leftover feed from dairy cows has been shown to enhance the reproductive performance of goats during the non-breeding season, thereby supporting continuous production (Machado-Ramos et al., 2023). However, year-round breeding often requires more intensive management and can be associated with higher costs and ethical concerns related to hormone use.

### 6.2 Economic analysis of seasonal breeding implementation

The economic benefits of seasonal breeding are multifaceted. By aligning breeding cycles with favorable environmental conditions, farmers can optimize feed utilization and reduce costs associated with supplementary feeding during off-seasons. For instance, targeted nutritional supplementation during specific periods can improve reproductive outcomes and reduce the need for costly hormonal treatments (Ehrhardt and Barbara, 2023). Additionally, the use of photoperiodic treatments to induce sexual activity in bucks can enhance the effectiveness of the 'male effect,' leading to higher conception rates and improved productivity.

Economic analyses have shown that implementing seasonal breeding strategies can lead to significant cost savings and increased profitability. For example, the use of photoperiod-treated bucks has been demonstrated to efficiently induce the male effect, resulting in higher fecundity and productivity, particularly in breeds with high reproductive seasonality (Zarazaga et al., 2021). Moreover, the integration of circular economy principles, such as using dairy cow feed leftovers, can further enhance reproductive performance and reduce feed costs, benefiting marginal goat producers.

### 6.3 Long-term benefits for farm productivity

In the long term, seasonal breeding strategies can lead to sustainable improvements in farm productivity. By optimizing reproductive cycles to align with natural environmental cues, farmers can achieve more consistent and predictable production levels. This stability can enhance the overall efficiency of farm operations and reduce the risks associated with market fluctuations (Decourt et al., 2019).

Furthermore, genetic improvements in reproductive efficiency, such as selecting for traits that enhance out-of-season breeding capabilities, can provide long-term benefits. Studies have shown that genetic selection for traits like out-of-season kidding ability and reduced age at first kidding can improve lifetime productivity without adversely affecting milk yield (Desire et al., 2017). Additionally, the use of alternative methods to hormonal treatments, such as kisspeptin analogs, offers promising avenues for sustainable reproductive management.

## 7 Future Directions in Seasonal Breeding of Goats

### 7.1 Innovations in reproductive biotechnology

Innovations in reproductive biotechnology hold significant promise for enhancing goat reproduction rates, particularly in overcoming the challenges posed by seasonal breeding. One promising approach involves the use of exogenous hormones such as human chorionic gonadotropin (hCG) to stimulate ovarian follicle development and improve luteal function and embryo implantation rates during the non-breeding season. Studies have shown that administering 300 IU of hCG 14 days post-artificial insemination can significantly enhance fecundity rates and embryo efficiency indices, thereby boosting out-of-season reproductive outcomes (Bustamante-Andrade et al., 2021). Additionally, advancements in artificial insemination (AI) and embryo transfer (ET) technologies, including the use of photoperiodic treatments and the male effect, have been shown to synchronize ovulation without the need for hormones, although further research is needed to match the fertility rates achieved with hormonal treatments (Luo et al., 2019; Grizelj, 2022).

### 7.2 Integrating seasonal breeding with precision farming

Integrating seasonal breeding strategies with precision farming techniques can further optimize reproductive efficiency in goats. Precision farming involves the use of advanced technologies such as sensors, data analytics, and automated systems to monitor and manage livestock more effectively. For instance, targeted supplementation with leftover feed from dairy cows has been shown to improve reproductive performance in goats managed under extensive systems. This circular economy approach not only enhances out-of-season reproductive outcomes but also promotes sustainability by reducing waste (Machado-Ramos et al., 2023). Moreover, understanding the environmental factors controlling the timing of the annual reproductive cycle, such as photoperiod, can help develop sustainable breeding techniques tailored to local conditions, thereby stabilizing production and income for goat producers (Delgadillo, 2011).

### 7.3 Policy recommendations for sustainable goat farming

To ensure the sustainability of goat farming, policy recommendations should focus on promoting the adoption of advanced reproductive biotechnologies and precision farming techniques. Governments and agricultural organizations should invest in research and development to further explore the potential of hormone-free synchronization methods and the use of genetic improvements to enhance reproductive efficiency (Notter, 2012; Dardente et al., 2016). Additionally, policies should encourage the dissemination of knowledge and technologies to goat farmers, particularly in regions with limited access to resources. Training programs and extension services can help farmers implement best practices in reproductive management, thereby improving herd productivity and sustainability (Nunes and Salgueiro, 2011). Finally, policies should support the integration of circular economy principles in livestock farming, promoting the use of agricultural by-products to enhance reproductive performance and reduce environmental impact.

## 8 Concluding Remarks

The research on effective seasonal breeding strategies for improving goat reproduction rates has yielded several key insights. Firstly, the photoperiod has been identified as a major environmental factor controlling the timing of the annual breeding season in goats, particularly in subtropical regions. By manipulating the photoperiod and using the 'male effect,' it is possible to stimulate sexual activity in both male and female goats during the non-breeding season, thereby stabilizing production throughout the year. Additionally, the breeding season significantly influences the efficiency of assisted reproductive technologies, such as in vitro embryo production, with higher cleavage and blastocyst yields observed during the peak breeding season. Furthermore, targeted nutritional supplementation, such as using dairy cow feed leftovers, has been shown to enhance out-of-season reproductive performance in goats managed under extensive systems. Hormonal treatments, including the use of human chorionic gonadotropin (hCG) and kisspeptin analogs, have also been effective in improving luteal function, ovulation rates, and embryo implantation during the anestrous period. Lastly, reproductive management techniques, such as estrus synchronization and artificial insemination, have been crucial in facilitating year-round production and genetic improvement in dairy goats.

For farmers, it is recommended to adopt photoperiodic treatments combined with the 'male effect' to induce and synchronize estrous behavior in goats during the non-breeding season. This approach can help stabilize production and income throughout the year. Additionally, incorporating targeted nutritional supplementation, such as dairy cow feed leftovers, can significantly enhance reproductive outcomes during the anestrous period. Farmers should also consider using hormonal treatments, such as hCG or kisspeptin analogs, to improve ovulation rates and embryo implantation efficiency during out-of-season breeding.

For researchers, further studies are needed to optimize the use of photoperiodic treatments and the 'male effect' in different environmental and management conditions. Investigating the long-term effects of targeted nutritional supplementation on reproductive performance and overall health of goats is also crucial. Additionally, exploring alternative hormonal treatments and refining existing protocols for estrus synchronization and artificial insemination can contribute to more sustainable and efficient breeding strategies. Research on genetic improvement through selective breeding and crossbreeding should continue to enhance reproductive efficiency and adaptability to various climatic conditions.

Improving goat reproduction through effective seasonal breeding strategies is essential for stabilizing production and enhancing the economic viability of goat farming. By leveraging environmental cues, such as photoperiod, and integrating innovative nutritional and hormonal treatments, farmers can achieve higher reproductive efficiency and year-round production. Continued research and collaboration between farmers and scientists are vital to developing and refining these strategies, ensuring they are sustainable and adaptable to diverse farming systems and climatic conditions. Ultimately, these efforts will contribute to the growth and resilience of the goat farming industry, benefiting both producers and consumers.

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## Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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