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Seasonal influence on male reproductive organs in farm animals: A review

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Abstract

The present review aims at focusing the seasonal effects on various physiological and structural changes in the male genital organs as males are equally important in maintaining the reproductive cycle of any species and its survivability in terms of changing environmental factors. The male fertility is directly linked to herd fertility. Sub-fertility in males leads to delays in conception, prolonged calving intervals, reductions in the calf crop and may increase culling rate due to reproductive failure. Changes in the day-light ratio and temperature can influence the seasonal physiological, morphological and biochemical changes which, in turn affect the sexual behavior and semen quality in farm animals.

Keywords: Male fertility, season, temperature, day light ratio

Introduction

Reproduction is a fundamental biological process for any mammalian species that is responsible for its survival and regeneration. The reproductive performance of any individual is dependent on the genotype and environment (Moreira and Rodrigues, 2015) [8]. The male fertility is directly linked to herd fertility. Sub-fertility in males leads to delays in conception, prolonged calving intervals, reductions in the calf crop and may increase culling rate due to reproductive failure. Annual evaluation of each bull's suitability for breeding is strongly recommended (Ptaszynska, 2009) [10].

The reproductive activity of any species depends upon several factors; one of them is the climatic influence, which is a decisive factor for its semen quality. The reproductive seasonality refers to a period specific phenomenon in which there is reduction in reduced sexual activity of certain species during a certain period of the year, mainly regulated by climatic factors such as photoperiod, temperature and air humidity. Many mammalian species have adopted certain physiological mechanisms for maintaining their reproductive efficiency against the environmental adversity. The ability to reproduce is considered the most positive evidence of animal adaptability to a particular environment. In tropical climates, high ambient temperature is one of the main limiting factors of reproductive efficiency that affects testicular thermoregulation, thereby interfering the process of spermatogenesis and thus decreasing semen quality (Moreira and Rodrigues, 2015) [8]. The aim of this review is to explain the influence of climatic aspects, such as photoperiod and temperature on morphology of male reproductive organs of farm animals.

Regulation of male reproduction

Two regulatory systems govern the reproductive process in mammals. The endocrine system and the nervous system, each have a specific role, and a subtle interplay between the two is essential for the cascade of events that results in the birth and successful rearing of healthy offspring. The hormones responsible for the development and maintenance of the male phenotype are the gonadotropins viz; interstitial cell stimulating hormone (ICSH or LH) and follicle stimulating hormone (FSH) produced by pituitary gland, the androgenic steroid hormones, including testosterone and inhibin, produced by the testes.

Hypothalamic Gonadotropin releasing hormone (GnRH) stimulates the release of FSH and ICSH. In the male, FSH in conjunction with testosterone acts on the sertoli cells of the seminiferous tubules at the time of puberty to initiate sperm production.

Thereafter; throughout the adult life, FSH acts directly on the seminiferous tubules (germ cells and sertoli cells) stimulating spermatogenesis. The sertoli cells produce inhibin, which has a negative feedback effect on FSH secretion by the pituitary gland.

ICSH (LH) stimulates the production of testosterone by the Leydig cells. The secretion of ICSH is inversely related to the blood levels of testosterone and estradiol, as testosterone exerts a negative feedback effect on ICSH secretion by suppressing the pulsatile GnRH release from the hypothalamus. Although ICSH is known to induce biological responses in both Leydig and Sertoli cells, ICSH-specific receptors have only been found on the Leydig cells. This suggests that the action of ICSH on Sertoli cells is mediated through a paracrine mechanism. Receptors specific for FSH are present principally on Sertoli cells and to some extent on spermatogonia.

Testosterone is also necessary for spermatogenesis (acting on the Sertoli cells). The presence of functional androgen nuclear receptors has been demonstrated in Leydig, Sertoli and peri-tubular cells in testicular tissue. Testosterone and other androgens are responsible for the differentiation and maturation of the male reproductive organs, the growth of male secondary characteristics, and the behavior consistent with the male's role in reproduction. During sexual maturation, the Sertoli cells mature in terms of both their biochemical capability and their morphology. Thus the so called blood-testis barrier is formed. These Sertoli cells are involved in production of unique regulatory proteins such as the androgen-binding protein (ABP), nourishment of developing spermatozoa, phagocytosis of damaged spermatozoa, production of bicarbonate and potassium rich fluid used for the transport of mature sperm cells and production of estradiol from testosterone (Ptaszynska, 2009) [10].

Environmental stimuli are received by the senses and transmitted to the brain. With respect to reproduction, examples of sensory input from the environment include information received via the eyes, nose and touch. The optic, olfactory and sensory nerves transmit the messages to the brain. The brain translates the information and, as necessary, reacts by sending impulses along nerve fibers to a target organ.

Seasonality in reproduction

In temperate latitudes, animals face with recurrent, seasonal changes in temperature, climate and food availability which can influence their reproductive activity. One of the common features of most wild, and some domesticated, species is the development of seasonal reproduction favoring birth at an optimal time of year, usually spring, which allows the newborn to grow under optimal conditions of climate and food availability before the following winter. This means that periods of sexual activity alternate with periods of sexual inactivity. Among the domesticated species, sheep, goats and horses have retained the strongest seasonality in their reproductive processes. In sheep and goat, for instance, sexual activity begins as the day length becomes shorter (short-day breeders) and in horses, sexual activity starts when day length increases (long-day breeders). In temperate and cold climates, this results in horses, sheep and goat giving birth to their young in spring when sufficient food is likely to give them the best chance of survival (Chemineau *et al.*, 2008) [3].

For any given species, the breeding season is usually very stable throughout life, with relatively constant timing for the start and end of female ovulatory activity and a similarly consistent period of maximum sperm production in males. This precise and sustained timing is due to a complex mechanism that allows both sexes to synchronize the expression of their sexual activity and breeding season; in alignment with external environmental factors. Mainly two factors are responsible for seasonality in animal reproduction viz; Photoperiod and Thermal stress.

Influence of photoperiod

The photoperiod, represented by the length of a day, is the duration period of light in a certain place depending on the latitude and season. The phenomenon of one's ability to respond to the duration of daily light is called as photoperiodism. The annual reproductive cycle of seasonal breeders depends on the changes in day length and melatonin secretion profile, thus being classified as the negative or positive photoperiod animals (Moreira and Rodrigues, 2015) [8].

The pineal gland is the main regulatory organ in the seasonality of breeding; it registers day length via the eyes and a complex of neural connections. The pineal gland produces indoleamines, of which melatonin is the most important. Melatonin is produced and secreted during the night (dark). As days become shorter, the animal's exposure to melatonin increases. This exerts a stimulating effect on GnRH secretion by the hypothalamus in short-day breeders such as sheep and goat. In long-day breeders, like horse, increased melatonin exposure has adverse effect that inhibits GnRH release by the hypothalamus. Thus differences in day length are recognized and translated into signals that are able to turn sexual activity on or off (Thiery *et al.*, 2002) [13]. Buffaloes are a short-day seasonal polyestral or a continuous polyestral animal that depends on the proximity to the equator. Camels exhibit seasonal breeding behaviors regulated predominantly by photoperiod. In regions characterized by minimal variation in day length, photoperiodic influence declines, leaving thermal stress, nutritional status, health condition, and livestock management systems as the primary drivers of reproductive seasonality. (Moreira and Rodrigues, 2015) [8].

Influence of thermal stress

The adaptability of domestic animals is determined by the magnitude of solar radiation that directly affects the behavior and physiology. Physical, biochemical and behavioral adjustment of an animal is an attempt to prevent the negative effects of thermal stress. The acclimatization to a high temperature environment includes the immediate response is the form of reduced food intake, increased respiration rate, water intake and hormonal changes that affect the responsiveness to environmental stimuli. It is further followed by a decline in the hormonal secretion like that of growth hormone, catecholamine and glucocorticoids, decreased digestion and metabolism, thereby reducing the metabolic energy production and animal breeding. Under temperate climatic conditions, the semen concentration and number of motile spermatozoa in ejaculates of bull are lower in summer than in winter and spring. In regions where the predominant climate type is hot and humid, the respiratory rate and skin temperature rise, whereas there is a decrease in sweating resulting in a decrease in the loss of

body heat causing thermal stress that ultimately reduce sperm quality and changes in semen composition in the bull (Mathevon *et al.*, 1998) ^[7].

Normal spermatogenesis in stallions occurs at a physiological baseline of approximately 35 °C, rendering scrotal thermoregulation essential for testicular health. Swine exhibit heightened sensitivity to thermal stress owing to poor physiological heat dissipation capabilities. As a result, elevated environmental temperatures in late summer induce heat-stress-related reproductive impairment in males (Moreira and Rodrigues, 2015) ^[8].

Effect of season on morphology of male reproductive organs

Depending on the season, adult males have reproductive cycles that are expressed by morphological and biochemical changes in the testes. Moreover, mammalian spermatozoa produced in the testes must mature in the epididymis to acquire their fertilizing capability. Specific proteins secreted by epithelial cells of the epididymis and factors generated by accessory glands modulate the structure and function of the sperm plasma membrane. The size and secretory activity of epithelia in the epididymis as well as in the accessory glands are influenced by testosterone (Dominguez and Aguilera, 2013) ^[4].

Scrotum

The scrotal circumference (SC) measurement is an essential aspect of breeding soundness examination that is as an indicator of puberty, total sperm production, semen quality, pathological conditions of the testes, as well as the sub-fertility or infertility of a bull. The SC is reported to be affected by seasons. The small SC during summer is ascribed to thermal degeneration of the testes. The seminiferous tubules make up 77% of testicular volume, and increased environmental temperature have a deleterious effect on these tubules resulting in a smaller volume of the testes and hence a smaller SC (Yunis *et al.*, 2003) ^[14].

Testis

Evolutionary placement of the testes outside the abdominal cavity enables vital scrotal thermoregulation in most mammals. Thin, highly vascularized skin combined with countercurrent heat exchange, blood flow adjustment, dynamic positioning, and sweating keeps testicular temperatures 2 °C to 6 °C cooler than core body temperature. Adult stallions show a 36% increase in Sertoli cell numbers during the breeding season compared to the non-breeding season. This increase, accompanied by higher FSH levels, directly drives seasonal gains in testicular weight and daily sperm production (Johnson and Thompson, 1983) ^[5].

Inhibin is a glycoprotein hormone produced by Sertoli cells and seminiferous tubules. In the male, inhibin may act in conjunction with testosterone in the control of FSH release at the pituitary. In stallions concentrations of inhibin in plasma vary according to seasonal reproductive state and are positively correlated with testicular size and testosterone secretion. As long-day seasonal breeders, stallions show pronounced seasonal fluctuations in testicular dynamics, marked by substantial secretion of bioactive and immunoreactive dimeric inhibin into circulation. Immunohistochemical co-localization of inhibin subunits α and β with aromatase and 3β -HSD in Leydig cells—

alongside subunit expression in Sertoli cells—suggests dual-cell endocrine activity and local paracrine modulation of Leydig cell steroidogenesis. Moreover, the strong seasonal correlation between circulating inhibin and estradiol underscores its utility as an endocrine biomarker for evaluating testicular status. (Nagata *et al.*, 1998) ^[9].

Scrotal insulation for 48 hours causes peak heat-stress damage in bulls 12 to 21 days later, reducing Sertoli cell production of androgen-binding protein. *Bos indicus* bulls resist high temperatures better than *Bos taurus* or crossbreds because their spermatid cords feature thinner, longer testicular arteries that sit closer to surrounding veins, maximizing arterial blood cooling (Brito *et al.*, 2004) ^[2].

The reduction in testis weight during summer may be due to exposure to heat stress which causes degeneration in the germinal epithelium and to a partial atrophy in the seminiferous tubules. In respect to testicular volume, the size of the testis is greatly increased due to increase in the development of interstitial tissue during winter and spring season which may be attributed to the increase spermatogonia, spermatocytes, spermatids and spermatozoa. The increased testes dimension during breeding season reflects higher spermatogenesis activity affected by increasing testosterone concentration and development of interstitial tissues (Zeidan and Abbas, 2004) ^[16].

High temperatures disrupt testicular thermoregulation, causing degeneration of germinal cells and testicular tissue. This results in poor semen quality, abnormal sperm, and reduced motility, leading to male subfertility or infertility. Histological findings show that heat stress selectively damages germ cells while sparing somatic cells and preserving endocrine function. (Rasooli *et al.*, 2010) ^[11].

In buffalo bull mean testicular weight and the mean diameter of the organ is higher during the mating period (October-May) than during the non-mating period (June-September). Histological evaluation of testicular seminiferous tubules showed that the spermatogenesis is conserved also in the resting period. Tubular diameters are significantly smaller during the non-mating summer months. Smaller testicular volumes together with minor values of tubular diameters might indicate a decreased spermatogenesis (Arrighi *et al.*, 2010) ^[1].

The seasonal activity of the camel which is regarded as short day breeder, change from long to short day seems to stimulate synthesis and release of gonadotropin hormones from the anterior pituitary gland, which in turn stimulate testicular activity and sexual behavior. The testes weight, testicular volume, scrotal circumference and testes tone firmer score of the dromedary camels are significantly higher during breeding than non-breeding season either in hot-dry or hot-humid months. The testis weight, testicular volume and scrotal circumference during non-breeding season in hot-humid months are significantly lower than hot-dry months. The testis of the camel during the non-breeding season in hot-humid months shows some degenerations and vacuolations in the seminiferous tubule (Maiada *et al.*, 2013) ^[6].

Epididymis

Buffalo bulls show slightly higher epididymal weights during the non-mating season, driven by regional structural changes. In summer, the corpus epididymis shrinks in tubular diameter and epithelial height, impairing sperm maturation functions. Conversely, the cauda epididymis

expands in both diameter and cell height due to sperm accumulation from reduced mating frequency. These seasonal shifts reflect an overall decline in male reproductive tract activity during late spring and summer (Arrighi *et al.*, 2010) ^[1].

Camel epididymal structure and sperm quality peak during spring, marked by maximum organ weight, wider duct lumens, thicker muscle layers, and elevated PAS-positive secretions. Scanning electron microscopy shows healthy sperm in spring, but smaller, abnormal sperm in other seasons. Epithelial height and stereocilia length peak in autumn. Throughout the year, principal cell nuclei shift from active, vesicular forms in spring to condensed, heterochromatic forms in summer and autumn, illustrating strong seasonal regulation of epididymal function (Zayed *et al.*, 2012) ^[15].

Accessory glands

The ampullary vas deferens of Gaddi rams and bucks exhibits seasonal morphometric and functional activity. Glandular lumen diameter, epithelial cell height, and nuclear dimensions peak in autumn and reach a lowest value in summer. Secretory activity and apical blebs follow the same pattern, staining strongly PAS positive carbohydrates. This indicates high mucopolysaccharide production in autumn to nourish ejaculated sperm (Suri *et al.*, 2008) ^[12].

Conclusion

Daylight ratio and ambient temperature serve as the primary climatic drivers of seasonal physiological, morphological, and biochemical adaptations in livestock, directly shaping male reproductive behavior and semen quality. Extreme heat stress disrupts systemic thermoregulation, causing degeneration of the testicular parenchyma and germinal epithelium. This structural damage impairs semen parameters marked by elevated morphological defects, reduced motility, and decreased sperm vigor which serves as a major etiology for male sub fertility and infertility. During the active breeding season, Sertoli cell numbers rise, increasing total testicular weight and daily sperm production. Similar seasonal structural changes occur in the epididymis and accessory sex glands, driven by seasonal shifts in testicular hormones.

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