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Maximizing the Reproductive Efficiency of Cattle: A Review Benefits of Sexual Puberty Induction in Heifers Through Hormonal Protocols

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Abstract:- The induction of puberty in cattle is of great value in maximizing reproductive efficiency with the aim of promoting greater financial and economic gains from livestock activity. Hormone treatment has been used worldwide in heifers as a way to improve reproductive efficiency. This work aims to present the different protocols used to induce puberty in heifers and the associated benefits for the cow as well as for the farm.

Keywords:- *Puberty induction; Reproductive efficiency; Heifers.*

I. INTRODUCTION

It is expected that by 2050, the world population will grow by more than a third, reaching more than 9 billion people and therefore the pressure for food production will increase by about 70% (Zhang et al., 2021). Livestock in general plays a key role in the production and supply of food of animal origin Waters-Bayer and Bayer, 1992; Nkadimeng *et al*., 2021; Direito, 2022). Cattle production is fundamental in promoting food security as it provides protein of high biological value (meat and milk) (Mkize and Zishiri, 2021). In some African countries, such as Mozambique, cattle contribute to the fertilization of agricultural fields and is used for animal traction, thus increasing the income of the peasants, in addition to being used as dowries in weddings and traditional ceremonies (Herrero et al., 2013; Mutami, 2015; Direito, 2022; Nkadimeng et al., 2021; Mkize and Zishiri, 2021).

Given the importance of cattle due to the global pressure for food and its utilities in general, the need to ensure greater production and productivity in livestock farming and increase profits becomes clear. Thus, management focused on replacement heifers, especially reproductive, can contribute to achieving these goals (Abuelo et al., 2021). This work aims to present the different protocols used to induce puberty in heifers and the associated benefits for the cow as well as for the farm.

II. MAXIMIZING REPRODUCTIVE EFFICIENCY

The delay in the reproductive life of the dams has the consequences of an increase in the herd of females that are not breeding, a reduction in the efficiency of calf production, resulting in a decrease in profit and a delay in the genetic selection process. The improvement in reproductive performance, by reducing the age at first calving (IPP) of females, has a significant impact on the productive indicators of the farm. It is therefore essential that heifers enter puberty at the earliest possible age.

A. Age at Puberty

From the reproductive point of view, puberty is defined as the manifestation of reproductive capacity (Martins et al., 2021), which occurs when an animal acquires the ability to ovulate an oocyte with the presentation of estrous behavior (Augusto *et a*l., 1997; Forde *et al*., 2011; Martins *et al*., 2021), with development and maintenance of a functional corpus luteum with a normal lifespan (Gonzalez-Padilla et al., 1975; de Lima et al., 2020). Given this definition, puberty can be seen as an economic indicator in beef cattle (Baruselli et al., 2018). de Lima et al. (2020) and Dyck, (1988) defines it as the beginning of reproductive activity, which is marked by changes in gonadotropin concentration and by an increase in circulating sex steroid hormones which involves a complex physiological and molecular process (Gonzalez-Padilla et al., 1975; Masello et al., 2019; Kowalik et al., 2022).

The period corresponding to the 40-60 days prior to the first ovulation is designated as pre-puberty (Cardoso et al., 2020). This phase involves the transition from one period of ovarian inactivity to another, in which the final stage of maturation of the hypothalamic-pituitary-gonadal axis and the beginning of ovulations occur (Heslin et al., 2020). For this reason, mating soon after the first estrus followed by ovulation is not advised, as fertility in this period has been reported to be low, mainly due to the occurrence of a short estrous cycle associated with premature luteolysis of the corpus luteum between the 8th and 8th. 12 days (Carvalho et al., 2008; Holland et al., 2018) resulting in a serum concentration of progesterone lower than 1.0 ng/ml on day 9 of the cycle (Côrtes et al., 2021), which prevents maintenance of pregnancy, since the critical period for the maternal recognition of the embryo occurs from the 15th to the 19th days.

The final maturation of the reproductive tract of the future mother results from exposure to ovarian steroids, from estrous cycles after puberty (Forde et al., 2011; Adams et al., 2018). Among the hormones involved in the physiology of puberty, LH is considered the primary endocrine factor for the heifer to reach puberty and this is only possible from the reduction of the negative feedback exerted by estradiol (Baruselli et al., 2018), a phenomenon that is observed in the prepubertal phase. Pulsatile LH secretion is established in calves at around 1 to 2 months of age (Anderson et al., 1996) and increases around 3 and 5 months of age (Tsutsumi and Webster, 2009). Subsequently, LH secretion decreases and remains relatively low (static phase) until a further increase in LH secretion (prepubertal phase) culminating in puberty (Patterson et al., 1990; Anderson et al., 1996; Cardoso et al., 2020; Martins et al., 2021).

One of the causes of the increase in the frequency of LH pulses in the prepubertal phase is a consequence of the lower sensitivity of the hypothalamus to the negative feedback exerted by estradiol (Ataide Junior et al., 2021; Delchiaro et al., 2022) resulting in follicle growth antral and increased estradiol production, followed by a transient elevation in LH secretion (Dysart et al., 2021). In heifers, plasma estradiol concentration remains low until the prepubertal period, when it gradually increases until the time of the first ovulation (Codognoto et al., 2022). In addition to the changes observed in the hypothalamic-pituitary-gonadal axis during the period before puberty, the sexual organs also undergo morphophysiological changes, providing adequate conditions for the establishment of pregnancy as well as an increase in the weight of the uterus, cervix and vagina, being that prepubertal heifers generally have a lower uterine diameter than pubertal heifers (Solano et al., 2000; Byrne et al., 2018; Bertogna et al., 2021).

B. Age of heifers at first calving

Management focused on age at first calving at two years of age has allowed maximizing the productive life of heifers(Lasheen et al., 2018), as those with greater sexual precocity have a longer reproductive life than late ones (Aranda -Avila, Magaña-Monforte, Segura-Correa 2010; Byrne et al. 2018; Adoligbe et al. 2020). As a result, heifers that have their first calving close to 24 months of age reach their maximum productivity (Burns et al., 2010; Ekowati et al., 2018; Cardoso et al., 2020). There are differences between Bos indicus and Bos taurus cattle in relation to the onset of puberty. In general, puberty occurs later in Bos indicus heifers, which is reflected in the age at first calving, which in these animals can occur at 40 months of age (Day, 2004; Cooke et al., 2021).

Factors involved in the onset of puberty include age (Martins et al., 2021), body weight (Cardoso et al., 2020) and genetic variations (Dyck, 1988; Bertogna et al., 2021). Age at puberty for Zebu heifers ranges from 22 to 36 months (González et al., 1986; Martins et al., 2021) and age at first calving between 44 and 48 months (Aranda-Avila et al., 2010; Martins et al., 2021). In taurine breeds, the first ovulation occurs between 7 and 12 months, with the first service around 15 months (Patterson et al., 1990; Hanotte et al., 2000; Cooke et al., 2021; Delchiaro et al., 2022). The Landim bovine within the Sanga group present in the Southern region of Mozambique, specifically in the provinces of Maputo, Gaza and Inhambane, widely known as Nguni (Carvalheira et al., 1995; Maciel et al., 2012; King et al., 2021), in turn, is relatively earlier, which can be confirmed in the study by Carvalheira et al. (1995) who studied the Landim and Africander breeds at the Chobela Research Station and obtained an age at first calving of 39.5 for Landim and 42.8 for Africander. Maciel et al. (2012), in turn, evaluating the reproductive performance of two Nguni ecotypes (Nguni and Landim) reared in subtropical environments, found an average of 35±5 months at first calving.

Body weight affects the age of onset of puberty in cattle and its monitoring through daily weight gain control and body weight assessment is crucial as it allows predicting the onset of puberty, which makes it easy to select females that will be able to be incorporated in their first breeding season (Houghton et al., 1990; Ayres et al., 2014; D'Occhio et al., 2019; Cooke et al., 2021). In general, larger breeds are later and heavier when they reach puberty (Heslin et al., 2020). Beef heifers need to reach about 60 to 65% of their adult live weight to reach puberty (Dickinson et al., 2019). The weaning weight is essential for heifers to reach puberty and the higher the weaning weight, the better, according to the requirements of each breed, without them becoming obese, since the excess of adipose tissue in heifers during the pre-weaning can result in reduced subsequent performance of these animals (Cooke et al., 2021; Kasimanickam et al., 2021).

Genetic variations play an influence both within and between breeds and this can clearly be seen in the evaluations of age and weight effects at puberty between *Bos taurus* and *Bos indicus*. *Taurine* heifers generally enter at puberty between 10 - 15 months with body weight ranging from 270 - 350 kg, and calving is estimated at 24 – 26 months of age, while zebu heifers reach puberty later and with greater weight compared to to adult weight, presenting an age at first calf that can reach 44 - 48 months of age (Maciel et al., 2016; Carvalheira et al., 1995; Aranda-Avila et al., 2010; Figueiredo et al., 1997).

III. USE OF HORMONES ON REPRODUCTIVE EFFICIENCY

Hormones have been strategically used as a valuable alternative to increase reproductive efficiency in cattle (González et al., 1986; de Lima et al., 2020) as they allow inducing and anticipating puberty in heifers before the breeding season. (Gonzalez-Padilla et al., 1975; Carvalho et al., 2008; Martins et al., 2021). Some hormones, such as progesterone analogues (P4), administered orally (melengestrol acetate, MGA) (Patterson et al., 1990), via subcutaneous implants (norgestomet, Crestar) (González et al., 1986), or by intravaginal devices containing P4 (CIDR, DIB, PRID and SINCROGEST) (Ataide Junior et al., 2021), have been used.

Anderson et al. (1996) evaluated the mechanism by which exposure to progestins induces puberty in heifers. These results suggest that progestogens induce puberty by providing greater secretion of LH, allowing follicular growth, which results in greater production of estradiol by the ovarian follicles and LH surge, inducing ovulation and, consequently, puberty. Another mechanism involved is the decrease in hypothalamic estradiol receptors, inducing negative feedback effects of estradiol on GnRH secretion, thus enabling an increase in LH secretion (Day, 2004).

de Lima et al. (2020) evaluated the effect of puberty induction using single-dose injectable P4 on AI conception rates and found that progesterone induced a 50% increase in uterine development at 21 days and an 18% i*ncrease in follicle diameter*. Assuming that progesterone has acted to make the uterus and ovaries physiologically more prepared for reproduction sooner. In addition, there was an increase of about 7.7% (iP4: 46.0% vs. NoiP4: 38.3%) in AI conception rates in the progesterone-treated heifer group. Abouel-Ghaitb (2021) studied the effect of treatments with GnRH and progesterone device (CIDR) plus eCG (1000 or 500 IU) on the induction and synchronizati*on of puberty onset in buffalo* heifers which resulted in a greater number of large *follicles and rates of* conception significantly higher (P<0.05) *than* all groups and concluding that hormones can be an effective alternative for the induction and synchronization of puberty in buffaloes too.

IV. CONCLUSION

To achieve an optimal reproductive performance of cattle, it is necessary to extract maximum efficiency from each female. Heifers represent the guarantee and maintenance of production and therefore, farm management must pay special attention to this category in order to extract the maximum possible gains in the production phase and less expenses in the rearing phase. This requires each animal to have a calving every 12-13 months, with the first calving at 24 months of age and puberty entering at 14-15 months. Reproductive management in general is fundamental and hormones can represent an alternative for maximizing reproductive efficiency and obtaining greater profits, but it is the combination of several factors such as nutrition, health and genetic selection that guarantees the best results in livestock activity. Heifers that start their reproductive life earlier, produce more weaned calves during their productive life, have better reproductive rates, and therefore bring more profit to farms.

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REFERENCES

[1]. ABOUEL-GHAITB, Hasab, 2021a. Progesterone-based hormonal treatments to induce and synchronize the onset of puberty in buffalo-heifers. *Kafrelsheikh Veterinary Medical Journal*. 15 outubro 2021. vol. 19, no. 1, p. 20–25.

[2]. ABUELO, Angel, CULLENS, Faith e BRESTER, Jill L., 2021. Effect of preweaning disease on the reproductive performance and first-lactation milk production of heifers in a large dairy herd. *Journal of Dairy Science*. 1 junho 2021. vol. 104, no. 6, p. 7008–7017.

[3]. ADAMS, Caroline, CHEN, Xi e MOENTER, Suzanne M., 2018. Changes in GABAergic Transmission to and Intrinsic Excitability of Gonadotropin-Releasing Hormone (GnRH) Neurons during the Estrous Cycle in Mice. *eNeuro*. 8 novembro 2018. vol. 5, no. 5, p. 71-81.

[4]. ADOLIGBE, M. C. et al., 2020. Muturu cattle breed management in the smallholder farming area of the Ouémé district in the south of Benin: rearing practices, objectives, and constraints. *Tropical Animal Health and Production*. 1 novembro 2020. vol. 52, no. 6, p. 3015–3025.

[5]. ANDERSON, L. H., MCDOWELL, C. M. e DAY, M. L., 1996. Progestin-induced puberty and secretion of luteinizing hormone in heifers. *Biology of Reproduction*. maio 1996. vol. 54, no. 5, p. 1025–1031.

[6]. ARANDA-AVILA, Ildefonso, MAGAÑA-MONFORTE, Juan G. e SEGURA-CORREA, Jose C., 2010. Effects of breed type and age at first calving on length of productive life in a cow–calf system in Southeastern Mexico. *Tropical Animal Health and Production*. 1 dezembro 2010. vol. 42, no. 8, p. 1737–1741.

[7]. ATAIDE JUNIOR, Gilmar Arantes et al., 2021. Early resynchronization of follicular wave emergence among Nelore cattle using injectable and intravaginal progesterone for three timed artificial inseminations. *Animal Reproduction Science*. 1 junho 2021. vol. 229, p. 106759.

[8]. AUGUSTO, L et al., 1997. Onset and Duration of Oestrus Related to the Time of Ovulation and Fertility in a Herd of Nguni Cattle in South Mozambique. . 1997. P. 303–307.

[9]. AYRES, H. et al., 2014. Inferences of body energy reserves on conception rate of suckled Zebu beef cows subjected to timed artificial insemination followed by natural mating. *Theriogenology*. 1 setembro 2014. vol. 82, no. 4, p. 529–536.

[10]. BAEZ, Giovanni M. et al., 2016. Effect of uterine size on fertility of lactating dairy cows. *Theriogenology*. maio 2016. vol. 85, no. 8, p. 1357–1366.

[11]. BAKAE, T. et al., 2022. Assessment of genetic diversity and relationship of the two Sanga type cattle of Botswana based on microsatellite markers. *Tropical Animal Health and Production*. 10 junho 2022. vol. 54, no. 4, p. 210.

[12]. BARUSELLI, Pietro Sampaio et al., 2018. Timed artificial insemination: current challenges and recent advances in reproductive efficiency in beef and dairy herds in Brazil. *Animal Reproduction (AR)*. 2018. vol. 14, no. 3, p. 558–571.

[13]. BELLO, Nora Maria, STEIBEL, J. P. e PURSLEY, J. R., 2006. Optimizing ovulation to first GnRH improved outcomes to each hormonal injection of Ovsynch in lactating dairy cows. *Journal of dairy science*. 2006. vol. 89, no. 9, p. 3413–3424.

[14]. BERTOGNA, Kássila Fernanda et al., 2021. Parameters associated with sexual precocity of Nellore heifers in integrated systems. *Agroforestry Systems* [em linha]. 14 outubro 2021. [Acesso em 14 janeiro 2022].

[15]. BIHON, Amare e ASSEFA, Ayalew, 2021. Prostaglandin based estrus synchronization in cattle: A review. *Cogent Food & Agriculture*. 1 janeiro 2021. vol. 7, no. 1, p. 51.

[16]. BO, Gabriel et al., 2018. Programs for fixed-time artificial insemination in South American beef cattle. *Periodikos* [em linha]. 2018. [Acesso em 28 junho 2022]. Disponível em: http://animal-reproduction.org/article/doi/10.21451/1984-3143-AR2018-0025Anim Reprod, vol.15, n 1, p.952-962.

[17]. BOULTON, A. C., RUSHTON, J. e WATHES, D. C., 2017. An empirical analysis of the cost of rearing dairy heifers from birth to first calving and the time taken to repay these costs. *Animal*. 1 janeiro 2017. vol. 11, no. 8, p. 1372–1380.

[18]. BRITO, Lindomar Sousa et al., 2020. Effects of equine chorionic gonadotropin administered via the Baihui acupoint on follicular ovarian dynamics and the luteal function of cattle during an ovulation synchronization treatment regimen for fixed-time artificial insemination. *Animal Reproduction Science*. 1 dezembro 2020. vol. 223, p. 31.

[19]. BURNS, B. M., FORDYCE, G. e HOLROYD, R. G., 2010. A review of factors that impact on the capacity of beef cattle females to conceive, maintain a pregnancy and wean a calf—Implications for reproductive efficiency in northern Australia. *Animal Reproduction Science*. 2010. vol. 122, no. 1–2, p. 1–22.

[20]. BYRNE, C. J. et al., 2018. Plane of nutrition before and after 6 months of age in Holstein-Friesian bulls: II. Effects on metabolic and reproductive endocrinology and identification of physiological markers of puberty and sexual maturation. *Journal of Dairy Science*. 1 abril 2018. vol. 101, no. 4, p. 3460–3475.

[21]. CAMPOS, M. S. et al., 1994. Genetic Parameters for Yield and Reproductive Traits of Holstein and Jersey Cattle in Florida1. *Journal of Dairy Science*. 1 março 1994. vol. 77, no. 3, p. 867–873.

[22]. CARDOSO, R. C. et al., 2020. Nutritional control of puberty in the bovine female: prenatal and early postnatal regulation of the neuroendocrine system. *Domestic Animal Endocrinology*. 1 outubro 2020. vol. 73, p. 106434.

[23]. CARVALHEIRA, J. G. et al., 1995. Comparison of Landim and Africander cattle in southern Mozambique: I. Body weights and growth. *Journal of Animal Science*. dezembro 1995. vol. 73, no. 12, p. 3519–3526.

[24]. CARVALHO, J. B. P. et al., 2008. Effect of early luteolysis in progesterone-based timed AI protocols in Bos indicus, Bos indicus×Bos taurus, and Bos taurus heifers. *Theriogenology*. 15 janeiro 2008. vol. 69, no. 2, p. 167–175.

[25]. CASTRO, Natália Ávila de, 2019. Ações da Prostaglandina F2α e Paraoxonase-1 na ovulação e prenhez de bovinos. [em linha]. 27 fevereiro 2019. [Acesso em 18 agosto 2022].

[26]. CAVESTANY, D et al., 2007. Reproductive efficiency in grazing lactating dairy cows under a programmed reproductive management system. *Australian Veterinary Journal*. 2007. vol. 85, no. 4, p. 141–147.

[27]. CEDEÑO, Andrés et al., 2020. Effect of estrus expression or treatment with GnRH on pregnancies per embryo transfer and pregnancy losses in beef recipients synchronized with estradiol/progesterone-based protocols. *Theriogenology*. 1 novembro 2020. vol. 157, p. 378–387.

[28]. CODOGNOTO, Viviane M. et al., 2022. Can blood progesterone concentration identify non-pregnant buffaloes to support oestrous resynchronization? *Reproduction in Domestic Animals*. 2022. vol. 57, no. 6, p. 673–677.

[29]. COOKE, R. F. et al., 2021. Effects of body condition score at initiation of the breeding season on reproductive performance and overall productivity of Bos taurus and B. indicus beef cows. *Animal Reproduction Science*. 1 setembro 2021. vol. 232, p. 106820.

[30]. CÔRTES, L. R. et al., 2021. Administration of a single dose of 300 IU of human chorionic gonadotropin seven days after the onset of estrus improves pregnancy rate in dairy goats by an unknown mechanism. *Domestic Animal Endocrinology*. 1 janeiro 2021. vol. 74, p. 106579.

[31]. CRISTOFORI, F. et al., 2005. Artificial Insemination Using Local Cattle Breeds in Niger. *Tropical Animal Health and Production*. 1 fevereiro 2005. vol. 37, no. 2, p. 167–172.

[32]. DAY, M. L., 2004. Hormonal induction of estrous cycles in anestrous Bos taurus beef cows. *Animal Reproduction Science*. 2004. vol. 82, p. 487–494.

[33]. DE LIMA, R. S. et al., 2020a. Effect of a puberty induction protocol based on injectable long acting progesterone on pregnancy success of beef heifers serviced by TAI. *Theriogenology*. 15 setembro 2020. vol. 154, p. 128–134.

[34]. DE LIMA, R. S. et al., 2020b. Effect of a puberty induction protocol based on injectable long acting progesterone on pregnancy success of beef heifers serviced by TAI. *Theriogenology*. 15 setembro 2020. vol. 154, p. 128–134.

[35]. DELCHIARO, S. B. et al., 2022. Antral follicle count, productive and reproductive parameters in Bos indicus and Bos indicus-taurus prepubertal heifers with early puberty induction. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*. 10 junho 2022. vol. 74, p. 390–398.

[36]. DICKINSON, Sarah E. et al., 2019. Evaluation of age, weaning weight, body condition score, and reproductive tract score in pre-selected beef heifers relative to reproductive potential. *Journal of Animal Science and Biotechnology*. 26 fevereiro 2019. vol. 10, no. 1, p. 18.

[37]. DISKIN, M.G e KENNY, Day, 2014. Optimising reproductive performance of beef cows and replacement heifers. *Animal : an international journal of animal bioscience* [em linha]. maio 2014. vol. 8 Suppl 1. [Acesso em 14 janeiro 2022].

[38]. D'OCCHIO, Michael J., BARUSELLI, Pietro S. e CAMPANILE, Giuseppe, 2019. Influence of nutrition, body condition, and metabolic status on reproduction in female beef cattle: A review. *Theriogenology*. 1 fevereiro 2019. vol. 125, p. 277–284.

ISSN No:-2456-2165

[39]. DYCK, G. W., 1988. Factors influencing sexual maturation, puberty and reproductive efficiency in the gilt. *Canadian Journal of Animal Science*. 1988. vol. 68, no. 1, p. 1–13.
[40]. DYSART, Lacey M. et al., 2021. Effects of administration of exogenous estradiol benzoate on follicular, luteal, and uterine hemodynamics in beef cows. *Animal Reproduction Science*. 1 setembro 2021. vol. 232, p. 106817.
[41]. DZIUK, P. J. e BELLOWS, R. A., 1983. Management of Reproduction of Beef Cattle, Sheep and Pigs. *Journal of Animal Science*. 1 julho 1983. vol. 57, no. suppl_2, p. 355–379.
[42]. ETTEMA, J. F. e SANTOS, J. E. P., 2004. Impact of Age at Calving on Lactation, Reproduction, Health, and Income in First-Parity Holsteins on Commercial Farms. *Journal of Dairy Science*. 1 agosto 2004. vol. 87, no. 8, p. 2730–2742.
[43]. FABRE-NYS, C. e MARTIN, G. B., 1991. Roles of progesterone and oestradiol in determining the temporal sequence and quantitative expression of sexual receptivity and the preovulatory LH surge in the ewe. *The Journal of Endocrinology*. setembro 1991. vol. 130, no. 3, p. 367–379.
[44]. FIGUEIREDO, R. A. et al., 1997. Ovarian follicular dynamics in nelore breed (Bos indicus) cattle. *Theriogenology*. 1 junho 1997. vol. 47, no. 8, p. 1489–1505.
[45]. FONTES, Pedro L. P., OOSTHUIZEN, Nicola e CLIFF LAMB, G., 2020. Chapter 4 - Reproductive management of beef cattle. Em: *Animal Agriculture* [em linha]. Academic Press. p. 57–73.
[46]. FORDE, N. et al., 2011. Oestrous cycles in Bos taurus cattle. *Animal Reproduction Science*. 1 abril 2011. vol. 124, no. 3, p. 163–169.
[47]. GONZÁLEZ, Suellen, ASSUNÇÃO, Igor e DUARTE, James, 1986. Induced puberty in prepuberal zebu heifers treated with norgestomet and pregnant mare serum gonadotropin. *Theriogenology*. julho 1986. vol. 26, no. 1, p. 27–36.
[48]. GONZALEZ-PADILLA, E., NISWENDER, G. D. e WILTBANK, J. N., 1975. Puberty in Beef Heifers. II. Effect of Injections of Progesterone and Estradiol-17β on Serum LH, FSH and Ovarian Activity. *Journal of Animal Science*. 1 junho 1975. vol. 40, no. 6, p. 1105–1109.
[49]. HANOTTE, O. et al., 2000. Geographic distribution and frequency of a taurine Bos taurus and an indicine Bos indicus Y specific allele amongst sub-Saharan African cattle breeds. *Molecular Ecology*. 2000. vol. 9, no. 4, p. 387–396.
[50]. HERBISON, Allan E., 2020. A simple model of estrous cycle negative and positive feedback regulation of GnRH secretion. *Frontiers in Neuroendocrinology*. 1 abril 2020. vol. 57, p. 100837.
[51]. HESLIN, J. et al., 2020. Age at puberty and pregnancy rate in beef heifer genotypes with contrasting nutritional intake from 8 to 13 months of age. *Animal Reproduction Science*. 1 janeiro 2020. vol. 212, p. 106221.
[52]. HOLLAND, Sarah C. et al., 2018. Comparison of luteolysis and timed artificial insemination pregnancy rates after administration of PGF2α in the muscle or the ischiorectal fossa in cattle. *Animal Reproduction Science*. 1 novembro 2018. vol. 198, p. 11–19.
[53]. HOUGHTON, P. L. et al., 1990. Effects of body composition, pre- and postpartum energy level and early weaning on reproductive performance of beef cows and preweaning calf gain. *Journal of Animal Science*. maio 1990. vol. 68, no. 5, p. 1438–1446.
[54]. KASIMANICKAM, R. K. et al., 2020. Cyclicity, estrus expression and pregnancy rates in beef heifers with different reproductive tract scores following progesterone supplementation. *Theriogenology*. 15 março 2020. vol. 145, p. 39–47.
[55]. KASIMANICKAM, Ramanathan K., KASIMANICKAM, Vanmathy R. e MCCANN, Madison L., 2021. Difference in Body Weight at Breeding Affects Reproductive Performance in Replacement Beef Heifers and Carries Consequences to Next Generation Heifers. *Animals*. outubro 2021. vol. 11, no. 10, p. 2800.
[56]. KNICKMEYER, E. R. et al., 2019. Evaluation of split-time artificial insemination following administration of a long or short-term progestin-based estrus synchronization protocol in beef heifers. *Theriogenology*. 15 julho 2019. vol. 133, p. 179–186.
[57]. KOIDE, Junji e TINGA, Benedito Isac, 2021. Viability of smallholder dairy cattle management and its intensification strategies based on whole-farm analyses in southern Mozambique. *Tropical Animal Health and Production*. 18 janeiro 2021. vol. 53, no. 1, p. 130.
[58]. KOWALIK, Magdalena K. et al., 2022. Effect of Steroid Hormones, Prostaglandins (E2 and F2α), Oxytocin, and Tumor Necrosis Factor Alpha on Membrane Progesterone (P4) Receptors Gene Expression in Bovine Myometrial Cells. *Animals*. janeiro 2022. vol. 12, no. 4, p. 519.
[59]. LEPEN, J.M, 1993. Influence of first calving age and nutrition on the performance of early mated Nguni heifers. *S.Afr.J.Anim.Sci*. 1993.
[60]. LESMEISTER, J. L., BURFENING, P. J. e BLACKWELL, R. L., 1973. Date of First Calving in Beef Cows and Subsequent Calf Production. *Journal of Animal Science*. 1 janeiro 1973. vol. 36, no. 1, p. 1–6.
[61]. LOPES, G. et al., 2013. Evaluation of reproductive and economic outcomes of dairy heifers inseminated at induced estrus or at fixed time after a 5-day or 7-day progesterone insert-based ovulation synchronization protocol. *Journal of Dairy Science*. 1 março 2013. vol. 96, no. 3, p. 1612–1622.
[62]. LUSBY, K. S., WETTEMANN, R. P. e TURMAN, E. J., 1981. Effects of Early Weaning Calves from First-Calf Heifers on Calf and Heifer Performance. *Journal of Animal Science*. 1 novembro 1981. vol. 53, no. 5, p. 1193–1197.
[63]. MACIEL, Sonia Maria Ataide et al., 2012. Factors influencing reproductive performance of cows from different Nguni ecotypes in southern Mozambique. *Tropical Animal Health and Production*. 1 março 2012. vol. 44, no. 3, p. 435–444.

[64]. MACIEL, Sónia Maria Ataíde et al., 2016. Factors influencing the reproduction and production performance of the Nguni cattle ecotypes in South Africa. *Tropical Animal Health and Production*. 1 janeiro 2016. vol. 48, no. 1, p. 75–85.

[65]. MADUREIRA, Guilherme et al., 2020. Progesterone-based timed AI protocols for Bos indicus cattle II: Reproductive outcomes of either EB or GnRH-type protocol, using or not GnRH at AI. *Theriogenology*. 15 março 2020. vol. 145, p. 86–93.

[66]. MAHDAVI-ROSHAN, H. et al., 2020. Size and number of corpora lutea and serum progesterone concentrations when administering two doses of eCG in an estrous synchronization treatment regimen for dairy cattle. *Animal Reproduction Science*. 1 novembro 2020. vol. 222, p. 106620.

[67]. MARQUES, Leticia Ribeiro, 2021. FATORES ASSOCIADOS À EFICIÊNCIA REPRODUTIVA DE VACAS LEITEIRAS COM O USO DE UM SISTEMA AUTOMATIZADO DE MONITORAMENTO DE ATIVIDADE. . 2021. P. 79–79.

[68]. MARTINS, T. et al., 2017. Impact of estradiol cypionate prior to TAI and progesterone supplementation at initial diestrus on ovarian and fertility responses in beef cows. *Theriogenology*. 1 dezembro 2017. vol. 104, p. 156–163.

[69]. MARTINS, T. et al., 2021a. Puberty attainment and reproductive performance of yearling Bos indicus-influenced heifers after two sequential treatments with progesterone. *Animal Reproduction Science*. 1 agosto 2021. vol. 231, p. 106803.

[70]. MASELLO, M. et al., 2019. Reproductive performance of replacement dairy heifers submitted to first service with programs that favor insemination at detected estrus, timed artificial insemination, or a combination of both. *Journal of Dairy Science*. 1 fevereiro 2019. vol. 102, no. 2, p. 1671–1681.

[71]. MISZURA, A. A. et al., 2021. Implications of growth rates and compensatory growth on puberty attainment in Nellore heifers. *Domestic Animal Endocrinology*. 1 janeiro 2021. vol. 74, p. 106526.

[72]. MUGWABANA, Thinawanga Joseph et al., 2018. The effect of assisted reproductive technologies on cow productivity under communal and emerging farming systems of South Africa. *Journal of Applied Animal Research*. 1 janeiro 2018. vol. 46, no. 1, p. 1090–1096.

[73]. PATTERSON, D. J., CORAH, L. R. e BRETHOUR, J. R., 1990. Response of prepubertal Bostaurus and Bosindicus × Bostaurus heifers to melengestrol acetate with or without gonadotropin-releasing hormone. *Theriogenology*. 1 março 1990. vol. 33, no. 3, p. 661–668.

[74]. PLESHKOV, Vladimir Aleksandrovich et al., 2022. Influence of Spermatozoid Qualitative Indicators on Cow Fertility when Applying Artificial Insemination and Oocyte Fertility under in Vitro Conditions. *Revista Electronica de Veterinaria*. 24 março 2022. P. 14–23.

[75]. POHLER, Ky Garrett et al., 2020. New approaches to diagnose and target reproductive failure in cattle. *Animal Reproduction*. 15 setembro 2020. vol. 17, no. 3, p. 57.

[76]. RODRIGUES, A. D. P. et al., 2014. Effect of interval from induction of puberty to initiation of a timed AI protocol on pregnancy rate in Nellore heifers. *Theriogenology*. 15 setembro 2014. vol. 82, no. 5, p. 760–766.

[77]. ŞAHIN, Özcan et al., 2022. Effect of inseminator on reproductive performance in dairy cattle. *Tropical Animal Health and Production*. 28 março 2022. vol. 54, no. 2, p. 146.

[78]. SALES, José Nélio de Sousa et al., 2019. Pre-TAI protocol strategies to increase reproductive efficiency in beef and dairy cows. *Animal Reproduction*. 2019. vol. 16, p. 402–410.

[79]. SAMKANGE, Alaster et al., 2019. Conception rates and calving intervals of different beef breeds at a farm in the semi-arid region of Namibia. *Tropical Animal Health and Production*. 1 setembro 2019. vol. 51, no. 7, p. 1829–1837.

[80]. SARTORI, R. e BARROS, C. M., 2011. Reproductive cycles in Bos indicus cattle. *Animal Reproduction Science*. 1 abril 2011. vol. 124, no. 3, p. 244–250.

[81]. SEMMELMANN, Cláudio Eduard Neves, LOBATO, José Fernando Piva e ROCHA, Marta Gomes da, 2001. Efeito de sistemas de alimentação no ganho de peso e desempenho reprodutivo de novilhas Nelore acasaladas aos 17/18 meses. *Revista Brasileira de Zootecnia*. junho 2001. vol. 30, no. 3, p. 835–843.

[82]. SILVA, Eduardo P. et al., 2018. Optimizing timed AI protocols for Angus beef heifers: Comparison of induction of synchronized ovulation with estradiol cypionate or GnRH. *Theriogenology*. 1 novembro 2018. vol. 121, p. 7–12.

[83]. SILVA, T. V. et al., 2015. Synchronized ovulation for first insemination improves reproductive performance and reduces cost per pregnancy in dairy heifers. *Journal of Dairy Science*. 1 novembro 2015. vol. 98, no. 11, p. 7810–7822.

[84]. SOLANO, J. et al., 2000. Sexual behavior of Zebu cattle (Bos indicus) following estrous induction by Syncro-Mate B, with or without estrogen injection. *Physiology & Behavior*. 1 dezembro 2000. vol. 71, no. 5, p. 503–508.

[85]. THIBIER, M e WAGNER, H. -G, 2002. World statistics for artificial insemination in cattle. *Livestock Production Science*. 1 março 2002. vol. 74, no. 2, p. 203–212.

[86]. TSCHOPP, Juan Carlos et al., 2022. Effect of the addition of GnRH and a second prostaglandin F2α treatment on pregnancy per artificial insemination in lactating dairy cows submitted to an estradiol/progesterone-based timed-AI protocol. *Theriogenology*. 1 agosto 2022. vol. 188, p. 63–70.

[87]. TSUTSUMI, Rie e WEBSTER, Nicholas J. G., 2009. GnRH pulsatility, the pituitary response and reproductive dysfunction. *Endocrine Journal*. 2009. vol. 56, no. 6, p. 729–737.

[88]. VISHWANATH, R, 2003. Artificial insemination: the state of the art. *Theriogenology*. 15 janeiro 2003. vol. 59, no. 2, p. 571–584.