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IMPORTANCE OF FACTORS IN THE PROCESS OF STIMULATING AND MAINTAINING LACTATION IN SEASONAL SHEEP*

Edyta Molik, Michał Błasiak, Karolina Nahajło

Uniwersytet Rolniczy, Katedra Biotechnologii Zwierząt, Rędzina 1B, 30-248 Kraków

Seasonality in sheep is a characteristic encompassing not only breeding itself, but also lactation. One of the main hormones conditioning both initiation and maintenance of lactation is prolactin. In livestock, changes in photoperiod length play a very important role as they determine yield and productivity. Light-day length is of particular importance in short-day animals (such as sheep), where photoperiod length is associated with changes in the level of melatonin. The modulating effect of melatonin on prolactin secretion takes place via two different mechanisms. The first mechanism is linked to the circadian rhythm, when melatonin stimulates release of prolactin through a factor conventionally known as tuberalin. However, this effect is short-lived and most likely applies only to prolactin stored in the lactotropic cells of the pituitary gland. The second mechanism regulating secretion of prolactin is associated with the annual rhythms of secretion, wherein melatonin directly affects the secretion of prolactin. Under natural conditions, the maximum concentration of prolactin in sheep occurs during the long-day period, during which time the level of melatonin decreases. The lowest prolactin concentration is observed over the short-day period, when in turn the melatonin level is at its highest. Changes in secretion of prolactin during lactation in sheep undoubtedly affect milk yield. In sheep, a very close relationship is observed between length of day, prolactin secretion, and milk yield and biological activity of milk.

Key words: seasonality, sheep, prolactin, melatonin, lactation

Role of melatonin and the biological clock in sheep

Basic physiological processes aimed at transfer of genetic information to the offspring are, in many species, dependent on the seasons and natural rhythms associated with them. The signal informing animals (horses, sheep, roe deer, hamsters, gophers) about the upcoming reproductive season are changes in light-day length – information about such changes reaches the organism through a multi-neural path transforming the light stimulus into a biochemical signal in the form of melatonin. Seasonality of the

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reproductive cycle in sheep is related to season of the year and photoperiod length as the recurring reproductive cycle is an endogenous rhythm encoded genetically (Morgan, 2000). Activation of the retinohypothalamic tract and the process of melatonin synthesis it involves is a complex phenomenon. Melatonin exhibits biological activity by acting indirectly through calmodulin in cell cytoplasm or directly by affecting the cell nucleus (Wójtowicz and Jakiel, 2002). In pharmacological terms, its receptors are referred to as MT_1, MT_2 and MT_3. The first two are members of the G protein-coupled receptor family, and the third is coupled with chionic quinone reductase 2 (QR2) reductase. In addition to the pineal gland, melatonin synthesis occurs in the retina of the eye, Harder's gland, skin and digestive tract. Melatonin of intestinal origin is not controlled by the biological clock mechanism, as opposed to the pineal and retinal melatonin, and its role remains unexplained. Studies in sheep have shown that concentration of melatonin in cerebral spinal fluid in the area of the third ventricle is the highest and exceeds several times over the concentration of this hormone found in peripheral blood (Stirland et al., 2001). The presence of melatonin receptors has been confirmed in the central nervous system (CNS) and in particular in the cerebral cortex, retina, hippocampus, pars tuberalis of the pituitary and SCN (suprachiasmatic nuclei). Melatonin binding sites have also been identified in the lamina muscularis of blood vessels, in the reproductive system and the heart. MT_1 melatonin receptors are also present in large quantities in PT (pars tuberalis), hence melatonin may affect secretion of hormones of the anterior pituitary gland (Morgan, 2000; Johnston, 2004). Biosynthesis and secretion of melatonin, also known as the "hormone of darkness", depend on light conditions and are linked to the circadian rhythm associated with the endogenous biological clock. Melatonin concentration increases significantly at night, regardless of lifestyle of the given animal (diurnal-nocturnal, diurnal or nocturnal). Different vertebrate species demonstrate different rhythmic changes in melatonin concentration in the body over 24 hrs, referred to as A, B and C profiles (Reiter, 1991). Profile A, observed in mice and hamsters, is characterized by an increase in melatonin levels in the blood in the second half of the dark phase. Profile B (hens, squirrels, rats, humans) demonstrates maximum melatonin concentration between 2 and 3 am with a subsequent slow and steady decrease until dawn. Profile C (sheep, domestic cat) shows a rapid increase in melatonin concentration just after dusk, with high concentration of the hormone throughout the entire dark phase. Signal processing in the area of suprachiasmatic nuclei and PT occurs at the molecular level. Interdependent biological clock genes (*Clock*, *Per1*, *Per2*, *Cry1*, *Cry2*, *Rev-erbα* and *CK1ε*; Hazlerigg et al., 2004) are present in the PT area and in the SCN. Circadian rhythmic changes in the amount of mRNA of the above genes were observed both in SCN and in PT, which was related to changes in melatonin concentration. Both the increase in melatonin concentration as well as *Cry1* gene expression occurred at the beginning of the dark phase, while *Per1* expression took place before dawn (Lincoln et al., 2003). It was also shown that *Cry1* gene expression occurs under the influence of melatonin, whereas expression of *Cry2* takes place without participation of this hormone (Dardente, 2007). In animals subjected to pinealectomy, *Per1* gene was not expressed in PT; however, the procedure did not block the expression of this gene in the SCN. Administration of exogenous melatonin to individuals after pineal gland removal induced expression of *Per1* in PT.

In genetically modified mice unable to produce melatonin and in individuals where the gene for the MT_1 receptor had been blocked, no expression of the *Per1* gene in PT was noted. The results of these studies indicate that *Per1* expression is dependent on melatonin. The results of research focused on biological clock genes in the SCN in mammals showed that the BMAL1/CLOCK protein complex encoded by the *Bmal1*, *Clock* genes causes activation of the *Per1*, *Per2*, *Cry1*, *Cry2*, *Rev-erbα* genes (Kavakli and Sancer, 2002). The *RevErbα* gene encodes a protein inhibiting transcription of the *Bmal1* gene. As a result of transcription and translation of the *Per* and *Cry* genes, a large PER/CRY protein complex is formed. This complex is translocated to the cell nucleus, where it functions as a factor regulating transcription of other biological clock genes. Several kinases work together to phosphorylate molecular clock components. Phosphorylation has different effects on the circadian period. These effects are dependent on the kinase involved, the time of day and the proteins being phosphorylated. Phosphorylation modulates the period of circadian rhythms by controlling the start, duration, and termination of both the activating and also by repressing phases of the molecular clock mechanism (Sahar et al., 2010). For example, casein kinase 1 epsilon (CK1ε) is a member of the serine/threonine family of protein kinases, known to phosphorylate a broad range of substrates (Klimowski et al., 2006). Nuclear CK1ε increases BMAL1 phosphorylation, which in turn enhances CLOCK:BMAL1-mediated transcription *in vitro*. Phosphorylation of BMAL1 by CK1ε is not dependent on the presence of the PER protein. It is suggesting that CK1ε phosphorylates BMAL1 at a time when the inhibitory complex is not bound to the CLOCK:BMAL1 heterodimer (Eide et al., 2002). The heterodimeric PER/CRY protein inhibits transcription of genes such as *RevErbα*, *Per* and *Cry*, which are also subjected to regulation by the BMAL1/CLOCK protein complex (Lincoln et al., 2003). Inhibitory activity of the *RevErbα* gene on the *Bmal1* gene is relieved thanks to the PER/CRY complex. Expression of the *Per1*, *Cry1* and *RevErbα* genes as a result of exposure to light stimulus was studied in the Soay sheep. One group of animals was exposed to sudden light (simulation of long-day conditions), while the second group was steadily acclimatized to this stimulus. In both groups of animals, *Perl* expression increased in daytime while *Cry1* expression grew during the night. Therefore, the influence of melatonin sets off the mechanism of fast regulation of *Per1* and *Cry1* gene expression. In contrast, in animals undergoing acclimatization to the light stimulus, *RevErbα* expression occurred gradually in response to long-day conditions and took place later than in the not-acclimated group (Hazlerigg et al., 2004; Dardente, 2007). Moreover, the effects of melatonin with a focus on BMP-4 activity in the regulation of PRL secretion by pituitary lactotrope cells was investigated. The increase in melatonin at night plays a key role as a biological clock, which also affects the immune system, activates secretion of various hormones, growth factors and antioxidants. The results of Ogura-Ochi et al. (2017) suggested that melatonin acts as a functional modulator for the pituitary BMP system that can induce PRL secretion.

Role of melatonin and prolactin in sheep lactation

Lactation is the last stage of the reproductive cycle. Secretory function of the mammary gland is important in the process of rearing the young, and is dependent on proper functioning of multiple physiological processes, especially those involving the endocrine system. Lactation consists of mammogenesis, lactogenesis, galactopoiesis and involution (drying off). A delicate balance of factors must be reached to ensure a healthy course of lactation. The main hormone responsible for processes related to lactation is prolactin, a hormone of the somatomammotropin group. The primary source of PRL in the body are lactotropic cells present in the pars anterior (adenohypophysis) of the pituitary gland. While prolactin synthesis occurs mainly in these lactotropic cells in the anterior pituitary, the presence of both PRL and PRL receptors has also been confirmed in the posterior pituitary (neurohypophysis) and in the mammary gland (Gregory et al., 2007). The main structure controlling the secretion of PRL is the hypothalamus. Various types of lactotropes are present in the anterior pituitary. The process of differentiation of said cells into particular types is not fully understood, and is probably associated with different maturity stages of lactotropic cells. It is likely that the future function of PRL is determined by the type of lactotropes involved in its production (3 such types exist; Stojilkovic et al., 2010). Changes in prolactin concentration depend on light conditions and the melatonin profile. A long melatonin signal, typical for short-day animals, inhibits secretion of PRL in the pituitary gland. Administration of exogenous melatonin to rams and ewes via implants during the long-day period inhibits secretion of PRL. During short days, or under the influence of exogenous melatonin, a decrease in both dopaminergic system activity and prolactin concentration was observed (Ciechanowska et al., 2013). Changes in melatonin and prolactin profiles in sheep are interlinked. In sheep, the short-day period causes an increase in MLT secretion and a decrease in PRL concentration, which indirectly inhibits lactation (Molik et al., 2012). Regulation of PRL secretion by melatonin most likely takes place via two mechanisms. In the case of the circadian rhythm, melatonin might either directly influence PRL secretion – which applies to the hormone stored in the lactotropes – or the process might occur through the tuberalin peptide, which activates PRL gene expression in the anterior pituitary lactotropes (Johnston, 2004). On the other hand, the annual rhythm of PRL secretion is directly induced by melatonin, affecting lactotropic cells due to its lipophilicity (Morgan, 2000). Melatonin has no direct effect on PRL gene expression in lactotropes, which in connection with the large number of melatonin receptors present in the pars tuberalis points to melatonin regulating PRL release through a specific factor. It was confirmed that PT cells synthesize a peptide called tuberalin, which stimulates secretory activity of lactotropic cells (Johnston, 2004). In the spring, increases in PRL concentration are observed at dawn and before dusk. In the summer, the maximum concentration is noted in the middle of the dark phase, while the autumnal profile of PRL is characterized by an increase in concentration in the first half of the light phase and at the end of it.

Productivity of livestock is strongly related to photoperiod length. It has been experimentally shown that lactogenesis and galactopoiesis are controlled by changes in light conditions contributing to modulation of melatonin and prolactin secretion, which translates into an increase or decrease in milk yield (Molik et al., 2007). Short-day animals give birth in the winter, and the rearing of offspring falls over the period of lengthening-day conditions, when environmental factors stimulate the milk production process (Dahl and Tuckert, 2000). Research conducted on Polish long-haired sheep, on animals that lambed in June and were subjected to artificial long-day conditions (16L:8D) until mid-November showed that milk yield in these individuals was higher (26%) than in ewes remaining in natural day-length conditions. Although the artificial photoperiod contributed to prolongation of lactation and increase in milk yield, it did not stop the decline in milk production and drying off in November (shortening-day period). Studies carried out on dairy sheep showed that milk yield of sheep entering the lactation phase in the day-lengthening season is definitely (50%) higher than that of animals starting milk synthesis under short-day conditions. The response to the shortening photoperiod was an increase in melatonin concentration, a decrease in PRL concentration and a decrease in milk yield (Molik et al., 2007).

Role of growth hormones and thyroid hormones in sheep lactation

Milk production is determined by a balance of many stimuli – photoperiod length and changes in the PRL profile being just two of them. An important role is also played by the somatotropic system (GH – Growth Hormone, IGF1 – Insulin-Like Growth Factor 1), thyroid hormones and many other substances. The process of maintaining lactation requires participation of a large number of hormones such as PRL, GH, estrogens, progesterone, glucocorticoids, oxytocin, PL (placental lactogen) and insulin-like growth factors (somatomedins, such as IGF1). Somatomedins belong to the group of metabolic hormones coordinating the body's response to stressors and metabolic changes (Bonnet et al., 2002). Increase in GH concentration is stimulated by the young suckling, as heightened growth hormone concentration is observed at the beginning of lactation. Studies in sheep have shown that changes in both GH and PRL concentrations depend on length of day and are related to changes in the pineal melatonin profile (Gomez-Brunet, 2008). Research has shown that somatomedins stimulate growth of mammary epithelial cells both *in vitro* and *in vivo*. Detection of the presence of growth factors such as EGF and IGF in milk suggests that they are synthesized and transported by mammary epithelial cells. Research results point to a significant role of somatomedins in the regulation of mammary gland growth and morphogenesis (Imagawa et al., 1994). Interaction of IGF and GH is necessary in the processes of coordination of epithelial cell differentiation and proliferation. IGF has been also shown to act as a mediator in relation to growth hormone during mammogenesis in rodents (Plath-Gabler et al., 2001). In addition, *in vitro* studies have demonstrated the stimulatory effect of insulin on maintaining normal histological structure and functioning of the mammary gland. Insulin is necessary for indirect action of GH on mammary gland cells as it activates IGF1 receptors (Imagawa et al., 1994). In subsequent experiments it was confirmed that IGF both acts as a stimulator of lactic epithelial cells *in vitro* as well as stimulates synthesis and secretion of IGF binding proteins (IGFBPs) in mice and sheep (McGrath et al., 1991). In sheep mammary gland tissue, IGF1, IGF2 and IGFPs mRNA was detected, which is at least partial evidence that the mammary gland is the source of all these compounds. The role of IGF in particular phases of functioning of the mammary gland is, especially in ruminants, complicated. It is known that during lactation the levels of GH and PRL in the blood increase as a result of suckling stimulus (Misztal et al., 2008). Heightened GH secretion during lactation remains under the control of GHRH and endogenous opioids (McMahon et al., 2001). In recent years the focus of attention of the scientific community was salsolinol, a dopamine derivative. It has been shown that concentration of this substance increases in the case of various dysfunctions of the dopaminergic system (Antkiewicz-Michaluk, 2002). Salsolinol stimulates the release of PRL in rodents (Toth et al., 2002) and in ruminants (Hashizume et al., 2009). In lactating ewes, the presence of salsolinol in the MBH was confirmed, and increase in its concentration in response to sucking by the young was observed (Misztal et al., 2010). Administration of salsolinol to the third brain ventricle during lactation increases PRL concentration. The antagonist of salsolinol is a compound named 1-MeDIQ (Mravec et al., 2004). This substance inhibits PRL release and neutralizes the stimulating effect of suckling on PRL secretion in rats (Bodnár et al., 2004). A similar effect was observed in sheep in whom 1-MeDIQ acts directly on the CNS. 1-MeDIQ inhibits the increase in concentration of noradrenaline (NA), which is a mediator between salsolinol and GH (Mravec et al., 2004). Interestingly, 1-MeDIQ does not affect changes in GH concentration resulting from mammary gland stimulation in the form of suckling by the offspring. In sheep, both during the lamb rearing season and outside it, PRL concentration decreases after administration of 1-MeDIQ to animals (Misztal et al., 2010). It has been experimentally shown that salsolinol has no direct effect on the GH profile during lamb rearing. In contrast, rats given simultaneously salsolinol and 1-MeDIQ showed no statistically significant changes in the levels of pituitary hormones, with the exception of prolactin (Radnai et al., 2005). An important role in the processes of initiation and maintenance of lactation in small ruminants is played by thyroid hormones, which until recently were considered to function only as metabolic hormones. Thyroid hormone production is mainly controlled by negative feedback regulation of the HPT (hypothalamic – pituitary – thyroid) axis. Thyroliberin (TRH) produced in the hypothalamus penetrates into the pituitary gland and stimulates secretion of thyroid-stimulating hormone (TSH) in the anterior pituitary gland. Under the influence of TSH, thyroid produces T4 (thyroxine) and T3 (triiodothyronine – a prohormone for T4). T4 and T3 are substances involved in regulating the body energy management and biosynthesis of milk (Toidini, 2007). The level of thyroid hormones in sheep changes depending on the stage of lactation. At the beginning of the process, concentration of these substances is low; however, over time, thyroxine level increases. Thyroid hormones, especially T3, exert a suppressive effect on PRL gene expression, which may impact milk yield. In ewes exposed to high temperature, concentration of T3 and T4 as well as milk yield all decreased. It has been experimentally shown that in sheep the secretion of thyroid hormones is related to length of day. *In vitro* studies of thyroid explants showed higher thyroxine concentration in short-day conditions and lower in the lengthening-day season (spring), while for T3 higher levels were observed in the summer, and lower in the short photoperiod season. In addition, an increase in T3 concentration under the influence of exogenous melatonin was noted (Klocek-Górka et al., 2010). Productivity of livestock (milk production, growth and development, hair growth) is largely dependent on the proper balance of thyroid hormones (Reinert and Wilson, 1996). T3 (3-5-3 triiodothyronine) is considered to be the most biologically active thyroid hormone (Toidini, 2007).

In ewes thyroxine reaches its peak level at the beginning of pregnancy, which decreases just before delivery and after lambing. Animal productivity depends not only on the level of nutrition, environmental factors and genetic potential – thyroid hormones are a key link in the most crucial stages of life (reproduction, lactation) (Tucker, 2000).

Conclusions

Seasonality of the reproductive cycle in sheep is related to season of the year and photoperiod length as the recurring reproductive cycle is an endogenous rhythm encoded genetically. Productivity of livestock is strongly related to photoperiod length. It has been experimentally shown that lactogenesis and galactopoiesis are controlled by changes in light conditions contributing to modulation of melatonin and prolactin secretion, which translates into an increase or decrease in milk yield. Milk production is determined by a balance of many stimuli – photoperiod length and changes in the PRL profile being just two of them. An important role is also played by the somatotropic system, thyroid hormones and many other substances. Studies in sheep have shown that changes in both GH and PRL concentrations depend on length of day and are related to changes in the pineal melatonin profile. Animal productivity depends not only on the level of nutrition, environmental factors and genetic potential – thyroid hormones are a key link in the most crucial stages of life.

References

Antkiewicz-Michaluk M. (2002). Endogenous risk factors in Parkinson's disease: dopamine and tetrahydroisoquinolines. Pol. J. Phar., 54: 567–572.

Bodnár I., Mravec B., Kubovackova L., Toth E.B., Fulop F., Fekete M.I.K. (2004). Stress as well as suckling-induced prolactin (PRL) response is blocked by a structural analogue of the putative hypophyseotrophic PRL-releasing factor, salsolinol (SAL). J. Neur., 16: 208–213.

Bonnet M., Delavaud C., Laud K., Gourdou I., Leroux C., Dijane J., Chilliard Y. (2002). Mammary leptin synthesis, milk leptin and their putative physiological roles. Repr. Nut. Dev., 42: 399–413.

Ciechanowska M., Misztal T., Przekop F. (2013). Prolactin and the physiological regulation of its secretion. A review. J. Anim. Feed. Sci., 22: 79–89.

Dahl G.E., Tuckert B.A.H.A. (2000). Photoperiodic effects on dairy cattle: A review. J. Dairy Sci., 83: 885–893.

Dardente H. (2007). Does a melatonin-dependent circadian oscillator in the pars tuberalis drive prolactin seasonal rhythmicity? J. Neuroendocrinol., 19: 657–666.

Eide E.J., Vielhaber E.L., Hinz W.A., Virshup D.M. (2002). The circadian regulatory proteins BMAL1 and cryptochromes are substrates of casein kinase Iepsilon. J. Biol. Chem., 277: 17248–17254.

Gomez-Brunet A. (2008). Endogenous circannual cycles of ovarian activity and changes in prolactin and melatonin secretion in wild and domestic female sheep maintained under a long-day photoperiod. Biol. Repr., 78: 552–562.

Gregory S.J., Brooks J., McNeilly A.S., Ingleton P.M., Tortonese D.J. (2007). Gonadotroph-lactotroph associations and expression of prolactin receptors in the equine pituitary gland throughout the seasonal reproductive cycle. J. Reprod. Fertil., 119: 223–231.

Hashizume T., Onodera Y., Shilda R., Isobe E., Suzuki S., Sawai K., Kasuya E., Nagy G. M. (2009). Characteristics of prolactin-releasing response to salsolinol (SAS) and thyrotropin-releasing hormone (TRH) in ruminants. Dom. Anim. Endoc., 36: 99–104.

Hazlerigg D.G., Andersson H., Johnston J.D., Lincoln G. (2004). Molecular characterization of the long-day response in the Soay sheep, a seasonal mammal. Current. Biol., 14: 334–339.

Imagawa W., Yang J., Guzman R., Nandi S. (1994). Control of the mammary gland development. Phys. Repr., 51: 1033–1063.

Johnston J.D. (2004). Photoperiodic regulation of prolactin secretion: changes in intra-pituitary signaling and lactotroph heterogeneity. J. Endocrinol., 180: 351–356.

Kavakli J.H., Sancer A. (2002). Circadian photoreception in humans and mice. Molec. Interventions, 2: 484–492.

Klimowski L.K., Garcia B.A., Shabanowitz J., Hunt D.F., Virshup D.M. (2006). Site-specific casein kinase 1epsilon-dependent phosphorylation of Dishevelled modulates beta-catenin signaling. FEBS J., 273: 4594–4602.

Klocek-Górka B., Szczęsna M., Molik E., Zięba D. (2010). The interaction of season, leptin, and melatonin levels with thyroid hormone secretion, using *in vitro* approach. Small Rum. Res., 2: 231–235.

Lincoln G.A., Andersson H., Hazlerigg D. (2003). Clock genes and the long-term regulation of prolactin secretion: evidence for a photoperiod/circannual timer in the pars tuberalis. J. Neuroendocrinol., 15: 390–397.

McGrath M., Collier R., Clemmons D., Busby W., Sweeney C., Krivi G. (1991). The direct *in vitro* effect of insulin like growth factor (IGFs) on normal bovine mammary cell proliferation and production of IGF binding proteins. J. Endocrinol., 129: 671–678.

McMahon C.D., Radcliff R.P., Lookingland K.J., Tucker H.A. (2001). Neuroregulation of growth hormone secretion in domestic animals. Dom. Anim. Endoc., 20: 65–87.

Misztal T., Górski K., Tomaszewska-Zaremba D., Molik E., Romanowicz K. (2008). Identification of salsolinol in the mediobasal hypothalamus of lactating ewes and its relation to suckling-induced prolactin and GH release. J. Endocrinol., 198: 83–89.

Misztal T., Górski K., Tomaszewska-Zaremba D., Fulop F., Romanowicz K. (2010). Effects of structural analogue of salsolinol, 1-MeDIQ, on pituitary prolactin release and dopaminergic activity in the mediobasal hypopthalamus in nursing sheep. Brain Res., 1307: 72–77.

Molik E., Misztal T., Romanowicz K., Wierzchoś E. (2007). Dependence of the lactation duration and efficiency on the season of lambing in relation to the prolactin and melatonin secretion in ewes. Livestock Sci., 107: 220–226.

Molik E., Misztal T., Zięba D. (2013). The effect of physiological and environmental factors on the prolactin profile in seasonally breeding animals. In: György M. Nagy (ed.), Prolactin, Intech-Open., 7: 121–138.

Morgan P.J. (2000). The pars tuberalis: The missing link in the photoperiodic regulation of prolactin secretion. J. Neuroendocrinol., 12: 287–295.

Mravec B., Bodnar I., Fekete M.I., Nangy G.M., Kevetnansky R. (2004). Salsolinol, an antagonist of prolactoliberine, induces an increase in plasma catecholamine levels in the rat. Aut. Neur., 115: 35–40.

Ogura-Ochi K., Fujisawa S., Iwata N., Komathubara M., Nishiyama Y., Tsukamoto-Yamauchi N., Inagaki K., Wada J., Otsuka F. (2017). Regulatory role of melatonin and BMP-4 in prolactin production by rat pituitary lactotrope GH3 cells. Peptides, 94: 19–24.

Plath-Gabler A., Gabler C., Sinovatz F., Berisha B., Schams D. (2001). The expression of the IGF family and GH receptors in the bovine mammary gland. J. Endocrinol., 169: 38–48.

Radnai B., Kandar Z., Somogyvari-Vigh A., Mergel Z., Olah M., Fulop F., Vecsernyes M., Nagy G.M. (2005). Salsolinol induces a decrease in cyclic AMP at the median eminence and an increase at the adenohypophysis in lactating rats. Brain Res. Bull., 65: 105–110.

Reinert B.D., Wilson E.E. (1996). The thyroid and the hypothalamus-pituitary-ovarian axis in American tree sparrows (*Spizella arborea*). Gen. Comp. Endocr., 103: 60–70.

Reiter R.J. (1991). Pineal melatonin: cell biology of its synthesis and of its physiological interactions. Endocr. Rev., 12: 151–180.

Sahar S., Zocchi L., Kinoshita C., Borrelli E., Sassone-Corsi P. (2010). Regulation of BMAL1 protein stability and circadian function by GSK3beta-mediated phosphorylation. PLoS One., 5:e8561.

Stirland J.A., Johnston J.D., Cagampang F.R.A., Morgan P.J., Castro M.G., White M.R., Davis J.R.E., Loudon A.S.I. (2001). Photoperiodic regulation of prolactin gene expression in the Syrian hamster by a pars tuberalis-derived factor. J. Neuroendocrinol., 13: 147–157.

Stojilkovic S.S., Tabak J., Bertram R. (2010). Ion channels and signaling in the pituitary gland. Endocr. Rev., 31: 845–915.

Toidini L. (2007). Thyroid hormones in small ruminants: effects of endogenous, environmental and nutritional factors. Animal, 1: 997–1008.

Toth B.E., Bodnar I., Homicsko G.K., Fulop F., Fekete M.I., Nagy G.M. (2002). Physiological role of salsolinol: its hypophysiotrophic function in the regulation of pituitary prolactin secretion. Neuro. Terat., 24: 655–656.

Tucker H.A. (2000). Hormones, mammary growth, and lactation: a 41-year perspective. J. Dairy. Sci., 83: 874–884.

Wójtowicz M., Jakiel G. (2002). Melatonin and its role in the reproductive process. Gin. Pol., 12: 1231–1237.

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EDYTA MOLIK, MICHAŁ BŁASIAK, KAROLINA NAHAJŁO

STRESZCZENIE

Sezonowość u owiec jest cechą determinującą nie tylko aspekty hodowli, ale także dotyczy laktacji. Jednym z głównych hormonów odpowiedzialnych za zapoczątkowanie i utrzymanie laktacji jest prolaktyna. U zwierząt gospodarskich zmiana długości dnia wpływa na ich produkcyjność. U zwierząt dnia krótkiego (takich jak owce) długość dnia wiąże się ze zmianami sekrecji melatoniny. Modulujące oddziaływanie melatoniny na sekrecję prolaktyny odbywa się za pomoc dwóch mechanizmów. Pierwszy mechanizm jest powiązany z rytmem dobowym, wówczas melatonina hamuje uwalnianie prolaktyny przez czynnik umownie nazywany tuberaliną. Jednak efekt ten jest krótkotrwały i najprawdopodobniej dotyczy tylko prolaktyny zamagazynowanej w komórkach laktotropowych przysadki mózgowej. Drugi mechanizm regulujący wydzielanie prolaktyny związany jest z rocznym rytmem sekrecji, w którym melatonina bezpośrednio wpływa na wydzielanie prolaktyny. W warunkach naturalnych maksymalne stężenie prolaktyny u owiec występuje w okresie dnia długiego, wówczas sekrecja melatoniny ulega obniżeniu. Natomiast najniższe stężenie prolaktyny obserwuje się w warunkach dnia krótkiego, kiedy z kolei stężenie melatoniny jest najwyższe. Zmiany w sekrecji prolaktyny w trakcie laktacji u owiec niewątpliwie wpływają na wydajność mleka. U owiec długość dnia istotnie wpływa na sekrecje prolaktyny, wydajność mleka i jego aktywność biologiczną.

Słowa kluczowe: sezonowość, owce, prolaktyna, melatonina, laktacja