Chapter

Chemical Signaling in Bovines: Understanding the Behavior and Way of Communication

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Abstract

Chemical signals that mediate communication within animals of a species have been referred to as 'pheromone' a Greek word comprised of 'pheran' (means to transfer) and 'hormon' (to excite). These chemical messengers are transported outside the body and have a direct developmental effect on hormone levels and behavior, and therefore, have a potential role in modulating animal behavior and reproductive management. The sources of these chemical messengers are urine, vaginal secretions, feces, saliva, milk, sweat, breath and specialized cutaneous glands including the odor produced from hair and wool. After their release, are perceived through the olfactory system, eliciting both behavioral and endocrine responses characterized by profound effects on reproductive activity via the hypothalamic system that generates pulses of gonadotropin-releasing hormone. Their potential to transform the animal behavior and reproduction management has led to development and use of synthetic pheromones to manipulate estrous cycle, enhance estrous behavior, determination of time of estrus, and also facilitating collection of semen. Pheromones can act as a marker to detect estrus, diagnosing early pregnancy in farm animals and used for improving sexual desire. There is huge scope of application of pheromones once chemically synthesized and characterized, and would be of great interest to livestock owners and consumers. This chapter will discuss in detail the role of chemical signaling in shaping the behavior, reproduction and understanding the ways of communication in bovines.

Keywords: chemical signaling, pheromone, animal behavior and reproduction

1. Introduction

Lot of commonalities in chemical signaling have been observed between vertebrates (mammals) and invertebrates (insects), phylogenetically two distant taxa sharing common ancestors 550 million years back. Despite the fact, different taxa among vertebrates and invertebrates comprise of thousands of species, this commonality has been maintained, mainly due to selective constraints imposed by a terrestrial lifestyle that resulted in dominance of fewer animal phyla in terrestrial habitats. The dominance of Mammaliaformes has been attributed to nocturnal lifestyle that reduces the risk of getting predated from dominant archosaurs [1]. Similar trend has been seen in night active insects that were observed to be having larger body sizes than day active insects sharing the same communities [2]. The nocturnal behavior may have resulted in decreased reliance on visual signals, and full reliance on chemical signals mediated by various mechanisms such as acquisition of hairs in mammals and insects that helped in dispersing chemical signals such as, tail hair tufts in Asian elephants [3], and hair pencils in male noctuid moths [4]. Also certain behavioral aspects are common in mammals and insects that are mediated by chemical signals, such as territory marking, or living in families, and recognition of individuals or group members [5]. Similarities have also been observed in signal processing pathways mediated by chemosensory proteins, olfaction and gustation that have evolved independently. In both the groups membranes of chemosensory cells are modified to increase surface area positioned in proximity to a number of accessory cells and these cells are bathed in liquid through which odorants travel to reach receptors [6]. Also neurons of booth the groups express same protein, synapsing in the same glomerulus, and olfactory cells project directly to the brain. However, olfactory receptor gene families and regulatory process of protein expression by neurons differ between mammals and insects [7]. Despite the organizational similarity in mammals and insects, differences have been observed in olfactory receptors and gustatory receptor proteins. In terms of taste, similarities have been observed in the organization of gustatory systems, recognizing nutritionally important dietary constituents such as bitter, carbon dioxide, water and sweet in insects, and bitter, salty, sour, sweet and umami in mammals [8]. In both mammals and insects chemicals involved in communication are secondary metabolites, derived from primary metabolic processes that show tremendous structural diversity due to differences in selective forces arising from different ecologies. Chemical signals involve primary metabolites such as amino acids, nucleotide bases, sugars, fatty acids and glycerol as starting materials that are utilized to produce secondary metabolites having conservative elemental composition mostly composed of carbon, oxygen, hydrogen, and nitrogen [9]. Chemical signals in terrestrial and aquatic environments differ significantly, and this structural variation has been attributed to the medium through which chemical signals travel. Diffusion in air is a function of molecular weight, that means lighter weight compounds will diffuse faster, such as most insect sex pheromones (MW 200–300) [10]. In contrast, diffusion of chemical signals in aqueous environment depends on water solubility (independent on molecular weight), conducive for signal transmission of biologically important large polar molecules such as proteins [10].

The term Pheromone was coined by karlson and Luscher in 1959 and the name of first pheromone extracted from Honey Bee was proposed as *Bombykal* [11]. Pheromone is a biologically active substance like hormone, a chemical substance secreted externally in urine, feces, or by sub-cutaneous glands or other biological secretions that cause specific reaction in a receiving animal. Exteroceptive cues playing a role in male and female interaction include olfactory, visual, auditory and tactic stimuli, that trigger a specific behavior or physiological change in recipient's endocrine or reproductive system [12]. Extensive studies in insects, rodents, swine, sheep, goats and cattle have established the strong influence exerted by the pheromones secreted by the male on reproductive activity in the female. It has been demonstrated that the urine of male mice, rats, feral species and other wild rodents contains a priming pheromone that is responsible for hastening puberty in the females. Pheromones in the wool, wax and urine of a ram are sufficient to stimulate ewes to ovulate, while the buck has a strong characteristic seasonal odor. The mere presence of the boar at the time of insemination of the sow improves sperm transport and ovulation, while the presence of the vasectomized bull has been reported to hasten the onset of puberty in heifers and also early resumption of ovarian activity in cattle following parturition [13].

2. Understanding pheromones and chemical signaling in bovines

2.1 Types of pheromones

On the basis of chemical structure, nature of molecules, mechanism of action, interactions and functions pheromones can be classified into various types, as described below:

2.1.1 Releaser pheromones

This type of pheromone elicit an immediate short term behavioral response (degraded quickly) either acting as attractant or repellent [14]. It has been observed that some organisms use powerful attractant molecules to get the attention of their mates as far as two miles or even more. These type of pheromones have been observed to stimulate immobilization reflex in sow, that is caused by the sex pheromones (released in the saliva) synthesized in the testes of boar, chemically identified as the steroids, 5α-androst-16-en-3-one and 5α-androst-16-en-3α-ol [13].

2.1.2 Primer pheromones

These pheromones mediate slow developing and longer-lasting changes to the endocrine state or development through activating the hypothalamic–pituitary–adrenal axis [13]. Priming pheromone resulted early puberty in prepubertal heifers receiving weekly oronasal treatments (7-week experimental period) with bull urine as against water-treated heifers [15]. Similarly, priming pheromones from males have been observed influencing induction of puberty, shortening of postpartum anestrus and the termination of seasonal anestrus in case of mammals, more pronounced effect observed in case of small ruminants [16]. Similar effect has been observed in case of gilts exposed to a mature boar, resulting in early onset of puberty and synchronizing effect on first oestrus [17].

2.1.3 Signal pheromones

These pheromones inform about individual or group identity crucial for parent-offspring recognition and mate choice. These pheromones cause short-term responses mediated by the central nervous system through neurotransmitter release, such as, gonado tropic releasing hormone (GnRH) in rats elicit a lordosis behavior. Teaser bulls exhibit flehmen behavior upon receiving the estrus specific chemical signal from females [13].

2.1.4 Major urinary proteins (MUPs) and odorant binding protein (OBPs)

First described in mouse and rat, MUPs and α2u proteins are lipocalins synthesized in the liver and excreted in the urine, and have got similarity with OBPs discovered in the nasal tissues of several vertebrates.

The MUPs have several important roles such as, transporting the pheromone in biological fluids, extending period of bioavailability by delaying the pheromone liberation, and modulating the pheromone activity [13].

2.2 Characterization of bovine pheromones

Dispersion of various estrus-specific compounds isolated from different samples such as vulvar swabs, vagina, urine, milk, feces, saliva and blood have been demonstrated in the bovine body [18]. Nine estrus-specific compounds comprising of four amines, one ether, one alcohol, one diol, and two ketones, isolated from samples of estrus cows, tested positively in a bull behavioral assay [19]. Analysis of urine from cows at different stages of cyclicity had revealed presence of estrus specific pheromones such as 1-iodo undecane and di-n-propyl phthalate [20], the 1-iodo undecane have been also detected from feces of cows at different stages of the estrus along with acetic acid and proprionic acid [21]. Analysis of saliva have revealed five estrus-specific compounds, i-e, acetic acid, pentanoic acid, phenol 4-propyl, proprionic acid and trimethylamine, among which the role of trimethylamine in attracting the bull to the estrous cow has been proved in a bioassay [22]. Higher levels of 1-hexadecanol have been found in urine samples collected during estrous against the samples collected during the luteal phase, the compound supposed having a pheromonal effect in different animal species [23]. Various volatile compounds have been identified from bovine estrous urine such as 6-amino undecane, 2-butanone, coumarin, 1,2-dichloroethylene, 9-octadecenoic acid and squalene, found responsible for improving reproductive function of a bull in terms of enhanced libido and semen production [24]. Acetaldehyde an estrus specific pheromone from bovine vaginal secretions, was found helpful in predicting estrus and ovulation by monitoring its levels in blood, breath, milk, saliva, sweat, and its levels were found sharply decreased before, and at onset of estrus [25]. A gradual increase in the concentration of free fatty acids in estrous vaginal discharge before estrus and a sharp decline post estrus was observed, and it was noted that ruminal concentration of fatty acids affect the concentrations in urine but not in the vaginal discharge [26]. Quantification of methyl heptanol from vaginal secretion has been exploited as a method for detecting bovine estrus [27].

2.3 Biostimulation in bovines

Biostimulation (bull effect) a stimulatory effect of male upon female reproductive parameters, due to pheromones, result in the induction of oestrus and ovulation through genital stimulation, and therefore, has got potential in improving reproductive efficiency in livestock including bovines. It has been observed that significant proportion of heifers exposed to bull urine attained early puberty against the proportion of heifers not exposed, suggesting presence of priming pheromone in the bull urine [28]. Similar observation of early puberty attainment due to social interactions between bulls and prepubertal heifers [29], and also due to exposure to vasectomized bulls at significantly lower age of 23.1 months, as against 26.4 months in non-exposed heifers has been made [30]. In multiparous cows duration of post-partum anestrous was decreased when exposed to bulls [12], and interval to estrus was shorter in exposed cows [31]. Exposure to the androstenone a boar sex pheromone, was found having positive effect on reproductive parameters such as earlier onset of cyclicity at puberty and better results from artificial insemination in cows [32]. In a bioassay a mixture of compounds consisting of acetic acid, 1-iodo undecane and propionic acid from estrus cows were smeared on the genitalia of non-estrous cows, thereafter bulls were allowed to sniff the cows for 30 min, and it was observed that bulls displayed significantly longer flehmen behavior and increased number of mounts than the individual compounds and control, indicating the possible role of these chemicals in the induction of mating behavior [21]. Also various volatile compounds from bovine estrous urine (6-amino undecane, 2-butanone, coumarin, 1,2-dichloroethylene, 9-octadecenoic acid and squalene), resulted in improved reproductive function of a exposed bull in terms of enhanced libido and semen production [24]. Several mechanisms of biostimulation have been postulated such as, pre-estrus progesterone rise associated with bull exposure in postpartum cows, resumption of cyclicity due to luteinizing hormone (LH) release following exposure resulting in positive feedback for LH release in the hypothalamus to estrogen (overriding inhibitory effects of low concentration of estrogen on the hypothalamus), and increased sensitivity of the ovary to LH by increasing the number of LH receptors [13, 31].

2.4 Application of pheromones in bovines

Pheromones have a lot of potential in modulating animal behavior, and enhancing cattle reproduction and management.

1. Pheromones have a role in attaining early puberty and decreasing duration of post-partum anestrous (discussed in Section 2.3)

2. Various pheromones have been exploited in diagnosis of estrus such as quantification of methyl heptanol from vaginal secretion as a method for detecting bovine estrus.

3. Pheromonetherapy, first used in the dog and cat, can be applied to animal species including bovines, in reducing anxiety and phobia, modulating animal behavior and helping to build a good maternal relationship. Pheromones have proved an economic and alternative role in estrus synchronization against hormonal treatment, early onset of puberty and reduction of postpartum anestrus period; and therefore, is a viable management tool in tropical areas, where livestock production is overwhelmed with constraints [33].

4. Pheromones have a role in influencing the standing posture and therefore, help in assisting artificial insemination, as has been observed in sows exposed to boar saliva, resulted in immobilization reflex [34].

5. The female urinary sex pheromones have a role in assisted reproductive technology by causing penis erection and increasing the amount of sperms in bovines [33].

6. The bovine appeasing substance (BAS) is a technology using appeasing pheromones consisting of a mixture of fatty acids, having composition similar to the original substance as produced by the dam at calving [35]. BAS has been used to reduce agonistic behavior in various animal species, thus stimulating feeding behavior and weight gain, and thus helped in improvement of post-weaning performance and reduced post-weaning mean haptoglobin concentrations. BAS administration helps in improved milk yield, reduced somatic cell count of dairy cows, and improved performance and reduced duration and costs of medication in case of pre-weaning dairy calves [35, 36].

3. Conclusion

Chemical messengers or pheromones have a direct developmental effect on hormone levels and behavior, and therefore, have a potential role in modulating animal behavior and reproduction management. The cattle pheromones acts as efficient means to decrease calving interval, post-partum anestrus period, optimized milk production, reducing anxiety and phobia, building a good maternal relationship, and helps in assisted reproductive, artificial insemination and BAS technologies. Pheromones have proved an economic and alternative role in estrus synchronization against hormonal treatment, and their potential to transform the animal behavior and management of reproduction has led to development and use of synthetic pheromones to manipulate reproduction and behavior, and once chemically synthesized and characterized, have got huge scope of application that is beneficial for livestock owners.

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