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Buck Effect in Goat Reproduction: A Review

Devaraj Sankarganesh*, Gnana Thiraviam Annis Inncia and Shibu Angelin Grace

School of Bio Sciences and Technology, Vellore Institute of Technology (VIT), Vellore - 632014, Tamil Nadu, India; devarajsankarganesh@gmail.com

Abstract

Goats are seasonal breeders in the temperate regions. Therefore, female goats do not ovulate or express oestrous cycles during the non-breeding season. 'Buck effect' has been well studied in goats, where the introduction of adult intact males helps in the resumption or advancement of ovulation in anestrous females, thereby complementing reproduction during non-breeding seasons. The exogenous hormones or extended photoperiod treatments induce sexual activity in males during the non-breeding season. In the buck effect, exposure to sexually active males is believed to deliver various cues (physical, visual, chemical, and tactile) that induce sexual activity in females. The involvement of chemical cues was considered a potential chemical signal related to the buck effect; therefore, various scent sources of males have been tested to identify those chemosignals. Positively, buck effect pheromone (4-ethyloctanol) was identified in the scent glands of sexually intact males. This pheromone effectively induced Multiple Unit Activity (MUA) volleys in female goats and activated the GnRH pulse generator. Simultaneously, variable factors of the buck effect (time and duration of buck exposure, gonadal and developmental statuses of males and females, male-to-female ratio, prior sexual experience, etc.) have been analysed, and studies are ongoing. Altogether, progressive research on the buck effect and chemical communication in goats has yielded significant deliverables for use in goat production systems and applied research. This review narrates goat reproduction, with a special focus on the buck effect, pheromones, and behaviour.

Major Findings: The buck effect is a feasible, cheap, and non-invasive approach for managing goat reproduction. Buck effect is mostly mediated by androgen-driven mechanisms rather than female reliance on male physical cues alone. Testosterone, in particular, play a pivotal role in modifying the sebaceous glands structurally and functionally, thereby enhancing pheromonal signaling that might contribute in part, to the buck effect.

Keywords: Buck effect, GnRH, Ovulation, Pheromones, Photoperiod, Puberty, Sexual behaviour

1. Introduction

Goats provide meat, milk, manure, and fibre and play a key role in the global livestock economy. According to Redden and Throne[1], India is the second largest producer of goats. In India, goats are said to be a "poor man's cow," as goat rearing helps fulfil the farmer's financial needs. Goat productivity primarily depends on effective reproductive management. Reproductive management is a multifactorial phenomenon that depends on the gonadal, physiological, and health status of both males and females.

2. Buck Effect

Goats are seasonal breeders (in the temperate regions) that are reproductively active during autumn and winter and inactive during spring and summer. The female goats/does experience seasonal anoestrous during the non-breeding season and do not exhibit oestrous or ovulation during this time. Bruce[2] documented that introducing a male goat to anoestrous females provided a novel stimulus that ultimately terminated anoestrous in females, and the females ovulated. This effect was later defined as the 'buck effect'. Positively, the 'buck effect' is

*Author for correspondence
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considered beneficial in managing reproduction in goats, whereby the introduction of a sexually active buck helps in the resumption of ovulation in females during seasonal anoestrous. It has been confirmed that reproductive quiescence in females depends on many factors and is modulated by the sociosexual interactions between males and females[3], in that the quality of males is also important. Generally, extended photoperiod treatments and/or melatonin administration are used to stimulate and induce reproduction in males. The presence of bucks induces the buck effect and oestrous behaviours in female goats. This is perhaps due to olfactory and other sensory stimuli from the bucks[4]. Therefore, the buck effect is a feasible approach for managing goat reproduction, as it is inexpensive and non-invasive[5].

2.1 Cues Involved in the Buck Effect (Visual, Chemical and Auditory)

Manipulation of the oestrous cycle using exogenous hormones is a widely used approach to synchronise and induce oestrous in farm animals. Mgongo[6] studied the combinatorial effect of buck effect and hormone administration on oestrous induction in goats. The females expressed luteolysis and oestrous behaviours; however, the buck-mediated effect was not elucidated. The visual cues of females and the chemical cues of males were assumed to have produced this effect. The gonadal status of males is also vital in inducing the buck effect. To validate the role of androgens in oestrous induction, the females were exposed to two different groups (androgenised wethers [post-pubertal castrated males], and testosterone-treated females). Oestrous was induced in the females of both groups, implying the key function of androgens in inducing the buck effect[7]. This study suggests that females pay less attention to male physical cues, as they also respond to testosterone-treated females.

2.2 Attributes of the Buck

2.2.1 Sexual Status and Photo-stimulation

In addition to visual and chemical stimuli, the sexual status of bucks is also crucial in regulating the buck effect. Flores *et al.*[8] exposed sexually inactive and sexually active bucks (subjected to photoperiod and melatonin administration) to female goats. The sexually active bucks induced oestrous behaviours and ovulation in all the females. In contrast, no females showed oestrous behaviours when exposed to sexually inactive bucks. This study implies that the active sexual status of males is a key factor in inducing oestrous. However, the role of multisensory cues has not been focused on in this study, but it is highly warranted. The active sexual status and expression of sexual behaviours in males are largely dependent on testosterone concentration, which can be induced by photoperiod treatment. The photo-stimulated bucks showed complete sexual behaviours (sniffing, nudging, and mounting) and induced the buck effect[9]. Rivas-Munoz *et al.*[10] exposed females to two different groups of bucks (natural photoperiod and artificial photoperiod). The bucks in the artificial-photoperiod-treated groups induced oestrous behaviours and shortened the oestrous onset in the females within a short exposure time (4 h/day). In farm animals, LH surges occur when they are exposed to sex pheromones or pheromone sources of conspecifics. Therefore, the potential of photo-stimulated bucks to maintain LH levels in female goats was investigated. The continuous presence of photo-stimulated bucks increased LH levels in seasonally anoestrous females, eventually reducing the negative feedback of oestradiol on LH secretion. It was substantiated that the physical presence of photo stimulated bucks provided all possible cues (both olfactory and non-olfactory) to modulate LH levels in anoestrous goats[11].

Considerable variations have been observed in the characteristics of bucks under different climatic conditions. For instance, when subjected to photoperiod, bucks at temperate latitudes showed increased testicular activity and testosterone levels. Upon introduction into herds of females, these bucks increased the ovulation rate compared to the females exposed to typical bucks. This study suggests that photo-stimulation is a viable approach for managing reproduction in bucks at temperate latitudes[12]. In line with Mellado and Hernandez[13], the gonadal status of the buck was examined to establish the buck effect. The exposure of gonadally intact bucks advanced ovulation (1.5 months before) in females, whereas the effect was not the same in castrated or control buck-exposed females. Thus, it was suggested that

the somatosensory cues of the intact bucks might have played a significant role in the acceleration of puberty in the female goats. Luna-Orozco *et al.*[14] also attested to the beneficial effect of photo-stimulation to induce sexual behaviours in the bucks and to use them in inducing the buck effect.

2.2.2 Sexual Behaviour of Bucks

Many ungulates express flehmen behaviour during olfactory investigations of a scent source. During the flehmen response, males elevate their heads to bring the Vomeronasal Organ (VNO) into a horizontal position to facilitate the transfer of non-volatile chemical cues. In male goats, the flehmen response was more frequent when exposed to the urine of females and after copulation[15]. In addition to the flehmen behaviour, male goats express a unique behaviour called 'self-enurination'. Typically, male goats urinate on their beards, neck, and chest and lick it, indicating dominance status[16]. This behaviour was observed prominently in bucks when they were close to estrous females and prevented mating from occurring. However, when the buck is allowed to mate with a female, self-enurination significantly decreases[17]. On the other hand, copulation behaviour depends on the number of estrus females available for mating. Generally, males attempt to copulate with females during proestrous or early oestrous onset. During copulation, the ejaculation and mating frequency of males depend on the number of oestrous females available. Also, oestrous females are typically mated multiple times by the same male, or single females mate with two or three different males[18].

Besides, the absence of potential mates (females) induces the expression of homosexual behaviours in male goats. Briefly, homosexual behaviours were prominent when the males were separated from females and reduced when the males were adjacent to the females. Furthermore, homosexual behaviours showed seasonal variation, as the behaviours were highly expressed during the rut but were independent of testosterone concentration[19].

Therefore, in addition to sexual status, the sexual behaviours of males are also crucial in stimulating LH secretion in females. In this purview, Vielma *et al.*[20] tested females with two groups of bucks (sedated bucks and awake bucks), where the LH pulse generation in females did not differ during the initial hours; however, in sedated-bucks exposed females, the LH pulse decreased within 4 to 8 h. It is highly plausible that the sedated males might not express active sexual behaviours, including vocalisation[20]. In another study, the non-sedated bucks expressed sexual behaviours during pre- and post-introduction to females and induced the buck effect. With this, it was suggested that the physical contact of females with the males provided physical, visual, olfactory, and tactile cues, which induced an LH surge in the females[21].

2.2.3 Auditory Cues in the Buck Effect

In addition to visual and chemical cues, auditory cues complement the buck effect. For instance, the importance of auditory cues (vocalisation behaviour) in the buck effect was studied, in that the recorded vocalisations of a buck produced an effect similar to that of a live buck. The expression of oestrous behaviours with increased LH pulse was also observed in females exposed to vocalisation[22]. Therefore, it can be assumed that the female responses to vocalisations may be innate. However, vocalisation alone may not be considered a cue that induces the buck effect. For instance, boar exposure is essential for detecting oestrous in sows, and it has been proposed that physical, visual, auditory, and sensory stimuli are critical for producing the boar effect in pigs[23].

2.2.4 Familiar vs. Unacquainted Bucks

Another interesting notion is that exposure to the familiar buck (previously exposed) or unacquainted bucks (switched in between) did not influence the buck effect. Both types of buck-exposed females did not show any difference in ovulation and pregnancy rates. However, the sexual behaviours of the newly introduced males were prominent (sniffing, nudging, and mounting) but did not influence the regulation of oestrous and ovulation[24]. Munoz *et al.*[25] also conducted a similar study and found no physiological difference in the females exposed to familiar or unacquainted males. They suggested that the sexual behaviours of the males are important in producing

the buck effect, and the degree of familiarity with the buck stimuli has no or minimal role in inducing the buck effect.

2.2.5 Breed-Dependent Buck Effect

Zarazaga *et al.*[26] utilised two different buck breeds to examine the effect of breed on buck effect. Interestingly, females in the buck-exposed group showed oestrous behaviours and ovulated without a significant difference; however, fertility rates differed. This variable effect was based on the interaction of females with the buck, where one breed interacted highly with the females, whereas the other did not. This implies that the buck effect cues are not breed-dependent. Therefore, any breed of buck can be used to induce buck effect; however, it is crucial to note that sexual behaviours differ among different breeds.

In addition, the effects of breed on the expression of sexual behaviour in male goats were examined. When exposed to oestrous females, Egyptian-Nubian bucks required less time to mount, and their sniffing, nudging, and vocalisation behaviour were higher than those of Damascus bucks. The mating frequency was also higher in Egyptian-Nubian bucks, resulting in a higher pregnancy rate and larger litter sizes. However, the number of ejaculations did not influence kidding, pregnancy, or litter size in female goats. Therefore, it can be inferred from this study that the sexual behaviours of male goats differ according to breed, and these sexual behaviours may account for the reproductive outcomes of males[27].

2.2.6 Hierarchy in Males

Similar to other terrestrial species (*e.g.*, blackbuck), goats also show a social hierarchy. For instance, the introduction of previously unknown bucks elicited a stress response and altered the reproductive characteristics of resident bucks. After mixing the bucks, cortisol concentration increased, and body weight significantly reduced in both groups. However, the body weight of the resident bucks was higher than that of the introduced bucks at the end of the treatment. Conversely, motile spermatozoa, testosterone concentration, and scrotal circumference were lower in introduced bucks than in resident bucks[28]. Grouping or re-grouping affects the well-being of all animals. It may take more time for newly introduced animals to habituate to a new environment. In addition, housing conditions, area, and age of the animals also have implications. Therefore, all these factors must be considered prospectively to confirm the social hierarchy of male goats. In another study on dominant and subordinate bucks, no differences were observed in semen parameters, body weight, and scrotal circumference. However, dominant bucks began courtship behaviour earlier and mated with the females more frequently than subordinate bucks. Conversely, flehmen response and anogenital sniffing were reduced in dominant males. However, the grouping of dominant and subordinate males did not affect their status, as both groups showed elevated cortisol and reduced testosterone levels[29]. However, Ungerfeld *et al.*[30] suggested that testosterone concentration does not play a role in the agonistic behaviour of males. This contrasts with the report on blackbucks, where the highly dominant and fighting blackbucks had the highest testosterone levels compared to other males in the colony[31].

3. Attributes of Females

3.1 Social Status and Prior Sexual Experience

The social status of females also determines the establishment of the buck effect. When housed with an androgenised wether, dominant females showed frequent LH pulse with greater LH concentrations than subordinate females did. Furthermore, the association index and oestrous behaviour expression were significantly higher in dominant females than in subordinate ones. This effect in dominant females may be due to their close association with the bucks[32]; however, the ovulation rates did not differ. In this purview, the investigation of social hierarchy may have potential value regarding the buck effect. The association between previous sexual experiences of female goats and the onset of the buck effect was also studied, in that, LH pulse, onset of oestrous, and oestrous behaviours did not differ between sexually experienced and inexperienced female goats. This implies that the buck effect is not dependent

on the previous sexual experience of females. Instead, the efficiency of the buck effect has been suggested to be buck-dependent, as the sexual behaviours and olfactory cues of the bucks play a pivotal role[33].

3.2 Isolation of Females

Various attributes of females have been tested in the buck effect. In this sense, the isolation of female goats from bucks was considered a requisite to stimulate oestrous[34]. Gallego-Calvo *et al.*[35] revealed that either prior introduction of males or absence of males did not influence fertility, fecundity, prolificacy, and productivity in females. In a subsequent study, females were isolated for different periods before being introduced to the bucks. Interestingly, there were no changes in oestrous activity, ovulation, fertility, or fecundity after introducing isolated females or females that were co-housed with males. This study further substantiates the findings of Zarazaga *et al.*[36] that the previous isolation of females is not a requirement to produce the buck effect.

4. General Attributes

4.1 Exposure Time Length and Buck Effect

All the above studies have proven that the buck effect helps manage reproduction in goats. However, it may not be possible to expose the females to bucks all the time owing to the costs associated with buck maintenance. In this context, it is necessary to validate the time length of exposure of the buck to induce the successful buck effect. Therefore, different time points were analysed to determine the optimal time at which the buck effect is produced, and ovarian activity was measured using plasma progesterone levels in female goats. It was found that daily 4 h exposure of males was sufficient to induce the buck effect, and the effect was similar in 16 h exposed females[37]. In another study, the length of buck exposure was further reduced, and the possible time point that produced the maximum buck effect was examined. The timing between the introduction of males and the first ovulation occurrence did not differ between females exposed for 15 min, 30 min, 1 h, and 2 h[38]. From this, we infer that the females effectively perceived all possible cues from the buck, even during a very short period (15 min). It was proved that 4 h exposure of does produced an intense stimulation, whereas reduced time (15 min, 30 min, 1 h, or 2 h) produced a weaker stimulation. In contrast, a short time for maximum days induced ovulation at the same trend, in that 15 min of exposure to bucks for 15 days induced ovulation in female goats. It also has economic implications in that the same buck could be reintroduced to another group of females (after 4 h) if a large commercial farm has only a few males and many female goats[39]. Ponce *et al.*[40] compared the day lengths (1, 5, 10, and 15 days) on the buck effect. The ovulatory responses did not differ between the least (1 d) and maximum number (15) of days exposed females; however, one-day exposed females showed a short luteal phase. This study recommended continuous male exposure as a practical approach to induce male effect, which contrasts with Bedos *et al.*[38]

All these studies proved that the exposure time controls the buck effect only by observing the ovulation rate. However, the underpinning molecular evidence, such as GnRH responses, has not been evaluated but is highly warranted for these approaches.

4.2 Male vs. Female Ratio

Considering the economic implications, the number of males should be as low as possible to produce the maximum buck effect in a higher number of females. In this sense, the male-to-female ratio was examined to establish the buck effect. For instance, the male: female ratio (1:9) was kept constant, and the bucks were consecutively used with three groups of females (4 h/day for 15 days), and the resulting buck effect was evaluated. It was revealed that a 1:9 ratio could regulate and induce great ovulatory and reproductive responses in anoestrous females. Therefore, a 1:9 ratio with a 4 h exposure for 15 days was suggested as optimal[41]. In another study, a 1:20 (male-to-female) ratio showed a better ovulation rate, reproductive responses, fecundity, and fertility. Indeed, the effect did not differ between 1:5 and 1:20. The 1:5 ratio could help in the efficient dispersal of the cues to females; therefore, the 1:5 ratio was highly recommended. It can be assumed

that the efficiency of males could be reduced owing to the increased number of females. Therefore, when provided with many females, the buck may not produce the same effect as it does in a smaller colony[42]. These results contrast with those of Bedos *et al.*[38]; however, the number of bucks required to induce a significant buck effect is still undetermined and requires further investigation.

4.3 Oestrous Synchronisation and Buck Effect

The oestrous synchronisation approach is widely used in farm animals, whereby the use of exogenous hormones helps synchronise oestrous in a group of females, thereby facilitating timed artificial insemination. However, not all females respond to exogenous hormones. In addition, small-scale farmers do not adopt hormonal synchronisation, especially in the case of small ruminants. In goats, hormonal treatment (Sincromate-B (SMB)) did not influence the oestrous response and pregnancy in females unless they were exposed to bucks. Interestingly, when SMB-treated females were subjected to the buck effect, they ovulated earlier. It has been suggested that buck exposure produces a synergistic effect with SMB in synchronising oestrous and inducing ovulation[43]. Ungerfeld and Orihuela[44] also evaluated the effects of oestrous synchronisation and subsequent buck exposure. Fluorogestone acetate sponges were used to synchronise the oestrous cycle in female goats, and these females were subsequently exposed to bucks after removing the sponge. As a result, an increase in progesterone levels was observed in these females, which decreased after four days. It seems that the timing of buck exposure is vital in increasing the concentration of progesterone, which ultimately regulates ovarian activity[44].

The continuous contact of bucks with oestrous-synchronised Boer female goats was studied. The constant presence of bucks accelerated oestrous onset, shortened oestrous duration, and decreased oestrous onset time in CIDR-treated females. The interval from CIDR removal to ovulation did not differ between control and buck-exposed females; however, the occurrence of ovulation was significantly higher in the buck-exposed group than in the control group. In this study, the bucks were aproned to prevent them from copulating but were allowed to physically interact with the females. It is crucial to note that close contact of bucks is sufficient to modulate the oestrous activities in females due to the possible involvement of other cues (physical, visual, and auditory). The continuous presence of bucks (aproned) with the female group could be considered an intermediate level of stimulation, as the buck without any restriction to mate provided the maximum stimulation[45].

Nivedita *et al.*[46] compared the effect of buck exposure with intra-vaginal progesterone sponges in synchronising oestrous in goats. The buck effect led to oestrous synchronisation in 50% of goats, whereas intravaginal progesterone sponges induced 100% oestrous in females[46]. However, the bucks were only exposed for 72 h, which is lower than that in other studies, and a higher exposure time may be required to produce the complete buck effect. In another study, 25 mg of progesterone and buck stimulation shortened the ovulatory cycle, whereas 5 mg or less did not shorten the ovulatory cycle[47], implying that the concentration of progesterone used for synchronisation needs optimisation.

4.4 Buck Effect Pheromones: Attempts and Evidence

Although the physical presence of a gonadally intact buck was shown to produce the buck effect, the role of olfactory cues is still crucial. Therefore, identifying olfactory cues responsible for the buck effect is important. Numerous studies on the buck effect have aided in the identification of olfactory stimuli in this phenomenon. Since there was a considerable variation between the gonadal status of intact, castrated, and prepubertal males, all these statuses were examined to identify and confirm the chemical cues related to the buck effect.

Sugiyama *et al.*[48] identified 4-ethyl-fatty acids in the sebaceous glands in the neck regions of male goats, among which 4-ethyl octanoic acid was highly associated with a strong goaty odour. The sebaceous glands from other body areas of male goats also contained 4-ethyl-fatty acids. In contrast, fatty acids from young males and females differed from those secreted by adult males; therefore, 4-ethyl branched fatty acids were ascribed to adult males. It was also delineated that juveniles secrete lipids that contain typical fatty acids, which may turn

into specific fatty acids during maturation[49]. However, the gonadal influence on fatty acid secretion has not been demonstrated in hormonal replacement therapies. Hillbrick *et al.*[50] confirmed the presence of ethyl-branched fatty acids extracted and quantified in the lipids of the fleece of castrated goats. In intact males, a few more specific volatile fatty acids were identified. Although the fleece samples of castrated goats expressed a slight buck odour, the odour was not similar to that of intact goats, which might be due to the presence or absence of unique compounds. Surprisingly, none of the buck-specific fatty acids (4-ethyl fatty acids) were detected in the fleece of prepubertal goats, possibly because of sexual immaturity.

In addition, attempts have been made to confirm the pheromone source responsible for the buck effect. To verify the origin of buck odour production, pooled hair samples collected from male goats were presented using a mask, and females were allowed to sniff/smell them for 4 h. Positively, multiple unit activity (MUA) was detected, and the MUA volley interval was shortened in female goats. In addition, LH pulse frequency increased, indicating increased GnRH activity. The hair samples used in this study were collected from the head, cervix, and shoulder regions of male goats and were pooled. A single hair source may be sufficient to induce both MUA volley and LH pulse, and the presence of other hair samples could produce a synergistic effect in the female goats. All hair samples may contain the same compounds or different compounds that may synergistically produce the buck effect[51]. However, this study did not identify the pheromone compound(s) responsible for the buck effect.

In an entirely different approach, canvas masks containing buck hair or a fraction of buck hair extract were tested on anestrus ewes. The ewes showed a surge in LH levels, which increased significantly compared to baseline. Thus, the inter-relationship between pheromones in goats and sheep was revealed; however, no further studies have been conducted on this aspect[52]. Stimulation is possible if the compounds in the buck hair are similar to those in ram hair samples. However, in line with previous studies, other sensory cues (tactile, visual, and physical) are also crucial to the buck effect. Therefore, the response of ewes to bucks (when physically presented) remains undetermined. Even though the ram responded to the buck pheromone, it only lasted briefly. In addition, the identity of male-effect compounds in goats and sheep has not yet been compared. A comparative study was performed to further delineate the relationships between sheep and goats. The hair samples from bucks and wool samples from rams were used to induce MUA volleys in female goats. Hair samples were collected from the parietal and shoulder regions of the bucks and the parietal-cervical region of the rams. When the buck hair and ram wool samples were exposed to the ovariectomised does, the latency of the MUA volley was significantly shortened. However, the latency was further shortened, and pulsatile LH secretion was observed in buck-hair-exposed does. Taken together, this study proved that ram wool acts in an interspecific manner, in that it is effective in inducing MUA volleys and LH in does[53]. Nevertheless, the similarities between these compounds have never been assessed, although a later study identified the major compounds only in bucks and not in rams.

As evidenced earlier, the primary hormones involved in the buck effect production are believed to be androgens. It was proven that testosterone treatment in castrated goats restored the structure and size of the sebaceous glands, and the absence of testosterone atrophied the gland. Thus, the role of testosterone in developing the sebaceous glands was revealed. Moreover, 5 alpha-reductase (a key enzyme in androgen biosynthesis) activity was higher in the sebaceous glands of testosterone-implanted castrated goats[54]. In a follow-up study, gland samples from testosterone-implanted castrated goats were extracted with diethyl ether and presented to ovariectomised female goats, which induced MUA in them[55]. Taken together, these results reveal the role of testosterone in the structural modification and functional improvement of the sebaceous glands.

Intact bucks in the early stages of life possess no odour in any scent gland; however, a faint smell was perceptible in the cornual gland of some males. Interestingly, at eight months, the cornual glands of male goats showed a distinct buck odour, and the odour scores were higher than those of castrated males. When male goats were 20 months old, the buck odour was highly perceptible, and at this stage, castrated males did not secrete any odour. Based on histomorphology, the buck odour is believed to

be secreted from the mental gland and partially from other small glands in the neck and head region of intact male goats[56]. Iwata *et al.*[57] demonstrated that 4-ethyloctanoic acid (4-EOA) (a major constituent of buck odour), when kept at room temperature, is fractionated into derivatives and effectively induces primer pheromone activity in ovariectomised females (primer pheromones induce long-term physiological changes in the receiver). The derivatives of 4-ethyloctanoic acid include the methyl ester of 4-EOA, octanoic acid, and 4-ethyloctanoic acid 2,6-di-t-butyl-4-methylphenol.

In a hallmark study, Murata *et al.*[58] identified the primer pheromones involved in the buck effect. The advantage of this study lies in the unique custom-made head cap and gas adsorbent used to capture volatiles (buck effect pheromone) from the head region of male goats. The compound was identified as 4-ethyloctanal, which is absent in the head region of castrated male goats. Real-time electrophysiological monitoring revealed that buck hair activates the GnRH pulse generator. Furthermore, the cocktail of the synthesised compounds elicited MUA and increased serum LH levels in does. Among the 18 compounds in the mixture, 4-ethyloctanal elicited the highest percentage of positive responses. As expected, the removal of 4-ethyloctanal from the mixture significantly reduced the MUA. In this way, the synergistic effect conferred pheromonal activity in goats, similar to that in other mammals. In line with this, we also provided evidence that the cornual glands of male goats secrete sebum, which contains as many as 14 volatile compounds. These compounds may function as buck effect molecules but warrant behavioural validation in the female goats[59].

5. Conclusion

Behavioural and endocrinological evidence is compelling in support of buck effect pheromones. Compounds identified in the head region of the intact buck exhibited synergistic effects in establishing the buck effect. It is highly possible that not all the compounds in the mixture, but a few, may have maximum potential, and when combined with the most effective molecule, exhibit a superior buck effect on females. In this regard, identifying an appropriate mixture of compounds is highly pertinent for effectively managing goat reproduction. In addition, there are only limited studies on the functioning of the olfactory system of goats in response to the buck effect, in that the involvement of the olfactory system/subsystem has not been elucidated. In this sense, it is important to unravel the olfactory pathway to establish the buck effect. There could also be fundamental, structural and functional differences in the olfactory systems/subsystems, particularly in the olfactory secretome of adult and juvenile females during the reproductive and non-reproductive seasons. Similarly, the role of multisensory cues needs to be deciphered. The roles of visual, tactile, and auditory cues must be verified in synergy with olfactory cues to understand the buck effect. For this purpose, deciphering the sociosexual coordination of GnRH neurons and kisspeptin receptors is appropriate. A comprehensive approach that integrates all these viewpoints would provide a holistic solution for harnessing the buck effect.

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Author Contribution

Devaraj Sankarganesh: Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Visualization. Gnana Thiraviam Annis Inncia: Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Data curation. Shibu Angelin Grace: Formal analysis, Writing – review & editing.