Applied Animal Behaviour Science 269 (2023) 106109

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Wool-pulling behaviour appears in a production system with grazing restriction and can be assessed through wool inspection

Ricard Parés, Pol Llonch *, Xavier Such, Xavier Manteca

Department of Animal and Food Science, School of Veterinary Science, Universitat Autònoma de Barcelona, Bellaterra, Barcelona 08193 Spain

A R T I C L E I N F O

Keywords:
Sheep
Farm
Welfare
Wool-pulling
Aggressive behaviour
Welfare indicator

A B S T R A C T

Sheep flocks can be reared in different production systems that differ in the duration of indoor housing and grazing restriction. Indoor housing can lead to aggressive interactions, such as blocking, threats and butts, whereas grazing restriction may cause wool-pulling. Wool-pulling is an abnormal behaviour that appears in confined flocks and affects the wool condition of affected animals. Wool condition has been included in some sheep welfare assessment protocols, but in most cases the causes of wool alteration are not addressed. Therefore, it would be useful to establish whether changes in wool condition may be attributable to wool-pulling behaviour. The aim of this study was to find out the effect of grazing restriction on the prevalence of wool-pulling behaviour, assessing wool cover as an indicator of this behaviour, and to analyse the effect of grazing restriction on the prevalence of aggressive behaviours. Two groups of twenty Ripollesa pregnant ewes were used, a temporary grazing group (G) and a permanently housed group (H). Group G had access to pasture daily from 10:00 h to 15:00 h, while Group H remained in the barn throughout the experimental period (10 weeks). The behaviour of all sheep was video-recorded along a ten-week period, two days per week 45 minutes each day, and an ethogram that included wool-pulling, aggressive behaviours, resting and rumination was developed and used. Wool-pulling was observed exclusively in Group H. On the other hand, a four-scale score of wool cover was used to assess wool pulling behaviour, and the score evolved significantly different in both groups. In Group G, no change in wool-cover was observed whereas in Group H, wool-cover change was observed in eleven out of twenty ewes throughout the experimental period. A positive correlation was found ($R=0.98$, $P=0.01$) between wool pulling observed by direct observation and wool-cover assessment, and it was concluded that wool cover is a potentially useful indicator of wool-pulling behaviour. The frequency of aggressive behaviours was higher in Group H than in Group G during the entire experimental period (35 ewes vs. 11, $P=0.04$), which suggests that it was caused by grazing restriction.

1. Introduction

Sheep flocks can be reared in a wide range of systems, and thus grazing restriction can appear to a different extent depending on the system. Ewes could be kept indoors at the end of gestation and the post-lambing period, or even during drought periods or lack of grass. Grazing restriction involves the lack of a natural behaviour (Albright, 1993; Von Keyserlingk et al., 2009) and, thus, it could induce abnormal behaviours like wool-pulling. On the other hand, when sheep are kept indoors, competition for resources can appear and it can lead to aggressive interactions, such as blocking, threats and butts (Erhard et al., 2004). Space allowance can also increase aggressive interactions (Jorgensen et al., 2009a; Vick et al., 2017).

Wool-pulling is an abnormal behaviour that appears in confined flocks and alters wool condition (Fraser and Broom, 1997). The affected animals have sparse wool and naked skin (Xiao-Yun, 2011), and in severe cases the entire fleece can be removed (Fraser, 1983), but no specific signs of wool-cover alteration have been defined as an indicator of wool-pulling behaviour. Some authors have observed bald patches produced by wool-pulling over the rump, back, and sometimes in the neck of affected animals (Morgan et al., 1986), whereas others suggest that they appear first in the back and then, progressively, all areas can be affected in time (Reinhardt, 2005). In summary, bald patches caused by wool-pulling can appear in all areas and no specific pattern has been defined.

In other species, integument (skin, hair or feather) alterations have

* Corresponding author.
E-mail address: pol.llonch@uab.cat (P. Llonch).

https://doi.org/10.1016/j.applanim.2023.106109
Received 12 June 2023; Received in revised form 31 October 2023; Accepted 1 November 2023
Available online 4 November 2023

already been used to assess abnormal behaviour. In laying hens, feather loss has been successfully used to assess pecking behaviour (Welfare Quality® Project, 2009). In pigs, tail lesions have been used to assess tail-biting behaviour (Honeck et al., 2019; Brünger et al., 2019), whereas skin lesions have been used to assess aggressiveness (Turner et al., 2006).

Wool-pulling, also called wool-biting, is a specific sheep behaviour that must be differentiated from the licking behaviour that occurs in several species and that has been defined as an abnormal behaviour of farm animals (Bergeron et al., 2006). Other abnormal behaviours have been defined as "pica" or allotrophagia when animals eat materials other than their normal feed (Firyal, 2007; Salem, 2017). Licking and "pica" are behaviours different from wool-pulling, but also cause with wool loss, alopecia or wool alterations. Several studies have analysed different parameters in animals affected of wool loss or alopecia, and all of them have found reduced blood mineral levels, mainly zinc and cooper (Salem, 2017; Akgul et al., 2000; Firyal, 2007). Other authors have found lower levels of haemoglobin and Packed Cell Volume (PCV) in affected animals (Ebrahim, 2015). Some studies suggest other causes like lack of fibre (Firyal, 2007; Bello et al., 2020), but it remains unclear whether altered wool condition is caused by feeding materials other than normal feed or specifically by wool-pulling behaviour. Lack of long fibre in the diet has also been found to be a factor affecting rumination and abnormal oral behaviours, since it increase pseudorumination and can lead to wool-pulling, crate chewing, licking or excessive grooming. Pseudorumination seems to appear when insufficient regurgitated fibre reaches the mouth (Campion, Leek, 1997). Infestations with internal parasites have also been suggested to induce pica (Kataria et al., 2018).

There are other factors that affect wool condition, including non-visible external parasites such as scabies. The main ectoparasitic skin disease in adult sheep is *Sarcoptes sabiei* dermatitis, found in many European countries. The infestation usually begins in non-woolly body regions but spreads to other body parts causing alopecia and histopathological lesions, including epidermal hyperplasia and hyperkeratosis (Doukas et al., 2021). Some infectious diseases such as dermatophiloses (*Dermatophilus congolensis*) or fungal dermatoses, caused by different species of fungi, mainly *Trichophyton verrucosum,* can also affect wool condition (Martin, Aitken, 2000). Macro-ectoparasites, including myasis, can also produce wool loss. Two main myasis can be found in Europe: wohlfahrtiosis, caused by *Wohlfahrtia magnifica* and sheep strike, caused by *Lucilia sericata*, both causing fleece loss (Hall, 1997). Myasis development is closely related to temperature, and therefore its importance may increase in the near future due to climate change (Shields, Orme-Evans, 2015). However, when bald patches are caused by parasites or infectious diseases visible skin alterations appear, like hardened or reddened skin, which makes it possible to differentiate the cause of bald patches. Indeed, some authors consider that bald patches of the skin produced by wool-pulling can be distinguished from other causes (Chiezey, 2010).

Wool condition has been suggested to be considered in sheep welfare assessment (Phytian et al., 2011), and it has been included in some sheep welfare assessment protocols (AWIN, 2015), but the causes of wool alteration are not addressed. Therefore, it would be useful to establish whether changes in wool condition may be attributable to wool-pulling behaviour as suggested in previous studies (Parés et al., 2023).

The factors that induce wool-pulling remain unclear. Some authors refer to management and husbandry factors, and suggest that it appears when sheep are chronically restricted in pens of limited size (Fraser, 1983), or a restrictive environment (Cooper, Jackson, 1996). Husbandry deficiencies have also been suggested (Reinhardt, 2005). Other authors suggest that wool-pulling can appear in confined sheep due to small particle-sized feed, that does not stimulate rumination (Chiezey, 2010). However, other authors consider that grazing in sheep is a non-replaceable behaviour and wool-pulling may appear as a redirected behaviour of sheep deprived of adequate levels of activity or oral stimulus (Vasseur et al., 2006). Knowing the consequences of grazing restriction on wool-pulling could be useful to monitor the welfare of sheep.

Behavioural responses can be a sign of a lack of welfare (Cockram, 2004), and therefore the observation of aggressive behaviours can be useful to assess the effect of grazing restriction on sheep flock welfare.

The aim of this study is to find out the effect of grazing restriction on the prevalence of wool-pulling behaviour, assessing wool cover as an indicator of this behaviour, and to analyse the effect of grazing restriction on the prevalence of aggressive behaviours.

2. Material and methods

2.1. Animals and management

Forty Ripollesa pregnant ewes from the experimental flock of the Autonomous University of Barcelona were chosen. Sheep were born on the same experimental farm and reared as one group. The average age of selected ewes was 4.6 ± 1.8 years, and average prolificacy in previous years was 1.7 ± 0.4 lambs per ewe per year. Average body condition score was 2.54 ± 0.24.

Selected ewes were housed in an open barn on the same farm. Two groups were established: a temporary grazing group (G) and a permanently-housed group (H), and were balanced according to age and body condition. Both groups were housed next to each other, separated by a metal-bars fence, having constant visual contact between them. The size of each pen was 10 ×20 metres, with a stocking density of 2.5 m^2/ewe. Feed was provided in a feed trough 20 m long in each pen, at one side of the barn, making 1.0 m of feed trough per ewe, so all animals could feed simultaneously. Both groups had one water point. Sheep were housed with a bedding of straw, which was renewed weekly. There was a two-week adaptation period, during which ewes from both groups went out to pasture, along with the rest of the sheep on the farm. The experiment was performed in autumn during 10 weeks after the two-week adaptation period. From the first experimental day, Group G had access to pasture daily from 10:00 h to 15:00 h, while Group H remained in the barn throughout the experimental period (10 weeks). Both groups were fed with alfalfa hay in the barn with a vitamin-mineral supplement. In order to ensure good feeding in both groups, and taking into account that Group G fed in pasture, alfalfa hay was provided *ad libitum* to maintain the same body condition score in both groups.

2.2. Animal measurements

Individual assessment of all animals was performed in weeks one, four, seven and ten, based on the nutritional and health status of the animals and the evaluation of wool cover. Nutritional, health and wool-cover criteria for assessment are shown in Table 1 and Fig. 1. Nutritional and health status included body condition score, external parasites, nasal discharges, ocular symptoms, udder condition, lesions and presence of diarrhoea. Wool-cover was visually assessed using a four-scale score, considering areas with wool loss and their skin condition. Areas with wool loss and hardened or reddened skin were attributed to other causes than wool-pulling, such as external parasites or infectious diseases, and were not considered. Only areas with wool loss and no hardened or reddened skin were attributed to wool-pulling, and their extensions were also considered. The four-scale score proposed (Fig. 1) has been previously used in other studies (Parés et al., 2023). In addition to wool cover, the body localisation of bald patches was also recorded, considering the following parts: neck and top of shoulders, back, loins and rump (Table 2 and Fig. 2).

During the assessment, each ewe was individually restrained by an assistant and the observer assessed each of the indicators. The observer was always the same person, an experienced veterinarian who had received previous training on the indicators to be measured.

Table 1
Score criteria for nutritional, health and wool cover indicators.

Indicator	Scoring criteria	Reference	Score
Body condition score (BCS)	1–5 point scale according to Russell (1969).	Russell 1969	1: Emaciated 2: Thin 3: Average 4: Fat 5: Obese
External parasitisation	The inner part of the auricular pavilion on both sides is inspected; presence of external parasites is recorded. Wool is inspected to observe wool patches with hardened skin caused by scabies; body and head skin is inspected to observe lesions caused by scabies.	Adapted from Taylor, 2010	0: Negative 1: Positive
Nasal discharges	Presence of liquid or serous discharge is evaluated, unilateral or bilateral.	Awin 2015	0: Absence of discharge 1: Presence
Ocular discharges	Presence of ocular discharge or epiphora in both eyes is evaluated.	Awin 2015	0: Absence of discharge or epiphora 1: Presence
Udder health	The udder is palpated and visualised, and the following alterations are evaluated: presence of fibrous tissue, lesions in the udder skin, lesions on nipples and signs of mastitis.	Adapted from Awin 2015	0: Healthy udder 1: Altered udder (lesions on skin, lesions on nipples or presence of fibrous tissue) 2: Mastitic udder (pain or heat)
Lesions	The animal is checked on both sides of the body, four limbs and head, and presence of the following lesions is recorded: lesions on skin with blood or crust, linear lesions, dermatitis in the auricular pavilion, keratitis and ocular trauma.	Adapted from Awin 2015	0: Absence (no lesions observed) 1: Minor injuries (linear lesions <2 cm, dermatitis or keratitis) 2: Major injuries (lesions with blood or crust, linear lesions <2 cm or ocular trauma)
Diarrhoea	While ewe is restrained, its tail is lifted back and only the anal sphincter is observed. Presence of mucus, including purulent or bloody mucus, is evaluated.	Adapted from Awin 2015	0: Absence 1: Presence
Wool pulling	Wool is inspected; bald patches with no hardened skin, or reddened skin, and their extension, are recorded.	Parés et al., 2019	0: Absence 1: Low (bald patches $<$ 5 cm) 2: Medium (bald patches clearly visible) 3: High (bald patches greater than 50% of wool extension) *When several bald patches are observed in the same animal, it is only considered the extension of the largest bald patch.*

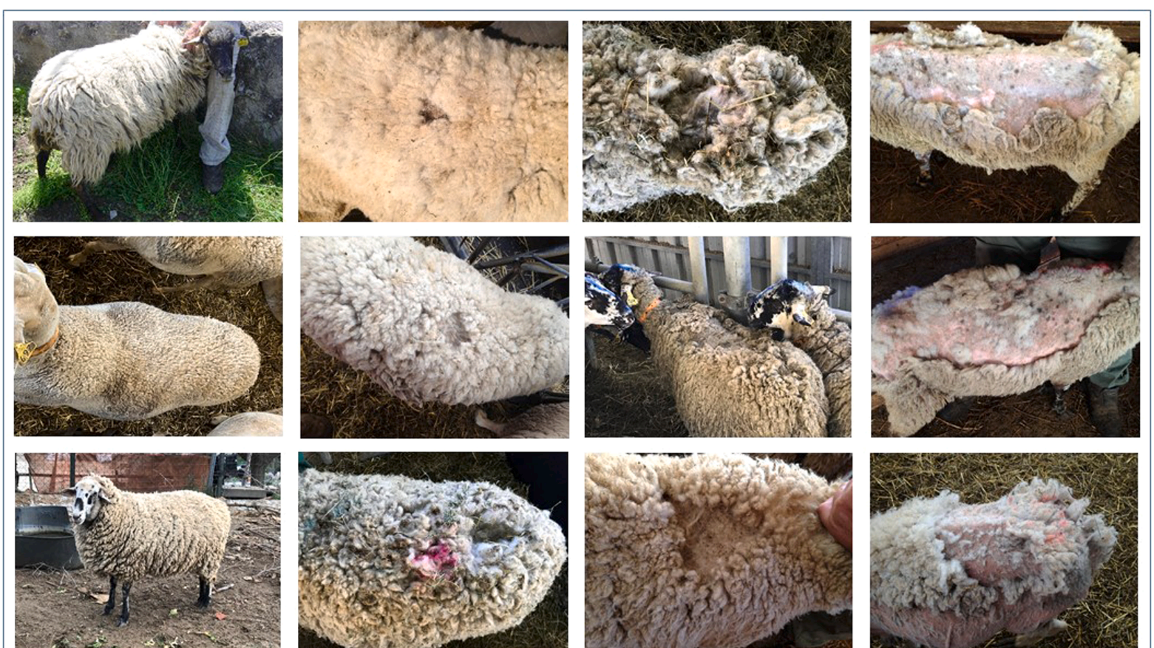

Fig. 1. Wool pulling pictures according to the 4-score criteria.

2.3. Behaviour measurements

Behaviour of all sheep was video-recorded using a digital video-recording device (VS-101 P VioStor NVR; QNAP Systems Inc.; Taipei City, Taiwan). A digital colour camera (VIVOTEK IP7142; Vivotek Inc.; Taipei City, Taiwan) was set up in the upper part of the pen at about 3 m high capturing the entire pen view. Infrared light with photoelectric cells (830 nm and 500 W; Dennard 2020; Hants, UK) was set up at each end of the pen to allow video-recording during the night. An ethogram was defined including the following behaviours: resting, rumination,

Table 2
Body localisation of bald patches of bitten ewes and wool pulling score at the end of the experiment. When several bald patches were observed in the same animal, the wool-pulling score only considered the extension of the largest bald patch.

	Neck and top of shoulders	Back	Loins	Rump	W-P score
Ewe 1	-	-	√	√	2
Ewe 2	-	-	-	√	1
Ewe 3	-	-	-	√	1
Ewe 4	-	√	-	√	2
Ewe 5	√	-	-	-	1
Ewe 6	√	-	-	√	1
Ewe 7	-	-	-	√	1
Ewe 8	-	-	-	√	1
Ewe 9	-	√	√	√	2
Ewe 10	-	-	√	-	1
Ewe 11	√	-	-	-	1

aggressive behaviours and wool-pulling. Behaviour was recorded two days per week along a ten-week period, in the following intervals: morning (from 06:00–06:15 h), afternoon (from 16:00–16:15 h) and evening (from 21:00–21:15 h).

Behaviours were analysed according to the methods proposed by Bateson and Martin (2021). Resting was analysed by scan-sampling where the number of ewes resting was recorded over the 15-minute observation period, at five-minute intervals by direct observation. Rumination was analysed by focal sampling, where the number of ewes ruminating was recorded at Minutes 0, 5, 10 and 15 by direct observation. Aggressive behaviours were recorded by continuous sampling over the 15-minute observation period, including threats and head butts. A threat was considered as the butting movement towards the opponent without contact, the "low stretch" (the sheep extends its neck forward and horizontal to the ground) taking a few steps back, or the approach to other sheep turning the head downwards pointing the horns towards the opponent (Fisher and Matthews, 2001). Head butts were considered as the frontal butt to the head of another sheep, or the butt with the head into the side or rump of the other sheep (Lynch et al., 1992). Wool-pulling behaviour was recorded by continuous sampling over the 15-minute observation period. One biting event was considered when an animal pulled wool from another until stopping for a period longer than 5 seconds, or changing her target to a different animal (Huang, Takeda, 2018).

2.4. Statistical analysis

Resting and rumination were analysed as repeated measures using weakly mean values. Each variable was analysed with a Generalized Linear Model using the MIXED procedure containing the fixed effects of treatment (G or H), week of the experimental period, day, measuring hour and interactions of treatment per day and per hour, and random effect of the animal between treatments. Aggressive behaviours and visually observed wool-pulling events were also analysed as repeated measures from the total weakly observed behaviours with a Generalized Linear Model using the MIXED procedure containing the same fixed effects and interactions. Wool-cover score mean of each group was analysed as a repeated measure along sampled weeks (one, four, seven and ten). All values were normally distributed and analysed as continuous variables. Spearman's correlation was used to analyse the relationship between wool-cover score and observed wool-pulling events. All statistics were performed using SAS 9.3 (SAS Institute Inc.) Statistical differences were considered significant at $P<0.05$.

3. Results

All animals maintained the same health and nutritional status in both groups throughout the experiment, as indicated by the variables assessed. No significant variations were observed in body condition score. No nasal discharges, ocular symptoms or diarrhoea were observed during the study. Two animals (one of each group) were observed as being affected by lesions in udder skin (score=1), and one animal of the H group had one minor injury in its body from the first assessment (score=1).

Wool-pulling behaviour was visually observed at a very low prevalence and thus it was not possible to determine which ewes participated in wool-pulling. It was never observed in Group G throughout the experimental period, whereas in Group H it was observed in weeks five,

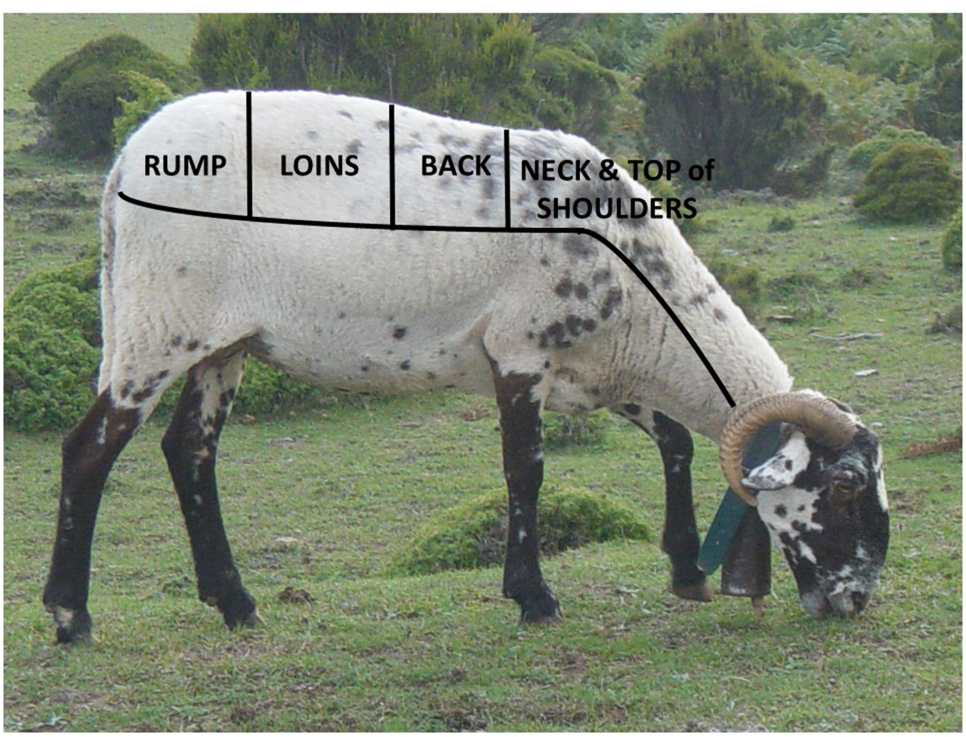

Fig. 2. Parts of the sheep body to be considered to define the location of bald areas.

six, seven, eight and ten, in a progressive increase over the experimental period. When more than one event occurred in the same week, it was observed in different animals. No ewes biting their own wool were observed during direct observations. Events of wool-pulling were always observed in the afternoon. Wool-cover evolved significantly differently in both groups throughout the experimental period. In Group G, no change in wool-cover was observed in any ewe, and thus flock mean score was zero. On the other hand, in Group H, wool-cover change was observed in eleven out of twenty ewes throughout the experimental period. The number of affected ewes increased progressively, from two affected ewes in week four to eleven affected ewes in week ten. As a consequence, the wool-cover score average of the flock increased progressively, reaching a 0.7 mean flock value in week ten, significantly higher than that in Group G ($P<0.001$). In Group H, a significant correlation was observed among observed events of wool-pulling behaviour and wool-pulling score ($R=0.98$, $P=0.01$). Wool-cover score and total number of wool-pulling events over the experimental period are shown in Fig. 3.

Ewes with altered wool cover showed bald patches in different parts of the body, but not with the same prevalence. From the eleven affected ewes, eight of them (73%) showed bald patches in the rump, which was clearly the most affected part. Bald patches in the neck and top of the shoulders were observed in three animals each (27%), and the back in two animals (18%). The areas of alopecia included one or more of the different body regions considered (Table 2).

The total number of observed aggressive behaviours throughout the experiment was 46 events, 35 of which were in group H (76%) and 11 were in group G (24%), being significantly higher in Group G ($P=0.04$). In Group H, aggressive behaviours were especially higher from Weeks Two to Six, and decreased from Week Seven to the end of the experiment. Thus, no consistent time trend was observed of aggressive behaviours throughout the experimental period. Furthermore, in Group H, aggressive behaviours were observed at a higher prevalence in the afternoon period than in the morning and evening. Total number of aggressive behaviours throughout the experimental period is shown in Fig. 4.

The average number of ewes resting and ruminating over the ten-week experimental period is shown in Fig. 5. There were no significant differences in the average number of ewes resting and ruminating between Groups G and H over the ten-week experimental period, but both behaviours showed differences according to the time of the day, the morning being the period with more ewes resting and ruminating, as compared to the afternoon (resting: 17.5 ± 1.4 ewes in the morning *vs.* 3.6 ± 1.7 ewes in the afternoon, $P<0.05$; ruminating: 8.2 ± 1.8 ewes in the morning *vs.* 1.7 ± 1.1 ewes in the afternoon, $P<0.05$).

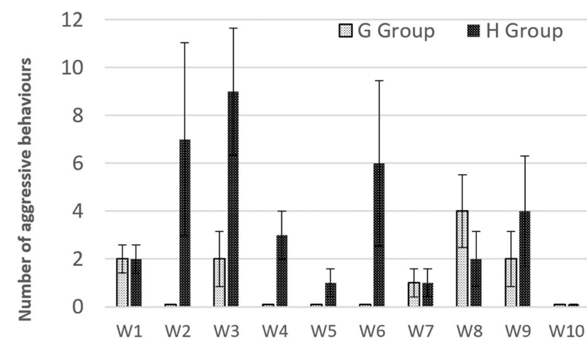

Fig. 4. Number of aggressive behaviours throughout the ten-week experimental period in G and H groups. "W" means each week on the experimental period.

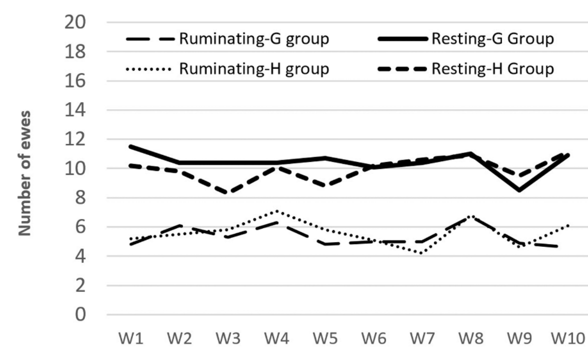

Fig. 5. Number of ruminating and resting ewes along the ten-week experimental period in group G and H according to the methods proposed by Bateson and Martin (2021). "W" means each week on the experimental period.

4. Discussion

In ewes, fleece condition and wool cover have been proposed as an animal-based indicator in sheep welfare assessment (Phytian et al., 2011), but as a multiple cause indicator. AWIN protocol (2015) includes fleece condition as one of the indicators, without specifying the cause of origin. In some studies, bald patches in the back areas have been described, but the cause of wool loss could not be elucidated (Morgan et al., 1986). Our results support that cause of origin of bald patches should and can be differentiated from other causes like external parasites or infectious diseases, in accordance with other studies (Chiezey, 2010).

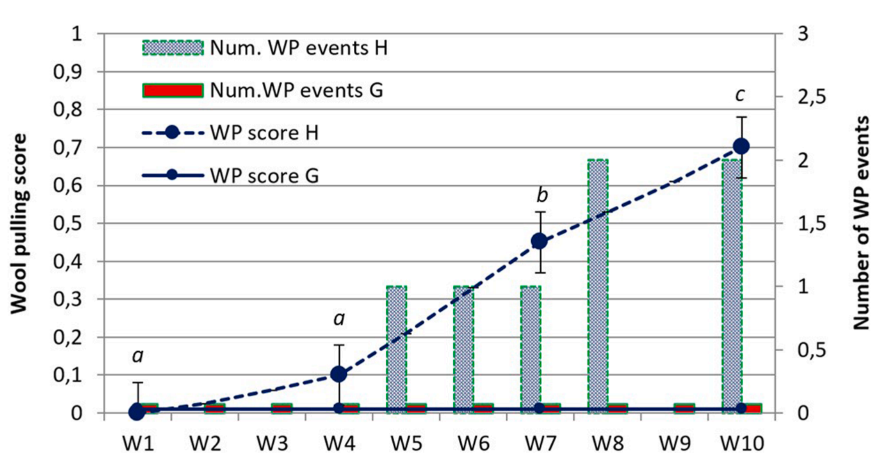

Fig. 3. Number of wool pulling behaviours observed by video-recording in group G (red bars) and H (blue bars) and wool pulling score in G group (solid line) and H group (dotted line). "W" means each week on the experimental period. "WP events" means wool-pulling events and "WP score" means wool-pulling score.

From our results, we propose an animal-based indicator to assess wool-pulling behaviour in sheep, which is based on wool cover. It could be a precise measure for an abnormal behaviour based on an integumental alterations, like feather loss to assess pecking behaviour in lying hens (Welfare Quality® Project, 2009), tail lesions to assess tail-biting behaviour in pigs (Honeck et al., 2019; Brünger et al., 2019) or skin lesions to assess aggressiveness (Turner et al., 2006). In our experiment, it was a feasible indicator to use on-farm and, in addition, it was accurate, because the flock score significantly increased both with increasing number of affected animals and individual indicator scores. The use of an animal-based indicator allows the assessment of a behaviour that is difficult to be directly observed on-farm, because of its low prevalence and its appearance varies throughout the day, being more visible in the evening.

In our study, both groups were fed with alfalfa hay and thus there is no reason to assume that lack of long fibre was an issue. Lack of long fibre diets have been suggested to cause abnormal oral behaviours because they decreaserumination, but as expected, reduced rumination was not observed in any of the two experimental groups. This gives further support to the hypothesis that wool-pulling behaviour in H group was not caused by diet but by lack of grazing.

Our results show that the rump is clearly the most affected body region and this could be due to the rump being the most exposed body region. Therefore, the most affected areas could depend on the pen design or space allowance. According to the literature, it is not clear which areas of the body are most affected when wool-pulling occurs. Some authors consider that the most affected areas are the neck, shoulder and abdomen (Abd El-Raof, Ghanem, 2006), and the shoulders and chest (Huang, Takeda, 2015). Other authors consider that this appears first in the back, but that all areas can be affected in time (Reinhardt, 2005). In young rams, the most affected areas have been found on the shoulder and over the hip (Chiezey, 2010).

In our experiment, there were 11 animals of Group H with wool loss attributed to wool-pulling, which were not identified as the youngest ones. It was not possible to identify the hierarchical rank of these animals in the flock. Wool-pulling is usually performed by dominant sheep to subordinate animals (Fraser, 1983; Reinhardt, 2005). Some authors consider younger and weak animals as the most affected ones, being repeatedly bitten by the others (Chiezey, 2010). In wild deer, pelt-biting has been reported, individuals of lower hierarchical rank, lighter individuals than heavier and younger individuals by older ones being more affected (Pérez-Barbería et al., 2021). During the course of the study, wool-pulling behaviour did not spread from group H to group G despite the proximity of these two groups, and thus there was no evidence of social learning of wool-pulling behaviour.

In our experiment, ewes were confined with a stocking of 2.5 m^2/ewe, although in the AWIN protocol (2019) 1.5 m^2/ewe is considered sufficient to ensure good welfare. In addition, good bedding conditions were also ensured during the experiment, therefore these conditions do not support that wool-pulling be caused by a restrictive environment or husbandry deficiencies. According to the literature, factors that trigger wool-pulling behaviour are multiple. Housing and animal management deficiencies are some factors that can lead to wool-pulling. Husbandry deficiencies like crowding results in chronic stress that can induce wool-pulling (Reinhardt, 2005; Dwyer, Lawrence, 2008). Restricted environment (Cooper, Jackson, 1996) or limited-sized pens (Fraser, 1983) can also induce this behaviour. Farm management seems to be associated with wool-pulling, but it cannot fully explain the development of this behaviour, and space allowance limit to induce wool-pulling is 2 m^2/ewe (reviewed by Huang, Takeda, 2015).

Feeding has also been reported as one of the causes of wool-pulling. According to Chiezey (2010), it is a vice produced in confined animals fed diets of small particle size, which do not stimulate rumination, and can be solved by adjusting the diet to a correct texture. Rolled hay has been reported to repress wool-biting by providing appropriate oral stimulation, and its provision has been suggested as a method to control wool-pulling (Huang, Takeda, 2018). Lack of minerals has also been suggested to produce it (Taha, 2012; Al-Saad et al., 2010; Abd El-Raof, Ghanem, 2006). In particular, deficiencies in copper, zinc, iron (Ebrahim, 2015) and sulphur have been suggested to induce wool-pulling behaviour (Xiao-Yun, 2011). In our experiment, both groups were fed with long-sized alfalfa hay fibre and were vitamin-mineral supplemented, therefore type of feeding cannot be attributed to cause wool-pulling.

Wool-pulling has been defined, too, as a redirected behaviour, which is consistent with our results. It is considered as an abnormal behaviour that appears when sheep are deprived of adequate levels of activity or oral stimulus (Vasseur et al., 2006) and not a stereotypic behaviour. It can be associated with farm management and feeding but these factors cannot fully explain the development of this behaviour (Huang, Takeda, 2015). It has been suggested tearing grass while grazing as being a movement of normal foraging behaviour, and the lack of this movement induces wool-pulling (Huang, Takeda, 2018). In our experiment, both groups were managed in the same conditions and no apparent feeding causes can be attributed to inducing wool-pulling behaviour. Thus, we suggest that grazing restriction was the factor causing wool-pulling.

According to the results of this experiment, wool-cover assessment could be an interesting indicator to be included in a welfare protocol assessment, in order to evaluate exclusively wool-pulling behaviour. Loss of wool cover caused by other causes, such as external parasites or dermal infections, should be evaluated in a separate scoring system in order to assess welfare deficiencies included in the good health section of welfare protocols. In line with this, previous studies (Parés et al., 2023) have evaluated the presence of external parasites, including scabies and mites, using a specific score.

In commercial farms, restrictions in access to pasture may be unavoidable in specific situations (EFSA, 2014). But according to our results, wool-pulling appears from weeks of restriction, therefore restrictions during lambing and post-lambing could be performed without negative welfare consequences. In other situations of pasture restrictions, like drought periods or adverse weather conditions, long restriction periods taking weeks should be avoided (Bernués et al., 2011).

In our experiment, ewes were housed at a density of 2.5 m^2/ewe, and thus the level of aggressive interactions cannot be attributed to a deficiency in space allowance (AWIN, 2019). The prevalence of aggressive behaviours in a flock can be considered an indicator of good welfare. Indeed, aggressive behaviours decrease when stocking density increases (reviewed by El Sabry et al., 2023). The level of aggressive behaviours is sensitive to changes in space allowance, especially in the resting area (Boe et al., 2006), and pen design (Jorgensen et al., 2009a), and the most prevalent aggressive interaction is pushing (Jorgensen et al., 2009b). Indeed, aggressive interactions have been reported to be reduced when space allowance increases from 0.75 to 2.25 m^2/ewe, and for pregnant ewes it has been recommended that a space allowance not be lower than 1.50 m^2/ewe (Vick et al., 2017). Other authors (Averós et al., 2014) observed the patterns of activity inside the pen better when space allowance increased from 1 to 3 m^2/ewe. Visual contact between animals has also been considered an important factor to avoid abnormal behaviours (Jorgensen et al., 2009b), which was ensured in our trial. Aggressive behaviours can also appear when there is competition in access to feeders (Richmond et al., 2017). In our trial, all ewes had simultaneous access to feed, and we discarded it as a negative effect.

We observed in a higher prevalence of aggressive behaviours in Group H during the entire experimental period, and this suggests it was caused by grazing restriction. As previously mentioned, grazing is a natural behaviour for sheep and its reduction has a negative effect on their welfare (Bergeron et al., 2006). Therefore, we concluded that the higher prevalence of aggressive behaviours could be an indicator of a welfare decrease caused by grazing restriction.

In contrast with wool-pulling behaviour, the level of aggressive behaviours did not increase progressively throughout the experimental period, but rather they reached a maximum at the third week, which suggests a progressive adaptation over weeks, observed by other authors (Done-Currie et al., 1984).

5. Conclusions

Wool-pulling behaviour is difficult to be visually observed in a farm because the low frequency of the behaviour. Wool-pulling behaviour is a redirected behaviour that appears when grazing is restricted. However, it can be assessed through wool-cover condition. The four scale score of wool cover to assess wool-pulling behaviour is a feasible indicator that could be included in welfare protocols to be used on sheep farms. The level of aggressive behaviours such as buttings and threats also increase when grazing restriction exists, and they could be monitored in an on-farm welfare assessment.

CRediT authorship contribution statement

Ricard Parés: conception and design of the study, acquisition, analysis and interpretation of data; drafting the article. **Pol Llonch**: contribution to drafting the article, revising it critically for important intellectual content. **Xavier Such**: revising it critically for important intellectual content. **Xavier Manteca**: revising it critically for important intellectual content

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abd El-Raof, Y.M., Ghanem, M.M., 2006. Clinical and haemato-biochemical studies on cases of alopecia in sheep due to deficiency of some trace elements. SCVMJ X (1), 17–27.

Akgul, Y., Agaoglu, Z.T., Kaya, A., Sali, T., 2000. The relationship between the syndromes of wool eating and alopecia in Akkaraman and Morkaraman sheep fed corn silage and blood changes (haematological, biochemical and trace elements). Isr. J. Vet. Med. 56, 23–37.

Albright, J.L., 1993. Nutrition, feeding, and calves. J. Dairy Sci. 76, 485–498.

Al-Saad, K.M., Al-Sadi, H.I., Abdul-Majeed, M.O., 2010. Clinical, hematological, biochemical and pathological studies on zinc deficiency (hypozincemia) in sheep. Vet. Res. 3 (2), 14–20.

Averós, X., Lorea, A., Beltran de Heredia, I., Arranz, J., Ruiz, R., Estevez, I., 2014. Space availability in confined sheep during pregnancy, effects in movement patterns and use of space. PLoS One 9 (4), e94767.

AWIN, 2015. AWIN Welfare assessment protocol for sheep. DOI:10.13130/AWIN_SHEEP:2015.

Bateson, M., Martin, P., 2021. Measuring behaviour: An Introductory Guide. Cambridge university press,.

Bello, T., Hussaini, M., Oyelowo, B., Hassan, R., Oke, B., Idris, S., 2020. Hair plucking and alopecia in a flock of sheep in Zaria, Nigeria. Sahel J. Vet. Sci. 17, 34–36.

Bergeron, R., Badnell-Waters, A.J., Lambton, S., Mason, G., 2006. Stereotypic oral behaviour in captive ungulates: foraging, diet and gastrointestinal function. Stereo Anim. Behav.: Fundam. Appl. Welf. 19–57.

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., Casasús, I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: synergies ans trade-offs. Livest. Sci. 139, 44–57. https://doi.org/10.1016/j.livsci.2011.03.018.

Boe, K.E., Berg, S., Andersen, I.L., 2006. Resting behaviour and displacements in ewes – effects of reduced lying space and pen shape. Appl. Anim. Behav. Sci. 98, 249–259. https://doi.org/10.1016/j.applanim.2005.10.001.

Brünger, J., Dippel, S., Koch, R., Veit, C., 2019. "Tailception": using neural networks for assessing tail lesions on pictures of pig carcasses. Animal 13 (5), 1030–1036.

Campion, D.P., Leek, B.F., 1997. Investigation of a "fibre appetite" in sheep fed a "long fibre-free" diet. Appl. Anim. Behav. Sci. 52, 79–86.

Chiezey, N.P., 2010. Hair pulling in confined sheep fed a finely ground ration: case report. Livest. Res. Rural Develp. 22 (3), 52.

Cockram, M.S., 2004. A review of behavioural and physiological responses of sheep to stressors to identify potential behavioural signs of distress. Anim. Welf. 13, 283–291.

Cooper, J., Jackson, R., 1996. A comparison of the feeding behaviour of sheep in a straw yard and on slats. Appl. Anim. Behav. Sci. 49, 99.

Done-Currie, J.R., Hecker, J.F., Wodzicka-Tomaszewska, M., 1984. Behaviour of sheep transferred from pasture to an animal house. Appl. Anim. Behav. Sci. 12 (1-2), 121–130.

Doukas, D., Liakou, Z., Tontis, D., 2021. *Sarcoptes scabiei* dermatitis in adult sheep: an immunohistochemical study of 34 chronic cases with extensive lesions. J. Hell. Vet. Med Soc. 72 (1), 2755–2764.

Dwyer, C., Lawrence, A., 2008. Introduction to Animal Welfare and the Sheep. In: The Welfare of Sheep. Animal Welfare, vol 6. Springer,, Dordrecht. https://doi.org/10.1007/978-1-4020-8553-6_1.

Ebrahim, Z.K., 2015. Clinical, hematological and biochemical studies on wool eating syndrome in sheep. Alex. J. Vet. Sci. 46, 95–99.

EFSA, 2014. Scientific opinion on the welfare risks related to the farming of sheep for wool, meat and milk production. EFSA J. 12 (12), 3933. https://doi.org/10.2903/j.efsa.2014.3933.

El Sabry, M.I., Motsei, L.E., Abdel-Mageed, I.I., Almasri, O., 2023. Space allowance impacts behavior, productivity, reproductivity and immunity of sheep—a review. Trop. Anim. Health Prod. 55 (3), 207.

Erhard, H.W., Fàbrega, E., Stanworth, G., Elston, D.A., 2004. Assessing dominance in sheep in a competitive situation: level of motivation and test duration. Appl. Anim. Behav. Sci. 85, 277–292.

Firyal, S., 2007. Pica (depraved appetite; allotrophagia) in domestic animals and man. Pak. Vet. J. 27, 208–210.

Fisher, A., Matthews, L., 2001. The social behaviour of sheep. In Social behaviour in farm animals. CABI publishing,, Wallingford UK, pp. 211–245.

Fraser, A.F., Broom, D.M., 1997. Farm Animal Behaviour and Welfare. CAB International, Oxon, UK. ISBN 0-85199-160-2.

Fraser, 1983. The behaviour of maintenance and the intensive husbandry of cattle, sheep and pigs. Agriculture, Ecosystems and Environment, 9(1):1-23.

Hall, M.J.R., 1997. Traumiatic myasis of sheep in Europe: a review. Parassitologia 39, 409–413.

Honeck, A., Gertz, M., grosse Beilage, E., Krieter, J., 2019. Comparison of different scoring keys for tail-biting in pigs to evaluate the importance of one common scoring key to improve the comparability of studies–a review. Appl. Anim. Behav. Sci. 221, 104873.

Huang, C.Y., Takeda, K.I., 2015. The wool-biting behaviour of sheep: a short review. Anim. Behav. Manag. 51 (2), 65–72.

Huang, C.Y., Takeda, K.I., 2018. Effect of the proportion of roughage fed as rolled and baled hay on repressing wool-biting behaviour in housed sheep. Anim. Sci. J. 89 (1), 227–231.

Jorgensen, G.H.M., Andersen, I.L., Boe, K.E., 2009a. The effect of different pen partition configurations on the behaviour of sheep. Appl. Anim. Behav. Sci. 119 (1-2), 66–70.

Jorgensen, G.H.M., Andersen, I.L., Berg, S., Boe, K.E., 2009b. Feeding, resting and social behaviour in ewes housed in two different group sizes. Appl. Anim. Behav. Sci. 116, 198–203.

Lynch, J.J., Hinch, G.N., Adams, D.B., 1992. The behaviour of sheep: Biological principles and implications for production. CAB international,.

Martin, W.W., Aitken, I.D., 2000. Enfermedades de la oveja. Segunda edición. Editorial Acribia, S.A., Zaragoza, España. ISBN 84-200-0987-3.

Morgan, K.L., Brown, P.J., Wright, A.I., Steele, F.C., Baker, A.S., 1986. An investigation into the aetiology of "wool slip": alopecia in ewes which are housed and shorn in winter. Vet. Rec. 119, 621–625.

Parés, R., Llonch, P., Manteca, X., Such, X., 2023. Sheep welfare assessment of meat-purpose farms from Spain in different breeds and production systems. Front. Anim. Sci. 4, 1218495.

Pérez-Barbería, F.J., García, A.J., López-Quintanilla, M., Landete-Castillejos, T., 2021. Pelt biting as a practical indicator of social and environment stress in farmed red deer. Animals 11 (11), 3134.

Phytian, C.J., Michalopoulou, E., Jones, P.H., Winter, A.C., Clarkson, M.J., Stubbings, L. A., Grove-White, D., Cripps, P.J., Duncan, J.S., 2011. Validating indicators of sheep welfare through a consensus of expert opinion. Animal 5 (6), 943–952.

Reinhardt, V., 2005. Hair pulling: a review. Lab. Anim. 39, 361–369.

Richmond, S.E., Wemelsfelder, F., De Heredia, I.B., Ruiz, R., Canali, E., & Dwyer, C.M., 2017. Evaluation of animal-based indicators to be used in a welfare assessment protocol for sheep. Frontiers in Veterinary Science, 4:210.

Salem, N., 2017. Clinical and laboratory investigations associated with Sheep's Allotrophagia. Vet. Med. J. 63 (3), 1–6.

Shields, S., Orme-Evans, G., 2015. The impacts of climate change mitigation strategies on animal welfare. Animals 5, 361–394.

Taha, R., 2012. Hematological, biochemical and hormonal studies on postpartum alopecia in ewes. J. Am. Sci. 8 (9), 968–972.

Turner, S.P., Farnworth, M.J., White, I.M., Brotherstone, S., Mendl, M., Knap, P., Lawrence, A.B., 2006. The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. Appl. Anim. Behav. Sci. 96 (3-4), 245–259.

Vasseur, A.B., Paul, A., Atkinson, A., Colditz, A., Fisher, A.C., 2006. Effects of dietary fibre and feeding frequency on wool biting and aggressive behaviours in housed Merino sheep. Aust. J. Exp. Agric. 46 (1), 777–782.

Vick, S.G., Oyrehagen, O., Boe, K.E., 2017. Effect of space allowance and flooring on the behaviour of `pregnant ewes. J. Anim. Sci. 95, 2032–2040.

Von Keyserlingk, M.A.G., Rushen, J., de Passillé, A.M., Weary, D.M., 2009. Invited review: the welfare of dairy cattle—Key concepts and the role of science. J. Dairy Sci. 92 (9), 4101–4111.

Xiao-Yun, S., 2011. Studies on wool-eating ailment in guizhou semi-fine wool sheep. Agric. Sci. China 10 (10), 1618–1623.