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A pilot study evaluating the behaviour of grazing sheep feeding on an anti-methanogenic feed additive from an automated feeder

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ABSTRACT

Context. Regular provision of feed additives to reduce ruminant methane production has shown promising outcomes; however, appropriate carrier pellet delivery systems for grazing sheep are lacking. **Aims.** This pilot study investigated the behavioural and social patterns of grazing sheep when offered Asparagopsis-treated pellets by using a modified Nedap electronic sow feeder (ESF). **Methods.** Seventy grazing Merino wethers were divided into two equal groups, with the first group being put in a paddock with the feeder for 35 days before the second group was introduced. During the first 21 days, the feeder was programmed to deliver 30 g of pellets per sheep, six times per day, then increased to eight times per day for the remainder of the study. Parameters recorded by the Nedap for each visitation by sheep included feeder entry and exit time and whether or not pellets were dropped. Additional behavioural parameters were annotated from video recordings, including aggressive interactions, whether sheep finished eating and causes of incomplete feeding. **Key results.** In Group 1, 82.3% of the sheep visited the feeder, with 4.4 $\pm$ 0.3 (mean $\pm$ s.e.) feeding visits per day. In Group 2, only 28.6% of the sheep visited, averaging only one feeding visit per day. The daily mean feeder occupation time after feed was dispensed ranged from 69.6 $\pm$ 3.5 to 77.5 $\pm$ 1.4 s. In Group 1, animals that used the feeder had at least 8% lower mean daily visit frequency in Weeks 6 and 7 compared with other weeks. In Group 2, the mean feeder visit was at least 26% higher in Week 9 than in Weeks 7 and 8. Displacement by other sheep was the main reason for incomplete feeding events, followed by self-initiated disturbance. **Conclusions.** Grazing sheep successfully learnt to consume supplementary feed multiple times per day from the ESF. However, the lower participation rate of Group 2 could indicate a need for training and/or fewer animals per feeder. **Implications.** Further research to evaluate the impacts of training periods, social learning, and dominance with multiple groups of sheep and multiple feeders within a paddock will contribute towards recommendations for producers on how to effectively deliver anti-methanogenic supplements with electronic feeders to sheep at pasture.

Keywords: aggression, behaviour, displacement, feed additive, grazing sheep, incomplete feeding, Merino, Nedap electronic sow feeder.

Introduction

Enteric methane, produced primarily by grazing ruminants, contributes over 71% of the 17–18% of total greenhouse gas emissions attributed to agricultural sector in Australia (Black *et al.* 2021; Badgery *et al.* 2023). Mitigating these emissions has become a major research priority, with several anti-methanogenic compounds such as *Asparagopsis* spp., 3-nitrooxypropanol (3-NOP), and Agolin showing promising results, reducing enteric methane emissions by 15–90% in sheep, dairy, and beef cattle under controlled conditions (Almeida *et al.* 2021; Smith *et al.* 2022). Some additives, such as *Asparagopsis*, require multiple daily doses to achieve maximum efficacy, highlighting the need for practical and reliable delivery systems in grazing environments (Alvarez-Hess *et al.* 2024; Adam *et al.* 2025).

Whereas the efficacy of these additives has been well-documented in indoor settings, their success in pasture-based systems depends largely on consistent delivery and animal acceptance. Delivering uniform doses to individual grazing animals poses practical challenges, particularly in extensive systems where additives can be administered only at strategic locations, for example, by using supplementary feeders. In this context, understanding how grazing sheep interact with supplementary feeding systems, including their learning patterns, visit frequency, and social influences, is critical. Systems capable of delivering precise quantities of additives to individual sheep in grazing conditions remain limited (Vaintrub *et al.* 2021; Tzanidakis *et al.* 2023). Most existing studies on automated feeders for small ruminants involve group-housed animals in confined environments, typically in research settings (Gipson *et al.* 2006; Faltys *et al.* 2014; Muir *et al.* 2020).

Automated feeding technologies have been widely used in livestock research under controlled conditions to enable individualised feed delivery and intake measurement. These include systems for cattle (Chizzotti *et al.* 2015; Cramer *et al.* 2020), pigs (Nielsen *et al.* 1995; Hyun and Ellis 2002), and sheep (Behrendt *et al.* 2020; Ferreira *et al.* 2025; Gao *et al.* 2025). Such systems use radio-frequency identification (RFID) to recognise individual animals and regulate feed delivery, often with physical barriers that permit access for only one animal at a time (Simanungkalit *et al.* 2021; Tzanidakis *et al.* 2023). One such system is the Nedap electronic sow feeding (ESF) system, originally designed for pigs. It delivers defined feed portions to individual pigs in group housing, while recording feeding times. However, its design with a single feeding outlet may lead to queuing or competitive behaviour, especially during peak feeding periods (Bench *et al.* 2013). Whether these systems can be adapted for use in extensive, pasture-based sheep production remains unclear. Their adoption depends not only on operational factors, such as initial cost of the feeder and associated costs, portability, power supply, weather resilience, and ease of refilling, but also on how individual animals interact with the technology. Key behavioural considerations include whether sheep can learn to use automated feeders, how quickly they adapt, and the extent to which their interactions are shaped by social learning or dominance hierarchies. For instance, the inclusion of naïve sheep alongside trained individuals may facilitate learning via social transmission (Villalba *et al.* 2012; Kearton *et al.* 2022; Vartparonian and Leu 2024), although the inherently social nature of sheep may also lead to increased competition around feeding stations, potentially restricting access for subordinate individuals (Erhard *et al.* 2004; Bøe and Andersen 2010).

The aim of this study was to assess whether sheep could be trained to regularly use an automated feeder under field conditions and to evaluate the influence of flockmates on individual feeding behaviour and overall flock learning success. This pilot study used a modified version of the Nedap ESF system to deliver small quantities of supplementary pellets to individual sheep grazing in a shared paddock. This system was selected because of its robust data-recording capabilities, which met the specific requirements of the study. We hypothesised that sheep would learn to regularly visit the feeder following a training period, and that newly introduced animals would learn through social interaction with trained flockmates. We also expected that competitive behaviour might emerge as sheep accessed feed through a single-feeder outlet.

Materials and methods

Animals and experimental design

The experimental design was reviewed and approved by the University of New England Animal Ethics Committee (ARA23-26). The experiment was conducted from May to August 2023, with 70 merino wethers in a paddock fitted with a modified Nedap electronic sow feeder (Nedap, N.V., Netherlands) at the Kirby SMART Farm, University of New England, Armidale, NSW, Australia. The sow feeder was modified by replacing the feeding crate with a race in front of the feeding trough to protect an animal from being displaced by others while feeding. Furthermore, the feeder was mounted with a step for refilling the hopper and a wider aluminium base to enhance its stability. Otherwise, all the features were the same as in the Nedap ESF designed for group-housed pigs (Fig. 1). The animals used for the experiment were randomly selected from a commercial flock of 500 sheep at the UNE SMART Farm. Selected animals were weighed and scored for body condition (scale: 1–5; Russel 1984) and checked for good health. Animals were accepted only if the body condition score was >2. The wethers had

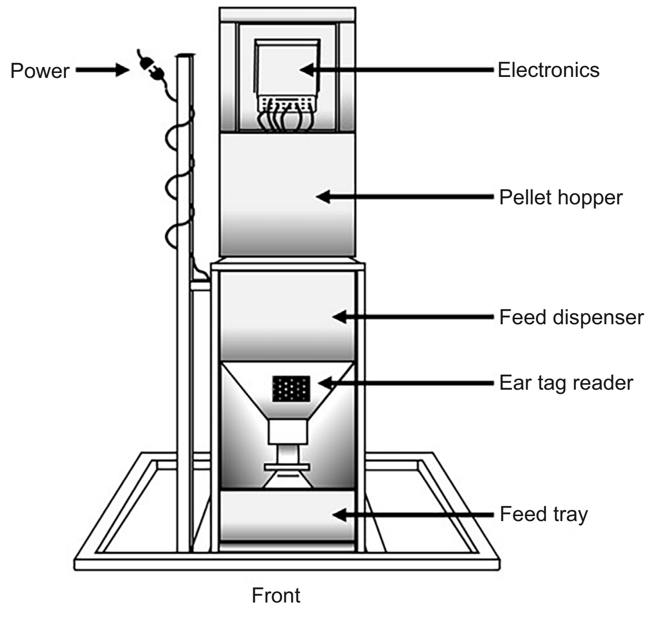

Fig. 1. A diagram showing the features of the Nedap electronic sow feeder, modified for use by grazing sheep.

an age of 1–2 years at the start of the experiment. All sheep were treated for internal parasites with Tridectin (Virbac, Australia) 1 day before the start of the experiment and again with Startect (Zoetis, Australia) (both oral drench) on the following day, at the recommended dose rate. All sheep were tagged with an electronic identification (Allflex HDX tags, Capalaba, Qld, Australia) before introducing them to the feeder.

The experiment started by randomly splitting the selected 70 1–2-year-old wethers (initial liveweight: 42.9 ± 0.5 kg) into two equal groups and spray marking as they came through the race, with each group consisting of 35 animals. The number of sheep allocated per feeder was determined on the basis of the capability of Nedap ESF system, which can feed up to 60 sows per feeder (Thomas *et al.* 2018). Given that only one feeder was available for this pilot study, the sheep were smaller in size, and the feeder was used solely to deliver supplementary feed rather than the full ration as is conventional in the pig industry, it was assumed that a single feeder could accommodate up to 70 sheep. The first group (Group 1) was moved to the experimental paddock (~2 ha), with the initial plan of training them on visiting the Nedap ESF for 2 weeks before bringing the second cohort (Group 2) into the paddock. The two groups were to be trained together for a further 1 week, followed by 3 weeks of measurement. However, because of technical issues observed on the feeder during the training of the first cohort, the introduction of Group 2 into the paddock was delayed until Week 6 to allow time for the technical issue related to the RFID tag reader to be fixed. The RFID tag reader was initially mounted on the right side of the feeder, whereas the sheep were tagged on the left ear, resulting in inconsistent signal detection because of the distance between the ear tag and the reader. Relocating the RFID tag reader to a more central position resolved this issue. Group 1 was trained to use the feeder by trailing pellets around the feeder for 3 weeks. During the first week, a protective race was built using metal fencing panels (1 m length × 1 m height) in front of the feeder outlet to protect sheep that accessed the feeder. The race was initially about 1.2 m wide and was gradually narrowed down to 30 cm by the end of Week 2, to allow only one sheep at a time in the feeder (Fig. 2). When Group 2 was introduced to the study in Week 6, the sheep were trained by trail feeding together with Group 1 for 1 week only. It was assumed that this group could learn from the experienced Group 1 animals through social learning (Vartparonian and Leu 2024). Measurements on the 70 animals were then subsequently conducted for another 3 weeks (Fig. 3).

The Nedap ESF was filled with 6-mm length all-purpose pellets (Mort and Co. Stockfeeds, Guyra, NSW, Australia) formulated with *Asparagopsis taxiformis* (Asparagopsis) extract infused in canola oil (SeaFeed™) and programmed to dispense the pellets on positive identification of the animal's RFID tag. Only Asparagopsis-treated pellets were used, as only one feeder was available for this pilot study. Changes in sheep behaviour directly as a result of the feed additive was not anticipated on the basis of previous studies (Li *et al.* 2018; Adam *et al.* 2025), which demonstrated no difference in intake between treated and untreated pellets. The maximum number of feeding sessions per sheep was manually set on the Nedap ESF software system at six times per day during the first 3 weeks and increased to eight times per day from Week 3 until the end of the experiment (Week 9) to increase the chance of accessing the feeder more frequently per day. The maximum number of feeding sessions was determined with the aim of shortening the interval between sessions from 4 to 3 h and encouraging sheep to visit the feeder more frequently each day, while causing minimal interruption to their natural grazing behaviour. Assuming that animals feed around the clock, the pellet drops were evenly spread throughout 24 h a day, with 30 g of the Asparagopsis-treated pellets dispensed during each feeding session. Each animal was allocated only 30 g of pellets at 3-h intervals on positive identification via RFID tag, and no compensation was provided for the missed feeding intervals. As part of farm management, all sheep were removed from the paddock for crutching at Week 7 for 2 days, before being returned. Sheep were grazing on native pasture, while also having access to the Nedap ESF system and drinking water was provided through a water trough during the study period (May to July). The average minimum temperature during the study was 0.0°C, and the average maximum temperatture was 15.8°C. Supplementary Rhodes grass hay was provided to sheep at an allowance of two 20-kg bales per 35 sheep per day, starting from Week 3 because of declining pasture availability in the paddock on the basis of visual observation.

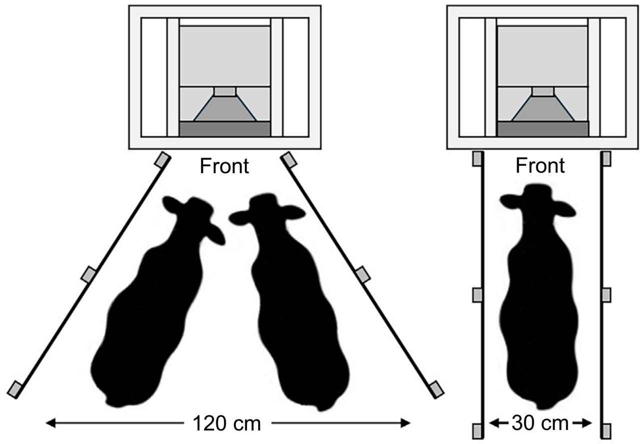

Fig. 2. The Nedap electronic sow feeder with a race built in front of the feeding trough. The race was initially wide (1.2 m left image) during sheep training and the width reduced to approximately 30 cm (right image) after the training period.

Data collection

Data on every animal's visit, including feeding as well as non-feeding sessions, were recorded automatically by the feeder software. Information on time of visit to the feeder (month/day/year-h/min/s), number of pellet drops, both entry and exit time, and individual animal identification number were

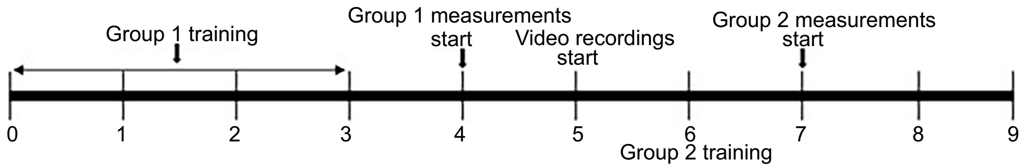

Fig. 3. Experimental timeline (week) relative to sheep introduction to the Nedap electronic sow feeder and activities performed during the study.

recorded and stored on a central database (Velos cloud) managed by Nedap. Raw data were downloaded from the Nedap database in a csv format file and transformed using the power query editor function in MS Excel for further analysis. Data for feeding sessions were distinguished from non-feeding sessions on the basis of the recorded pellet drop (30 g) for each visit linked to a known sheep RFID tag number. Partial and incomplete feeding could not be distinguished based on the recorded data. Random drops linked to unknown numbers were identified and removed from data analysis.

Video observations

To capture additional data to those recorded by the Nedap system, information on sheep behavioural patterns, around and while in the feeder, was captured using three GoPro video cameras (Hero5; GoPro, San Mateo, CA, USA) installed at different locations in the paddock. The first camera was installed above the feeding trough to capture information on whether the respective sheep finished their dispensed pellets on each visit. The second camera was installed at 8 m to the right side of the Nedap and the third camera was installed 16 m in front of the Nedap to capture any behavioural interactions around the feeder. Camera 2 and Camera 3 were 15 m apart. All sheep were spray-marked with numbers on both lateral sides of the body to assist in identifying individual animals in the video recordings. The two animal groups were marked using different colours to allow visual identification of Group 1 from Group 2. The first group was marked with numbers 1–35 by using a red colour spray, whereas the second group were marked with numbers 36–70 by using a blue spray. The video recording was conducted daily from 06:00 hours to 17:00 hours, for 5 weeks. The recording started 1 week prior to combining the two groups, followed by four consecutive weeks when the 70 animals were together. The frequencies of specific behavioural parameters observed were recorded on the basis of a predefined ethogram (Table 1).

Selected video recordings were chosen on the basis of image quality and full-day coverage. Some recordings were incomplete or unclear because sheep occasionally knocked the camera out of position or disconnected the battery cable when rubbing against the camera mounting post. Observations were conducted by an experienced observer across 4 days per week, which was selected as a representative sample time period while aligning with observer availability to analyse the large video dataset. These observations were made during the week prior to combining of the two groups (Week 5), at combining (Week 6), the middle of the measurement period after the two groups were combined (Weeks 7 and 8), and during the last week of the study (Week 9). A total of 32 h of video were analysed, selected across 4 days per week, with 1-h segments recorded during each peak feeding period in the morning and aftrenoon throughout the study period. Peak feeding visits in the morning (AM, between 9:00 hours and 11:30 hours) and in the afternoon (PM, between 12:00 hours and 15:30 hours) were identified from the daily data summary of the feeding visits obtained from the Nedap software interface (Nedap Now). Sheep behaviour was then manually annotated from the corresponding videos continuously for 1 h within the peak visit periods on the basis of the ethogram in Table 1. Behavioural interactions that were captured by the video camera were restricted to those displayed within 1 m of the feeder. Additional behaviours of individual sheep recorded within 5 m of the feeder were observed every 5 min over the same 1-h period by using a scan sampling technique. Individual animal ID based on the painted numbers was noted for each behaviour observed. In total, observations were conducted across 32 h of footage (1 h × 2 daily peak visit periods (AM/PM) × 4 days × 4 weeks).

Feeder data and statistical analyses

The individual animal visit data from the Nedap database were used to calculate the daily proportion of animals that visited the feeder, daily feeding frequency and mean daily feeding duration per animal. Individual animal data comprised an animal ID, entry and exit time of a visit and the amount of feed dropped (30 g). In total, 24,776 visits, including feeding and non-feeding sessions, were recorded during this study, of which 24,768 were valid visits linked to known tag numbers and eight were linked to unknown tag numbers. Of the valid visits recorded, 6705 were visits with feeding and 18,063 were visits with non-feeding. Visit durations were calculated as the time between animal entry and the entry of a different animal to the feeder. The time difference between the animal entry and exit time were not used, because those were close to zero for most animal visits. This is because animals frequently withdrew their heads from the feed trough, causing ear-tag reading to disconnect within a few seconds. Once the ear-tag reading was disconnected, the feeder did not re-read the same animal's ear tag until the entry of a different animal. Visit durations were averaged for each animal for each day. Visits with a duration of more than 5 min were excluded from calculating the average duration, considering the delay

Table 1. Ethogram used for studying behavioural interactions of Merino sheep while exposed to a Nedap electronic sow feeding system.

Category	Behaviour	Description
Aggressive interactions initiated within 1 m of the Nedap	Butting (IBUT)	Forceful contact of head with another sheep
	Pushing (IPu)	Using body (neck, forelimb) to apply pressure to another sheep from behind or side in feeder
	Mounting (IMT)	Elevate and position both front legs on a part of another sheep
	Pawing (Ipaw)	Lift front leg to contact another sheep
	Displacement from feeder (IDFeed)	Moved other sheep while in the feeding position
	Displacement from position (IDPos)	Moved other sheep from a position of waiting within 1 m of the feeder
	Total aggressive counts initiated (TAI)	Sum of IBUT, IMT, Ipu, IDFeed, IDPos, Ipaw
Aggressive interactions received within 1 m of the Nedap	Butting (RBUT)	Received forceful contact of head from another sheep
	Pushing (Rpu)	Received head or body pressure from another sheep from behind or side in feeder
	Mounting (RMT)	Received another sheep elevating and positioning both front legs on their body
	Pawing (Rpaw)	Received contact of one front leg from another sheep
	Displacement from feeder (RDFeed)	Moved away by another sheep while in the feeding position
	Displacement from position (RDPos)	Moved away from another sheep while waiting within 1 m of the feeder
	Total aggressive counts received (TAR)	Sum of RBUT, RMT, Rpu, RDFeed, RDPos, Rpaw
Individual animal behaviour within 1 m of the Nedap	Waiting (Wait)	Standing with head in the direction of feeder and close to another sheep
	Blocking (BLK)	Standing within the race and preventing other sheep from entering
	Feeding (FD)	Active eating of the pellets after Nedap reads the sheep ear tag and drops the pellets
	Finish eating (Fin)	Sheep finishes eating all dispensed feed within one visit
	Displaced feeding	Disturbed by another sheep
	Self-initiated disturbed feeding	Sheep spends a shorter time in feeder/jumps out quickly in the absence of any other discernible external factors
Individual animal behaviour within 5 m of the Nedap	Waiting	Standing with head in direction of feeder and close to another sheep
	Grazing	Head down and eating pasture
	Standing	Sheep standing with head in a different direction to Nedap
	Lying	Sheep with four legs flexed and with the abdomen fully or partially in contact with the ground

between each animal visit and that all animals could finish 30 g of pellet drop within 5 min. Data from Days 35–37 and Day 53 were excluded from the analysis because of Nedap software malfunction and sheep removal from the paddock for crutching respectively. In total, 14.8% (3677/24,768) of data points were excluded from the data analysis.

The daily proportion of animals that visited the Nedap ESF was expressed as a percentage of the total number of animals for each group. The mean number of daily visits per group was calculated by dividing the total visits over 24 h by the number of animals in the group. For the analysis of diurnal patterns of animal visits to the feeder, data were summarised by counting the number of visits recorded per hour for each animal during the study period.

Data were analysed using JMP (ver. 17.1) statistical software (SAS Institute, Cary, NC, USA). The mean number of weekly feeding and non-feeding visits, and the weekly mean duration of time the animals spent during feeding and non-feeding visits to the Nedap ESF, were analysed separately for Group 1 and Group 2. A generalised linear mixed model was used with experimental week as a fixed factor and individual animal as a random factor. ANOVA was used to test for the significance of the fixed factor.

Video analysis data on individual animal behaviour within 1 m of the feeder and aggressive interactions (initiated and received) were collated and summarised using descriptive statistics of frequency and proportion. The proportion of feeding finished or not finished was calculated in relation to the total number of feeding events observed. The frequency of different behavioural events observed per individual animal was calculated from the total number of behavioural events recorded from the video analysis. Data from video observations were summarised and presented in descriptive statistics because the data were unable to meet the assumptions of statistical testing.

Results

Overall animal visits recorded by the Nedap ESF

In total, 24,776 visits were recorded by the Nedap ESF during the study. Of these, 18,063 (72.9%) were non-feeding visits and 6711 (27.1%) were feeding visits to the feeder. Among the 6711 feeding visits recorded by the Nedap ESF, 0.12% were random drops linked to unknown numbers that were not associated with the experimental sheep and 1.46% were attributed to multiple drops per feeding sessions when only one drop was expected per session (Table 2).

Percentage of animals fed and the number of days animals attended the Nedap ESF for feeding

The percentage of animals feeding daily from the Nedap ESF for both Group 1 and Group 2 is summarised in Fig. 4. Overall, the number of animals visiting the feeder at least once during the study was 97.1% (34/35) and 71.4% (25/35) in Group 1 and Group 2 respectively. In Group 1, the overall mean percentage of sheep feeding from the feeder each day was 82.3% (29/35 per day) and this percentage remained largely unchanged throughout the study period. The mean percentage of animals that fed from the Nedap in Group 2 was 28.6% (10/35), with a mean daily feeding frequency of <1 (Fig. 4). Of the 14 days of measurement before combining groups, 74.3% of animals in Group 1 attended the Nedap ESF for feeding on at least 13 days and for the 28 days after combining, 74.3% had a feeding visit on at least 25 days (Fig. 4*b*, *c*). In Group 2, only 11.4% of animals attended the feeder for feeding on at least 17 days of the 21 days of measurement (Fig. 4*d*). Most animals in Group 2 (42.9%) did not visit the feeder for more than 4 days, with 31.4% of animals not visiting at all (Fig. 4*d*).

Table 2. Summary of sheep visits to the Nedap ESF during the study.

Category	Number of visits	Percentage (%)
Non-feeding visits	18,063	72.9
Feeding visits linked to known tag number	6705	27.1
Feeding visits linked to unknown tag number	8	0.03
Total	24,776	100

Frequency of animal feeding and non-feeding visits to the Nedap ESF

The frequency of visits per day and week for Group 1 and Group 2 are summarised in Fig. 5 and Table 3. In Group 1, the average daily feeding frequency per animal was 4.4 ± 0.3 (mean ± s.d.) of eight possible feeding visits. However, the mean daily frequency of non-feeding visits to the Nedap ESF was 11.3 ± 6.7 (mean ± s.d.) per animal. After the introduction of Group 2 into the study, a slight decrease in the frequency of feeding and non-feeding visits was observed for animals in Group 1 (Fig. 5). In Group 2, average daily

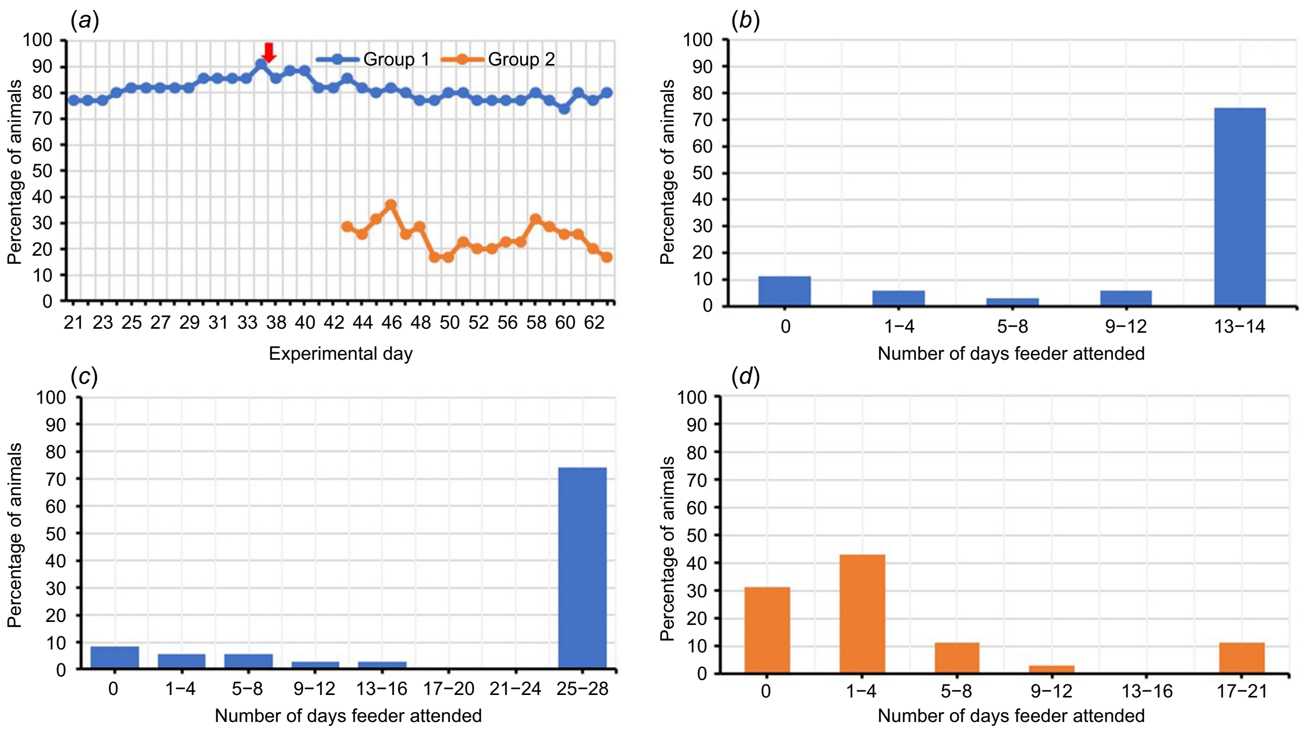

Fig. 4. (*a*) The percentage of sheep that fed from the Nedap electronic sow feeder each day; the percentage of sheep versus the number of days sheep attended the feeder for feeding (*b*) in Group 1 during the first 14 days of the measurement period before combining, (*c*) in Group 1 during the 28 days after combining, and (*d*) in Group 2 during 21 days of measurement. The red arrow shows the time when the two groups were combined.

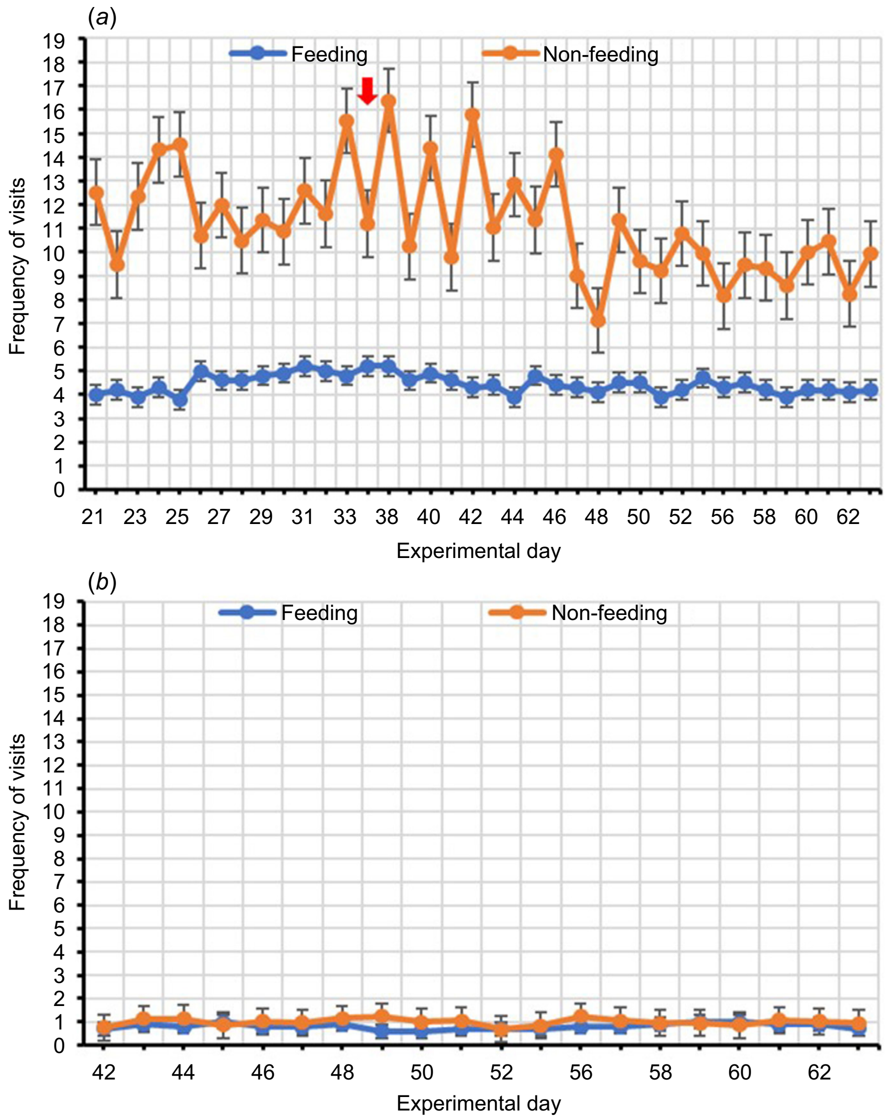

Fig. 5. The mean daily number (±s.e.m.) of feeding and non-feeding visits to the Nedap electronic sow feeder by (*a*) Group 1 and (*b*) Group 2 sheep used in the study. The red arrow shows the time when the two groups were combined.

Table 3. The mean number of daily visits to the Nedap electronic feeder by sheep in Group 1 and Group 2 by experimental week (mean ± s.e.).

Group	Category	Week						*P*-value
		4	5	6	7	8	9	
1	Non-feeding visits	11.7 ± 1.5	14.2 ± 1.5	8.9 ± 1.5	9.6 ± 1.5	9.1 ± 1.5	9.8 ± 1.5	0.001
	Feeding visits	4.3 ± 0.4	4.9 ± 0.4	4.4 ± 0.4	4.3 ± 0.4	4.2 ± 0.4	4.2 ± 0.4	0.04
	Visits for those that visited	20.6 ± 0.5	23.8 ± 0.5	18.4 ± 0.7	18.9 ± 0.5	20.4 ± 0.6	20 ± 0.5	0.001
2	Non-feeding visits				0.5 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.04
	Feeding visits				1.1 ± 0.3	0.5 ± 0.3	1.1 ± 0.3	0.24
	Visits for those that visited				8.4 ± 1.2	9.9 ± 1.1	13.4 ± 1.2	0.03

feeding and non-feeding frequencies were 0.7 ± 1.6 and 0.9 ± 3.1 (mean ± s.d.) per animal respectively.

The mean daily feeding frequency was significantly ($P < 0.04$) variable among experimental weeks in Group 1.

The frequency of feeding visits in Week 5 was significantly higher than in the other weeks, and there was a slight trend of reduced frequency of visits towards the end of the experiment (Table 3). In Group 2, the average daily feeding frequency was much lower and there was no significant difference in variability among the weeks ($P = 0.2$). In Group 1, the mean daily frequency of visits to the Nedap ESF among animals that visited the feeder was significantly ($P = 0.001$) different among the weeks, with a lower visit frequency being observed in Weeks 6 and 7 than in other weeks. In Group 2, this was significantly higher in Week 9 than in Weeks 7 and 8 (Table 3).

Mean duration of feeding and non-feeding visits to the Nedap ESF

The mean daily and weekly duration of time an animal spent during feeding and non-feeding visits to the Nedap ESF are summarised in Fig. 6 and Table 4. The overall mean time that an animal spent feeding on dispensed pellets in the feeding trough was 77.5 ± 1.4 and 69.6 ± 3.5 s (mean ± s.e.) in Group 1 and Group 2 respectively (Fig. 6). The overall mean time that an animal spent at the feeder during non-feeding visits was 92.3 ± 0.6 s in Group 1 and 112 ± 4.3 s in Group 2. The mean time that an animal spent during feeding and non-feeding visits at the Nedap ESF was significantly ($P < 0.02$) variable among experimental weeks. Higher mean time was recorded in Weeks 4 and 5 during feeding visits, and during non-feeding visits in Weeks 8 and 9, than in other weeks. This was not significant in Group 2 ($P > 0.05$) (Table 4).

Diurnal patterns of visits to the Nedap ESF

In Group 1, the highest mean visits per hour were recorded at approximately 06:00 hours, followed by at 11:00 hours, 14:00 hours, 16:00 hours and 22:00 hours before the two groups were combined. After the two groups were combined,

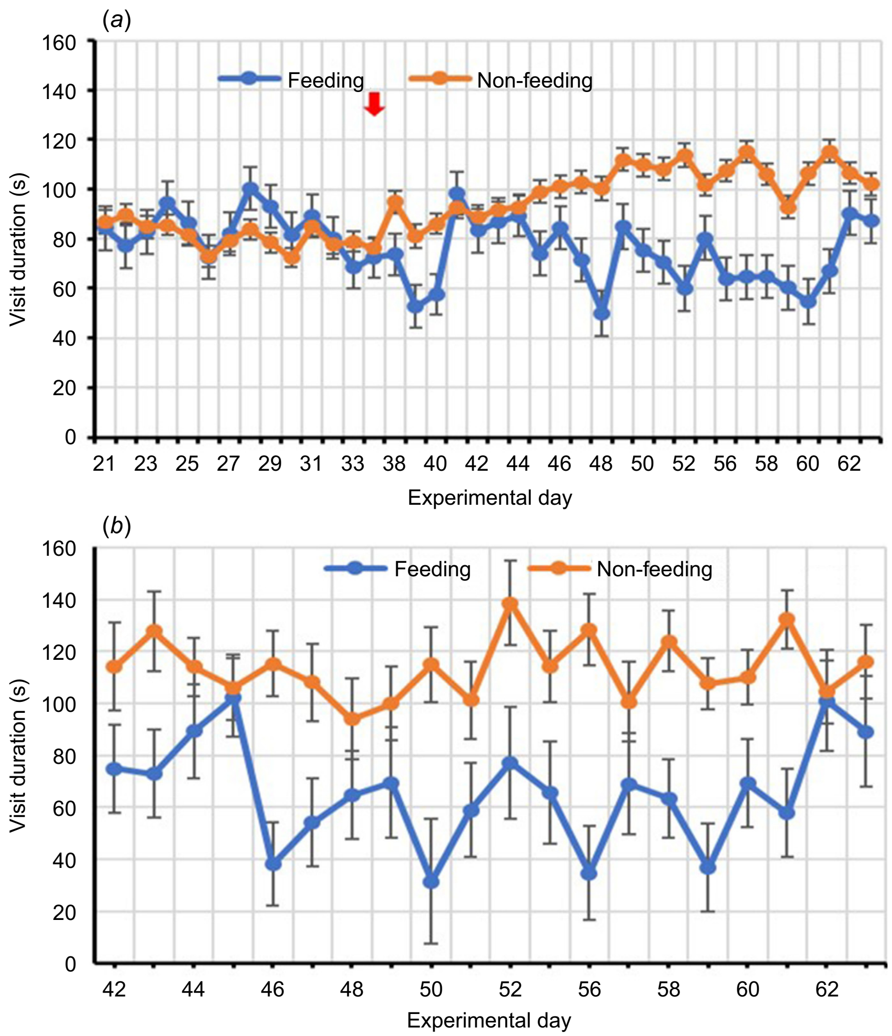

Fig. 6. Mean time (±s.e.m.) the sheep spent in the Nedap electronic sow feeding trough during the feeding and non-feeding session in (*a*) Group 1 and (*b*) Group 2 at each day of the study. The red arrow shows the time where the two groups were combined.

Table 4. The mean time (s) sheep in Group 1 and Group 2 spent during feeding and non-feeding visits to the Nedap electronic sow feeder by experimental week (mean ± s.e.).

Group	Category	Week						*P*-value
		4	5	6	7	8	9	
1	Non-feeding visits	85.1 ± 3.4	80.4 ± 3.3	88.4 ± 3.4	95.3 ± 3.4	106.3 ± 3.5	101.9 ± 3.5	0.001
	Feeding visits	82.8 ± 4.6	83.3 ± 4	69.9 ± 3.9	77 ± 4.2	74.8 ± 4.1	69.9 ± 3.9	0.02
2	Non-feeding visits				108.6 ± 8	116 ± 10.8	117.5 ± 7.5	0.7
	Feeding visits				73.2 ± 9.2	46.7 ± 10.6	68.5 ± 8.9	0.24

peak visits to the Nedap ESF were observed at 06:00 hours, 10:00 hours and 14:00 hours in Group 1 on each day, with a mean of 30, 33 and 32 visits respectively. However, in Group 2, the mean hourly visits were low (<4) throughout the day and the diurnal patterns of visits to the ESF were relatively similar, with no peaks in visits being observed throughout the study period. Visually, a pattern of more activity during the day than at the night-time was observed (Fig. 7).

Mean idle time for the Nedap ESF

Before the two groups were combined, the longest mean idle time when the Nedap ESF was not in use by sheep was recorded at 07:00 hours followed by at 10:00 hours and 11:00 hours in Group 1, with a mean of 31, 28 and 27 min respectively. After Group 1 and 2 were combined, the longest idle time was observed at 4:00 hours, 07:00 hours and 11:00 hours, with a maximum mean idle time of 14 min per hour (Fig. 8).

Individual animal behavior within a 1 m distance of the Nedap ESF

Numerically, the most common behaviour observed within 1 m of the feeder was sheep standing close together and facing the feeder (waiting), followed by feeding, in both Group 1 and Group 2 (Table 5). A numerical increase in the proportion of incomplete feeding events was observed in Group 1 after the introduction of Group 2 on Week 6, affecting both the AM and PM observation times (Table 6). Animal displacement from the feeder accounted for 71–100% and 50–100% of incomplete feeding in Group 1 and Group 2 respectively, throughout the study period. Self-initiated disturbance resulted in 0–28% and 0–50% of incomplete feeding observed in Group 1 and Group 2 respectively (Table 6).

Aggressive behavioural interactions initiated and received

The number of animals involved, and the number of events recorded for aggressive behavioural interactions initiated and received during the study are summarised in Tables 7 and 8. The analysis of video data in this study showed that butting was numerically the most frequent aggressive behaviour initiated (IBUT), followed by displacement from the feeder (IDFeed) and pawing (Ipaw) in Groups 1 and 2. No systematic variations were observed in the frequency of each aggressive behavioural interaction either over time or over the number of animals in the study. At Week 5, the percentage of animals that instigated aggressive behavioural interactions was 37.1% and 42.9% in the morning (AM) and afternoon (PM) respectively (Table 7). After the two groups were combined, the percentage of animals that initiated the aggressive behavioural interactions ranged from 22.9% to 37.1% in the AM and from 22.9% to 48.6% in the PM in Group 1, whereas, in Group 2, only 0–5.7% and 2.9–20% of animals were

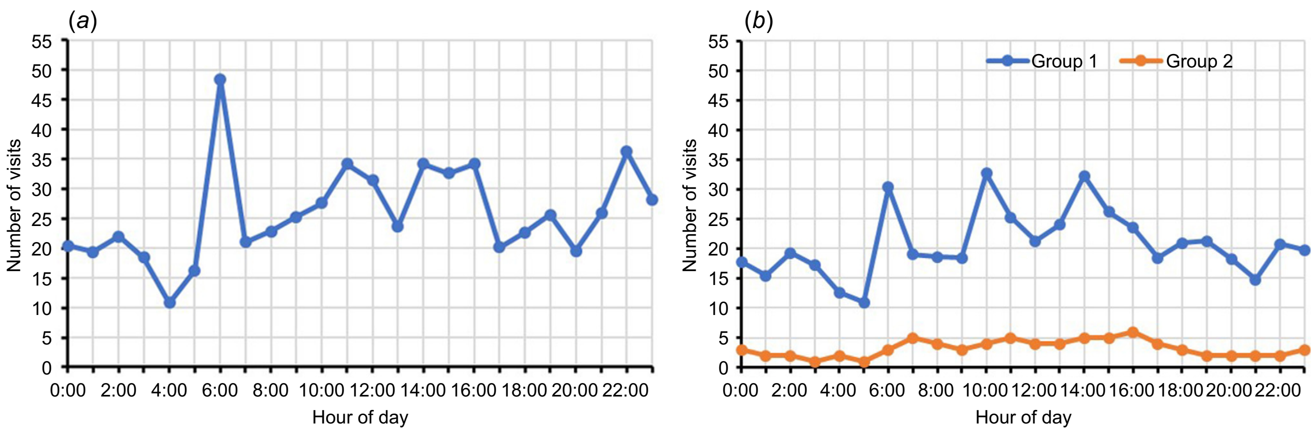

Fig. 7. The average number of visits per group to the Nedap electronic sow feeder recorded per hour by sheep over a 24 h cycle (*a*) before combining in Group 1 and (*b*) after Groups 1 and 2 were combined.

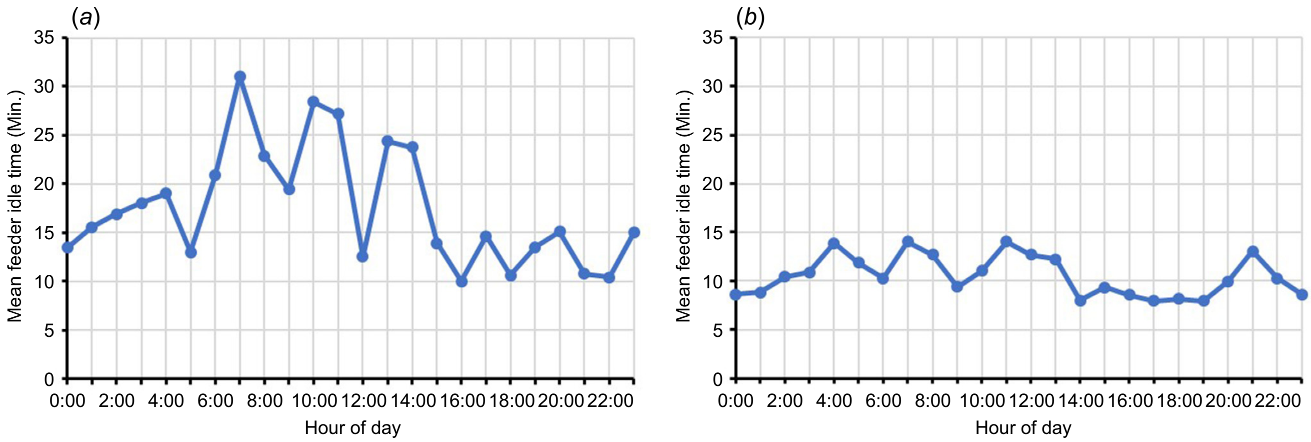

Fig. 8. Overall mean time (min) when the Nedap electronic sow feeder was not in use by the sheep (*a*) in Group 1 prior to combining with Group 2 (*a*), and (*b*) after the two groups were combined.

Table 5. Summary of individual animal behaviours exhibited within 1 m of the Nedap electronic sow feeder and number of animals involved for data collected at peak times in the morning (AM) and afternoon (PM) in selected weeks during the study period.

Behavioural parameter[A]	Time of day	Group	Week 5 (*n* = 35)[B]		Week 6 (*n* = 70)		Week 7 and 8 (*n* = 70)		Week 9 (*n* = 70)	
			Number of animals involved	Number of events (%)[C]	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)
Waiting	AM	1	27	125 (63.8)	26	177 (55.8)	24	116 (64.4	23	124 (54.4)
		2	–	–	18	47 (14.8)	8	13 (7.2)	10	33 (14.5)
	PM	1	27	149 (73.4)	25	119 (49.4)	27	137 (58.1)	28	160 (61.5)
		2			17	61 (25.3)	8	36 (15.3)	20	47 (18.1)
Retreat	AM	1	6	7 (4.1)	6	11 (3.5)	0	0 (0)	3	3 (1.3)
		2	–	–	1	1 (0.3)	0	0 (0)	1	1 (0.4)
	PM	1	4	4 (1.9)	1	1 (0.4)	0	0 (0)	2	2 (0.8)
		2	–	–	1	1 (0.4)	1	1 (0.4)	2	2 (0.8)
Blocked	AM	1	3	3 (1.8)	3	4 (1.3)	1	1 (0.6)	1	1 (0.4)
		2	–	–	0	0 (0)	0	0 (0)	0	0 (0)
	PM	1	2	2 (0.9)	2	2 (0.8)	2	2 (1.1)	0	0 (0)
		2	–	–	2	2 (0.8)	0	0 (0)	0	0 (0)
Blocking	AM	1	3	3 (1.8)	2	2 (0.6)	1	1 (1.1)	1	1 (0.4)
		2	–	–	2	2 (0.6)	0	0 (0)	0	0 (0)
	PM	1	2	3 (1.5)	0	0 (0)	2	2 (0.8)	0	0 (0)
		2	–	–	3	4 (0.2)	0	0 (0)	0	0 (0)
Feeding	AM	1	19	31 (18.3)	25	65 (20.5)	21	46 (25.6)	22	56 (24.6)
		2	–	–	7	8 (2.5)	3	3 (1.7)	5	9 (3.9)
	PM	1	26	45 (22.2)	25	43 (17.8)	23	47 (19.9)	22	44 (16.9)
		2	–	–	8	8 (3.3)	5	11 (4.7)	4	5 (2.2)
Total	AM	1	28	169 (100)	27	259 (81.7)	25	164 (91.1)	24	185 (81.1)
		2	–	–	26	58 (18.3)	9	16 (8.9)	10	43 (18.9)
	PM	1	28	203 (100)	16	165 (68.5)	27	188 (79.7)	28	206 (79.2)
		2	–	–	17	76 (31.5)	9	48 (20.3)	20	54 (18.8)

[A]See Table 1 for the ethogram of behaviours observed.
[B]*n* represents the number of sheep present in the paddock at each sampling week of the study.
[C]The number in parentheses represents the percentage of total observed behavioural events for a specific week and time period (AM or PM).

Table 6. Summary of animal feeding status and reason for incomplete eating of all dispensed feed from the Nedap electronic sow feeder in data collected at a peak time in the morning (AM) and afternoon (PM) in selected weeks during the study period.

Behavioural parameter[A]	Description[B]	Group	Week 5 (n = 35)[C]		Week 6 (n = 70)		Weeks 7 and 8 (n = 70)		Week 9 (n = 70)	
			AM	PM	AM	PM	AM	PM	AM	PM
Feeding status	Finished eating (%)	1	21/31 (67.7)	32/45 (71.1)	38/65 (58.5)	23/43 (53.5)	19/46 (41.3)	21/47 (44.7)	23/56 (41.1)	23/44 (52.3)
		2	–	–	4/8 (50)	5/8 (62.5)	1/3 (33.3)	3/11 (27.3)	2/9 (22.2)	2/5 (40)
	Eating not finished (%)	1	10/31 (32.3)	13/45 (28.9)	27/65 (41.5)	20/43 (46.5)	27/46 (58.7)	26/47 (55.3)	33/56 (58.9)	21/44 (47.7)
		2	–	–	4/8 (50)	3/8 (37.5)	2/3 (66.7)	8/11 (72.7)	7/9 (77.8)	3/5 (60)
Reason for incomplete feeding	Displaced (%)	1	9/10 (90)	13/13 (100)	20/27 (74.1)	20/20 (100)	23/27 (85.2)	20/26 (76.9)	25/33 (75.8)	15/21 (71.4)
		2	–	–	2/4 (50)	3/3 (100)	1/2 (50)	5/8 (62.5)	7/7 (100)	2/3 (66.7)
	Self-initiated disturbance (%)	1	1/10 (10)	0 (0)	7/27 (25.9)	0 (0)	4/27 (14.8)	6/26 (23.1)	8/33 (24.2)	6/21 (28.6)
		2	–	–	2/4 (50)	0 (0)	1/2 (50)	3/8 (37.5)	0 (0)	1/3 (33.3)

[A]See Table 1 for the ethogram of behaviours observed.
[B]The number in parentheses represents the percentage of total observed behavioural events for a specific week and time period (AM or PM).
[C]n represents the number of sheep present in the paddock at each sampling week of the study.

involved in initiating different aggressive behavioural interactions in the AM and PM respectively. Numerically, the percentage of animals receiving aggressive behaviour interactions was always higher than the percentage of animals initiating the aggression (Table 8). Of the overall events recorded for butting and displacement from the feeder initiated in this study, 49.6% and 39.7% respectively, were repeatedly caused by the same animal in Group 1. However, in Group 2, the highest percentage recorded for butting and displacement from the feeder initiated by the same animal was 11.8% and 11.1% respectively.

Individual animal behaviour within a 5 m distance of the Nedap ESF

Among individual animal behaviours observed within a 5 m distance of the Nedap ESF, animals standing (standing with the head facing in a different direction to feeder) and animals waiting (standing with the head facing in the direction of the feeder) were numerically the most frequent behaviours observed throughout the study in both groups (Table 9). Grazing around the Nedap was numerically the highest behavioural event observed at Week 5 (67–74.4%); however, this behaviour declined over time because of the depletion of pasture around the feeder. From the video data, it was anecdotally observed that some sheep were able to get more pellets beyond their allocation by aggressively butting other sheep from behind to displace them from the feeder while eating their portions, and consumed any remaining pellets.

Discussion

This pilot study aimed to understand individual and social behaviour of grazing sheep when anti-methanogenic feed supplements were delivered through the Nedap ESF system in a grazing paddock. The study showed that a 3-week training period resulted in daily visits to the feeder by most sheep, but when additional sheep were introduced to the paddock with only a 1-week training period, they did not socially learn from conspecifics. Social learning in sheep depends on observing other experienced animals, as demonstrated by Kearton *et al.* (2022), who showed that observing the mother ewe helped lambs learn to respond more quickly to a virtual fence after weaning when trained for 6 weeks. Therefore, the 1-week training period provided to Group 2 in this study may not have allowed them sufficient time to learn from the experienced Group 1 animals and adapt to feeding from the feeder. There were also competitive interactions around the feeder, with sheep being displaced from finishing their allocated ration, indicating that future feeder designs may need to be modified to minimise this.

The average voluntary daily feeding frequency from the Nedap ESF system by Group 1 sheep was four to five times per day (of a maximum allowance of eight) after a 21-day training period, with about 80% of the animals successfully feeding at the feeder. However, only a much smaller proportion of animals (30%) in Group 2 fed from the feeder with the daily frequency of one time per day following 7 days of training. Adaptation of sheep to the Nedap ESF within 3 weeks of training observed in the current study is in accordance with the previous study by Muir *et al.* (2021) who reported that sheep kept on unrestricted feed supplement adapted to an automated feeding system within 19 days. This demonstrated that grazing sheep can adapt to an electronic feeding system that allows multiple feeding sessions, provided sufficient training time is given.

The low feeding visits observed in Group 2 were possibly due to insufficient training given to the animals in this group, which resulted in only a lower proportion of sheep learning and consistently visiting the feeder. This emphasises the importance of the initial training period when sheep are

Table 7. Overall summary of aggressive behavioural events initiated within 1 m of the Nedap electronic sow feeder, and the number of individual animals involved for data collected at a peak time in the morning (AM) and afternoon (PM) in selected weeks during the study period.

Behavioural parameter[A]	Time of day	Group	Week 5 (n = 35)[B]		Week 6 (n = 70)		Weeks 7 and 8 (n = 70)		Week 9 (n = 70)	
			Number of animals involved	Number of events (%)[C]	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)
IBUT	AM	1	6	18 (37.5)	8	56 (30.1)	6	35 (33)	7	40 (24.8)
		2	–	–	2	13 (6.9)	0	0 (0)	2	21 (13)
	PM	1	9	67 (48.9)	7	72 (37.5)	8	28 (18.1)	10	58 (34.3)
		2	–	–	3	18 (9.4)	1	19 (12.3)	2	5 (2.9)
IPu	AM	1	2	3 (6.3)	8	12 (6.5)	4	4 (3.8)	6	11 (6.8)
		2	–	–	1	2 (1.1)	0	0 (0)	1	1 (0.6)
	PM	1	9	15 (10.9)	1	4 (2.1)	6	11 (7.1)	10	16 (9.5)
		2	–	–	4	7 (3.6)	1	2 (1.3)	0	0 (0)
IMT	AM	1	2	2 (4.2)	0	0 (0)	1	12 (11.3)	1	3 (1.8)
		2	–	–	0	0 (0)	0	0 (0)	0	0 (0)
	PM	1	2	2 (4.2)	0	0 (0)	1	5 (3.2)	1	5 (2.9)
		2	–	–	1	3 (1.6)	0	0 (0)	0	0 (0)
Ipaw	AM	1	6	9 (18.8)	9	41 (22)	5	14 (13.2)	8	21 (13)
		2	–	–	0	0 (0)	0	0 (0)	0	0 (0)
	PM	1	5	20 (14.6)	6	30 (16.6)	8	25 (16.1)	9	28 (16.6)
		2	–	–	1	3 (1.6)	0	0 (0)	0	0 (0)
IDFeed	AM	1	8	10 (20.8)	11	41 (22)	9	37 (34.9)	7	41 (25.5)
		2	–	–	1	7 (3.8)	0	0 (0)	2	9 (5.6)
	PM	1	10	27 (19.7)	4	30 (15.6)	13	39 (25.2)	10	37 (21.9)
		2	–	–	5	11 (5.6)	1	16 (10.3)	2	4 (2.4)
IDPos	AM	1	5	6 (12.5)	4	13 (6.9)	2	4 (3.8)	5	9 (5.6)
		2	–	–	1	1 (0.5)	0	0 (0)	1	5 (3.1)
	PM	1	5	6 (12.5)	3	13 (6.8)	8	9 (5.8)	10	16 (9.5)
		2	–	–	1	1 (0.5)	1	1 (0.6)	0	0 (0)
TAI	AM	1	13	48 (100)	13	163 (87.6)	8	106 (100)	10	125 (77.6)
		2	–	–	2	23 (12.4)	0	0 (0)	2	36 (22.4)
	PM	1	15	137 (100)	8	149 (78.8)	14	117 (75.5)	17	160 (94.7)
		2	–	–	7	40 (21.2)	1	38 (24.5)	2	9 (5.3)

IBUT, butting initiated; IPu, pushing initiated; IMT, mounting initiated; Ipaw, pawing initiated; IDFeed, displacement from feeder initiated; IDPos, displacement from position initiated; TAI, total aggressive interactions initiated.
[A]See Table 1 for the ethogram of behaviours observed.
[B]n represents the number of sheep present in the paddock at each sampling week of the study.
[C]The number in parentheses represents the percentage of total observed behavioural events for a specific week and time period (AM or PM).

first introduced to a new feeder. Compared with the first group that was trained in a smaller mob with a wide race initially placed in front of the Nedap ESF, a smaller proportion of animals in the second group managed to learn to visit the feeder. The presence of a narrow race in front of the feeder, without providing training to familiarise the sheep to the set-up, may have increased fear-related behaviour of the naïve animals and discouraged them from visiting the feeder. However, the mean daily frequency of visits to the Nedap ESF among animals that visited the feeder in Group 2 was significantly higher at Week 9. This suggests that observations across a longer period of time may have seen increased social learning (Kearton et al. 2022; Vartparonian and Leu 2024).

Prior experience to supplementary feeding systems and social interactions among animals have been shown to influence feeding behaviours such as frequency of visits to the feeding station and the amount of feed consumed (Bowman and Sowell 1997). In the current study, poor attendance observed in Group 2 was also influenced by the dominance

Table 8. Overall summary of aggressive behavioural events received within 1 m of the Nedap electronic sow feeder, and the number of individual animals involved for data collected at a peak time in the morning (AM) and afternoon (PM) in selected weeks during the study period.

Behavioural parameter[A]	Time of day	Group	Week 5 (n = 35)[B]		Week 6 (n = 70)		Weeks 7 and 8 (n = 70)		Week 9 (n = 70)	
			Number of animals involved	Number of events (%)[C]	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)
RBUT	AM	1	12	18 (37.5)	21	57 (30.6)	16	34 (32.1)	19	55 (34.2)
		2	–	–	6	12 (6.5)	1	1 (0.9)	3	6 (3.7)
	PM	1	16	67 (48.9)	19	48 (25.4)	19	34 (21.9)	17	41 (24.3)
		2	–	–	8	42 (22.2)	5	13 (8.4)	4	22 (13)
RPpu	AM	1	2	3 (6.3)	9	11 (5.9)	3	3 (2.8)	8	12 (7.5)
		2	–	–	2	3 (1.6)	1	1 (0.9)	0	0 (0)
	PM	1	11	15 (10.9)	5	9 (4.8)	8	12 (7.7)	7	14 (8.3)
		2			1	2 (1.1)	1	1 (0.6)	2	2 (1.2)
RMT	AM	1	2	2 (4.2)	0	0 (0)	7	11 (10.4)	3	3 (1.9)
		2			0	0 (0)	1	1 (0.9)	0	0 (0)
	PM	1	2	2 (1.5)	2	3 (1.6)	3	3 (1.9)	3	4 (2.4)
		2	–	–	0	0 (0)	1	2 (1.3)	1	1 (0.6)
Rpaw	AM	1	7	9 (18.8)	18	40 (21.5)	12	14 (13.2)	10	18 (11.2)
		2	–	–	1	1 (0.5)	0	0 (0)	2	3 (1.9)
	PM	1	16	20 (11.7)	7	16 (8.5)	15	21 (13.5)	10	22 (13)
		2	–	–	5	17 (8.9)	2	4 (2.6)	3	6 (3.6)
RDFeed	AM	1	7	10 (4.6)	22	42 (22.6)	17	34 (32.1)	21	44 (27.3)
		2	–	–	5	6 (3.2)	2	3 (2.8)	3	6 (3.7)
	PM	1	18	27 (19.7)	17	31 (16.4	23	46 (29.7)	17	35 (20.7)
		2	–	–	7	10 (5.3)	4	9 (5.8)	4	6 (3.6)
RDPos	AM	1	6	6 (12.5)	7	10 (5.4)	4	4 (3.8)	8	12 (7.5)
		2	–	–	3	4 (2.2)	0	0 (0)	1	2 (1.2)
	PM	1	6	6 (4.4)	6	10 (5.3)	6	9 (5.8)	9	12 (7.1)
		2	–	–	3	4 (2.1)	1	1 (0.6)	3	4 (2.4)
TAR	AM	1	17	48 (100)	25	160 (87.4)	20	100 (94.3)	21	144 (89.4)
		2	–	–	8	23 (12.6)	2	6 (5.7)	3	17 (10.6)
	PM	1	22	137 (100)	21	114 (73.5)	23	125 (80.6)	22	128 (75.7)
		2	–	–	8	75 (26.6)	6	30 (19.4)	5	41 (24.3)

RBUT, butting received; RPpu, pushing received; RMT, mounting received; Rpaw, pawing received; RDFeed, displacement from feeder received; RDPos, displacement from position received; TAR, total aggressive interactions received.
[A]See Table 1 for the ethogram of behaviours observed.
[B]n represents the number of sheep present in the paddock at each sampling week of the study.
[C]The number in parentheses represents the percentage of total observed behavioural events for a specific week and time period (AM or PM).

of Group 1 in accessing the feeder. The results of the diurnal patterns of visits to the Nedap ESF confirm this, where the mean feeding visits observed in Group 1 were consistently higher than in Group 2. Similarly, a higher percentage of animals in Group 1 (74.3%) were feeding daily from the feeder throughout the study period compared with animals in Group 2 (11.4%). These suggest that sheep in Group 1 were dominant in occupying the feeder because of their prior exposure and adaptation to the Nedap ESF system. Also, from our observations during the study, the majority of sheep in Group 1 were consistently queuing closer to the feeder during feeding visits than the sheep in Group 2, which stayed farther away from the feeder. A study conducted in pigs showed that external factors such as group size and feeder space allowance had a significant effect on pig feeding behavioural patterns (Fornós *et al.* 2022). However, it was evident from Nedap ESF data that when the feeder was not in use for a duration of up to 14 min (Fig. 8), animals from Group 2 still did not access the feeder during this period. This is possibly due to the fact that sheep are highly social animals and, therefore, if they are

Table 9. Individual animal behaviour exhibited within 5 m of the Nedap electronic sow feeder and the number of animals involved in data collected at a peak time in the morning (AM) and afternoon (PM) in selected weeks during the study period.

Behavioural parameter[A]	Time of day	Group	Week 5 (n = 35)[B]		Week 6 (n = 70)		Weeks 7 and 8 (n = 70)		Week 9 (n = 70)	
			Number of animals involved	Number of events (%)[C]	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)	Number of animals involved	Number of events (%)
Waiting	AM	1	15	24 (14.3)	19	31 (13.8)	11	12 (10.3)	10	13 (28.9)
		2	–	–	5	5 (2.2)	3	3 (2.6)	3	3 (6.7)
	PM	1	18	26 (15.1)	7	11 (6.5)	8	10 (10.3)	10	7 (9.3)
		2	–	–	2	2 (0.1)	4	5 (5.2)	6	4 (5.3)
Grazing	AM	1	29	113 (67.3)	28	108 (48.2)	0	0 (0)	3	3 (6.7)
		2	–	–	11	21 (9.4)	0	0 (0)	1	1 (2.2)
	PM	1	31	128 (74.4)	18	44 (26.2)	2	2 (2.1)	7	12 (16.0)
		2	–	–	12	28 (16.7)	0	0 (0)	5	15 (20.0)
Standing	AM	1	13	22 (13.1)	17	27 (12.1)	10	16 (13.7)	12	16 (35.6)
		2	–	–	14	16 (7.1)	11	16 (13.7)	6	8 (17.8)
	PM	1	18	20 (11.6)	19	41 (24.4)	21	46 (47.4)	14	24 (32.0)
		2	–	–	11	17 (10.1)	7	13 (13.4)	8	9 (12.0)
Lying	AM	1	2	9 (5.4)	3	8 (3.6)	8	50 (42.7)	0	0 (0)
		2	–	–	1	8 (3.6)	4	20 (17.1)	1	1 (2.2)
	PM	1	0	0 (0)	7	15 (8.9)	4	17 (17.5)	2	4 (5.3)
		2	–	–	3	10 (5.9)	1	4 (4.1)	0	0 (0)
Total	AM	1	31	168 (100)	32	174 (77.7)	21	78 (66.7)	17	32 (71.1)
		2	–	–	21	50 (22.3)	12	39 (33.3)	7	13 (28.9)
	PM	1	34	172 (100)	26	111 (66.1)	23	75 (77.3)	18	47 (62.7)
		2	–	–	21	57 (29.8)	9	22 (22.7)	14	28 (37.3)

[A]See Table 1 for the ethogram of behaviours observed.
[B]n represents the number of sheep present in the paddock at each sampling week of the study.
[C]The number in parentheses represents the percentage of total observed behavioural events for a specific week and time period (AM or PM).

grazing in the large paddock, they would be less likely to move away from the mob to access the feeder (Dumont and Boissy 2000; Sibbald and Hooper 2004).

In the present study, the mean time spent by the sheep in the feeding trough after pellets dropped ranged between 69.6 and 77.5 s, whereas the duration of feeder occupancy during non-feeding visits ranged from 94.3 to 112 s. The longer non-feeding visits observed suggests that animals were waiting in anticipation of the pellets to be dispensed. There may have also been a reduction in displacement and competition from nearby animals because the sound of feed falling into the trough was absent. The shorter feeding visits observed in the current study were due to high competition among animals as shown by frequent displacement from the feeder. Certain specific animals showed extremely high visits to the feeder on a daily basis and at the same time inducing different aggressive behavioural interactions towards other animals. This could further contribute to the animal displacement from the feeder and a shorter feeding time per visit observed in the current study. Previous studies conducted in pigs suggest that frequent visits by dominant pigs to the feeding station even after consuming their maximum allocated feed result in reduced feed intake by their pen mates (Edwards et al. 1988; Hunter et al. 1988).

The main cause for incomplete feeding events in the present study was animal displacement from the feeder, resulting from aggressive behavioural interactions induced by certain sheep, mainly from Group 1. An increase in the proportion of incomplete feeding events was observed from Week 6 to Week 9 at both the morning (AM) and afternoon (PM) sessions, coinciding with the introduction of the second group. The introduction of the second group led to an increase in the number of dominant sheep, which caused more displacement at the feeder. This, in turn, reduced the proportion of animals that were able to finish eating the dispensed pellets at a time. Some of the animals in Group 2 were also observed to instigate aggressive behavioural interactions. The number of animals that received aggressive behavioural interactions was always higher than the number of animals involved in initiating the aggressive behaviours in both groups. This indicates that only few animals were responsible for displacing other animals from the feeder and affecting the amount of feed consumed by other animals in the flock. Previous studies conducted in sheep and other domestic animals have shown that dominance behaviour affects access to feed (Llonch *et al*. 2018; Haskell *et al*. 2019; Bica *et al.* 2020). Dominant animals prevent other animals from consuming the desired amount of feed supplement, while often consuming well beyond their allocation (Bowman and Sowell 1997). The presence of individual animal protection within the feeder has been shown to influence animal feeding behaviour, including reducing the number of non-feeding visits per day and increased time spent feeding because of reduced disturbance while feeding (Brumm and Gonyou 2000; Averos *et al*. 2012). The design of the protective race built on the feeder used in the present study still allowed sheep to be disturbed from behind while feeding. The race therefore, in this case, did not serve the intended purpose of minimising animal displacement from the feeder.

Individual differences in behaviour among sheep have previously been documented where shy feeders are prone to self-initiated disturbance owing to their vigilant behaviour and sensitivity to external stimuli (Sibbald *et al*. 2009). Incomplete feeding that is self-initiated, as was observed with some animals in the current study, might also be due to shy feeders. A study conducted in lambs in a feedlot situation showed that shy feeders spent less time in the feeding trough and often exited early at their own will or to avoid aggressive behavioural interactions from other animals (Rice *et al*. 2016). The expression of natural behaviour, such as grazing, standing (head facing different direction to the feeder) and lying were the individual animal behaviours observed within a 5 m distance from feeder. Whether these behaviours were influenced by the presence of the feeder in the paddock or not, cannot be concluded from our findings and warrants further investigation by including a control measurement.

It has been acknowledged that data from pig electronic feeders are not free of errors (Eissen *et al*. 1999; Casey and Dekkers 2002; Jiao *et al*. 2016). The errors related to random drops linked to unknown tag numbers (0.12%) and multiple drops per feeding session (1.45%) reported in the current study (0.12–1.45%), are lower than reported by Casey *et al*. (2005), who found variable levels of errors related to unidentified visits (6.2–67.2%) in three pig experiments conducted using FIRE electronic feeders under pen conditions. However, a comparable result was reported by Eissen *et al.* (1998) who detected 0.95% visits with no identification in a study conducted in group-housed pigs. Factors such as equipment malfunction, animal feeder interactions, rodent activity and strong air currents have been suggested to cause errors in data generated from electronic feeders (Casey and Dekkers 2002; Casey *et al*. 2005). We did not identify the exact cause of the errors reported in the present study. The factors identified in earlier studies cannot be ruled out because the experiment was conducted under field conditions where the feeder was exposed to wide range of environmental factors.

The study was conducted during the winter (May to July) when cool temperatures and minimal pasture growth experienced. Because of this temperature, we postulate that animal visits to the feeder were evenly distributed throughout the day. The pasture quality in the paddock was poor because of the dying plant material; this could have also encouraged animals to go seeking for supplementary feed from the feeder.

Conclusions

This pilot study has provided an initial understanding of flock dynamics and sheep behaviour when an electronic feeder is used to provide anti-methanogenic supplementary pellets to grazing sheep. The study showed that sheep were capable of learning and adapting to an electronic feeding system with appropriate training, as demonstrated in Group 1, which had a longer training period with the feeder than did Group 2. However, the initial training conditions and flock size can significantly affect the learning success rate, and this warrants further investigation. There was also high competition among animals while feeding from the automated feeder. Incorporating refinements in the feeder design, such as increasing the number of feeding troughs per feeder and providing an effective barrier to protect feeding sheep, may address issues related to aggressive behaviours in sheep using the automated feeders. Further trials to evaluate the impacts of training regimes, social learning, and dominance with multiple groups of grazing sheep and multiple feeders within a single paddock will contribute toward recommendations for producers on designing and optimising use of electronic delivery systems in sheep grazing systems.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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