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Characterizing mating behaviour in broiler breeders via a vision based deep learning model

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ABSTRACT

Broiler breeder mating behaviour consists of rapidly performed sub-actions that determine the success of sperm transfer critical for egg fertility. It includes rooster mounting the hen followed by coordinated tail movements that enable cloacal contact. This study aimed to develop a vision-based deep learning (DL) model for automatically detecting the mounting phase, the period between mounting and decoupling during mating, and to evaluate its features over time. An experiment was conducted with four pens each containing 10 hens (Cobb 500F) and 1 rooster (Cobb MX strains) for four and a half months. Two cameras were stationed at each pen continuously recording broiler breeders daily. The DL model, YOLOv8, was fine-tuned and tested to detect two behavioural classes, mounting and non-mounting, with a dataset consisting of 2420 instances and further validated with independent dataset; the final model was applied on the experimental dataset to detect daily mounting phase events. Additionally, the welfare indicators footpad dermatitis (FPD) and gait score (GS), along with live weight, were periodically evaluated in broiler breeders and maintained within the Cobb recommended limits. Finally, a linear mixed model (LMM) was applied to evaluate individual and covariate effects of age, welfare and weight variables on the mounting phase results. The final model achieved 91.0 % and 90.0 % test accuracies in detecting mounting and non-mounting behaviours by roosters, respectively. The model detection results revealed an average 13.5 ± 4.2 mounts per rooster per day, with each one lasting 5.3 ± 0.8 seconds and happening with 70.6 ± 28.9 minutes inter-mounting interval. On average, 68.2 % of mounting phases were carried out with observable rooster and hen tail movements. Mountings that entailed tail movements lasted longer than the ones with none. The peak mounting activity was during the 16:00–20:00 followed by the 07:00–09:00 hours. Heavier roosters ($p < 0.0001$) and hens with poorer gait conditions ($p = 0.0179$) were less likely to engage in or sustain during mating. These findings may enhance understanding of the mating temporal dynamics and facilitate egg fertility analyses.

Introduction

A primary role of the broiler breeder industry is to provide fertile hatching eggs that produce broiler chickens, the world's leading source of animal-based protein. Due to the ever-growing global demand, the industry faces increasing pressure to enhance production efficiency. The broiler breeder farms, as a key stakeholder, need to foster and rapidly optimize production as well as eliminate adverse factors. One major challenge in the US broiler production industry has been the dwindling hatchability rates below 80 % for the past few years (USDA-NASS, 2024). Among other factors, egg fertility in broiler breeders is a key determinant of hatchability ratio (Jacob et al., 2000; van Emous et al., 2015).

Fluctuations in egg fertility level may arise due to various factors such as ineffective breeding practices, poor male-to-female ratios, or improper mating behaviours. While there have been considerable advancements in different aspects in broiler breeder management such as genetic selections, hatchery technology, environment control, or

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nutrition, the potential for optimal mating conducive to higher fertility rate is still to be fully realized (Adegbenjo et al., 2020; Buzala et al., 2015).

Mating behaviour involves a series of sequential actions synchronously performed by broiler breeders. In broiler breeder farms, it typically starts with a rooster directly approaching a hen, while seldomly it may engage in courtship behaviour by lowering one wing and circling her. The hen may show receptiveness by widening her wings and crouching, allowing the rooster to mount. Consequently, the rooster mounts the hen and may grab her neck aggressively to balance his body on her back. After positioning his body parallel to the hen's, the rooster moves his tail horizontally to prompt the hen to reciprocate by lifting her tail up, enabling the rooster to vertically lower his tail to achieve cloacal contact. Immediately, the semen is squirted through the established cloacae channel from the rooster to the hen. The pair decouples instantly after which the hen typically performs body shuffling, marking the end of the mating event (Mauldin, 2009).

Particularly, the mounting phase which begins with mounting and ends with the decoupling of the rooster and hen, is critical as it encapsulates tail movements facilitating cloacal contact, which in turn is the prerequisite for successful semen transfer. Successful matings, characterized by effective semen transfer, would significantly determine the fertility of the eggs produced for many subsequent days. As cloacal contact is not observable, studying these brief sub-actions (mounting and tail movements) and their features such as occurrence, duration, interval and frequency, may prove crucial in understanding successful matings. Therefore, detailed observation of this phase could help assess individual breeders' mating drive and receptiveness, identify inherent factors during mating, influencing egg fertility, and potentially contribute to enhancing hatchability rates. Nonetheless, studying the rapidly performed sub-actions with the classical methods, such as manually observing or analyzing video recordings, proves challenging, whereas precision livestock farming technologies is an option to be explored.

Few studies have successfully applied the vision-based deep learning (**DL**) models, based on convolutional neural networks (CNN), to detect the overall mating occurrence from images and videos of breeders. In one study, the Faster R-CNN model was employed to identify reproductive behaviours (mating, non-mating, egg-laying) in Muscovy ducks housed in traditional cages, achieving 86 % success rate for mating and 80 % for non-mating behaviours (Saenong et al., 2023). In another work by Wang et al. (2022), the YOLOv3 model was used to analyze the mating behaviour of Hy-Line Gray egg breeders in self-breeding cages, identifying six behaviours, including mating (which achieved 94.72 % precision). In a recent study, a YOLOv8-based model analyzed top-view videos to monitor mating behaviour in broiler breeders. The model used bird count changes to infer mating events, achieving about 92 % accuracy (Bodempudi et al., 2025). Additionally, technologies such as wireless acceleration sensors or sound analysers have also been employed to identify mating behaviour, achieving considerable success in smaller scales (Banakar et al., 2024; Lihua et al., 2019).

The literature in this area remains relatively limited, both in terms of DL model applications on different poultry sections, such as broiler breeders, as well as in-depth mating analysis for optimizing fertility, rather than merely focusing on mating occurrence detections. Due to the limited scope or temporally small datasets in the mentioned studies, newer models are required to be specifically tailored for broiler breeders, trained or fine-tuned over an extensive dataset, with an enhanced focus on detailed temporal analysis of mating behaviour and its sub-actions.

Given that the mating behaviour is both infrequent and brief, such an application of a deep learning model might prove effective in understanding subtle key sub-actions and their features by processing each second, thereby providing a detailed temporal understanding of the factors resulting in successful matings (Badgujar et al., 2024; Evangelista et al., 2023). Henceforth, this study focused on developing a vision-based deep learning model, i.e. fine-tuning YOLOv8 model, to automatically detect the mounting phase, and to analyze its features such as occurrence, daily frequency, duration, interval, and the incidence of tail movements by the roosters and hens. Additionally, the correlation of welfare indicators footpad dermatitis (**FPD**), gait levels (**GS**), and weight of the individual broiler breeders were examined with mounting phase features.

Material and methods

The experiment was conducted at the Johnson Research and Teaching Unit at the University of Tennessee Knoxville for five months between July 12th to November 24th, 2024. It included four experimental pens, each having 1.5 $m \times 3.0\, m \times 3.0$ m (Width-Length-Height) dimensions and the floor was covered with a 20–25 cm deep bedding comprised of black soil and mulch. Each pen contained 270-days old broiler breeders, consisting of 10 hens (Cobb 500F strain) and 1 rooster (Cobb MX strain) in observance to industry standards for stocking density and male-to-female ratio for mating (Cobb, 2024). Two more pens, containing 10 hens and 5 roosters separately, were kept as backups in case of mortality in the experimental pens.

As depicted in Fig. 1, each pen was equipped with a feeding trough, bucket drinker, 3 nest boxes for the hens to lay eggs, and two side and top view cameras (Amcrest 5MP). The side and top view cameras were installed at about 160 cm and 250 cm heights to sufficiently cover the pen area, respectively. The breeders' daily behaviour was recorded throughout the 15-hour light period, and the records were automatically saved in hard drives.

The experimental room was equipped with temperature, humidity, light intensity, and ammonia sensors. Two temperature and humidity sensors were stationed in pen#4 and pen#2 for continuous monitoring of the room. The room environment was maintained, as per the Cobb breeder management guidelines, at around 21.0 °C temperature and below 70 % humidity levels. Additionally, the ammonia levels were spot checked daily from the middle of room at the breeder eye levels and were strictly maintained below the hazardous 25 ppm levels. The light intensity was configured within the 50–100lux range in each pen and a 15hr light regimen was applied for catering optimal daily reproductive behaviours as per the Cobb guidelines. To maintain the light intensity within the recommended range at each pen, it was spot checked daily at the entrance, middle, and end of each pen and at birds' eye level.

Broiler breeder management

The hens and roosters were fed once per day for an hour in the morning between 09:00–10:00 (hh:mm), with the feeding quantities determined by experts based on their weekly measured weights. While the hens were fed jointly, each rooster was housed and fed separately in a smaller pen during this time to prevent access to feed allocated for the hens. The body weight targets for both hens and roosters were essential to be maintained to achieve necessary weight gains or losses to allow optimal sexual maturation. Additionally, maintaining weight levels was essential in rendering healthy gait levels for the breeders to perform their daily behaviours including mating.

Supervision and monitoring of key welfare indicators

Welfare indicators such as footpad dermatitis (FPD) and gait (GS) levels were assessed weekly to evaluate broiler breeder leg health. Footpad dermatitis was scored on a 0–4 scale and gait levels on a 0–5 scale, ranging from healthy to severe conditions, respectively (Kestin et al., 1992; Kittelsen et al., 2017; Welfare Quality, 2009). FPD was scored based on the existence of lesions and ulceration area developed on the footpad. Specifically, scores 0–2 would denote no lesion to moderate levels and ulceration areas smaller than 50 % of the surface area, while scores 3-4 would denote severe to entirely effected footpads.

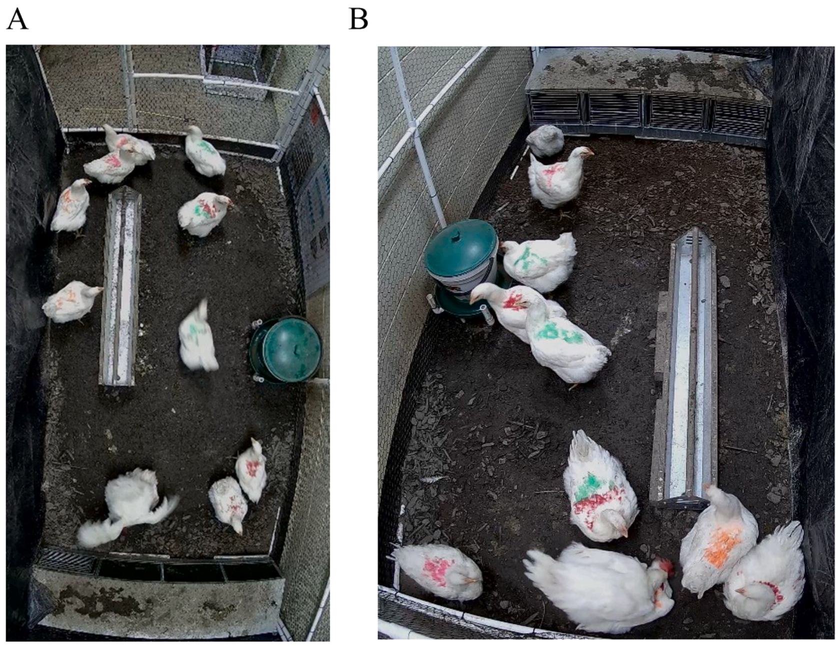


Fig. 1. (a) Pen top view. (b) Pen side view.

Meanwhile, the 0 to 5 GS levels were assessed based on individual broiler's walking ability which might range from no sign of lameness to minor defects, mildly limping, difficulty in walking, to severely disabled and unable to walk, respectively. These assessments were crucial as footpad dermatitis reflects litter quality and management effectiveness, while gait scoring helps identify locomotion issues that may indicate pain, or lameness affecting their mating capabilities, among other behaviours.

Mating feature selection

As mentioned before, mating behaviour involves a sequence of rapid interactions between roosters and hens, which may or may not result in successful semen transfer. It was essential to identify the most defining sub-actions during mating as well as the ones that were visually distinguishable for vision-based DL models to accurately detect, as depicted in Fig. 2a-b. Mating behaviour may constitute all or some of the following sub-actions: courting, mounting, tail movements, cloacal contact, semen transfer, decoupling, and wing shuffling, with each one performed by both or one of the involved parties. While the courting and wing shuffling happen with no physical contact, the rest of them, i.e. mounting phase, are realized when the rooster is mounted on top of the hen. The mounting phase is distinctively characterized by the rooster being on top of the hen.

As demonstrated in Fig. 2a; the mounting phase starts as the rooster mounts the hen, frame#1, and continues aligning itself by lowering its tail, and concurrently, the hen lifts its tail up and the cloacal contact is realized after which the semen transfer happens. Post semen transfer, the rooster lifts its tail up, depicted in frame#4, and they decouple; all these sub-actions usually happen rapidly within few seconds.

Henceforth, in this study the mounting phase constituting the observable sub-actions mounting and tail movements, was selected for the DL model to identify. Accurate detection of the entire mounting phase is beneficial for comprehensive analysis of mounting and tail movement characteristics, including their occurrence, frequency, duration, and inter-event intervals. Understanding these features' trends over a long period of time is essential for better understanding the mating dynamics and the end fertility rates.

Model development and application

The vision-based YOLOv8 (Ultralytics, 2024) DL was utilized in the mounting phase detection of broiler breeder mating events. This model has a unique architecture which renders outstanding applications in fast object localization and classifications as compared to its counterparts such as the Faster R-CNN model (Jaihuni et al., 2023). Architecturally different versions of the model provide flexibility in selecting from heavier to smaller ones feasible with different scales of dataset, processing hardware, and time requirements.

Dataset Preparation. Images were collected from various mating events and the ones where the rooster was positioned on top of the hen, were labelled as "mounting" class. Consequently, the images showing the rooster and hen not copulating were labelled as "non-mounting". For this purpose, the initial dataset consisted of 1,620 mounting class images and 800 images representing non-mounting class as depicted in Fig. 2a-b, respectively. Involving more complex and variable postures during the mating event, the quantity of the mounting class labelled images were selected higher as compared to the second one, in which visually less complex, i.e. individual roosters, and more consistent behaviours, such as feeding, drinking, or resting, were represented with.

The first class enabled the model to accurately identify true positives for mounting phase and its constituent sub-actions, while the second class helped differentiate it from other activities. Additionally, the YOLO model has a built-in implicit class named as "Background" used to classify anything other than the defined or annotated classes. It helps the model not to detect unannotated objects in the images, i.e. feeder, drinker, or colour-marked hens, essential in the learning process to optimize model performance.

We opted to use the videos from the side camera as the mounting positions, i.e., roosters positioned on top of the hens, were more visible and easier for detection from a parallel angle or view compared to the perpendicular view of the top camera. It helped in decreasing computational time and resource utilization as well.

Model Fine-Tuning and Application. Certain hyper-parameters were selected by trial and error: the number of epochs tested ranged between 50 and 150, batch size applied were between 4 and 32; default values were selected for the rest. The dataset was divided into an 80:20 ratio, with 80 % allocated for training (fine-tuning) and 20 % reserved for testing. To resolve the question about model's generalizability, the fine-

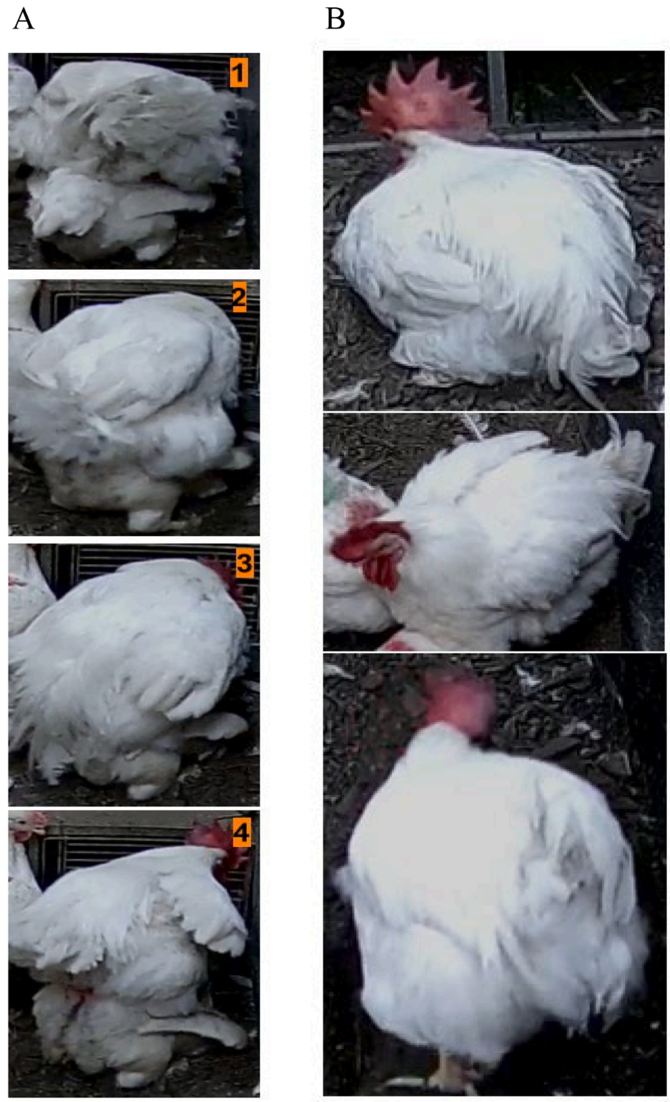


Fig. 2. (a) Frame by frame depiction of the mounting phase at one-second intervals. (b) Various non-mating behaviours.

tuned model was further validated with completely randomly selected mounting and non-mounting instances, compounding 300 images, collected manually from 8 days over the course of experiment.

The Precision (P), Recall, and mean Average Precision (mAP) metrics, Eqs. (1-3), were used to compare the performance of the model under different scenarios, respectively. While the Precision metric indicates the effectiveness of object detection-classifications in a specific class in an image (eq1), the Recall demonstrates overall prediction capability of the model with regards to all the classes (eq2), and the mAP shows the level the model is precise in providing both few false positives and captures overall correct object classes present in an image. Here, in Eqs. (3), Q represents the number of classes which were 2.

$$Precision = (True\ positives)/(True\ positives + Flase\ positives) \quad (1)$$

$$Recall = (True\ positives)/(True\ positives + Flase\ negatives) \quad (2)$$

$$mAP = \sum_{q=1}^{Q} Average\ Precision(q)/Q \quad (3)$$

In calculating these metrics, two confidence thresholds, 0.5 and above and a range of 0.5:0.95 were utilized. The former threshold included the predicted bounding box detections, i.e. predicted locations of mating events, which matched the ground truth, i.e. exact location of the mating event, by at least 50 %. While in the latter one, they were calculated at different confidence levels between 0.5 to 0.95, separated by 0.05, and finally their precision is averaged. While the first threshold provided a general capability of the developed model in locating mating and non-mating behaviours, the second one is a stricter measure indicative of its performance under higher confidence intervals. Consequently, a confusion matrix of the mounting, non-mounting, and background classes, was calculated from the application of the fine-tuned model on the test data, under both threshold categories.

Finally, the developed model was applied to the huge video dataset, with about 16 TB size, to identify frames of the mounting phase. One frame per second rate was chosen to balance precision in mounting behaviour analysis while optimizing computational efficiency. It provided sufficient detail for the model to accurately detect the mounting phase without excessive data analysis as well as providing the model with enough frames from any mounting phase for correct detection. To run the YOLO model with different architectures having millions of parameters on the gargantuan size of the video dataset, Google T4 strong GPU services were purchased. This approach ensured efficient utilization of processing hardware and time, preventing resource over-allocation while maintaining analytical accuracy.

Mounting phase features

The mounting phase variables were determined based on the detection and classification results of the fine-tuned YOLOv8 model application on the four pens' dataset. The detected instances containing the true and false positive mating classifications in each pen were then studied manually to identify mounting phase features, i.e. true positives, in detail, further refining the results. Hence, each mounting phase's occurrence, duration, the incidence of observable tail movements by the broiler breeders (hen or rooster or both), and the time of the day were recorded. Thereby, the total number of mountings per rooster per day, the duration of each mounting phase, and the interval between two consecutive matings at times t and $t+1$ were assessed. Additionally, the occurrence of the tail movements in each mating was revealed in detail, i.e. if a rooster and/or hen have demonstrated this behaviour.

Statistical analysis

In this study, the features derived from the detection results were mounting occurrence, mounting frequency, mounting duration, inter-mounting interval, tail movement frequency per rooster or hen per day. Additionally, welfare indicators, such as footpad dermatitis score (FPD), gait score (GS), weight (Kg), and physiological parameter age (days or weeks) were also assessed. The variables were measured repeatedly, daily or weekly, from the same broiler breeders in four pens. The housing conditions such as daily temperature, daily humidity, and room ammonia levels were continuously monitored and were assumed to affect all broiler breeders equally across the experimental pens. The normality of the variables was tested using the Shapiro-Wilk test and QQ plot. The variables were generally reported as mean $\pm$ standard error; while for the ones which did not pass normality, median and range (minimum, maximum) values were reported.

Because of the longitudinal nature of the data, repeated-measures correlation analysis was used to evaluate the relationships between daily average mounting frequency (by week) or mounting frequency with rooster tail movement (by week) and other variables (such as age hen FPD, hen GS, rooster FPD, rooster GS, weekly hen body weight, weekly rooster body weight) in R version 4.5.1 (R Core Team, 2025) package RMCORR version 0.7.0 (Bakdash and Marusich, 2024).

As there were one rooster and ten hens per pen, normality tests were applied on the hen related variables to check for their distribution and suitability to compare their means across the four pens. While for individual roosters, the means of the variables were directly compared.

Linear mixed model (**LMM**) analysis was applied to examine the significant effects in welfare indicators and mating variables among the hens across different pens with pen and hen nested within pen (denoted as hen[pen] as the random factor. The post hoc paired comparison test was performed for the significant categorical variables using Tukey's Honestly Significant Difference (HSD) test. The LMM model was further applied in determining the covariate effect of age, body weight, FPD, and GS on the mounting phase parameters. All the independent parameters were tested against mounting frequency using backward selection: the least significant variables were removed one at a time, based on statistical criteria ($p < 0.05$).

Consequently, the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used to compare the performance of different fitted models. Lower values of AIC and BIC indicate a better trade-off between a model's explanatory power and simplicity. Subsequently, residual diagnostics were performed for the LMM to assess normality using the Shapiro–Wilk test and Q–Q plots, ensuring that the normality assumption was met. A non-linear regression was used to identify the best fit for the daily net difference in tail movement (roosters' total tail movement frequency minus hens' total tail movement frequency The analyses were performed using JMP Pro version 17 (JMP Statistical Discovery LLC, 2025). $P < 0.05$ was considered significant.

Results

Room management

The room environment was controlled in relatively stable conditions with minor fluctuations, as demonstrated in Fig. 3a-c. The average temperature remained stable at 20.9 ± 1.2°C, while the average humidity was within the 63.8 ± 8.3 % acceptable range, though it occasionally exhibited volatility due to floor wetness in the pens; in the meantime, on average the room light intensity levelled at 68.3 ± 4.7 lux. On the other hand, the ammonia concentration was on average around 5.2 ± 2.1 ppm, well below the maximum allowed limit of 25 ppm; in case of any occasion with elevated ammonia concentration detected, it was treated immediately with bedding material renewal or continuous ventilation. Hence, overall, the indoor environment was kept optimal, contributing to less stress and welfare deteriorations in breeders.

Body weight growth

The weights of the broiler breeders were kept within the recommended limits and steady weight gains were maintained by weekly adjusting precise feed amounts of roosters and hens throughout the experiment. With an average weekly weight of 5.07 ± 0.33 Kg, the roosters outweighed the hens which had an average weight of 4.32 ± 0.39 Kg; while pen#4 rooster had the highest average weight among all the roosters, the average hen weight was highest in pen#2 followed by pen#1, as detailed in Fig. 4 and Table 1. While individual rooster's weekly weight differed among the pens, no significant differences in the mean hen weights across pens (all $p > 0.05$; normally distributed residuals with $W = 0.97$).

Footpad dermatitis and gait levels

The GS, essential for performing daily natural behaviours, was maintained on average below 2.0 scores indicative of normal to mildly deteriorated mobility conditions in broiler breeders. Overall, the roosters had better GS levels, (median=1.0, range= (1,2)), than the hens, (2.0, (1,3)). On the other hand, in the footpad dermatitis results stemming from various factors such as litter and floor conditions, the hens were relatively in better condition, (1.8, (0,4)), than the roosters, (2.0, (1,3)), as detailed in Table 2. The FPD and GS variables did not show normal distribution and failed to pass the normality tests. Meanwhile, the mean FPD and GS levels in hens did not show significant differences across the pens. On the other hand, individual rooster's mean GS and FPD were different across the pens.

These results, further revealed in Fig. 5.a-b, indicated optimal leg health conditions were achieved during the experiment. As the weight levels, air ammonia concentration, and litter quality were managed effectively, there were no critical deteriorations observed in FPD and GS levels.

DL model development

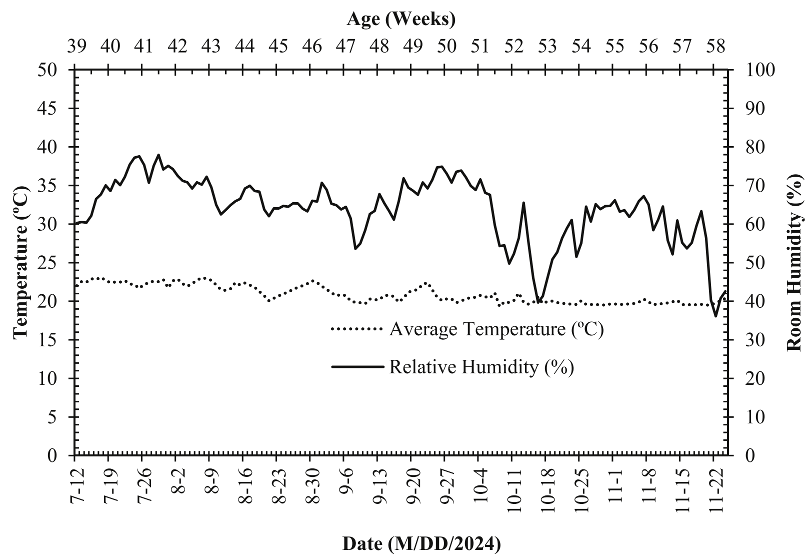
The YOLOv8 model was initially fine-tuned on approximately 1,100 images, collected from various mating instances, for detecting only one class, i.e. rooster positioned on top of the hen. The model effectively tracked the roosters but struggled with a high number of false positives (FP). For instance, when the model was applied on 15-minute video, it provided approximately 35 % of the instances as FPs. This confusion arose in the instances where the rooster was surrounded by multiple hens or was located right underneath the top camera. Hence, the model often overgeneralized various rooster postures as mounting as well as its decision boundary was not well-defined in one-class training, hence reducing its reliability for precise behaviour classification. To address this issue, the existing dataset was expanded to 2420 labelled images; 1,620 mounting class images and another 800 images of non-mounting behaviours were included as a second class.

Henceforth, as demonstrated in Fig. 6a-b, the model was substantially learnt to predict the locations of the mounting and non-mounting classes and to classify them in both 0.5 and 0.5:0.95 confidence threshold criteria. With 97.8 % and 98.7 % final accuracies in the precision and recall metrics, with 0.5 and above confidence threshold, the model's training trajectories are depicted in Fig. 6a, respectively. Consequently, the achieved mAP level, shown in Fig. 6b, was around 91 % for mounting and 90 % for non-mounting behaviours, under strict confidence threshold ranging between 0.5:0.95. This result was obtained at 50 epochs, as extending the training to 100 and 150 epochs did not yield further improvements in the precision, recall, and mAP levels as depicted in Fig. 7. The model was robust to learn the features of the dataset and converge within 50 epochs. This improvement allowed the model to better generalize between mounting and other daily actions, without falling significantly into overfitting issues, reducing false positive detections.

The test confusion matrix results of the fine-tuned model at different confidence thresholds are presented in Table 3a–b. Overall, the high precision in the prediction of true positives (324) and true negatives (160) match the training precision and recall rates of 97.8 % and 98.7 %, as shown in Table 3a, respectively. On the other hand, when the fine-tuned model was tested with the 0.5:0.95 confidence threshold, the confusion matrix shown in Table 3b resulted. Here, the model differentiated well between mounting and non-mounting classes while the number of misidentified classes as background slightly increased. The confusion matrix results showed considerable precision achieved by the model, probably stemming from its detection ability as well as moderate to high correlation levels between the test and training datasets.

The model's generalizability results validated on an additional 300 images under 0.9 and 0.5 confidence thresholds, are presented in Table 3c-d. The final model was effective in differentiating between mounting and non-mounting classes while missing on the identification of the non-mounting class. With stricter confidence thresholds, Table 3c, the model was able to detect all the mounting instances while missing some within the mounting phase under stricter thresholds. As the mounting phase usually lasted around 5 seconds, the model misidentified some postures within this duration but not all. This issue might have stemmed from the size of the training dataset, specifically, the number of non-mounting class which was low. On the other hand, with less strict confidence threshold, Table 3d, the model assigned a class to all the validation images, increasing the number of false

A



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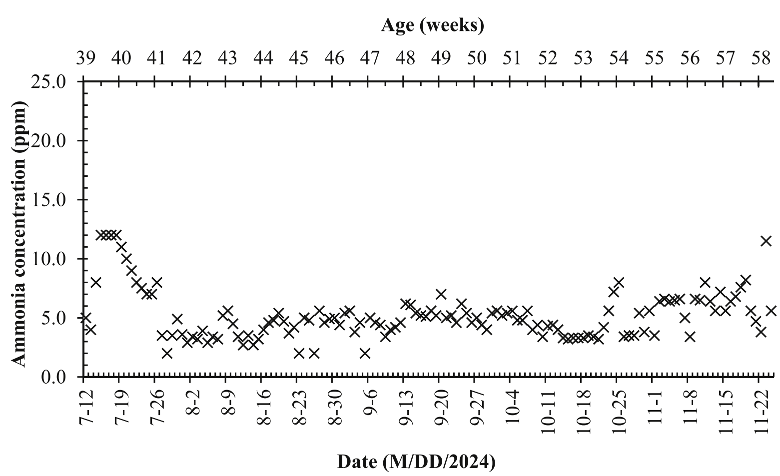

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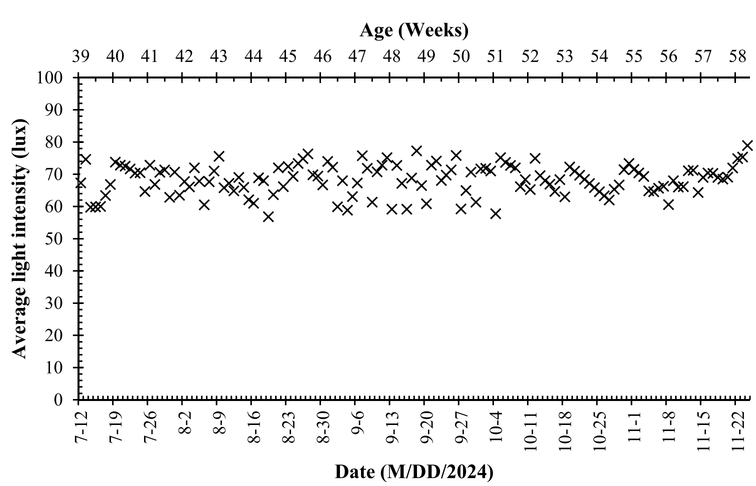


Fig. 3. Experiment room environment management (a) Daily average temperature and humidity levels. (b) Daily average ammonia levels. (c) Room light intensity.

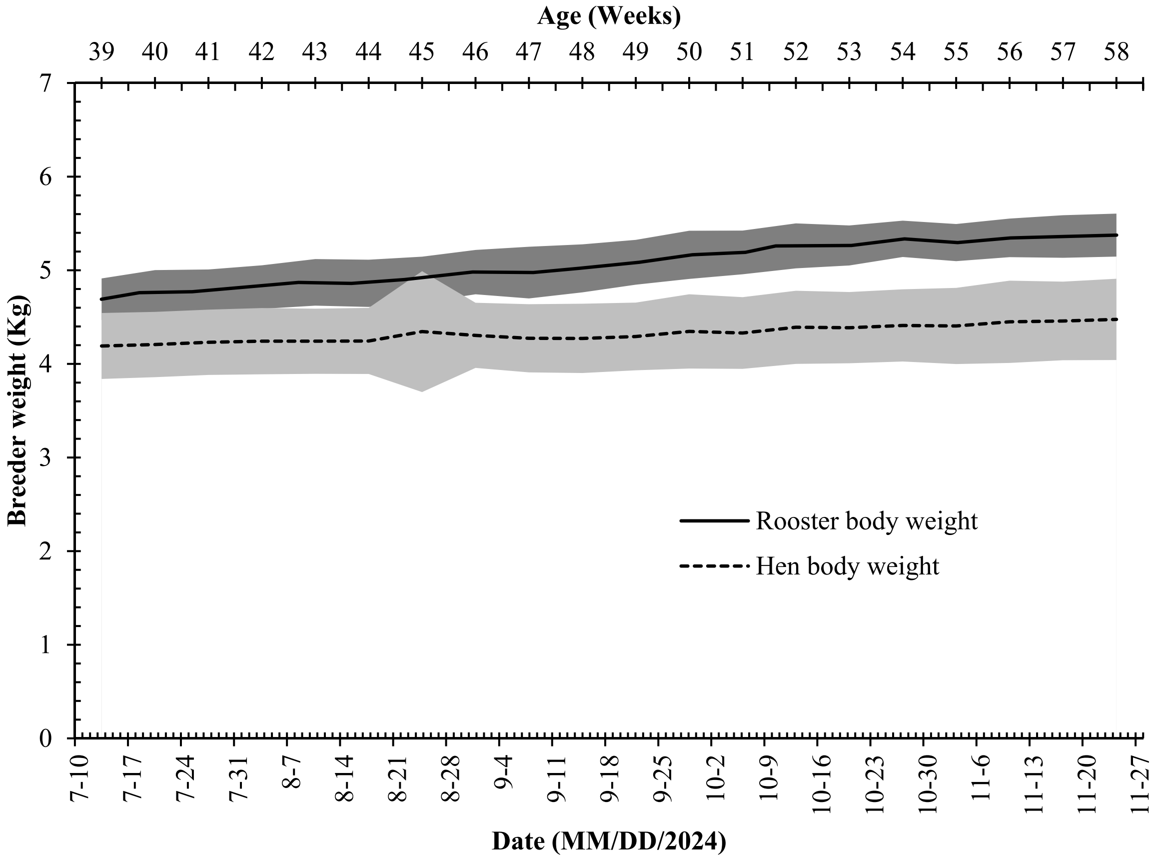


Fig. 4. Average weekly weight changes and their respective standard deviations (indicated by shaded areas) in broiler breeders.

Table 1
Weekly body weight of roosters and hens in the experimental pens (mean ± standard deviation).

	Hen (Kg)	Rooster (Kg)
Pen#1	4.27 ± 0.27	5.12 ± 0.20
Pen#2	4.38 ± 0.43	4.96 ± 0.21
Pen#3	4.26 ± 0.33	4.78 ± 0.28
Pen#4	4.37 ± 0.40	5.41 ± 0.24
Overall average	4.32 ± 0.39	5.07 ± 0.33

Table 2
Average weekly footpad dermatitis (FPD) and gait score (GS) in the experimental pens (median, (minimum, maximum)).

	Hen FPD	Hen GS	Rooster FPD	Rooster GS
Pen#1	1.5, (0,4)	2.0, (1.3)	1.4, (1,2)	1.0, (1,1)
Pen#2	2.0, (0,3)	2.0, (1,3)	3.0, (2,3)	1.0, (1,2)
Pen#3	2.0, (1,3)	1.6, (1,3)	2.0, (1,3)	1.0, (1,2)
Pen#4	1.0, (0,3)	2.0, (1,3)	3.0, (1,3)	2.0, (1,2)
Overall median, range	1.8, (0,4)	2.0, (1,3)	2.0, (1,3)	1.0, (1,2)

negatives as well as the false positives.

DL model application results

Upon application of the developed model on the whole dataset, the mounting phase characteristics for individual roosters were meticulously analysed and quantified. A total of 7269 mounting instances were detected by the model across the four pens and then individually analysed. The mounting phase dynamics over the experimental period provided essential insights about the overall mating characteristics as well as individual rooster performances over time.

Mounting Frequency and Duration. The individual roosters showed differing daily levels of mounting frequency and duration as depicted in Table 4. Overall, during a 15-hour daylight regime, the roosters exhibited an average mounting frequency of 13.5 ± 4.2 mounts per rooster per day, with each one lasting on average for 5.3 ± 0.8 seconds. The rooster in pen#1 performed the highest number of mountings per day while the rooster in pen#4 showed the lowest overall performance, in both mounting frequency and duration, and highest fluctuations over this period as demonstrated in Table 4.

Over the course of experiment, the daily mounting frequency had initial peak performance levels, at around 15–20 mounts per rooster per day, and steadily declined to about 10–15 mounts per rooster per day at the end of the experiment, with continuous fluctuations over time. The mating drive in the roosters and hens may have declined with age, potentially influenced by factors such as increasing weights and or changing welfare conditions, as was depicted in Figs. 4, and 5.

Meanwhile, the average mounting phase durations showed slight differences among roosters but were comparatively stable throughout the experimental period. Although, various factors which accumulated as the breeders aged, and which affected the frequency of mounting, were seemingly less influential on the duration of mounting.

The daily peak mounting activities of the roosters, i.e. hourly mounting occurrences expressed as a percentage of the daily total, were observed during the afternoon to evening hours (16:00–20:00) followed by the early mornings (07:00–09:00) period as shown in Fig. 8b. Possibly due to a more relaxed state, or circadian rhythms the roosters and hens were more inclined to follow a diurnal pattern and perform comparatively higher mounting attempts during these specific hours, while for the rest of the day they prioritized feeding, socializing or resting, as this hypothesis is also similarly supported by the research of Mauldin (2009).

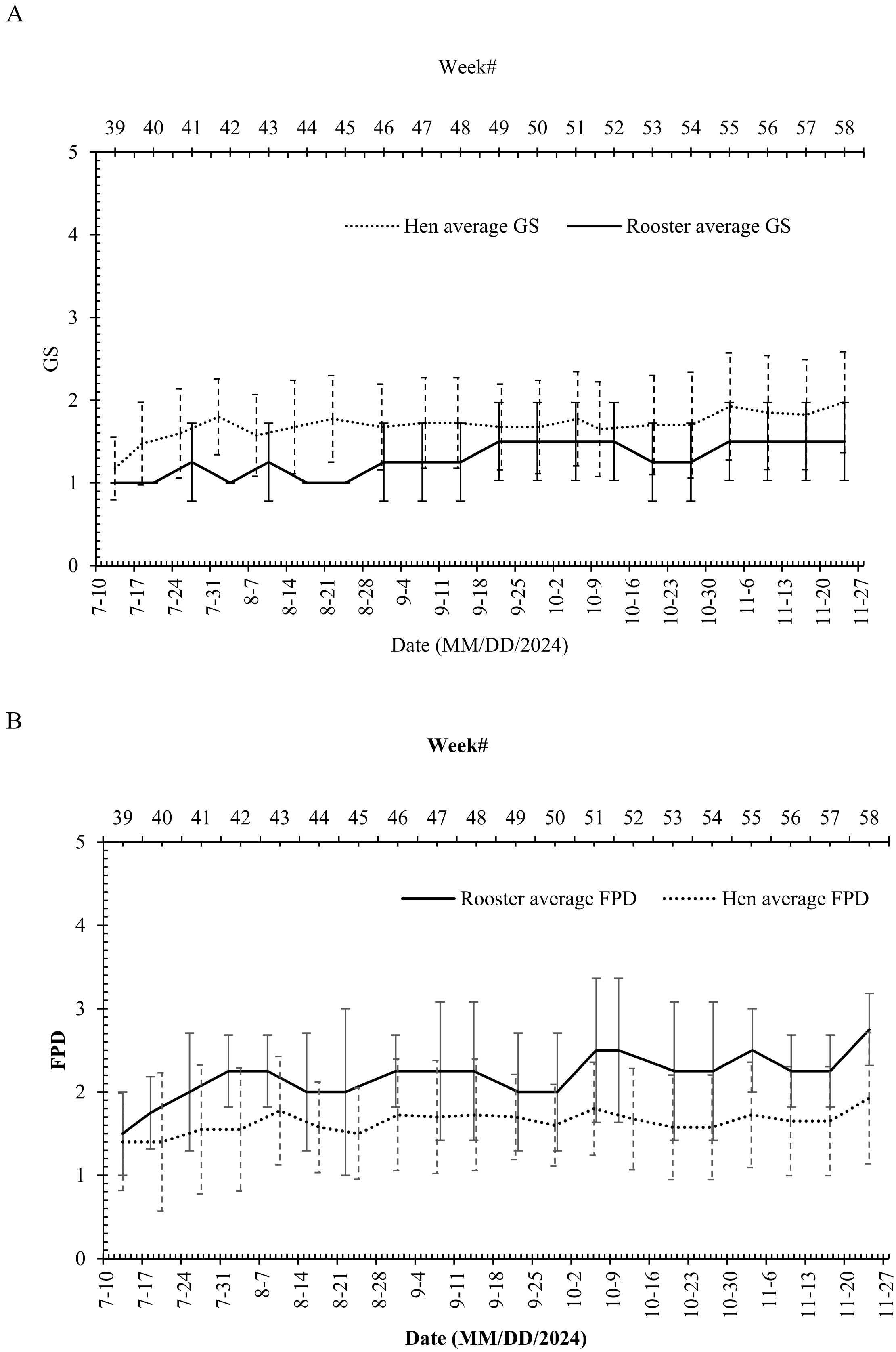
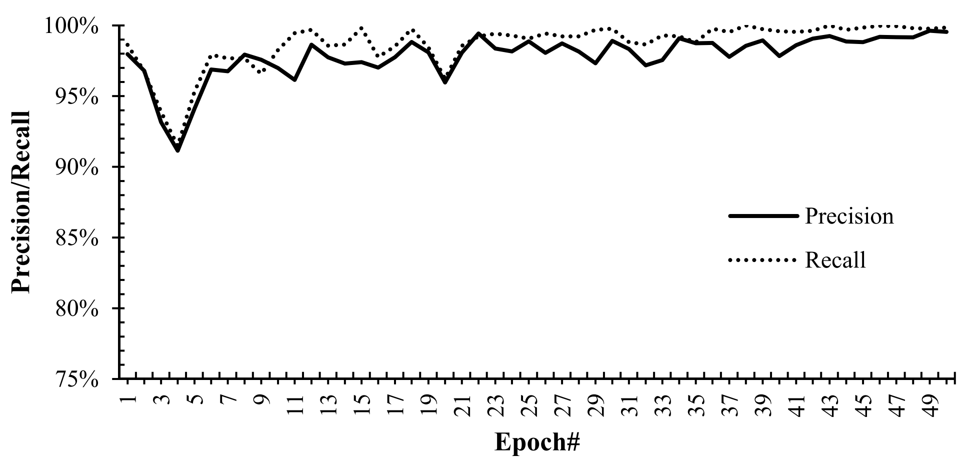


Fig. 5. Roosters and hens' welfare indicators (a) average weekly gait scores (b) average weekly footpad dermatitis levels and their respective standard deviations.

A



B

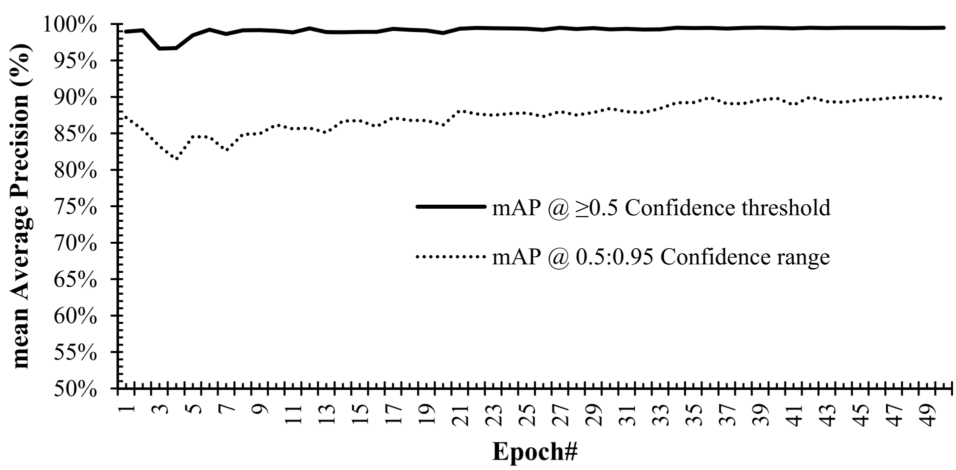


Fig. 6. YOLOv8m training and validation results (a) precision and recall metrics for confidence threshold≥0.5. (b) mAP level for confidence thresholds ≥0.5 and threshold ranging 0.5:0.95 range.

The inter-mounting interval elapsed between two consecutive mountings, i.e. mounting at times t and $t + 1$, provided another perspective into roosters and hens mating ability and reproductive drive. Overall, it took 70.6 ± 28.9 minutes for the subsequent mating event to happen after one, as presented in Table 4. The inter mounting interval increased over time as the number of mountings per rooster per day declined, as seen in Fig. 9a. Furthermore, as shown in Fig. 9b, the mounting activities were performed with the shortest interval, about 18.9 ± 4.0 minutes, during the evenings around 20:00, and then in the mornings around 06:00, with about 63.9 ± 11.4 minutes interval, and the longest interval, above 135.0 ± 28.6 minutes, around 10:00.

Insights into Mounting with Tail Movements. The broiler breeders demonstrated varying levels of mating behaviour with or without observable tail movement involved. On average, about 4 out of 5 or approximately 77.0 % ± 6.2 % of the total detected mounting instances across the four pens had been performed with some level of tail movements by the rooster, indicative of possible cloacal contact realization, as demonstrated in Table 5. The rooster in pen#1 showed the highest ratio in mounting with tail movement involved while the other ones had lower and comparable performance among themselves. On average, the mounting behaviour that entailed observable rooster tail movement lasted 5.4 ± 0.8 seconds, and the ones without any rooster tail movement observed, lasted 4.5 ± 1.9 seconds. Hence, it took longer for the roosters and hens to position their cloacae as demonstrated in the tail movements, as compared to the ones without any tail movements. The rooster in pen#1 was the most robust one, performing fast and highly efficient mounting behaviour across the pens.

Around 3317 out of 7269 mounting instances in the four pens, in which hen tail movements were visible to the observer, were closely investigated. As indicated in Table 6, the mounting instances were performed either by both or by none or at least one of the sides accepting or rejecting the mating behaviour. It was found that 68.2 % of the

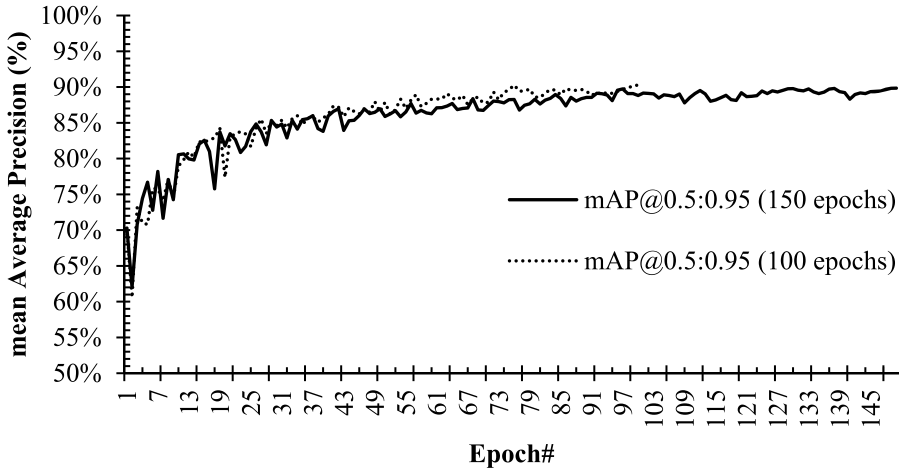


Fig. 7. YOLOv8m training mAP levels with two different epoch sizes, 100 and 150.

Table 3
Confusion matrix of the fine-tuned YOLOv8 model applied to the test dataset under (a) confidence threshold ≥0.5, (b) confidence threshold range 0.5:0.95, (c) model validation results with 0.9 confidence threshold, (d) model validation results with 0.5 confidence threshold.

	True mounting	True non-mounting	True background
A			
Predicted mounting	324	0	0
Predicted non-mounting	0	160	0
Predicted background	6	0	0
B			
Predicted mounting	324	0	0
Predicted non-mounting	0	160	0
Predicted background	11	6	0
C			
Predicted mounting	121	4	0
Predicted non-mounting	0	90	0
Predicted background	19	66	0
D			
Predicted mounting	146	17	0
Predicted non-mounting	5	138	0
Predicted background	0	0	0

Table 4
Daily average mounting frequency, average mounting duration and inter-mounting interval.

	Average daily mounting frequency	Average mounting duration (s)	Average Inter-mounting interval (min)
Rooster#1	15.3 ± 3.5	4.9 ± 0.9	61.1 ± 17.3
Rooster#2	13.5 ± 3.9	5.6 ± 0.7	68.5 ± 21.4
Rooster#3	12.6 ± 3.4	5.3 ± 0.9	71.7 ± 25.0
Rooster#4	12.5 ± 5.1	5.2 ± 0.7	81.0 ± 42.0
Overall average	13.5 ± 4.2	5.3 ± 0.8	70.6 ± 28.9

mountings were performed with both parties showing tail movements. On the other hand, 22.5 % of the times, i.e. about 1 in 5 mountings were performed with both hens and roosters initiating the mating and both halting the process by not showing any further synchronous tail movements. This ratio has been approximately constant throughout the experiment for the broiler breeders irrespective of age, both at the start of the experiment, where the mounting attempts were higher and during the end of the experiment, in which the mounting attempts had shown a gradual decline, as demonstrated in Fig. 8a.

Furthermore, it was found that compared to the hens, although close, the roosters had shown a little less tendency, 0.3 % of the time, to complete a mounting by denying any tail movement.

Statistical analysis of mounting behaviour

Repeated Measure Correlation Analysis. The age and weight factors exhibited by both broiler breeders had a significant effect ($p < 0.0001$) on daily mounting frequency irrespective of the rooster tail movement. The broiler breeders' GS levels in both the hens ($p < 0.0001$) and the roosters ($p < 0.0001$) revealed moderate correlations and significantly influencing the mounting behaviour. The FPD incidence, on the other hand, roosters ($p = 0.0004$) and hens ($p = 0.0041$), had significant effects with comparatively lower correlations with the mounting frequency, as shown in Table 7.

Combined Covariate Effects on Mounting Frequency. The linear mixed model regression results of the most significant factors, determined through backward selection approach, are depicted in Eqs. (4–7) and their respective AIC/BIC goodness-of-fit comparisons in Table 8. Here, specifically different combinations of rooster and hens' body weight and GS conditions were significant ($p < 0.05$) in explaining and/or predicting the mounting frequency with and without tail movements. As mating is a primarily physical activity, the hens and roosters with superior walking ability and optimal weights tended to perform higher.

As compared to mounting frequency predictions depicted in Eqs. (4–5), the mounting frequency with tail movements Eqs. (6–7) provided lower AIC/BIC values. The latter two equations better fitted the dataset in predicting and/or explaining the variations in the mounting frequency with tail movement levels. Furthermore, Eqn. (7) had the lowest AIC/BIC values as well as containing two variables, the weight of the rooster ($p < 0.0001$) and the GS of the hens ($p = 0.0179$), which made it the most suitable equation in terms of complexity. Meanwhile, the second-best model, Eqn. (6), consisted of average rooster GS ($p = 0.0067$), weekly hen body weight (pen average) ($p = 0.0060$), and average hen GS (0.0104).

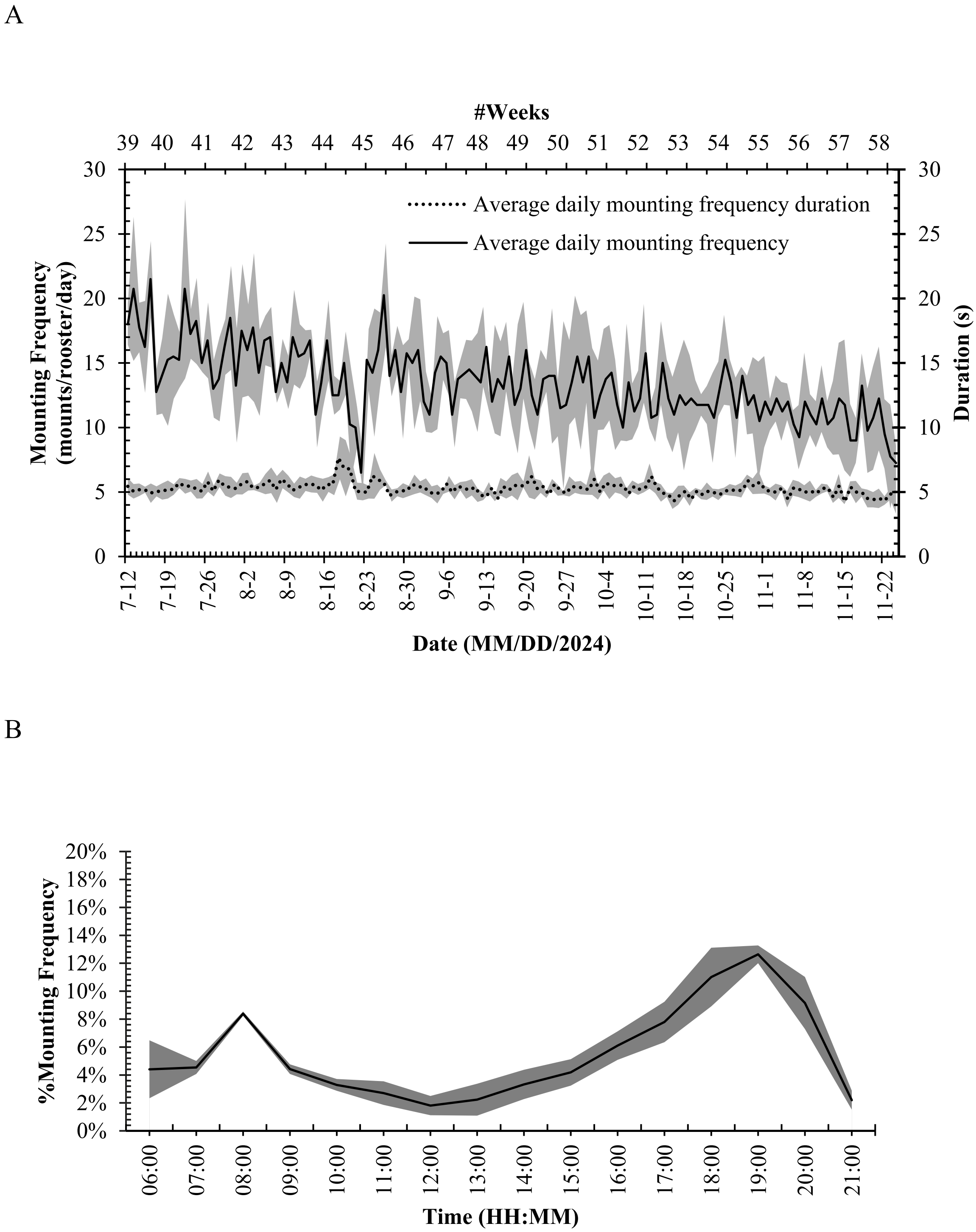


Fig. 8. Overall daily average mounting frequency and duration (a) and hourly mounting occurrence distribution (b) along with standard deviations (indicated by shaded areas) among across four pens.

$$Mounting\ frequency_{ij} = 68.1 - 1.8{*}GS_{rooster\,ij} - 10.7{*}Weight_{hen\,ij} - 3.6{*}GS_{hen\,ij} \quad (4)$$

$$Mounting\ frequency_{ij} = 26.9 - 2.4{*}GS_{rooster\,ij} - 6.1{*}GS_{hen\,ij} \quad (5)$$

$$Mounting\ frequency\ with\ tail\ movement_{ij} = 44.0 - 1.4{*}GS_{rooster\,ij} - 6.3{*}Weight_{hen\,ij} - 2.7{*}GS_{hen\,ij} \quad (6)$$

$$Mounting\ frequency\ with\ tail\ movement_{ij} = 34 - 3.9{*}Weight_{rooster\,ij} - 2.4{*}GS_{hen\,ij} \quad (7)$$

Discussions

DL model performance

In this study, the approach to train the model only on the distinctive appearances of roosters and not the hens, visually distinguishable

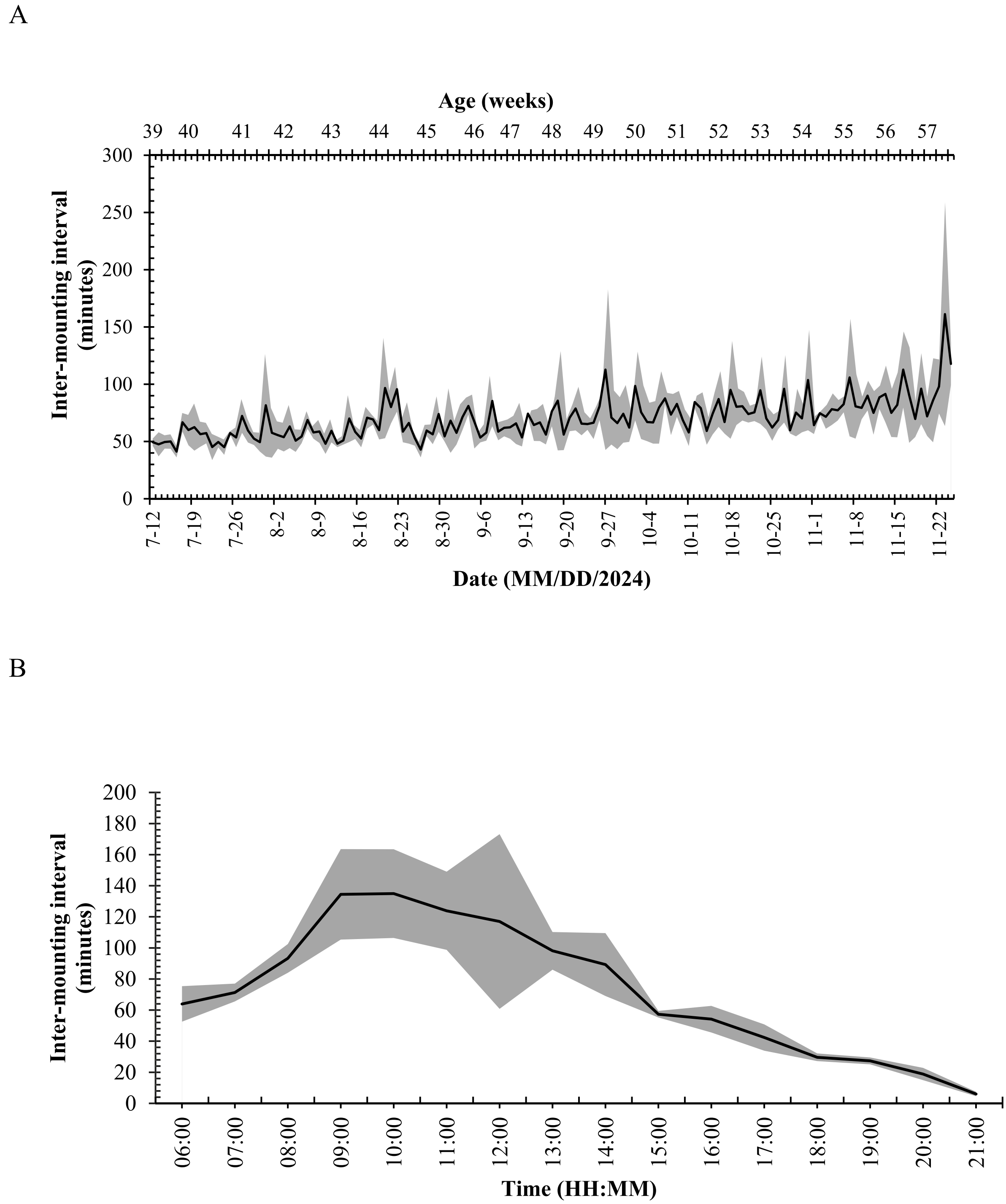


Fig. 9. Daily average inter-mounting interval (a) and inter mounting interval (b) along with respective standard deviations (indicated by shaded areas) over the experimental period.

mounting phase, and the non-mounting behaviour of the roosters proved efficient in building a model with less computational costs, hence easier to apply. In general, the fine-tuned model behaved as an effective rooster tracker, with over 91 % mAP accuracy, under strict object localization and classification confidence thresholds above 90 %, although it provided lower numbers of false positives as well. While the model's detection accuracy was comparable with the ones in recent literature, it surpassed them in detecting different sub-actions starting from the rooster mounting the hen, aligning itself and moving its tail for cloacal contact (Bodempudi et al., 2025; Saenong et al., 2023; Wang et al., 2022). The DL model excelled at detecting the mounting phase by analysing each consecutive frame in detail and processing immense amounts of data. It was able to detect and localize these instances across the pens wherever it had occurred, as demonstrated in Fig. 10a-c. The model could be further fine-tuned with datasets containing higher numbers of non-mounting behaviour labelled data as it may result in further decreasing the number of false positive detections.

Spatial and temporal characteristics in mating events

Possibly due to a more relaxed state, or circadian rhythms the roosters and hens were more inclined to follow a diurnal pattern and

Table 5
Occurrence and duration of tail movements during mounting phase.

Rooster	Tail movement		No tail movement	
	Mountings with tail movements (% of all mountings)	Duration of Mountings with Tail Movements (s)	Mountings without tail movements (% of all mountings)	Duration of mountings without tail movements (s)
Pen#1	87.7 %	5.1 ± 0.9	12.4 %	3.5 ± 1.4
Pen#2	73.2 %	5.8 ± 0.8	26.9 %	4.9 ± 1.7
Pen#3	73.3 %	5.3 ± 0.9	26.5 %	5.3 ± 2.5
Pen#4	73.80 %	5.6 ± 0.7	26.0 %	4.2 ± 1.3
Overall average	77.0 %±6.2 %	5.4 ± 0.8	23.0 %±6.2 %	4.5 ± 1.9

Table 6
Synchronization of tail movements between rooster and hen during the mounting. Data includes only those with tail movement visible to the assessor.

		Rooster	
		Tail moved	Tail not moved
Hen	**Tail moved**	2325 (68.2 %)	165 (4.8 %)
	Tail not moved	154 (4.5 %)	673 (22.5 %)

Table 7
Repeated measure correlation levels of production and welfare factors with overall mounting frequency and mounting frequency with rooster tail movement.

	Daily average mounting frequency (by week)		Daily average mounting frequency with rooster tail movement (by week)	
	Correlation coeff.	p-value	Correlation coeff.	p-value
Age	−0.75	<0.0001	−0.68	<0.0001
Average hen FPD	−0.32	0.0041	−0.36	0.0011
Average hen GS	−0.56	<0.0001	−0.52	<0.0001
Average rooster FPD	−0.39	0.0004	−0.42	0.0001
Average rooster GS	−0.44	<0.0001	−0.42	0.0002
Weekly hen body weight (pen average)	−0.63	<0.0001	−0.55	<0.0001
Weekly rooster body weight (per pen)	−0.71	<0.0001	−0.62	<0.0001

Table 8
Combined effects of production and welfare factors with overall mounting frequency and mounting frequency with rooster tail movement.

Model equation	AIC	BIC	Predictor variables	Predicted variables
Eqn. (4)	345.1	358.3	Average rooster GS, Weekly hen body weight (pen average), Average hen GS	Daily average mounting frequency (by week)
Eqn. (5)	356.5	367.6	Average rooster GS, Average hen GS	Daily average mounting frequency (by week)
Eqn. (6)	312.6	325.8	Average rooster GS, Weekly hen body weight (pen average), Average hen GS	Daily average mounting frequency with rooster tail movement (by week)
Eqn. (7)	312.2	323.3	Weekly rooster body weight (per pen), Average hen GS	Daily average mounting frequency with rooster tail movement (by week)

perform comparatively higher mounting attempts during morning and evening specific hours, while for the rest of the day they prioritized feeding, socializing or resting, as this hypothesis is also similarly supported by the research of Mauldin (2009).

The mating behaviour was predominantly observed in the far half of the pen, between the feeder and nest boxes, followed by the area between the entrance and feeder, as depicted in Fig. 10c. Here, for demonstration purposes, detections over a 5-day period, totalling 257 mating events of individual roosters are shown. The area surrounding the feeder and drinker was usually crusted, mostly due to water spillage from the drinker and excretions or manure; the broiler breeders here were primarily occupied with feeding or drinking activities. In contrast, primarily in the areas near the nest boxes in the pen that were drier and feasible for preening and resting, i.e. not crusted and hardened, the roosters were mostly observed engaged in mating. Since softer and drier areas provide greater stability for successful mating events, such zones need to be continuously managed and monitored within the pen environment.

Hence, for efficient broiler breeder farm management, designing distinctive spaces that promote stability while mating and planning daily tasks in the pens during mid-day deem important and may facilitate and even increase mating behaviour.

Mating features

The mounting phase occurred both very quickly and infrequently, roughly once per hour on average, with a duration of about 5 seconds, and the frequency decreased as roosters and hens aged ($p < 0.05$). While the mounting frequency decreased gradually over time, the tail movement ratio and time spent during mounting phase were mostly constant. On the other hand, it took longer for the roosters and hens to position their cloacae as demonstrated in the tail movements, as compared to the ones without any tail movements.

To clarify the difference in tail movements between roosters and hens its distribution was further investigated. As depicted in Fig. 11a, the number of days in which the mating demand, apparent in tail movements by the broiler breeders, was met equally, 26.7 % of the days, is less than the days it was not, 73.3 % of the days. Comparatively there were more days in which hens demonstrated heightened mating drive, i.e. tail movement, 41.4 % of the days, than the roosters did, 31.9 % of the days. Presented in Fig. 11b, the daily net difference in tail movement (roosters' total tail movement frequency minus hens' total tail movement frequency) revealed that during the first two-thirds of the experiment, there have been more tail movements shown by the hens than the roosters. However, approximately in the final third part of the experiment, specifically after 10/17/2024 shown in the Fig. 11b, the trend had reversed as the hens started to show declining numbers in tail movements, and possibly mating tendency, as compared to males.

Among the many underlying factors, static male to female ratio could have been an issue as the demand by either hens or roosters seems to be heightened during specific periods of the experiment. This result confirms the current literature around male to female ratio which recommend practices such as perioding spiking or introduction of new roosters during the breeding season (Sabah et al., 2023). Furthermore, these results also indicate the distinct role of hens in matings and suggest that while hens exhibit high mating demand during the early phases of the breeding season, their activity appears to decline in the later stages, likely due to physical strain and welfare deterioration, i.e. comparably

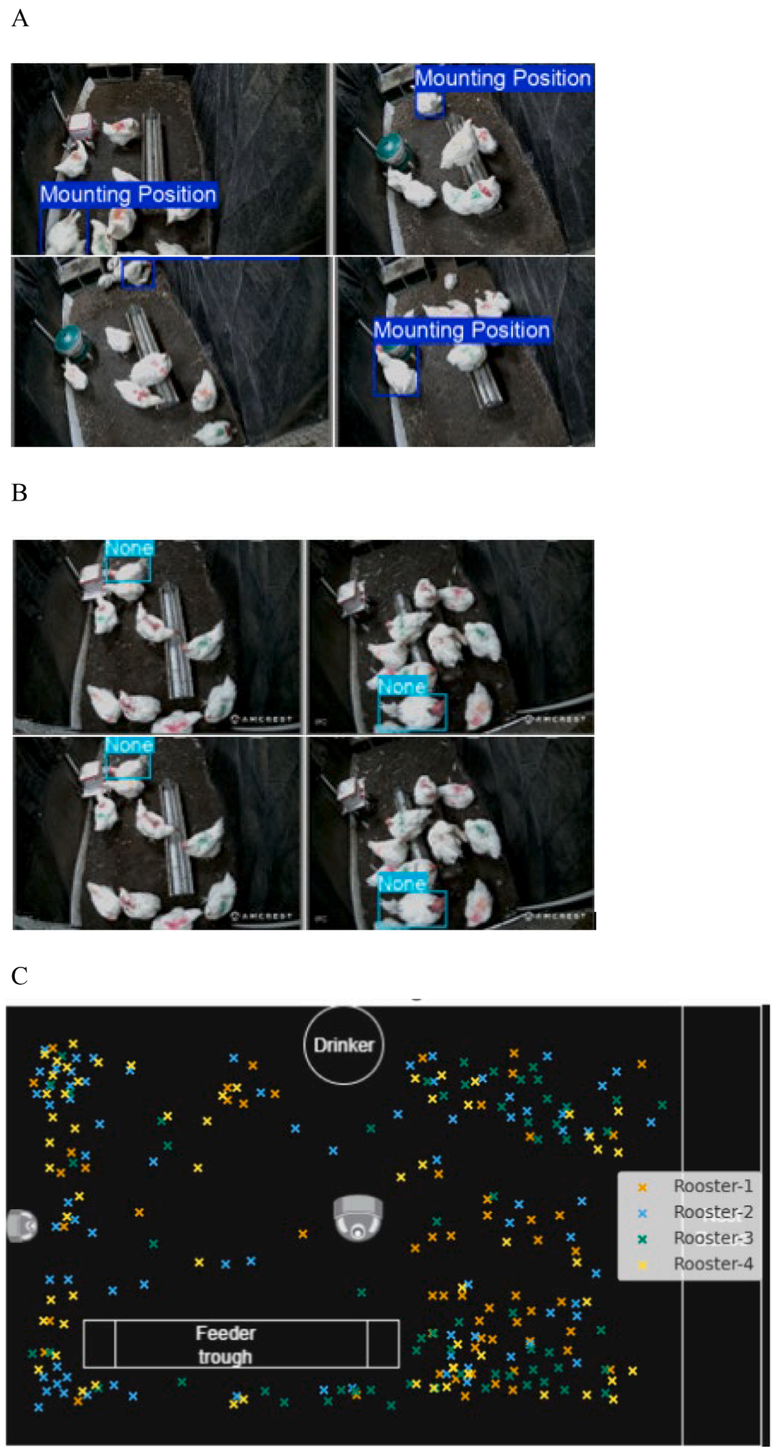


Fig. 10. Example instances involving mating and non-mating roosters that are successfully detected by the model. (a) Mounting class. (b) Non-mounting class. (c) Mating locations detected by the model (sampled from 5 days data).

roosters were physically more tolerant to decline as they aged (Moyle et al., 2010). Although replacing male breeders has been shown to improve fertility, this raises an important question: when should female breeder replacement be considered in the farms?

Welfare factors affecting mating

The roosters and hens were affected with differing levels of FPD and GS issues, which might have stemmed from their physiological, behavioural differences. While the roosters had bigger body weights, i.e. muscular and skeletal formation, they were less susceptible to gait deterioration as compared to the hens. Additionally, continuous daily matings during which hens were mounted by heavy roosters might have inflicted extra mechanical stress on their bodies and legs, resulting in poorer gait conditions. The daily mating events occurring frequently had resulted in feather loss on the backs as well as chests in some hens during the experimental period. Such wear and tear could have also resulted as some hens might have been favoured by a rooster and comparatively mated with more frequently.

On the other hand, FPD lesions were more visible in the roosters than

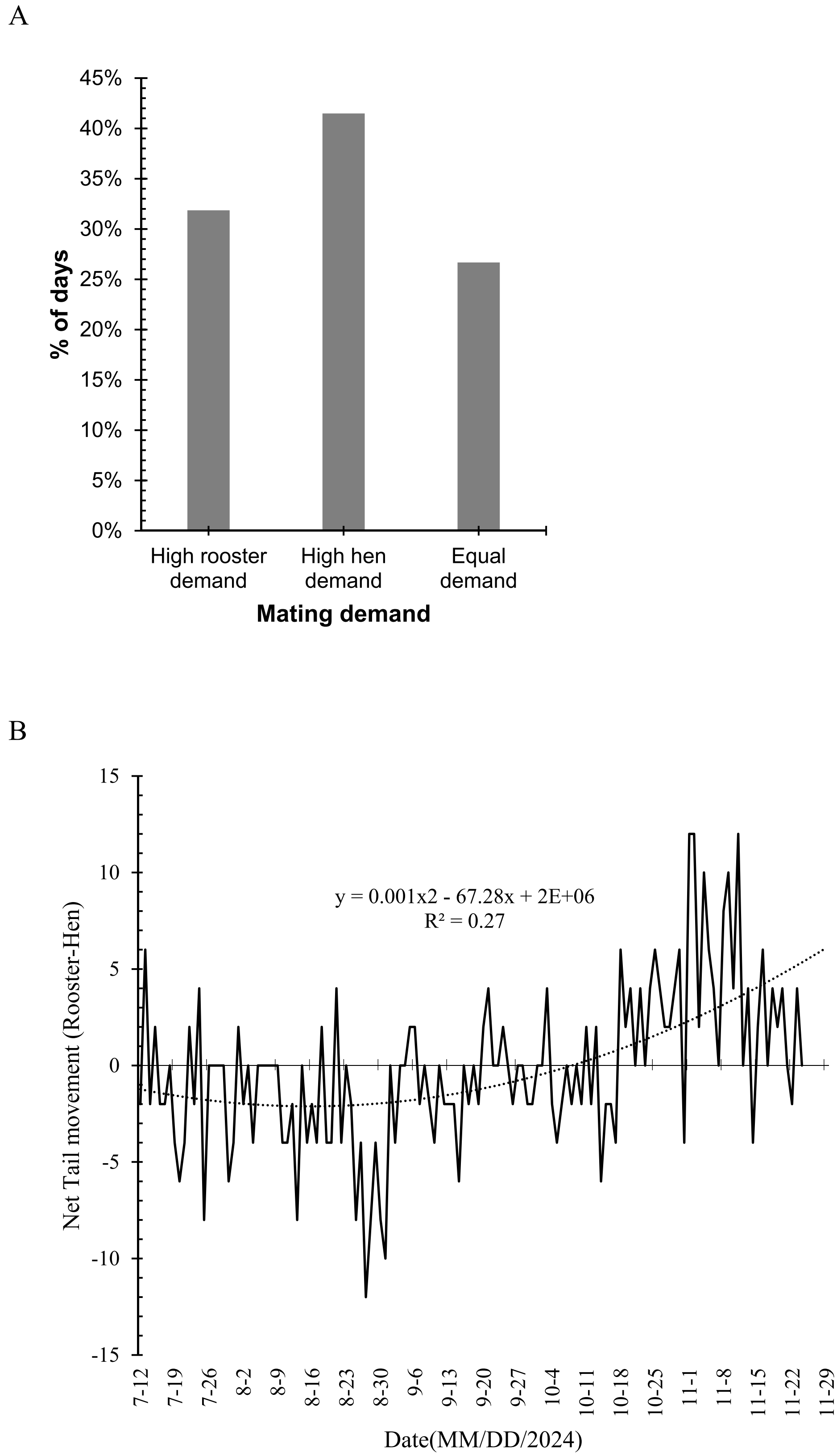


Fig. 11. Mating demand, evident in tail movements, comparison (a) and the daily difference in tail movements between rooster and hen during mounting (b). Data includes only those with tail movements visible in the recordings to the assessor.

hens, which might as well have resulted from their higher exposure to litter due to their larger footpads as compared to the hens. Leg health, evident in FPD and GS, in broiler breeders also showed significant negative individual correlations as well as were significant predictors of the level of mating performed, as depicted in in Table 7 and Eqs. (5)-(7) ($p < 0.05$).

Here, the importance of managing bedding conditions, body weight and other factors resulting in poor leg health conditions proves crucial in maintaining mating levels in broiler breeders, as also indicated in the literature (Hocking and Bernard, 2000; Kaukonen, 2017; Kittelsen et al., 2024; van den Oever et al., 2020). These results offer valuable insights into mating behaviour dynamics which could help in management practices for efficient breeding strategies such as optimal performance window for typical roosters, which might immensely optimize production supply.

Ethics approval

This study has been approved by the Institutional Animal Care and Use Committee (IACUC) at the University of Tennessee.

CRediT authorship contribution statement

M. Jaihuni: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Y. Zhao:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Conceptualization. **H. Gan:** Writing – review & editing, Methodology. **J. Moyle:** Methodology, Investigation, Funding acquisition. **T. Tabler:** Writing – review & editing. **H. Qi:** Writing – review & editing. **X. Zhu:** Writing – review & editing. **S.C.N. Hewage:** Data curation.

Disclosures

The authors declare that they have not known competing financial interests or proposal relationship that could have appeared to influence the work presented in this paper.

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