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Genetic parameter estimates for the use of an aviary with winter garden by laying hens

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ABSTRACT The behavioral activity of laying hens in an aviary is indicative of their welfare and health. Furthermore, hens' usage of the different locations within an aviary has been shown to influence laying performance and egg quality. For example, hens that spent a longer duration of time in the nest during laying were observed to have lower laying performance. Therefore, understanding genetics of laying hens' usage of the aviary could be important for predicting egg quality, production traits and health and welfare. The objectives of this study were to estimate genetic parameters for duration of time spent at different locations within the aviary and an adjacent winter garden using a multivariate repeatability model and to compare correlations between time spent in these locations. For this study, a total of 1,106 Dekalb white laying hens (Hendrix Genetics) were genotyped using a proprietary 60K SNP array. These hens had access to 5 different zones within the aviary, which included the top level tier, nest box tier, lower level tier, floor littered area and a winter garden. Hens were in the aviary for a total of 290 d and daily records of duration were collected for each hen visit to any location in the aviary, culminating in a total of 937,740 records. Heritability estimates ranged from 0.05 (0.01) to 0.28 (0.03) for the duration of time spent in the different zones. The lowest heritability was estimated for time spent at the lower level tier, while a higher heritability was estimated for time spent in the floor littered area. A moderately high negative genetic correlation of −0.59 (0.08) was observed between time spent in the top level tier and time spent in the floor littered area, while a favorable correlation of 0.37 (0.14) was found between time spent in the lower level tier and time spent in the winter garden. The findings of this study show that the duration of time spent at different zones within an aviary has genetic basis and could be used for selecting animals for better performance and higher welfare.

Key words: genetics, housing systems, aviary, welfare, hen behavior

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INTRODUCTION

Conventionally, battery cage housing systems have been used to keep commercial laying hens across most of the world. However, these types of housing system have raised ethical concerns as they generally restrict movement (Weeks and Nicol, 2006) and prevent the expression of natural behaviors such as: perching (Olsson and Keeling, 2002), dustbathing (Widowski and Duncan, 2000), nesting (Cronin et al., 2012), as well as foraging and exploring (Weeks and Nicol, 2006). As a result, more suitable housing systems that allows for greater hen welfare should be explored. With the recognized welfare problems, there has been an active process to investigate and adopt alternative housing systems (i.e., enriched cage and cage-free housing systems) (e.g., Decina et al., 2019; van Staaveren et al., 2021). For instance, Switzerland effectively banned all cage housing systems in 1992 (Häne et al., 2000) while the European Union (**EU**) prohibited the use of battery cages from 2012 (CEC, 1999) due to the inability to provide sufficient space for birds to exhibit their inherent behavior and movements. Similarly in 2016, the Egg Farmers of Canada (**EFC**) set a timeline of 2036 to perform an industry-wide staggered transition from the unenriched cage housing system to alternative housing systems (National Farm Animal Care Council, 2017). Following these initiatives, there has been an uptick in the use of noncage housing systems. According to the European Commission (2022), approximately 55% of commercial laying hens in the EU were kept using cage-free housing system in 2021 compared to 30 and 8% in 2009 and 1996, respectively (ITAVI, 2020).

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One of the increasingly popular alternatives to battery cage housing system is the aviary housing system. Aviaries are tiered structures that provide nest boxes for laying eggs, perches for perching, elevated areas for roosting, and a litter area for foraging and dustbathing (Sosnówka-Czajka et al., 2021). Accordingly, the use of aviaries is considered beneficial for skeletal development; previous research has found that pullets and laying hens reared in aviaries have stronger bone quality with improved musculoskeletal development compared to those reared in conventional cage systems (Regmi et al., 2015, 2017; Neijat et al., 2019). The authors suggested that the enhanced locomotive activities provided by the aviary systems resulted in the improved bone strength of the tibia and humerus. Sometimes, aviaries are adjoined to a winter garden with covered screens that provide access to natural sunlight and outside weather conditions (Häne et al., 2000; Bécot et al., 2021). The provision of a winter garden as part of the hen housing systems is a suitable option that tends to promote hen welfare in commercial settings. For example, hens that frequently use outdoor space or winter garden are observed to show less severe feather pecking characteristics than hens that frequently use the indoor space (Bestman and Wagenaar, 2003; Lambton et al., 2010). Hence, aviaries with winter garden could be beneficial for improving hen welfare by reducing the occurrence of severe feather pecking.

The transition to aviary systems has instigated the investigation of new phenotypic traits such as: nesting behaviors of hen, laying duration, frequency of passage and duration of time spent in the winter garden (Icken et al., 2011, 2012). These traits are economically important in aviary systems as they play a crucial role in laying performance of hens, which ultimately determines the number of saleable eggs produced. For example, hens that make use of the provided nest boxes within an aviary are more likely to develop nest-building behavior and less likely to display nest-seeking behavior (Cooper and Appleby, 1996). Likewise, hens displaying nest-building behaviors tend to sit longer in the nest before oviposition (Cooper and Appleby, 1996). These nest behaviors help prevent laying eggs in the floor area (off-nest), which are prone to breakage, stained with hen droppings, laborious to collect, and often times contaminated with eggshell bacteria (De Reu et al., 2006). Studying these new traits, Bécot et al. (2023) estimated heritabilities (standard errors (**SE**)) of 0.13 (0.02), 0.54 (0.06), and 0.24 (0.04) for laying rate in the nest, mean laying duration and percentage of nests used, respectively. Further, these authors reported a genetic correlation (SE) of 0.46 (0.09) between percentage of nest used and mean laying duration. In addition, using a twelve 28-day laying period, Icken et al. (2008) estimated heritability (SE) for the duration of stay in the winter garden that ranged from 0.04 to 0.32 (0.03−0.11). Based on previous research, part of the variation observed with aviary usage can be attributed to genetic etiology. However, research is lacking in the estimation of genetic components for the usage of the different zones that are provided in an aviary. Therefore, the objectives of this study sought to estimate genetic parameters of time duration spent in different zones within an aviary system using a multivariate repeatability mixed model and compare the genetic correlations estimated between these locations.

MATERIALS AND METHODS

Ethical Statement

The experiment was approved by the Veterinary Office of the Canton of Bern (BE4/2021) and met all cantonal and federal regulations for the ethical treatment of laboratory animals.

Animals and Management

The chickens used in this study were provided by Hendrix Genetics (5831 CK Boxmeer, The Netherlands) and comprised 1,124 white laying hens of the hybrid Dekalb with 230,594 daily collected movement records. The hens were all hatched in June 2021 and arrived as hatchlings from crosses of pure lines on the site of the Aviforum, Switzerland (www.aviforum.ch). Each chick wore a wing tag that indicated their sire. The chicks were placed into 8 pens each in an on-site rearing barn, stratified for sire with 100 sires in total. Four pens of the rearing barn contained the rearing aviary Landmeco Harmony, Landmeco A/S, Olgod, Denmark (4.89 × 4.55 m) and the other half had the rearing aviary Inauen Natura, R. Inauen AG, Appenzell, Switzerland (4.86 × 3.92 m). After approximately 11 wk, birds were given access to a winter garden with perches during daytime. Just before transfer to the production barn, at approximately 17 wk of age (**WOA**), 1,124 pullets from 25 of the 100 sires were fitted with a passive RFID tag (125 kHz) and a pen-specific color leg band. The allocation of pullets to 5 pens of 225 birds in the production barn was stratified for sire and pen as in the rearing barn. At 18 WOA, hens were transported from the rearing barn to 5 out of 20 pens in the production barn with a Bolegg Terrace aviary (Vencomatic Group, 5,521 DW Eersel, The Netherlands). The aviary system was an equipped 3-tiered aviary consisting of a top level tier (**TLT**), nest box tier (**NBT**), and lower level tier (**LLT**). In addition, the aviary had a floor littered area (**LIT**), and an attached winter garden area (**WG**), which was accessible from approximately 21 WOA onward.

Feeding, vaccination, duration of light, and other management procedures followed common guidelines and instructions for the Dekalb hybrid. The maximum length of light was 14 h from 03:00 to 17:00 and the natural light through windows was supplemented by artificial light, whereas access to the winter garden was between 10:00 and 16:00.

Recording System of Locations

To record and monitor the frequency of passage between zones and duration of time each hen was located in the earlier defined zones of the aviary (i.e., TLT, NBT,

Table 1. Descriptive statistics of the daily duration of time spent in different zones within the aviary.

Zones[1]	Number of records	Average duration[2]	Minimum duration[2]	Maximum duration[2]	Average number of visit
TLT	192,603	354.31	0.12	900	7.56
NBT	182,454	54.26	15.02	364	1.36
LLT	206,625	153.46	0.02	900	8.00
LIT	203,723	355.38	0.02	900	21.11
WG	152,335	37.57	0.02	360	5.61

[1]Top level tier (TLT), nest box tier (NBT), lower level tier (LLT), floor littered area (LIT), winter garden (WG).
[2]Average, minimum, and maximum duration are given in minutes.

LLT, LIT, and WG), the Gantner Pigeon Systems GmbH (6780 Schruns, Austria) was used. Thirty two 12-field SPEED antennas (75 × 35 cm) were distributed on the edges of all zones on both sides of the aviary, in 2 rows on the littered floor, before, and behind the pophole leading to the winter garden. A previous set up with only 1 row of antennas on the floor was validated (Gebhardt-Henrich et al., 2023, in review). Activity monitoring of the birds began 5 d after arrival in the aviary. The delayed start was to ensure that the hens adapt well into their unfamiliar environment and that the signals generated from the RFID were working appropriately. The last daily record collected from the birds was on d 290 (approximately 59 WOA) from the first day of arrival in the aviary. Duration of time was recorded in tenth of seconds and the maximum duration a hen could spend in a zone was restricted to 900 min because the aviary was only monitored for 15 h in a day. In addition, the maximum duration spent in the winter garden could not exceed 360 min. Thus, all time duration records that exceed 900 and 360 min of time spent in the different zones and winter garden, respectively, were removed from further analyses. Moreover, animals that died during the study (14 birds) or lost their RFID tags (4 birds) were removed. Furthermore, 68 d of unusual disturbances (e.g., health assessments for this or another project in the barn in other pens) were deleted. Only genotyped animals were kept for further analyses. Movement records were collected for each animal based on the number of visits and time spent at any particular zone. The time spent in minutes at a particular zone were then cumulated per day, therefore, each animal would be assigned a cumulative time spent in a zone for each day in the barn. In total, 1,106 animals with 937,740 cumulative daily movement records were retained for further analyses. Table 1 shows the number of records for the duration spent in different zones. The distribution of duration spent in the different zones using 25-day averages in presented in Figure 1. For this study, no pedigree information was available.

Genotype Data

All birds alive at 30 WOA were genotyped using a proprietary 60K SNP panel (Illumina Inc. 60K). For the

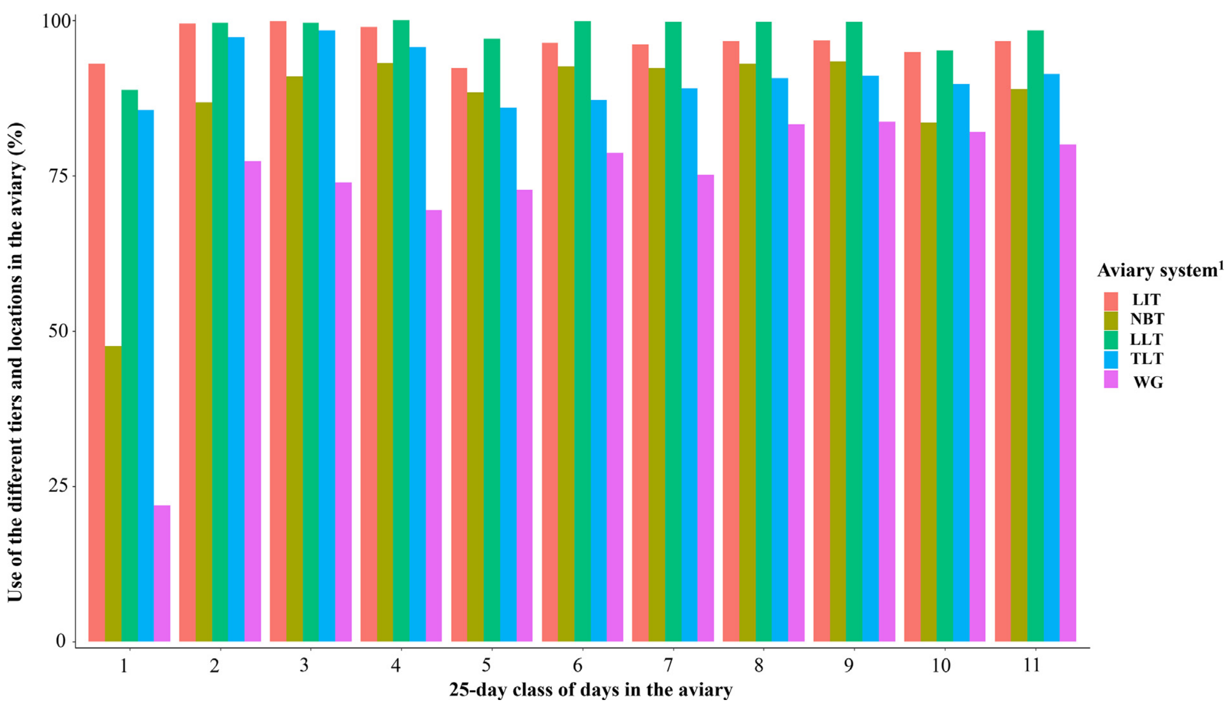

Figure 1. A 25-day average percentage of hens that used the different zones and locations within the aviary. [1]Floor littered area (LIT), nest box tier (NBT), lower level tier (LLT), top level tier (TLT), winter garden (WG).

genotypic quality control, only autosomal SNP markers with call rate greater than 0.95 and a minor allele frequency (**MAF**) greater than 0.05 were retained. After filtering for quality control, a total of 40,563 SNP markers with an average call rate greater than 99% remained.

Statistical Analysis

To estimate genetic parameters for duration spent in different zones of the aviary, a multivariate mixed model using repeated records was employed. In all, there were 5 traits that included the duration spent in the TLT, NBT, LLT, LIT, and WG. The model procedure was based on the best linear unbiased prediction (**BLUP**; Henderson, 1975) using genomic information to derive the genomic relationship matrix (**GRM**). This procedure is known as genomic best linear unbiased prediction (**GBLUP**) and was introduced by VanRaden (2008). The analysis was performed using the restricted maximum likelihood method implemented in ASReml 4.1. (Gilmour et al., 2015).

Genomic Best Linear Unbiased Prediction

For the multivariate mixed model, the following equation was used to estimate genetic components for duration spent in the different tiers:

$$\boldsymbol{y} = \boldsymbol{Xb} + \boldsymbol{Za} + \boldsymbol{Wpe} + \boldsymbol{e} \tag{1}$$

where $\boldsymbol{y}$ is a vector of the 5 measured traits for duration spent in the different zones (traits within hens), $\boldsymbol{b}$ is the vector of fixed effect that included: the overall mean, days in aviary, pen, and number of visits to the zone, $\boldsymbol{a}$ is a vector of random additive genetic effect, $\boldsymbol{pe}$ is a vector of random permanent environment effect, $\boldsymbol{e}$ is the random error term, $\boldsymbol{X}$, $\boldsymbol{Z}$, and $\boldsymbol{W}$ are incidence matrices the relates the fixed effects, random genetic effect and random permanent environment effect to the phenotype, respectively. The following assumptions were upheld for the random effects:

$$Var\begin{bmatrix} \boldsymbol{a} \\ \boldsymbol{pe} \\ \boldsymbol{e} \end{bmatrix} = \begin{bmatrix} \boldsymbol{G}\otimes\boldsymbol{C} & 0 & 0 \\ 0 & \boldsymbol{I}\otimes\boldsymbol{P} & 0 \\ 0 & 0 & \sum_{\boldsymbol{i}=1}^{\boldsymbol{N}+}\boldsymbol{E_i} \end{bmatrix} \tag{2}$$

where $\boldsymbol{G}$ is the genomic relationship matrix, $\boldsymbol{C}$ is the genetic (co)variances (order 5 × 5) matrix, $\boldsymbol{I}$ is the identity matrix, $\boldsymbol{P}$ is the permanent environment (co)variances (order 5 × 5) matrix, $\boldsymbol{E_i}$ is the residual (co)variances (order 5 × 5) matrix, N is the total number of records, $\otimes$ is the direct kronecker product, $\sum^{+}$ is the direct sum and all other terms have been defined previously.

Creating the Genomic Relationship Matrix

The genomic relationship matrix was created with the available genotyped animals using the method proposed by VanRaden (2008):

$$\boldsymbol{G} = \frac{\boldsymbol{ZZ'}}{2\sum p_i(1-p_i)} \tag{3}$$

where $\boldsymbol{Z}$ is a matrix with elements that have been centered using the allele frequencies, that is, $2p_i$ was subtracted from the original genotype values, p_i is the allele frequency of the second homozygote for the ith SNP.

RESULTS AND DISCUSSION

The present study investigated the use and duration spent in different defined zones in an aviary system. To achieve this, advanced RFID technology using transponders attached to laying hens was used to monitor the movement of the hens in the aviary. Using this technology, daily records of duration spent in the different zones were collected over the entire laying phase. Descriptive statistics of the cumulative daily records are presented in Table 1. The average daily use of the different zones by the hens varied across the observation period. The average duration spent in the different zones within the aviary ranged from 37.57 to 355.38 min, while the lowest and highest duration spent in a zone was observed for the WG and LIT, respectively. The average duration spent in the NBT was found to be 54.26 min, a value within the range reported by Bécot et al. (2023) for mean laying duration (**MLD**). Those authors reported 41 and 64 min MLD for Rhode Island Red (**RIR**) and White Leghorn (**WL**), respectively. The slight differences between studies may be due to different genetics, housing configurations, and trait definitions.

With our RFID system, we could not determine whether a bird had laid an egg during the nest visit. Therefore, we assumed that nest visits that lasted between 15 and 90 min during the first 8 h after light exposure resulted in oviposition. MLD was computed as duration that started when the hen enters the nesttier and ended when the hen left the nesttier when conforming to our definition of oviposition. In the current study, duration spent in the NBT was determined as the point of entry and exit of the actual zone (i.e., not the nest box itself, which was not within the capacity of our system) with or without oviposition.

The average percentage of hens that used the WG daily in the first 25 d of arrival in the aviary was approximately 22% (Figure 1). This result is in line with the observation reported by Icken et al. (2008), where a 26% WG usage was found for the first 28-d of the hens laying period. In addition, at the beginning of the arrival of the hens to the aviary, the average percentage of NBT used was approximately 48%. The low percentage could be attributed to hens coming into lay at different ages. In general, after the first 25 d of arrival in the aviary, the number of hens that used the different zones increased and the use was consistent over the observation period, showing evidence of a repeated behavior (Montalcini et al., 2023). The high repeatability for observed zones suggests that at that time most of the resources provided

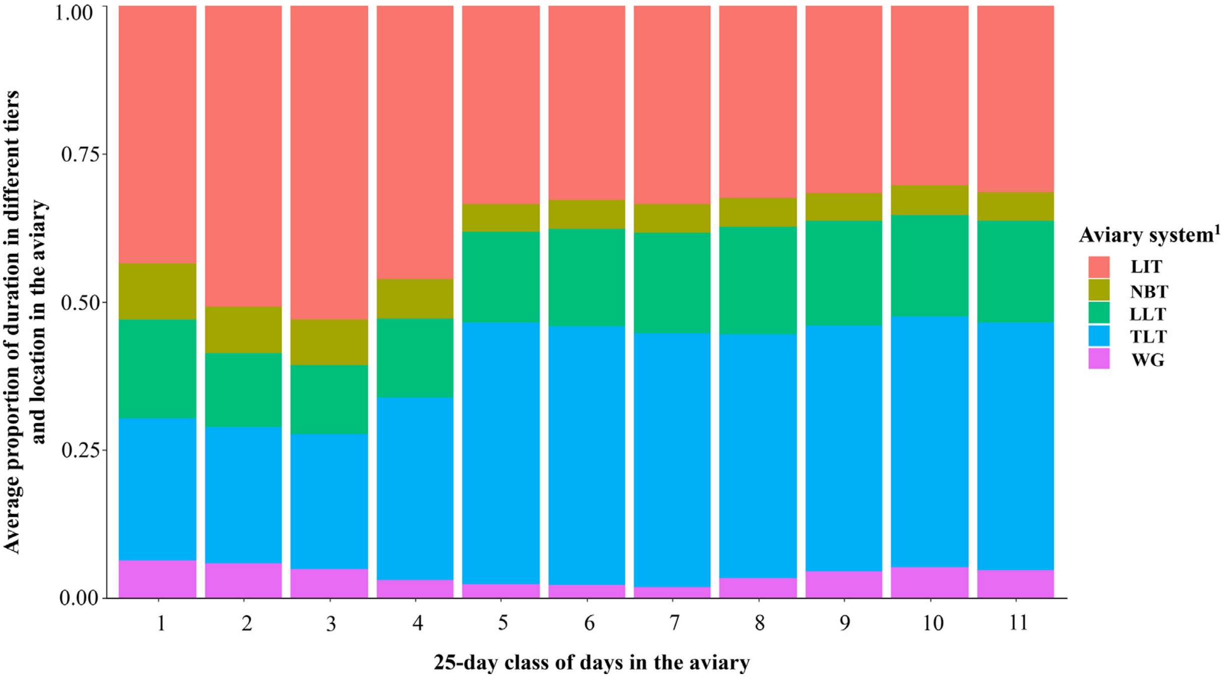

Figure 2. A 25-day proportion of the average time duration spent in the different zones and locations within the aviary. [1]Floor littered area (LIT), nest box tier (NBT), lower level tier (LLT), top level tier (TLT), winter garden (WG).

in the aviary system were being utilized by hens (Odén et al., 2002). Furthermore, a recent study with a comparable tracking system that took place in other pens of the same barn at the same time has reported a high to moderate repeatability of 0.66 and 0.52 for vertical distance traveled and nest box tier timing behavior within an aviary (Montalcini et al., 2023). This indicates the consistency between individual differences in the aviary.

The 25-day average proportion of duration is presented in Figure 2. Of all the zones, the hens stayed for longer duration in the LIT and TLT. At the beginning of the observation period, the average proportion of time spent in the TLT was 0.24, while 0.44 was spent in the LIT. With increasing age, the hens stayed longer in the TLT with a proportion of 0.41 compared to 0.31 at the LIT. This result suggests that hens prefer the highest level in the aviary for perching (Schrader and Müller, 2009). The lowest proportion of time stayed in any location was found in the WG with the proportion ranging from 0.02 to 0.06. During the first 2 to 3 wk after placement in the laying barn the WG was closed, which partly explains the very short duration in this zone in the beginning (Figure 1) Additionally, the short stay in the WG could be attributed to the restricted access, occasionally adverse temperature in the WG, perception of unattractiveness, or fearfulness of the birds when in the WG. In accordance with the study by Mahboub et al. (2004), fearfulness of birds was associated with high frequency of movement between the indoor and outdoor area and short stay in the outdoor area using Lohmann Selected Leghorn (**LSL**).

Genetic parameter estimates of behavioral traits in laying hens housed in aviary systems is in a nascent phase (Bécot et al., 2021, 2023). These behavioral traits encompass nesting behavior, laying behavior, movement within the aviary, and time spent in the different zones. The availability of multiple repeated measurements collected on the duration of stay in different zones in the aviary has enabled heritability and repeatability estimates (Table 2). Heritability estimates ranged from 0.05 to 0.28 (0.01−0.03) for duration spent in the LLT to LIT, respectively. For nesting behavior, the heritability for the duration spent in the NBT was estimated to be 0.11 (0.02). Comparatively, Icken et al. (2013) estimated heritability that ranged from 0.00 to 0.56 (0.00−0.12) for duration of stay in the nest using 12 flocks and a 28-day laying period. The results of the present study

Table 2. Estimates of residual variances (σ_e^2), additive genetic variances (σ_a^2), permanent environment variances (σ_{pe}^2), heritability (h^2), and repeatability (re) (standard errors are in parentheses).

Zones[1]	σ_e^2	σ_a^2	σ_{pe}^2	h^2 (%)	re (%)
TLT	40,901.30	5,779.55	13,867.10	9.55 (1.73)	32.45 (1.04)
NBT	292.82	42.50	36.43	11.43 (1.49)	21.23 (0.92)
LLT	29,034.00	1,919.53	5,308.19	5.29 (1.06)	19.93 (0.76)
LIT	5,805.73	3,402.53	3,151.02	27.53 (3.21)	53.03 (1.33)
WG	722.39	103.15	235.37	9.72 (1.81)	31.91 (1.06)

[1]Top level tier (TLT), nest box tier (NBT), lower level tier (LLT), floor littered area (LIT), winter garden (WG).

Table 3. Estimates of genetic correlations (above diagonal) and phenotypic correlations (below diagonal) (standard errors are in parentheses).

Zones[1]	TLT	NBT	LLT	LIT	WG
TLT		−0.11 (0.12)[2]	−0.50 (0.10)	−0.59 (0.08)	−0.54 (0.12)
NBT	−0.02 (0.01)[2]		0.53 (0.10)	−0.29 (0.09)	0.05 (0.12)[2]
LLT	−0.58 (0.01)	0.15 (0.01)		−0.17 (0.12)[2]	0.37 (0.14)
LIT	−0.25 (0.01)	−0.15 (0.01)	−0.09 (0.01)		0.06 (0.12)[2]
WG	−0.06 (0.01)	0.01 (0.01)[2]	0.03 (0.01)	−0.16 (0.01)	

[1]Top level tier (TLT), nest box tier (NBT), lower level tier (LLT), floor littered area (LIT), winter garden (WG).
[2]Nonstatistical significant based on absolute estimate values not 2× greater than the standard error.

are within the range reported by Icken et al. (2013). The varied range of heritability estimates could be attributable to the different flocks and age (different classes of 28-day laying period). The comparable result between the current and previous studies is interesting as our system did not allow for quantification of important egg production phenotypes such as egg quality. However, the comparable heritability, in combination with a high correlation between MLD of the current study and the egg production of half or full sibs from simultaneous field tests suggest the value of our measure "S. G. Gebhardt-Henrich (University of Bern, Bern, personal communication)." Although we are not able to link individual eggs with hens, the ability to provide a comprehensive profile of the animal that includes resources important to welfare (e.g., winter garden access) and general movement through the aviary with an indicator of egg laying behavior will be critical in future hen phenotyping efforts.

Furthermore, the estimated heritability for duration in the WG was 0.10 (0.02), which is within the estimates from previous studies with ranges from 0.04 to 0.32 (0.03−0.11) (Icken et al., 2008, 2011). The low to moderate heritability estimates reported in this study indicate that nesting behavior, and duration spent in the different zones within the aviary could be influenced by genetic components. Therefore, genetic improvement of these traits is achievable through selection. Repeatability estimates for traits included in this study ranged from 0.20 to 0.53 (0.01), with the lowest estimate found for the duration in the LLT and the highest found for the LIT. Low to moderately high repeatability estimates have also been found for commercial laying hens for spatial traits, which include vertical traveled distance, nest box tier timing, WG presence, and sleeping tier (Montalcini et al., 2023). Some of these traits are analogous to the traits analyzed in this study.

To have a well-balanced breeding objective, the correlations between economically important traits should be considered as selection for 1 trait could consequently produce a favorable or an unfavorable outcome in another trait. Genetic and phenotypic correlations are presented in Table 3. The genetic correlations between the duration spent in different zones varied from unfavorable −0.59 (0.08) to favorable 0.53 (0.10). The strongest negative correlation was observed between the TLT and LIT while the strongest positive correlation was between NBT and LLT. TLT was negatively correlated with all the other zones, which suggests that hens that spend longer time in the TLT often spend less time in the other zones.

The genetic correlation between the LIT and LLT was estimated to be 0.53 (0.10) indicating that hens that prefer the LIT also prefer the LLT. In general, the farther the distance between zones the more negatively they are correlated and conversely, closer zones are more positively correlated. These results are reasonable, given that hens move from zone to zone and rarely fly from the TLT to the LIT directly. Previous research has estimated a genetic correlation between behavioral and egg production traits. For example, Bécot et al. (2023) found a negative correlation between laying rates in the nest and MLD, suggesting that hens with higher MLD have lower laying rates in the nest. Therefore, estimating genetic correlations for duration spent in different zones in the aviary could serve as indicator for improving economically important traits.

CONCLUSIONS

The use of advanced tracking technology for monitoring the movement and behavioral patterns of laying hens in an aviary is attainable. These collected phenotypic records afford the opportunity to perform various phenotypic and genotypic analyses. With this information, the present study was able to determine that the duration of time spent in different locations within the aviary as a behavioral trait is heritable. Some of the traits recorded were observed to have positive and negative genetic correlations between them. Therefore, these traits could be genetically improved by selection strategies. Moreover, these traits could serve as indicator traits for production, fitness, as well as hen welfare traits. Further study is warranted to investigate these traits as longitudinal, to account for the spatial differences between records. A random regression model would be a better approach to capture these differences. In addition, genomic regions that influence these traits could be detected using a genome wide association study.

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DISCLOSURES

The authors of this study declare that they have no known conflict of interest or competing financial interests or personal relationships that influence the work reported in the present study.

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