Ramps and hybrid effects on keel bone and foot pad disorders in modified avaiaries for laying hens

J. L. T. Heerkens,*1 E. Delezie,∗ B. Ampe,* T. B. Rodenburg,† and F. A. M. Tuyttens*‡

∗Animal Sciences Unit, Institute for Agricultural and Fisheries Research (ILVO), Scheldeweg 68, B-9090 Melle, Belgium; †Behavioural Ecology Group, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands; and ‡Ghent University, Faculty of Veterinary Medicine, Salisburylaan 133, B-9820 Merelbeke, Belgium

ABSTRACT Non-cage systems provide laying hens with considerable space allowance, perches and access to litter, thereby offering opportunities for natural species-specific behaviors. Conversely, these typical characteristics of non-cage systems also increase the risk of keel bone and foot pad disorders. The aim of this study was twofold: 1) to investigate if providing ramps between perches (housing factor) reduces keel bone and foot pad disorders and 2) to test for genetic predisposition by comparing 2 different layer hybrids. In a 2 × 2 design, 16 pens were equipped either with or without ramps between perches and nest boxes (8 pens/treatment), and housed with either 25 ISA Brown or Dekalb White birds per pen (in total 200 birds/hybrid). Keel bone injuries and foot health were repeatedly measured via palpation and visual assessment between 17 and 52 wk of age and daily egg production was recorded. The relationships between the dependent response variables (keel bone and footpad disorders, egg production) and independent factors (age, ramps, hybrid) were analyzed using generalized linear mixed models and corrected for repeated measures. Ramps reduced keel bone fractures (F1,950 = 45.80, P < 0.001), foot pad hyperkeratosis (F 1,889 = 10.40, P = 0.001), foot pad dermatitis (F1,792 = 20.48, P < 0.001) and bumble foot (F1,395 = 8.52, P < 0.001) compared to pens without ramps. ISA Brown birds sustained more keel bone fractures (F1,950 = 33.26, P < 0.001), had more foot pad hyperkeratosis (F1,889 = 44.69, P < 0.001) and laid more floor eggs (F1,1883 = 438.80, P < 0.001), but had fewer keel bone deviations (F1,1473 = 6.73, P < 0.001), fewer cases of foot pad dermatitis (F1,792 = 19.84, P < 0.001) and no bumble foot as compared to Dekalb White birds. Age, housing and hybrid showed several interaction effects. Providing ramps proved to be very effective in both reducing keel bone and foot pad problems in non-cage systems. Keel bone and foot pad disorders are related to genetic predisposition. These results indicate that adaptation of the housing systems and hybrid selection may be effective measures in improving laying hen welfare.

Key words: keel bone, laying hens, aviary, foot health

INTRODUCTION

Laying hens in non-cage housing systems are offered more space and opportunities to perform natural behaviors in comparison to cage systems. At the same time, however, certain specific non-cage housing characteristics may also impair laying hen welfare by increasing the risk for keel bone and foot pad disorders (EFSA, 2005; Rodenburg et al., 2008; Sandilands et al., 2009; Heerkens et al., 2016).

Keel bone disorders are a serious concern for the welfare of laying hens, particularly when housed in non-cage systems (Sandilands et al., 2009; FAWC, 2010; Harlander-Matauschek et al., 2015). This concern is based on field studies in non-cage systems reporting that keel bone disorders can reach extremely high prevalences, affecting from 56% up to 97% of a flock near the end of a production cycle (Rodenburg et al., 2008; Wilkins et al., 2011; Petrik et al., 2015; Heerkens et al., 2016). A distinction can generally be made between keel bone fractures and keel bone deviations. After the healing process, fractures typically manifest themselves as callus formations at the fracture sites and may involve sharp, unnatural shearing or folding and/or fragmentation of the bone. Keel bone deviations are abnormalities in the shape of the keel bone, manifested as the bone’s deviation from a theoretically flat, 2-dimensional straight plane in either the transverse or sagittal plane (Casey-Trott et al., 2015). Other, more superficial injuries of the tissue surrounding the keel bone are skin wounds and hematomas (Heerkens et al., 2016). Fractures and deviations are believed to have
different causes. Due to the anatomical prominent position of the keel bone, it is usually the first point of when the bird collides with an object or surface (due to a fall or bad landing). Consequently, fractures are likely the result of (repetitive) collisions with structural elements of the housing systems. In contrast, deviations seem to originate mainly from prolonged pressure-load during perching (Sandilands et al., 2009; Pickel et al., 2011; Wilkins et al., 2011). Bone strength is influenced by genetics, environment and physical exercise (Fleming et al., 2007; Leyendecker et al., 2007) and affects susceptibility to keel bone disorders.

The major foot pad disorders in laying hens are hyperkeratosis, dermatitis and bumble foot. Hyperkeratosis is proliferation of the corneus layer of the foot pad skin and is caused by prolonged pressure load on foot pads during standing, grabbing and perching on a wire floor (Weitzenbürger et al., 2006; Röchlen et al., 2008). Foot pad dermatitis is the term for infected lesioning of the epithelium of the metatarsal pads (Wang et al., 1998). Bumble foot manifests as severe swelling and inflammation of the foot pad. This ailment is perceived to be particularly painful (Tauson and Abrahamsson, 1994). The prevalences of these foot pad disorders vary in non-cage systems and are associated with perch design, (wet) litter, and hybrid type (Abrahamssoon and Tauson, 1995; Wang et al., 1998; Weitzenbürger et al., 2006; Pickel et al., 2011).

Perch arrangements and ramps between perches affect the rate of successful landings and are associated with keel bone disorder prevalence (Scott et al., 1997; Stratmann et al., 2015a). Hens are not accomplished fliers, preferring wing-assisted-incline-running (WAIR) and walking to flying when attempting to reach higher or lower areas in their environment (Dial, 2003; Sandilands et al., 2009; Dial and Jackson, 2011; Stratmann et al., 2015a). Ramps facilitate walking and WAIR to all areas, eliminating the necessity to fly or jump and therefore reducing the number of falls and collisions (Kozak et al., 2015; Stratmann et al., 2015a).

The aim of our study was to investigate in more detail which particular keel bone disorders are affected by providing ramps in experimental aviary systems and how ramps may affect foot pad disorders. Genetic predisposition may affect the susceptibility for sustaining keel bone and foot pad disorders (Abrahamssoon and Tauson, 1995; Vits et al., 2005). Therefore, a second aim was to assess how various keel bone and foot-pad disorders in a brown (ISA Brown, IB) and white (Dekalb White, DW) commercial hybrid are affected by the presence of ramps. We hypothesized that laying hens housed in pens equipped with ramps would sustain fewer keel bone fractures and deviations. We expected ramps to increase foot pad hyperkeratosis due to mechanical compression on load on the foot pads (Tauson and Abrahamsson, 1994; Weitzenbürger et al., 2006; Röchlen et al., 2008) and decrease the prevalence of dermatitis due to improved foot pad hygiene (Tauson and Abrahamsson, 1994, 1996). The direction of the genetic effect was harder to predict. White hybrids are considered to have better flight and 3D-movement skills and have a lower body weight than brown hybrids, and thus would possibly encounter fewer collisions and collisions with a lower impact (Toscano et al., 2013; Scholz et al., 2014). The white hybrids also have weaker bones and thus are at increased risk for fractures and deviations (Habig and Distl, 2013).

**MATERIALS AND METHODS**

**Birds and Housing**

All animal procedures were approved by the Animal Ethics Committee of the Institute for Agricultural and Fisheries Research (ILVO) (EC2014/223). Dekalb White (DW) and ISA Brown (IB) chicks were reared on a commercial rearing farm in a commercial NivoVario® system (Jansen Poultry Equipment, Barneveld, the Netherlands) from d 1 until 17 wk of age, and pullets had access to wood shavings on the litter floor. All hens were beak trimmed at the hatchery. At the age of 17 wk, 200 hens per hybrid were transported from the rearing farm to ILVO’s poultry experimental facility (Melle, Belgium) and distributed randomly across 16 pens containing wood shavings. The experimental facility was equipped with dynamic ventilation with lateral air inlets at both sides. The ventilation rate could vary from 0 m³/hour to the maximum ventilation rate of 25,000 m³/hour, depending on the measured temperature. The temperature was recorded by means of a min/max thermometer. The local temperature was kept as close as possible to approximately 20°C. The hens were kept under conventional conditions for lighting (6 h dark, 18 h light). There was some variation in temperature and light level within the house, but this was equally distributed across treatments. Each pen measured 220 (L) × 350 (W) × 220 cm(H), and housed 25 hens (3080 cm²/hen usable space). Each pen housed either DW or IB hens; all hens were banded with colored and numbered plastic leg rings. Each pens was equipped with 3 wooden perches placed stepwise at respectively 60, then 120 and at highest 180 cm above the slatted tier. The slatted tier measured 220 × 100 × 45 cm. All perches were rectangular (104 × 5 × 3 cm) with rounded edges. Three nest boxes (35 × 35 × 30 cm) lined with AstroTurf® (www.astroturfpoultrypads.com/) were installed 110 cm above the slatted tier. Half of the pens was fitted with ramps that connected the floor, tier and perch with the adjacent perch, creating a continuous pathway that enabled hens to reach the littered floor, tier, perches or nest box without having to jump or fly (Figure 1). Specifically, one ramp connected the litter floor with the lowest perch, one ramp connected the lowest and the middle perch, one ramp connected the middle and the highest perch, one ramp connected...
the slatted tier with the first perch leading toward the nest box and one ramp connected that perch with the perch in front of the nest box. The ramps were 20 cm wide and constructed of galvanized metal wire. They were placed at an 45-degree angle between levels. Furthermore, pens were equipped with a feeding trough (125 cm) and a bell drinker (120 cm circumference) placed in locations away from the perches to prevent hens from defecating in the bell drinker or feeding trough. Hens were fed a pre-lay feed for 2 wk after arrival; from 19 wk of age onwards, a standard layers ration was fed (as finely ground meal) during the production cycle. Feed and water were provided ad libitum. A 2 × 2 design, with Housing [no ramps (NR) and ramps (R)] as the first factor and Hybrid (DW and IB) as the second factor resulted in 4 treatments; NR-DW, R-DW, NR-IB, R-IB. Erroneously Hybrid was not equally distributed over the Housing treatments, eventually leading to 3 R-IB pens, 3 NR-DW pens, 5 NR-IB pens and 5 R-DW pens.

Data Collection

During daily inspection from 20 wk to 52 wk of age, the number of first quality eggs, floor eggs, and hen mortality were recorded at pen level. Production rates (expressed as number of eggs laid per d per hen present) were calculated per pen per wk.

From 19 wk of age onwards, on 6 hens per pen keel bone injuries were scored on a 5-weekly interval, according to the method of Heerkens et al., (2016). Briefly, keel bones and their surrounding tissue were inspected for 1) skin hematomas, 2) wounds, 3) medial keel bone fractures, 4) caudal keel bone fractures, and 5) keel bone deviations. Hematomas of the skin surrounding the keel bone and wounds or scabs of the skin on the keel bone were scored binomially and recorded as either absent (0) or present (1). Palpation of the keel bones was performed by running 2 fingers along the bone (Wilkins et al., 2004) and was again scored for the presence (1) or absence (0) of fractures of the middle section (medial fracture) and fractures of the caudal end (last 1 cm) (caudal fracture). The combined of both possible keel bone fractures was transformed into a binomial ‘Total Fracture’ score [i.e., any fracture present (1) or no fractures (0)]. Deviations from theoretically perfect 2-dimensional straight plane in either the sagittal or transverse planes (Casey-Trott et al., 2015; Heerkens et al., 2016) were scored visually as well as via palpation. Deviation was scored as a straight keel bone (straight or <0.5 cm deviation), a keel with mild deviation (deviation between 0.5 and 1 cm) or a keel with severe deviation (>1 cm deviation). All observations were conducted by the same experienced observer. At 53 wk of age 115 hens were euthanized and taken to a dissection room in which the observer, blinded to the housing treatment, scored the keel bones for fractures and deviation. After dissection the keel bones were stored at −20°C and examined a few weeks later for the presence or absence of (old) fractures and deviation to calculate the accuracy of the palpation method (Casey-Trott et al., 2015; Petrik et al., 2013; Wilkins et al.,
During the post-dissection keel bone assessment, the observer was blinded to the pre-dissection score as well as blinded to both treatments (housing and hybrid).

Foot pad health was first scored at 29 wk of age on the same 6 birds that had been assessed for keel bone disorders and thereafter at 5-wk intervals as previously described for keel bone disorders. Foot pad health was scored by visual assessment of both feet for hyperkeratosis, foot pad dermatitis, and bumble foot (Heerkens et al., 2016). Hyperkeratosis, defined as proliferation of the corneus layer of toe and metatarsal skin of the foot pads (Weitzenbürger et al., 2006), as present (1) or absent (0). Foot pad dermatitis was scored as having (1) no dermatitis, (2) mild dermatitis with a small lesion (<0.2 cm) of the foot pad epithelium, or (3) severe dermatitis with a large lesion (>0.2 cm). Afterwards, the scores were transformed to a “Dermatitis present/absent” score, where no dermatitis was (0) and mild and/or severe dermatitis both counted as present (1). For both hyperkeratosis and dermatitis, no discrimination was made between the metatarsal pads and the toe pads. Bumble foot was defined as a high-grade swelling of the metatarsal foot pad visible from dorsal view and was again scored as present (1) or absent (0).

The observer was partially blinded to the housing treatment (R-NR) during the keel bone and foot pad assessments as the observations were executed in the walking corridor outside the pen. It was not possible to have the observer blinded for the hybrid treatment (DW-IB).

**Statistical Analysis**

To analyze the relationship between continuous dependent response variables (e.g., egg-laying rate, percentage floor eggs) and the independent variables (age, housing, hybrid, and their interactions) linear mixed models (LMM) were used. Housing design (R and NR) and Hybrid (DW and IB) were fixed effects in all models with pen as random factor. Non-significant interactions were removed from the final model (significance level of 0.05). The analyzed data were considered sufficiently normally distributed, based on the graphical evaluation (histogram and QQ-plot) of the residuals.

For the keel bone injury measurements, initially 6 focal birds per pen were followed according to identification of the leg rings (combination of color and number); however, due to the leg rings getting lost and numbers wearing off, hens could not unmistakably be identified anymore. For this reason, repeated measures on individuals were not taken into account in the analyses. To analyze the relationship between the binomial response variables (keel bone and foot pad disorders) and independent variables (age, housing, hybrid, and their interactions), similar generalized linear mixed models (GLMM) with the logit-link were used.

In case of posthoc pairwise testing, p-values were corrected with the Tukey-Kramer adjustment for multiple comparisons. In case of significant interactions with age, post-hoc tests were performed at 29, 39 and 49 wk of age. All analyses were performed using the GLIMMIX procedure of SAS 9.4 software (SAS Institute Inc., Cary, NC).

**RESULTS**

**Production**

Most floor eggs were laid in the NR-IB pens at 29 and 39 wk of age and the lowest number of floor eggs were laid in the NR-DW pens at 29 and 39 wk of age, whereas at 49 wk most floor eggs were laid in the R-DW pens (Table 1, Age∗Hybrid, P < 0.001). The direction of the Housing∗Hybrid interaction (P < 0.001) on the production of first quality eggs was not consistent over time between treatments (Table 1). Nonetheless, the most first quality eggs were laid in the NR-DW pens at all ages, but the difference was not significant at all ages. The laying rate differences decreased with age for the 4 treatments (Age∗Hybrid, P = 0.002).

**Keel Bone Injuries**

Prevalence of all keel bone disorders increased with age (Table 2, Figures 2 and 3). Ramps reduced the prevalence of medial fractures at all ages. Caudal fractures increased more with age when no ramps were provided. Total number of fractures were less prevalent in hens housed in pens with ramps at all ages. The presence of ramps resulted in a lower prevalence of mild deviations at all ages. Both keel hematomas and wounds showed an effect of Hybrid; DW had a higher prevalence for both disorders at all ages. An Age∗Hybrid interaction was found for medial fractures, with a more rapid increase of fractures with age in DW than IB. Caudal fractures were less prevalent in DW at all ages, and DW scored lower for any fracture present at all ages. For both mild deviation and severe deviation, an Age∗Hybrid interaction revealed increasing deviation over time for both hybrids, with DW having a significantly higher prevalence of mild and severe deviation after the continued laying period (49 wk of age) than IB. There were no Housing∗Hybrid interactions for any of the keel bone disorders. The accuracy of the palpation method was 69.9% for deviation, 70.4% for medial fractures, 70.4% for caudal fractures, and 87.8% for fractures prevalence.

**Foot Pad Disorders**

Dermatitis prevalence was higher in pens without ramps at all ages than in pens with ramps, but this difference decreased with age (Table 2, Figure 4). Ramps in the pen resulted in lower prevalence of bumble foot in
Hyperkeratosis 25.0
Footpad disorders
Bumble foot 1.0
Total fracture 60.0
±
Mild dermatitis 12.5
Hematoma 16.7

health disorders and egg production. To our knowledge, this is the first study to report on the convincingly positive effects of ramps on reduction of foot pad disorders. Moreover, this study confirms the recent findings by Stratmann et al., (2015a) that ramps effectively reduced keel bone fractures, keel bone deviations, and floor eggs. The 2 selected hybrids showed various differences in keel bone and foot pad disorders, indicating the potential for selective breeding against these disorders.

Age, housing and perch design, and hybrid type have previously been shown to affect foot pad disorders (Tauson and Abrahamsson, 1994; Abrahamsson and Tauson, 1995; Wang et al., 1998; Mahboub et al., 2004; Weitzenbürger et al., 2011). In a field-study on commercial aviaries (Heerkens et al., 2016), 60-week-old laying hens showed a prevalence of 42% for hyperkeratosis (range 14 to 70%), 28% for foot pad dermatitis (range 0 to 70%) and 1% for bumble foot (range 0 to 16%) at flock level. Gunnarsson et al., (1995) found that hyperkeratosis ranged

**DISCUSSION**

In the present study, we evaluated the influence of hybrid and the presence of ramps on keel bone and foot health disorders and egg production. To our knowledge, this is the first study to report on the convincingly positive effects of ramps on reduction of foot pad disorders. Moreover, this study confirms the recent findings by Stratmann et al., (2015a) that ramps effectively reduce keel bone fractures, keel bone deviations, and floor eggs. The 2 selected hybrids showed various differences in keel bone and foot pad disorders, indicating the potential for selective breeding against these disorders.

Age, housing and perch design, and hybrid type have previously been shown to affect foot pad disorders (Tauson and Abrahamsson, 1994; Abrahamsson and Tauson, 1995; Wang et al., 1998; Mahboub et al., 2004; Weitzenbürger et al., 2006; Rönchen et al., 2008; Pickel et al., 2011). In a field-study on commercial aviaries (Heerkens et al., 2016), 60-week-old laying hens showed a prevalence of 42% for hyperkeratosis (range 14 to 70%), 28% for foot pad dermatitis (range 0 to 70%) and 1% for bumble foot (range 0 to 16%) at flock level. Gunnarsson et al., (1995) found that hyperkeratosis ranged

**Table 1.** Least squares means (LSM) of egg production (%±S.E.) at 29, 39, and 49 wk of age for the 4 different treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Age: 29 wk</th>
<th>Age: 39 wk</th>
<th>Age: 49 wk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor eggs</td>
<td>0.4 ± 0.2&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.2 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.4 ± 0.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>First quality eggs</td>
<td>95.0 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96.0 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>95.1 ± 0.2&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Egg rate</td>
<td>95.7 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96.0 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96.0 ± 0.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**Table 2.** Mean percentage of prevalence (%±S.E.) and significance of effects on keel bone and footpad disorders at 29, 39, and 49 wk of age.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Age: 29 wk</th>
<th>Age: 39 wk</th>
<th>Age: 49 wk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor eggs</td>
<td>0.4 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.1 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.0 ± 0.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>First quality eggs</td>
<td>96.9 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>95.5 ± 0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94.5 ± 0.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Egg rate</td>
<td>97.1 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96.8 ± 0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94.6 ± 0.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1Bumble foot was not observed in ISA Brown. Housing effect was only tested within Dekalb White.
Figure 2. Least squares means percentages (±S.E.) for keel bone disorders (TotFrac = total fractures, MedFrac = medial fracture, CaudFrac = caudal fracture, Mild dev = mild deviation, Severe dev = severe deviation) in pens with ramps or without ramps. * indicates LSM differ significantly \((P < 0.05)\) between the pens with or without ramps for the respective disorder.

Figure 3. Least squares means percentages (±S.E.) for keel bone disorders (TotFrac = total fractures, MedFrac = medial fracture, CaudFrac = caudal fracture, Mild dev = mild deviation, Severe dev = severe deviation) Dekalb White and ISA Brown hens. * indicates LSM differ significantly \((P < 0.05)\) between the 2 hybrids for the respective disorder.

from 0 to 43\% and bumble foot from 0 to 17\% up to 77 wk of age in loose-housed laying hens at an experimental farm. Our study follows both of those studies by demonstrating that prevalence of foot pad disorders remains high throughout most of the production cycle. Severe foot pad lesions and bumble foot are most prevalent when hens are between 30 to 40 wk of age, after which the food pad usually heals by emptying of the pus (Tauson and Abrahamsson, 1994). We found that mild foot pad dermatitis increased continually over time, while severe foot pad dermatitis peaked at 29 wk of age and decreased afterwards. This decrease could thus be the result of healing with the severe dermatitis developing back to mild dermatitis. Providing ramps considerably reduced foot pad dermatitis and bumble foot at all analyzed ages. Tauson and Abrahamsson (1994) reported a lower bumble foot incidence in hens that had wire platforms installed as perch space compared to hens without such wire platforms. Prolonged and increased pressure load on the foot pads while standing, grabbing, and perching on a wire floor causes proliferative hyperkeratosis (Tauson and Abrahamsson, 1994; Tauson et al., 1999; Weitzenbürger et al., 2006; Röchert et al., 2008). Hyperkeratosis tended to be more present in pens with ramps at 29 wk of age, but at 49 wk of age, this disorder was reduced in those pens compared to pens without ramps. The surface area of the wire mesh ramps in this study represented only a small fraction of the available floor space, thus the prolonged pressure
load on the toe and foot pads is therefore most likely less relevant in this study. Nevertheless, the wire structure of the ramps may have scraped manure from the foot pads, thereby improving foot cleanliness and hygiene and reducing the detrimental effects of poor hygiene. Further investigation is needed to demonstrate whether the use of ramps leads to better toe and foot pad hygiene, because poor hygiene of the perch and the foot pads does increase foot pad dermatitis and bum- 

giene. Further investigation is needed to demonstrate whether the use of ramps leads to better toe and foot pad hygiene, because poor hygiene of the perch and the foot pads does increase foot pad dermatitis and bumble foot (Tauson and Abrahamsson, 1994; Wang et al., 1998; Rönchen et al., 2008). The possible positive influence of better foot hygiene on hyperkeratosis also needs further investigation.

The effect of the Hybrid category on foot pad health in our study confirms the genetic predisposition of brown hybrids to be more susceptible to hyperkeratosis but less susceptible to dermatitis as compared to white hybrids (Abrahamsson and Tauson, 1995; Abrahamsson et al., 1996; Tauson and Abrahamsson, 1996; Mahlbou et al., 2004; Weitzenbürger et al., 2006). Ramps had a greater effect on foot pad health in the DW compared to IB.

Keel bone disorders were affected by hen age and the different treatments. The prevalence of all keel bone disorders increased with hen age and was similar to prevalences found in both experimental and field studies towards the end of the laying period (Freire et al., 2003; Wilkins et al., 2004; Rodenburg et al., 2008; Käpelli et al., 2011; Petrik et al., 2015; Stratmann et al., 2015a; Heerkens et al., 2016). The accuracy of the palpation method in our study was similar to accuracy levels found in previous studies that used the palpation method to assess keel bone disorders on live animals in on-farm and experimental studies (Wilkins et al., 2004; Petrik et al., 2013; Stratmann et al., 2015b). At 29 wk of age hens without ramps already showed a much higher keel bone fracture prevalence compared to hens with ramps in their pens. This difference in prevalence decreased as hens aged. The differences in fracture prevalence after the peak-of-lay in pens with versus without ramps concur with the differences reported by Stratmann et al., 2015a) in an experimental aviary systems. The observations of the present study were obtained prior to the publication of Stratmann et al., 2015a), therefore, there was no expectancy bias based on the results of the latter study. It was, however, not possible having the observer blinded to the hybrid treatment in live birds, thereby, observer bias could have led to unconscious error in scoring (Tuftens et al., 2014). Ramps also reduced the prevalence of hematomas and wounds of the skin covering the keel bone. Fewer keel bone disorders are thus very likely the result of fewer collisions when ramps are present due to WAIR and walking up and down the system (Stratmann et al., 2015a). The effect of ramps on keel bone deviations was only observed later in the cycle. Keel bone deviations result from prolonged mechanical pressure during perching and are associated with perch shape (Tauson and Abrahamsson, 1994; Scholz et al., 2008; Pickel et al., 2011). Two of the 5 ramps per pen had a platform (Figure 1). These platforms possibly caused a lower mechanical pressure load on the keel bone compared the rectangular perches, which may have resulted in less keel bone deviation. However, it remains doubtful whether the lower level of deviation was indeed due to perching on the platforms, because these wire platforms only provided enough space for one or 2 hens per platform. The ramps, which facilitate WAIR and walking movements, reduce flight and vigorous and forceful wing-flapping (Stratmann et al., 2015a). During such vigorous wing-flapping, the pectoralis muscles generate enormous forces on the keel bone. Less flying due to the use of ramps may have reduced forces that could contribute to deviation of the keel bone, although the effect of those forces on keel bone disorders requires further investigation (Harlander-Matauschek et al., 2015).

The substantial hybrid effect on keel bone disorders demonstrates the role of genetic predisposition. As early as 1955, Hyre (1955) demonstrated that keel bone deformities were highly heritable. More recently, lines selected for high or low bone strength were shown to also differ in risk of keel bone fractures (Stratmann et al., 2016). Similar to our results, Vits et al., 2005 also found more keel bone deformities in a brown hybrid compared to a white hybrid. Selection for production traits in different hybrids may have resulted in trade-offs for traits, such as lower bone density and
breaking strength, thus leading to higher susceptibility to keel bone disorders (Hocking et al., 2003; Vits et al., 2005; Fleming et al., 2007). Differences in bone density and breaking strength between the 2 hybrids used in the present study might thus explain the effect on keel bone disorder prevalence as the incidence of fractures increases as bone strength declines (Bishop et al., 2000). The hybrid effect on keel bone disorders could also relate to differences in behavior or body weight. White hybrids move more easily through a complex environment and have a lower body weight compared to brown hybrids. The inferior navigation skills of brown hens are more or longer compared to brown hens (Faure and Jones, 1982; Schrader and Müller, 2009), but these were not included in the present study. Egg production traits (floor eggs, first quality eggs, egg rate) were affected by age, ramps, and hybrid. We could not demonstrate association between keel bone or foot pad disorders with production traits, most likely because age, ramps, and hybrid also affected keel bone and foot pad disorders and thus these factors may have been confounded. Ramps had beneficial effects on the production traits in the brown hybrid, whereas the white hens showed more beneficial production traits when no ramps were provided. Tauson et al., (1999) found that a brown hybrid laid more floor eggs compared to a white hybrid. Brown hens may use and navigate the complex environment less efficiently (Donaldson et al., 2012), or they may be in more pain due to the higher prevalence of keel bone fractures and thus prefer to stay on the floor (Nasr et al., 2012b). Nasr et al., (2012a; 2013) found that keel bone fractures were associated with reduced egg production. It is known that white hybrids produce more eggs than brown hybrids, but whether the better egg production of the white hybrid is related to the lower prevalence of keel bone fractures needs further investigation. In contrast, the higher-producing white hens may have weaker keel bones, thereby progressively weakening the keel bone and making it more vulnerable for deviation by prolonged pressure load during perching.

We conclude that providing ramps is an effective measure to reduce keel bone and foot pad disorders in non-cage systems for laying hens. The welfare benefits and relatively low-cost investment required could result in ramp installation becoming a valuable and feasible improvement for non-cage laying hen housing. Further testing on commercial aviaries seems warranted. The demonstrated hybrid effects on the investigated disorders offer opportunities to improve laying hen welfare by selective breeding for favorable traits.

**Table 3. Least squares means (LSM) for mild dermatitis and severe dermatitis (%±S.E.) at 29, 39 and 49 wk of age for the 4 different treatments.**

<table>
<thead>
<tr>
<th>Age: 29 wks</th>
<th>Treatment</th>
<th>Mild dermatitis</th>
<th>Severe dermatitis</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR-DW</td>
<td>30.9 ± 4.3a</td>
<td>6.2 ± 1.3b</td>
<td>11.0 ± 1.9b</td>
</tr>
<tr>
<td>R-DW</td>
<td>71.7 ± 8.9a</td>
<td>7.6 ± 3.2b</td>
<td>14.4 ± 5.2b</td>
</tr>
<tr>
<td>NR-IB</td>
<td>5.9 ± 1.5b</td>
<td>13.8 ± 6.9b</td>
<td></td>
</tr>
<tr>
<td>R-IB</td>
<td>5.9 ± 1.5b</td>
<td>13.8 ± 6.9b</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age: 39 wks</th>
<th>Treatment</th>
<th>Mild dermatitis</th>
<th>Severe dermatitis</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR-DW</td>
<td>53.5 ± 4.7a</td>
<td>14.6 ± 2.1b</td>
<td>18.5 ± 2.4b</td>
</tr>
<tr>
<td>R-DW</td>
<td>65.2 ± 7.6a</td>
<td>12.4 ± 3.3b</td>
<td>12.0 ± 3.1b</td>
</tr>
<tr>
<td>NR-IB</td>
<td>10.3 ± 2.2b</td>
<td>8.5 ± 3.2b</td>
<td></td>
</tr>
<tr>
<td>R-IB</td>
<td>10.3 ± 2.2b</td>
<td>8.5 ± 3.2b</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age: 49 wks</th>
<th>Treatment</th>
<th>Mild dermatitis</th>
<th>Severe dermatitis</th>
</tr>
</thead>
<tbody>
<tr>
<td>NR-DW</td>
<td>74.7 ± 4.0a</td>
<td>30.5 ± 3.6b</td>
<td>29.5 ± 3.6b</td>
</tr>
<tr>
<td>R-DW</td>
<td>58.0 ± 8.1a</td>
<td>19.5 ± 4.4b</td>
<td>9.9 ± 2.9b,c</td>
</tr>
<tr>
<td>NR-IB</td>
<td>17.4 ± 3.4b</td>
<td>5.1 ± 2.4c</td>
<td></td>
</tr>
<tr>
<td>R-IB</td>
<td>17.4 ± 3.4b</td>
<td>5.1 ± 2.4c</td>
<td></td>
</tr>
</tbody>
</table>

Shared superscripts (a-c) within rows indicate no significant difference (P < 0.05).


**ACKNOWLEDGMENTS**

The Institute for Agricultural and Fisheries Research (ILVO) and the Belgian Federal Public Service of Health, Food Chain Safety and Environment are acknowledged for funding this study (study acronym: LAYERHOUSE). The personnel of the ILVO experimental farm facilities, especially Jolien Vander Linden, are acknowledged for their practical assistance, and Miriam Levenson for an English-language review.
REFERENCES


Uitdehaag, K., T. B. Rodenburg, J. E. Bolhuis, E. Decuyper, and H. Komen. 2009. Mixed housing of different genetic lines of laying


