Risk factors associated with keel bone and foot pad disorders in laying hens housed in aviary systems

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ABSTRACT Aviary systems for laying hens offer space and opportunities to perform natural behaviors. However, hen welfare can be impaired due to increased risk for keel bone and foot pad disorders in those systems. This cross-sectional study (N = 47 flocks) aimed to assess prevalences of keel bone and foot pad disorders in laying hens housed in aviaries in Belgium to identify risk factors for these disorders and their relation to egg production. Information on housing characteristics and egg production were obtained through questionnaire-based interviews, farm records, and measurements in the henhouse. Keel bone (wounds, hematomas, fractures, deviations) and foot pad disorders (dermatitis, hyperkeratosis) were assessed in 50 randomly selected 60-week-old laying hens per flock. A linear model with stepwise selection procedure was used to investigate associations between risk factors, production parameters, and the keel bone and foot pad disorders. The flock mean prevalences were: hematomas 41.2%, wounds 17.6%, fractures 82.5%, deviations 58.9%, hyperkeratosis 42.0%, dermatitis 27.6%, and bumble foot 1.2%. Identified risk factors for keel bone disorders were aviary type (row vs. portal), tier flooring material (wire mesh vs. plastic slats), corridor width, nest box perch, and hybrid. Identified risk factors for foot pad disorders were aviary type (row vs. portal), free-range, and hybrid. Percentage of second-quality eggs was negatively associated with keel bone deviations (P = 0.029) at the flock level. Keel bone and foot pad disorders were alarmingly high in aviary housing. The identification of various risk factors suggests improvements to aviary systems may lead to better welfare of laying hens.

Key words: keel bone, housing system, aviary, foot health

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INTRODUCTION

Approximately 170 million laying hens were housed in non-cage systems in the EU in 2014 (EC-CIRCABC, 2014). Non-cage systems typically offer hens more space and opportunities to perform natural behaviors than cage systems (Rodenburg et al., 2005; Lay et al., 2011; Freire and Cowling, 2013). However, due to the increased freedom of movement and access to litter, laying hens housed in non-cage systems are at a higher risk for some health problems such as keel bone and foot pad disorders (Wang et al., 1998; Tauson, 2005; Rodenburg et al., 2008; Sherwin et al., 2010; Wilkins et al., 2011). The commercial non-cage systems with the largest flocks are generally the multi-tiered aviary systems. Aviaries come in two types, namely, row-type aviaries and portal-type aviaries (EFSA, 2005; Laywel, 2006). Both types provide a littered ground floor, on top of which a vertical metal structure with up to 4 tiers is erected. Portal aviaries have an extra tier connecting 2 stacks. Aviaries typically provide resources and structural elements, e.g., feeders, drinkers, and nest boxes and aerial perches, on one or more tiers (Heerkens et al., 2015; Tauson, 2005; LayWel, 2006), thereby encouraging the hens to navigate through the aviary system both horizontally and vertically (Fröhlisch et al., 2012). Access to the littered ground floor and multiple levels increases the total accessible surface and increases locomotive activities such as running and wing flapping (Leyendecker et al., 2005). It also allows hens to perform a diverse range of strongly motivated natural behaviors, such as foraging, dust-bathing, and perching. Allowing hens the opportunity to perform those behaviors contributes to improving their welfare (Lister and van Nijhuis, 2012). Keel bone disorders represent one of the most important and widespread welfare issues in commercial laying hens (Sandilands, 2011) as several studies have demonstrated alarmingly high prevalences of keel bone...
fractures in various non-cage systems, ranging from about 70 (Freire et al., 2003) to 80% (Wilkins et al., 2004, 2011; Kapelli et al., 2011) and up to 97% (Rodenburg et al., 2008). Keel bone fractures are caused by high-impact collisions with the housing structures, whereas deviations of the keel bone result from a prolonged pressure load on the keel during perching (Scholz et al., 2008; Sandilands et al., 2009; Pickel et al., 2011; Wilkins et al., 2011; Toscano et al., 2013; Stratmann et al., 2015). Both high- and low-impact collisions with the system as well as prolonged pressure load also can cause hematomas and wounds of the surrounding tissue of the keel bone (Casey-Trott et al., 2015). Keel bone fractures are believed to be painful and reduce mobility, as well being linked to negative performance traits such as increased feed conversion and reduced egg quality (Nasr et al., 2012a,b, 2013, 2014). No studies have been able to associate keel bone fractures with increased mortality.

Hyperkeratosis, foot pad dermatitis, and bumblefoot are the most common foot health problems in laying hens housed in non-cage systems. Foot pad dermatitis is an inflammation of the subcutaneous tissue of the foot pad, leading to necrosis and ulcerations. If severe, this may ultimately lead to a bulbous lesion and swelling called “bumble foot” (Wang et al., 1998; Weitzenbürger et al., 2006; Röngen et al., 2008). Bumble foot is considered to be painful and critically impairs the hen’s welfare (Lay et al., 2011). In general, the housing system (e.g., cage vs. non-cage), perching behavior, wet litter, scratching, perch and flooring material, and poor foot hygiene have been identified as causes of these foot health problems (Tauson and Abrahamsson, 1994, 1996; Wang et al., 1998; Weitzenbürger et al., 2006; Blokhuis et al., 2007; Röngen et al., 2008; Shimmura et al., 2010; Lay et al., 2011). Nevertheless, specific information on risk factors within aviary systems for these foot problems remains scarce.

Farms with non-cage systems are growing in both number and size (Tuyttens et al., 2011; EC-CIRCABC, 2014); therefore, risk factors must be identified that elicit keel bone and foot health problems and these issues should be resolved for this specific commercial housing system. The primary aim of this study was first to perform a cross-sectional exploration of the prevalence of keel bone and foot disorders in laying hens housed in the different commercial aviary systems in Belgium. Second, we wanted to identify specific aviary system characteristics, husbandry procedures, and hybrids as possible risk factors for these disorders. Finally, we wanted to investigate whether egg production is linked with these disorders.

MATERIAL AND METHODS

The 47 henhouses with aviary housing included in this study were part of a larger study on health and welfare problems of laying hens in aviaries (Heerkens et al., 2015). Farms were visited when the laying hens were approximately 60 wk of age (range 58 to 64 wk of age). All visits took place between August 2012 and December 2013 and were carried out by the same 2 observers. During a questionnaire-based interview with the farmer, information on farm management (e.g., feeding regime, light-dark cycle, daily time spent in the henhouse), henhouse (e.g., presence of covered veranda or free range, barn age), aviary system characteristics (e.g., type, manufacturer, system age, flooring type, perch orientation), and flock (e.g., hybrid, age, rearing, flock mortality, flock size) was collected. Width of the corridor between 2 stacks was measured in henhouses with row-systems (N = 37). Portal systems have no corridors between stacks, hence corridor width was not a relevant risk factor in portal-type aviaries. Egg production results (egg production rate, percentage second-quality eggs, percentage floor and system eggs) and cumulative flock mortality (percentage of dead hens since arrival on production farm) at 60 wk of age were obtained from farm records.

To obtain the prevalences for the respective keel bone and foot pad disorders at flock level, 50 randomly selected laying hens per henhouse were examined for keel bone and foot pad disorders. Birds were caught individually from various locations in the henhouse and from all tiers of the aviary system and were then released immediately after scoring. If a covered veranda or free-range area was available, a representative number of birds within the sample of 50 was scored from this area. For each flock each observer scored approximately half of the hens per farm to standardize observer bias.

Keel bones and the surrounding tissue were scored for 4 disorders, namely, skin hematomas, skin wounds, keel bone fractures, and keel bone deviation. The skin surrounding the keel bone may show an inflammatory response (Marsell and Einhorn, 2011), which is visually scored by scoring hematomas (absent or present). One flock was assessed in the dark to prevent a panic reaction; this flock could therefore not be scored for hematomas due to the low light conditions. The skin over the keel bone may show a scab that resulted from a previously sustained wound. The presence of a wound scab was scored either absent or present. Both the medial section of the keel bone and the caudal keel tip (last one cm) were scored via palpation for fractures (absent or present). The palpation method has been described by Wilkins et al. (2004) and was validated for accuracy and repeatability by Petrik et al. (2013). Palpation of the keel bone reveals calcium deposits or other malformations indicative of previous fractures. The combination of both fracture scores is referred to below as “total fracture”. The keel bone also was examined, by both palpation and visual assessment, for deviations. A deviation is defined as a keel bone with an abnormally shaped structure that deviates from a theoretically perfect 2-dimensional straight plane in either the sagittal or transverse planes (Casey-Trott et al., 2015). Keel bone deviation was scored on a 3-point scale respectively, a straight keel bone, a mild deviation, or a
### Table 1. Mean prevalence (± S.E.) at flock level for keel bone disorders and foot health as measured in 50 randomly selected hens at 60 wk of age in 47 flocks housed in Belgian commercial aviary systems.

<table>
<thead>
<tr>
<th>Disorders</th>
<th>Prevalence (%)</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>Keel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hematomas</td>
<td>41.2 ± 2.3</td>
<td>6 to 74</td>
</tr>
<tr>
<td>Wounds</td>
<td>17.6 ± 2.0</td>
<td>0 to 62</td>
</tr>
<tr>
<td>Medial fracture</td>
<td>65.6 ± 1.9</td>
<td>36 to 92</td>
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<tr>
<td>Caudal fracture</td>
<td>44.3 ± 2.1</td>
<td>6 to 78</td>
</tr>
<tr>
<td>Overall fracture</td>
<td>82.5 ± 1.6</td>
<td>60 to 100</td>
</tr>
<tr>
<td>Mild deviation</td>
<td>31.8 ± 1.4</td>
<td>12 to 52</td>
</tr>
<tr>
<td>Severe deviation</td>
<td>28.0 ± 1.5</td>
<td>10 to 62</td>
</tr>
<tr>
<td>Foot pads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperkeratosis</td>
<td>42.0 ± 2.2</td>
<td>14 to 70</td>
</tr>
<tr>
<td>Dermatitis</td>
<td>27.6 ± 2.3</td>
<td>0 to 70</td>
</tr>
<tr>
<td>Bumble foot</td>
<td>1.2 ± 0.4</td>
<td>0 to 16</td>
</tr>
</tbody>
</table>

severe deviation. A straight keel bone was assigned to keel bones with no or only a slight deviation (< 0.5 cm). A mild deviation was defined as a keel with deviation between 0.5 and one cm. A severe deviation was a keel bone with > one cm deviation. For statistical analysis, the prevalence of deviation was computed as a yes/no score for the presence of a mild deviation or severe deviation score (Table 1). For a total keel score (TKS), the scores of hematoma, keel wounds, medial keel fracture, caudal fracture, and deviation were summed to form a non-equidistant score. For TKS the presence of a hematoma, keel wound, medial fracture, and caudal fracture was given a score 1, and a score 2 was assigned in absence of the respective disorder. A severe deviation was given a score 1, a mild deviation a score 2, and straight keel bone was given a score 3. Hence, the minimum score of 5 represents the presence of a wound, hematoma, medial fracture, caudal fracture, and severe deviation, whereas the maximum TKS of 11 indicates the absence of any keel disorder.

Following inspection of the keel bones, both foot pads were inspected for foot pad dermatitis and hyperkeratosis. Foot pad dermatitis was scored on an ordinal scale (1 to 4): score 4 for no lesions on the foot pads, score 3 for a small lesion of the foot pad epithelium (< 0.2 cm), score 2 for a larger lesion (> 0.2 cm), and score 1 for swelling of the foot pad visible from dorsal view (“bumble foot”). Hyperkeratosis is proliferation of the cornes layer of toe and metatarsal pad skin. Prevalence of hyperkeratosis was scored on a dichotomous scale: proliferation of the foot pad epithelium was either present or absent. For both the scoring of foot pad dermatitis and hyperkeratosis, the foot with the worst scores was used for further analyses. Both feet were also scored on a dichotomous scale for missing toes or wounds on toes. The 2 observers were trained for the above-mentioned techniques in an extensive training workshop prior to the start of the farm visits. This training was part of the CORE Organic II project HealthyHens (www.coreorganic2.org). The inter-observer reliability between the 2 observers was measured by the prevalence adjusted bias adjusted kappa (PAKAB).

Statistical analyses were performed using R 3.0.1 for Windows and StatSoft. Inc. (2012) STATISTICA, version 11. The data were considered sufficiently normally distributed, based on the graphical evaluation (histogram and QQ-plot) of the residuals. In case of post-hoc pairwise testing, P-values were corrected with the Tukey-Kramer adjustment for multiple comparisons. The flock-level average of 50 individual hen scores per flock for keel bone and foot pad disorder was used for statistical analyses. The presented means for the scores are the least squares means (± S.E.). Linear models were used to investigate associations between animal based scores at flock level (keel and foot pad disorders), egg production, mortality, and the possible risk factors (i.e., independent variables). A stepwise model selection procedure was used with a separate model for each dependent variable. Only significant risk factors were included in the final model (significance level of 5%). The following factors were selected as independent variables for the models: aviary type (row vs. portal), free range availability (yes or no), flooring material of the aviary tiers (wire mesh vs. plastic slats), age of the barn, age of aviary system, nest box configuration (perch vs. platform), times fed per day, daily time spent in henhouse by stockperson, time spent in henhouse by stockperson per 1,000 hens present, presence of red mites (“absent”; “mild infestation: some red mites visible, but not in large quantities”; or “severe infestation: large clumps or quantities of red mites clearly visible”) (Heerkens et al., 2015). The 2 predominant hybrids, Lohmann Brown Classic (45%) and ISA Brown (28%), were included for the risk factor analyses and interpretation of results. All other hybrids were pooled together in one group consisting of 5 hybrids, including 4 brown hybrids and one white hybrid (respectively, Lohmann Brown Lite, Hy-line Brown, Bovans Brown, Novogen Brown, and Dekalb White). Initially this latter group was included in the risk factor analyses; however, due to its diversity it was excluded from any further interpretation of results. Only Lohmann Brown Classic and ISA Brown were used for further comparisons between hybrids.

**RESULTS**

The 47 henhouses in this study embody the majority of all aviary henhouses present in Belgium at the time this study was conducted (EC-CIRCABC, 2014). General information of the henhouses and flocks can be found in Heerkens et al., 2015. Briefly, there were 10 portal-type aviaries (21% of the aviaries) and 37 row-type aviaries (79%). Mean corridor width between stacks of row-type aviaries was 163 ± 10 cm (range 85 to 340 cm). Plastic-slatted flooring of the tiers was found in 16 aviaries (34%), whereas the other 31 aviaries (66%) had wire-mesh flooring of the tiers. The average flock age during the visit was 60.7 ± 0.3 wk and
cumulative flock mortality at 60 wk was 4.1% (range 0.9 to 12.8%). Flock size ranged from 6,000 to 70,532 hens (average of 31,469 hens). The mean egg production rate at 60 wk was 87.6 ± 0.7%, with 2.2% second-quality eggs, and 1.0% “floor” or “system” eggs. All flocks except for one organic flock had been beak-trimmed and were reared in various commercial rearing housing systems appropriate for aviary housing during the production cycle. Nine henhouses provided access to a free-range area (19% of the flocks).

The inter-observer reliability PAKAB score between the 2 observers for the keel bone disorders was 0.844, whereas the PAKAB for the foot pad disorders combined was 0.896. According to the classification of Fleiss et al. (2003) these PAKAB values are considered acceptable, as values between 0.4 and 0.75 are classified as fair to good and ≥ 0.75 as excellent agreement. Keel bone disorders were observed very frequently, with considerable variation among flocks (Table 1). Keel wounds had the lowest prevalence (17.6%), whereas overall keel bone fractures (defined as either a medial or caudal fracture or both) had the highest prevalence (82.5%). Deviations of the keel bone (either mild or severe) were observed in 59.8% of all scored hens. The mean TKS was 8.40 ± 0.03 with a within-flock variation of 1.26 and among-flock variation of 0.37 (calculated by random effects model). Only 4.3% of all hens had no keel disorders (TKS = 11), while 1.6% of all hens scored positive for all keel disorders (TKS = 5). There was also considerable variation among flocks for the prevalence of the different foot disorders (Table 1). Foot pad hyperkeratosis prevalence was the highest with 42.0%, foot pad dermatitis prevalence was 27.6%, whereas bumble foot prevalence was only 1.2%. Hens with missing toes or toe wounds were very rarely seen (both < 0.1%).

Aviary housing and husbandry characteristics that could be identified as risk factors for some of the keel and foot disorders were aviary type, system flooring material, hybrid, corridor width, nest box entrance configuration, free-range availability, and time of stockperson in the henhouse. In portal-type aviaries, keel wounds were more prevalent (37.5 vs. 12.6%, P < 0.001), medial keel fractures were less prevalent (55.6 vs. 68.3%, P = 0.005), and foot pad dermatitis scores were better (3.78 ± 0.08 vs. 3.52 ± 0.04, P = 0.004) compared to row-type aviaries. In aviaries with plastic slatted flooring, caudal tip fractures were less prevalent (36.5 vs. 50.0%, P = 0.019), and total fracture prevalence was also lower (76.1 vs. 85.5%, P = 0.003) compared to wire mesh flooring. In Lohmann Brown Classic hens, fewer caudal tip fractures (36.4 vs. 50.6%, P = 0.027) and less foot pad hyperkeratosis (27.3 vs. 51.6%, P < 0.001) were found compared to ISA Brown hens. The corridor width was negatively associated with prevalence of hematomas on the keel bone skin (F1,34 = 16.68, P < 0.001). Keel wounds were less prevalent with a perch instead of a platform in front of the nest box (20.4 vs. 29.7%, P = 0.006), and foot pad hyperkeratosis was less prevalent when hens had access to a free-range area (33.5 vs. 46.7%, P = 0.007). A high TKS, representing fewer keel disorders, showed a positive association with the time the stockperson spent in the henhouse per day (F3,42 = 5.291, P = 0.035). This appeared to suggest that the more time the stockperson spent in the henhouse, the fewer keel bone disorders would occur. However, this association disappeared when time was corrected for every 1,000 hens housed.

At flock level, the percentage of second-quality eggs was negatively associated with the percentage of hens with a keel bone deviation (F2,29 = 5.28, P = 0.029). A trend to a negative association between egg production rate and keel wounds (P = 0.059) was observed. We found no other significant associations between keel or foot disorders with egg production or mortality.

**DISCUSSION**

This field study demonstrated that mean flock-level prevalences for several keel and foot disorders show large variation among different aviary henhouses in Belgium. The 47 henhouses embody the majority of all laying hens held in aviaries in Belgium (EU-CIRCA,B, 2014; Heerkens et al., 2015) and therefore are likely to represent the current situation in Belgium. This study also identified several commercial aviary system characteristics, management, and hybrids as risk factors for some of the keel bone and foot pad disorders in laying hens. The alarmingly high prevalence of keel bone fractures (Table 1) is similar to those found in previous studies in non-cage systems (Freire et al., 2003; Wilkins et al., 2004; Rodenburg et al., 2008; Sherwin et al., 2010; Käppeli et al., 2011; Tarlton et al., 2013; Petrik et al., 2015), but are about 2 times higher than the prevalences generally found in enriched cages (Wilkins et al., 2004; Rodenburg et al., 2008). Previous studies that assessed foot pad problems in non-cage systems report similar and even higher prevalences to those found in our field study, ranging from zero to 39% for hyperkeratosis, up to 39% for foot pad dermatitis, and 24% for bumble foot (Simonsen et al., 1980; Abrahamsson and Tauson, 1995; Wang et al., 1998; Gunnarsson et al., 1995; Rögen et al., 2008).

To our knowledge, this study is the first to report the type of aviary (row- vs. portal-type aviaries) as a risk factor for keel and foot disorders. A much higher prevalence of keel wounds was found in portal-type aviaries, whereas medial keel fractures were less prevalent in those aviary types although the prevalence remained high. These differences may relate to birds moving differently within the system in the 2 aviary types and the difference of collision impact due to the distances the hens jump and fly in the specific aviary types. Laying hens originate from terrestrial birds that prefer ground-based movements, i.e., walking, running, and jumping (Dial and Jackson, 2011). Hens also prefer wing-assisted incline running (WAIR) rather than flying to reach an elevated area. Moreover, flight is used almost
exclusively for escape behavior (Harlander-Matauschek et al., 2015). Compared to their ancestors, modern hybrids also have poorer flight control due to the higher wing loading and heavier BW (Moinard et al., 2004). Due to the step-wise design of portal systems, movements in portal-type aviaries seem to comprise shorter distances and allow more walking, jumping, and WAIR-like movements, compared to movements in row-type aviaries, where hens make more long descents from the tiers to the ground floor. The short distances within the portal-type aviary may lead to more within-system movements and thereby to more low-impact collisions with the system. These repeated low-impact collisions may lead to damage and wounds of the skin due to the prominent position of the keel, and therefore result in more keel wounds in portal-type aviaries. The lower prevalence of medial keel fractures in portal-type aviaries is probably due to higher levels of short-distance movements, leading to fewer high-impact collisions compared to longer distance movements and flights in row-type aviaries. More short-distance movements and fewer high-impact collisions have previously been shown to decrease the prevalence of keel bone fractures (Stratmann et al., 2015). In that study, aviaries were equipped with ramps between tiers to allow more WAIR between tiers. Provision of those ramps resulted in 45% fewer falls, 59% fewer collisions, and, consequently, 23% less keel bone fractures, although the prevalence of keel bone fractures remained high. Further research is needed to specify more precisely the type of movements within the different aviary types.

Hens in row-type aviaries appear to spend more time on the ground floor (personal observations, not measured). This could explain the higher prevalence for foot pad dermatitis we found in row-type aviaries, as contact with litter leads to poorer foot pad hygiene and has been reported to increase foot pad dermatitis and bumble foot (Tauson and Abrahamsson, 1994; Blokhuis et al., 2007).

Another characteristic that can differ between aviary systems is the flooring material of the tiers in the aviary stacks as these are constructed of either metal wire or plastic slats. Effects of this flooring material on keel and foot disorders also were found. The larger slab-size or the sharper edges of the wire mesh (compared to plastic slats) might cause more fractures of the caudal tip of the keel bone during landing as this is the most fragile part of the keel bone. Further research is needed to test this hypothesis.

When possible, hens will directly jump to a designated area (e.g., a perch, tier, or other stack); when the jumps comprise shorter distances, the chance of a correct landing increases. Failures in landings inevitably lead to collisions with the system (Scott and Parker, 1994; Scott et al., 1997; Stratmann et al., 2015). The shorter the distance, the more hens may directly jump from stack to stack, thereby increasing the number of events in which the hens are at risk of sustaining a keel bone disorder. In the present study, we could confirm this hypothesis only by demonstrating that the prevalence of hematomas of the keel bone skin decreased as the width of the corridor between stacks increased. Scott and Parker (1994) demonstrated that a hen had an increasing risk of sustaining keel bone damage when the distance between perches was > one m. In our study, however no other keel bone disorders were associated with the corridor width. Further studies of birds’ movement patterns within and between the tiers and stacks in aviaries could possibly demonstrate the effect of long- and short-distance jumps and flights on the prevalence of keel bone disorders.

Hens in systems with a perch in front of the nest had fewer keel wounds. Pre-nesting behaviors, such as nest-site inspection, are strongly motivated behaviors (Freire et al., 1996; Struelens et al., 2008; Ringgenberg et al., 2014) that involve repeatedly entering and exiting the nest boxes. Providing a perch rather than a platform in front of the nest box apparently causes fewer collisions or scraping of the keel skin, resulting in fewer wounds sustained when housed in those systems.

The hybrid effect on fractures of the caudal tip of the keel bone and on footpad hyperkeratosis might be due to genetic predisposition, differences in bone strength or differences in perching behavior. However, further research is needed to more specifically identify the behavioral, physiological, and genetic traits and differences among those traits (Abrahamsson and Tauson, 1995; Abrahamsson et al., 1996; Kjaer, 2000; Schrader and Müller, 2009; Käpelli et al., 2011; Wilkins et al., 2011).

Flocks with access to a free-range area had a lower prevalence of foot pad hyperkeratosis, but there was no difference in foot pad dermatitis or bumble foot prevalence compared to hens without access to a free-range area. Hence we could not confirm Shimmura et al. (2010) who found more foot pad dermatitis in free-range systems. This is probably also closely related with free-range quality (grass cover, moisture, cleanliness) and usage.

The negative association between keel bone deviations and second-quality eggs indicates that flocks with a higher percentage of straight keel bones produce fewer second-quality eggs. Nasr et al. (2012a) found that hens with reduced keel bone strength had reduced egg quality. Keel bone deviations were not measured in their study, but the reduced keel bone strength may have caused more keel bone deviation in combination with a prolonged pressure load during perching (Pickel et al., 2011). In turn, stronger keel bones could have been associated with fewer deviations and increased egg quality, similar to our findings.

In conclusion, keel bone disorders can reach alarmingly high levels in flocks of laying hens housed in commercial aviary systems, and further research on improvement of housing, management, and hybrids should be conducted to resolve this critical laying hen welfare issue. Foot pad problems are also highly prevalent in those housing systems. Although the relations between these welfare problems and the hens’ environment are
very complex and multifactorial, several risk factors for keel bone and foot pad disorders have been identified. We could not demonstrate that the impaired welfare due to keel bone and foot pad disorders also resulted in noticeable effects on egg production. Based on our findings, we conclude that the high prevalence of keel disorders may be reduced to some extent by selecting an aviary design that best matches hens’ preferred manner of moving. Foot pad disorders may be reduced by selecting the most appropriate aviary construction materials (e.g., perches, aviary flooring) and maintaining dry litter. Genetic selection of laying hen hybrids also may further reduce the genetic predisposition for sustaining keel and foot disorders.

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