Keel bone fracture baseline in Kenyan cage-free hens

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Lead Author:

Lukas Jasiūnas

Key Contributors
Dr. Kikiope Oluwarore
Faisal Qureshi
Isaac Esparza

Feedback and questions:
info@healthierhens.com

Table of Contents

Executive Summary

This report provides an overview of a scoping case study and reasoning behind the need for such research. Keel bone fractures (KBF) are a serious welfare concern for egg-laying hens and have a myriad of possible causes, including housing, genetics, and dietary interventions. KBFs have been widely studied in the Global North, but lack data points in the Global South to safely extrapolate similarities. This case study was conducted to assess the prevalence and severity of KBFs in Kenyan laying hens kept commercially in cage-free farms.

Key findings:

- The overall average prevalence of KBFs was 42% (20-65%), determined by radiographic assessment, within previously published review ranges of 13.5-71% and 12.6-84.5% from the Global North.
- The prevalence of KBFs was significantly higher when assessed using palpation (>65%) or post-mortem assessment (>84%) when compared to radiography (≥30%)
- Contrary to the literature suggesting a link between keel bone deviations and fractures, this investigation did not observe such a connection (88% deviation prevalence but 40% fracture prevalence).
- Radiographic assessments indicated a relatively low average fracture severity score (2 compared to >3 in Global North data, using a 0-5 scale), possibly influenced by differences in housing systems and/or other potential protective factors.

The results of this study suggest that even in the Global South, KB damage is a significant welfare concern for laying hens in cage-free systems. Healthier Hens recommends that the Kenyan egg stakeholders take action to address KB damage. However, the findings also suggest potential protective factors affecting hen keel bone health in Kenyan cage-free farms, emphasising the need for further research into preventative measures and interventions for this welfare issue taking regional farming conditions into account.

Replicating this survey in other regions would help draw stronger conclusions. However, any further inquiries should implement standardised guidelines for assessing KBFs in hens. Further research should be conducted to better understand the causes of KB damage, any potential protection the observed farming conditions offer, and to develop effective interventions tailored to the specifics of the region.

02

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Their contributions enabled operations and enhanced the success and depth of the case study.

Introduction

Even as the world transitions to cage-free systems, hens remain vulnerable to several welfare issues [Campbell 2020]. In fact, in a recent study, hens living in cage-free aviaries spend countless hours in hurtful and disabling pain due to, for example, keel bone fractures (KBFs) [Schuck-Paim et al. 2021]. With many possible causes for these injuries – egg size, external traumatic events, perch type, bone quality – in order to reduce this pain multiple solutions must be researched, including dietary interventions. As many countries set timelines to ban cage systems, it is during these transitions, hens suffer as producers lack the proper knowledge to adjust to a new way of operation – often leaving hens without the proper rearing, feeding and management techniques that these new systems require.

The global North has a well-documented and widespread prevalence of egg-laying hen health and welfare issues associated with keel bone (KB) damage. We see that there is a need to assess how common such issues are in the African continent as scientific literature on this topic is sparse. Even though commercial layer hen breeds are similar to those in other regions, most common cage-free housing systems are single-tiered in East Africa, unlike the multi-tiered aviary systems in Europe or the US. This may potentially affect the prevalence and severity of fractures. Furthermore, we are observing lower productivity rates through conversations with farmers (77±0.3% (45-96%)), and small flock sizes (1250 hens (150-11000)). There are different feeding regimens - typically twice a day, 133±34 g/hen/day (70-250 g/hen/day, and most not providing minerals ad libitum - and hens being kept for a long duration (24.6±3 months (19-36 months)). There are additional factors that prevent the direct assumption of equivalent prevalence of KB damage. Healthier Hens is an animal health and welfare non-profit founded to find cost-effective interventions to mitigate the issues of poor bone health in egg-laying hens kept commercially. Kenya is our pilot country of operations.

Expected value

Many stakeholders we encountered expressed a need to have Afrocentric data to inform their decisions and actions. Therefore, we believe acquiring the first regional data on this relevant issue could be quite impactful in the long run. Since there is no such data available, Healthier Hens might still have a competitive advantage in getting an insight into the possible prevalence of KBFs on commercial cage-free farms. Depending on implementation success, the case study could also be used as a data collection example - it could provide an example for other stakeholders to collect data in other regions that have no published KBF data.

Literature Review

There are more than seven billion egg-laying hens in our farmed food system alive today [Schuck-Paim et al. 2021]. Chickens are by far the most populous farmed land animals globally and are generally kept in extremely low-welfare conditions. Egg-laying hens have been selectively bred to maximize their egg production, leading to an immense strain on their health. Without commercial farming, hens would naturally produce around 10-15 eggs per year, but in a factory farm setting, hens are selectively bred to lay more than 300 eggs a year [Clauer 2012].

Each egg laid by a hen requires a large amount of biological input, with nutrients such as calcium, phosphorus, and vitamin D3 playing a critical role. Hens are naturally great at foraging for nutrients, and now complete feed has been produced and formulated to meet biological requirements. Yet complete feed, a type of nutrition that is supposed to cover all of the dietary needs of a hen, has been optimized for egg production. It lacks emphasis on hen health and welfare, which can have dire effects on their bodies. For example, when a hen begins to develop an egg within their body, bone constituents can be mobilized to provide roughly 40% of the calcium in the eggshell [Nys and Le Roy 2018]. With factory-farmed hens now laying 30 times the amount of eggs than they would naturally, mineral and vitamin deficiencies are prevalent amongst egg-laying hens [Whitehead 2004]. This is one of the main contributing factors to high rates of bone fractures and osteoporosis on farms. Genetics and inadequate housing also play key roles. These deficiencies are found in all housing systems, and lead to constant and major pain for egg-laying hens, poor welfare, as well as an increase in mortality rates [Schuck-Paim et al. 2021].

Bone health

Since layer hens are active animals, engaging with their surroundings and other birds, adequate bone development and sustained integrity are vital for their health. Research by Heerkens et al. 2016, looking into commercial flock health in Belgium, found that issues related to physical injuries were common, with 41%, 18%, 82.5%, and 49% of the birds having experienced hematomas, wounds, keel bone fractures and deviations, respectively. They have also observed a negative association between keel bone deviations and second-quality eggs. Flocks with a higher percentage of straight keel bones produced fewer second-quality eggs. Nasr et al. (2012a) found a correlation between reduced keel bone strength and reduced egg quality.

Once fractures occur, healing is generally seen to be a lengthy process in laying hens, taking 6 to 8 weeks for the majority of hens. However, research has also recorded relatively delayed and even a lack of healing in as much as 16% of surveyed hens [Baur et al. 2020]. This suggests that hens experiencing fractures may be in pain and suffering for a significant portion of their lives [Toscano et al. 2020]. In a breakthrough study, Armstrong and colleagues (2020) recorded radiographs of brown laying hens throughout a production cycle based in a multi-tier aviary facility. They found that hens suffering from KBFs also experienced negative affective states akin to depression, lasting at least 3 weeks [Armstrong et al. 2020].

Wei and colleagues (2021) found that hens with KBFs had lower concentrations of sodium, phosphorus, and calcium in their bodies. Early research on human nutrition confirmed that potassium plays a key role in preventing bone damage and osteoporosis by helping preserve calcium in the bones [New et al. 2000] not to mention the many studies assessing the positive effects of phytase and omega 3 supplementation. There is also some evidence for antagonistic effects of trace elements. For example, measured lead content in fractured hen keels was elevated in a recent piece of research [Wei et al. 2021]. It is unknown whether lead toxicity might have flow-through effects on hen bone health besides the established impact of organ damage and immune system impairments [Kim et al. 2020]. It is clear that the dietary composition of the feed is an important factor that has a significant effect on bone development, health, and by extension - layer hen welfare.

Keel bone fractures

Keel bone damage is currently a global welfare concern for laying hens, as Campbell (2020) found that up to 95% of birds at the end of the laying cycle exhibit some type of keel bone damage. A comprehensive literature review of KBFs by Rufener and Makagon (2020) confirmed that the issue is affected by a multitude of factors, making it difficult to compare different studies and establish an average global prevalence. Hen age, strain, housing system, and other management factors play important roles. The researchers highlight that the general perception of cage-free leading to higher KB fracture prevalence may not be supported when the whole body of evidence is compiled and examined. However, the review established beyond any doubt that KBFs are indeed a prevalent problem (at least a third of all birds likely affected) in the laying hen industry, with reported incidence rates varying greatly across breeds, housing systems and methods of determination [Rufener and Makagon 2020].

Hens within alternative housing systems have opportunities to exercise, which leads to a strengthening of bones. Paradoxically, they can also suffer from higher rates of keel fractures and/or deviations brought on by the higher risk and force of collisions in cage-free housing systems, especially in fearful flocks. At the same time, caged hens suffer from more deformed keel bones, but have fewer fractures despite their lower bone mineral density compared to cage-free hens. In addition, it seems that white egg layers are more susceptible to deformations, while fractures were more frequent in hens with high laying rates. In general, egg laying rate decreased and adult body weight increased KB mineral density. There is some evidence for a positive relationship between adult body weight and keel bone mineral density, with heavier hens exhibiting higher bone densities [Habig et al. 2021]. Whereas KBs with high bone mineral density are reported to be less severely deformed in hens kept in cages. Similarly, Candelotto et al. (2017) found that laying hens with the greatest bone mineral densities were the most resistant to keel bone fractures, indicating that this property plays a key role in determining keel bones' breaking strength. However, conflicting evidence shows that hens' weight may play a role in elevating the risk of fractures [Campbell 2020]. Therefore, more research is needed to determine the effect of hen weight and bone density on the risk of developing KB deviations or fractures.

In addition to its high prevalence, keel bone damage is painful and can alter hens' behaviour. Recent research conducted on both brown and white hen strains shows that skeletal health is impaired across all birds kept in all housing systems. Management strategies such as the provision of ramps to access perches and tiers were proposed in aviary systems to reduce the incidence of keel bone damage, while bone strength can be improved through exercise opportunities, particularly when available during pullet rearing [Campbell 2020]. Improvements in housing systems and management practices will be an important part of the combined solution to addressing KB damage in egg-laying hens.

Fracture specifics

Although fractures are commonly believed to be caused by impact with perches, a recent study making use of computed tomography scans and histology, suggested that at least some fractures may result from internal pressures of egg laying, rather than high-energy collisions. Irrespective of the underlying cause, hens with KBFs experience pain; often exhibit reduced egg production, size and quality; and increased feed and water consumption. These injured birds also show a reduced ability to perch and fly. At the same time, hens with fractures spent less time resting and standing on the floor, while those with severe fractures spent more time perching, presumably to avoid descending from perches where they felt safer. Injured birds also spent less time being inactive, suggesting that they might feel uncomfortable, leading to restlessness. Recently, a study showed that hens with fractures had reduced hippocampal neurogenesis, indicating that they experienced a negative affective state while suffering from fractures [Campbell 2020]. This reinforces findings showing that KB injuries are painful for hens.

Baur et al. (2020) studied the health of layer hens kept in a cage-free arrangement on a Swiss research farm. A shocking 99% of hens showed at least one keel bone lesion and 97% had at least one keel bone fracture. In 77% of the cases, the caudal third (the lower part) of the keel bone was injured. The researchers recorded that, on average, the hens experienced three fractures each during the production cycle, with most fractures occurring between 31 and 33 weeks of age - just after the peak of lay. Upon reaching sexual maturity at around 16-18 weeks of age, the hens' bodies cease producing structural bone and the overall elasticity of the bones decreases. Although calcium retention efficiency improves with age, that does not seem to be enough as the risk of fractures increases. The researchers propose that the subsequent decrease in new fractures (after 33 weeks) could be partly explained by the further increase of calcium retention, solidifying the bone. The longitudinal study also included developing an estimate of how long such fractures take to heal. It found that, depending on the fracture type, some fractures took up to 36 weeks to heal, although most were fully healed by week 7 [Baur et al. 2020].

That same year, a review by Campbell found that brown hens are more susceptible to KBFs within aviary systems. The review also found that susceptible birds tended to produce eggs of lower breaking strength and that KBs from commercial strains exhibit the greatest likelihood of fracture. In general, it seems that underweight hens, those that have a high calcium turnover due to prolific egg production, and those without access to sunlight are more susceptible to breakages [Campbell 2020].

Despite having high bone density, a high-performing egg-laying line monitored by Eusemann et al. (2020) showed a significantly higher fracture risk than a lower-performing layer line. However, the risk and severity of KB deviations were unaffected by both egg production level and layer line, suggesting that KB fractures and deviations are two independent phenomena caused by different factors. Moreover, there is no consensus as to how deviations impact welfare, unlike fractures, where most publications point to reduced welfare outcomes. Eusemann et al. (2020) found that fracture prevalence increased the most between weeks 33 and 40, although the data did not support the hypothesis of continuous bone mass loss during lay. The recorded radiographic density increased in the latter stages, indicating that no significant loss occurred after the 40th week, and even that some bone mass recovery might have occurred. While caged hens may exhibit continuous bone mass depletion due to movement restriction, a housing system that allows for substantially more load-bearing movement seems to enable higher retention of bone integrity. However, the limitations inherent to the methodology used in this study did not allow the authors to distinguish between the degree of mineralization and different types of bone. This is important because medullary bone — egg-laying hens' primary calcium reserve — offers little structural integrity despite being relatively high in radiographic density. Therefore, radiographic evaluations of laying hens' bones should be accompanied by other measurements, such as morphological examination of bone structure, to more accurately determine the effects of diet and housing on bone strength [Eusemann et al. 2020].

Measurement techniques

The recent use of radiography allows fractures to be detected more accurately and even non-invasively. Among other techniques that allow assessing bone health non-invasively, Tracy and colleagues (2019) conducted a study, where researchers attempted to determine if training, with feedback on accuracy, could improve the assessment of bone fractures via palpation - a method where an expert can evaluate the bone condition by touch. The accuracy of portable radiography and sonography equipment was also evaluated. The researchers found that even with feedback, palpation remained an inaccurate method, while both radiography and sonography showed high accuracy in detecting fractures. On the other hand, palpation scored higher in assessing keel bone deviations. Specialized training would be warranted when evaluating bone health via palpation. Radiography exhibited excellent fracture predictive performance [Tracy et al. 2019]. We need to measure this data accurately because lower incidences of KBFs in laying hens could decrease economic losses for farmers and improve the welfare of the birds [Olgun and Aygun 2016].

Methodology

The case study was set out to get insights into whether KBFs are prevalent on Kenyan cage-free farms and how severe such injuries are when they do occur. To do this, 5 end-of-lay flocks were sought throughout Q4 of 2023. Of each flock, 20 hens were intercepted at the point of depopulation, when their keel bones were extracted post-slaughter at a commercial slaughter facility. Then, high-resolution radiographs were taken of the bones and trained multi-assessor scoring was employed to evaluate the status of the bones, as per Rufener et al., 2018. Four of us took the training and redid it before scoring each set of radiographs to counter intra- and inter-assessor variability. During the last two data collection exercises, palpation and visual assessments of KB status were carried out additionally by two trained vet professionals [Healthier Hens, 2024]. Besides checking levels of bias in KBF determination across methods, this also provided some information into the prevalence of keel bone deviations.

The farms and flocks were chosen via making use of Healthier Hens' network with the local egg farming community, by identifying flocks that meet the criteria of the case study. A small-scale commercial slaughter facility carried out the slaughter and was chosen due to experience with cage-free farming (the business also hosts a cage-free farm) and proximity to Nairobi. Due to their expertise in imaging and working with farmed animals, the radiography team of the Pathology Department at the University of Nairobi was recruited to record radiographs of the extracted KBs and utilize them.

Specific objectives

- Assess keel bone status in cage-free egg-laying hen flocks, noting possible incidence rates, fracture severities and locations.
- Compare the robustness of on-farm palpations and subsequent post-mortem scoring by trained veterinarians versus radiographic KB assessments and get data on KB deviation prevalence and location.

Geography

The sampled flocks were all housed in Kiambu county, Kenya, within 30 km of the slaughter facility, as indicated in the map below.

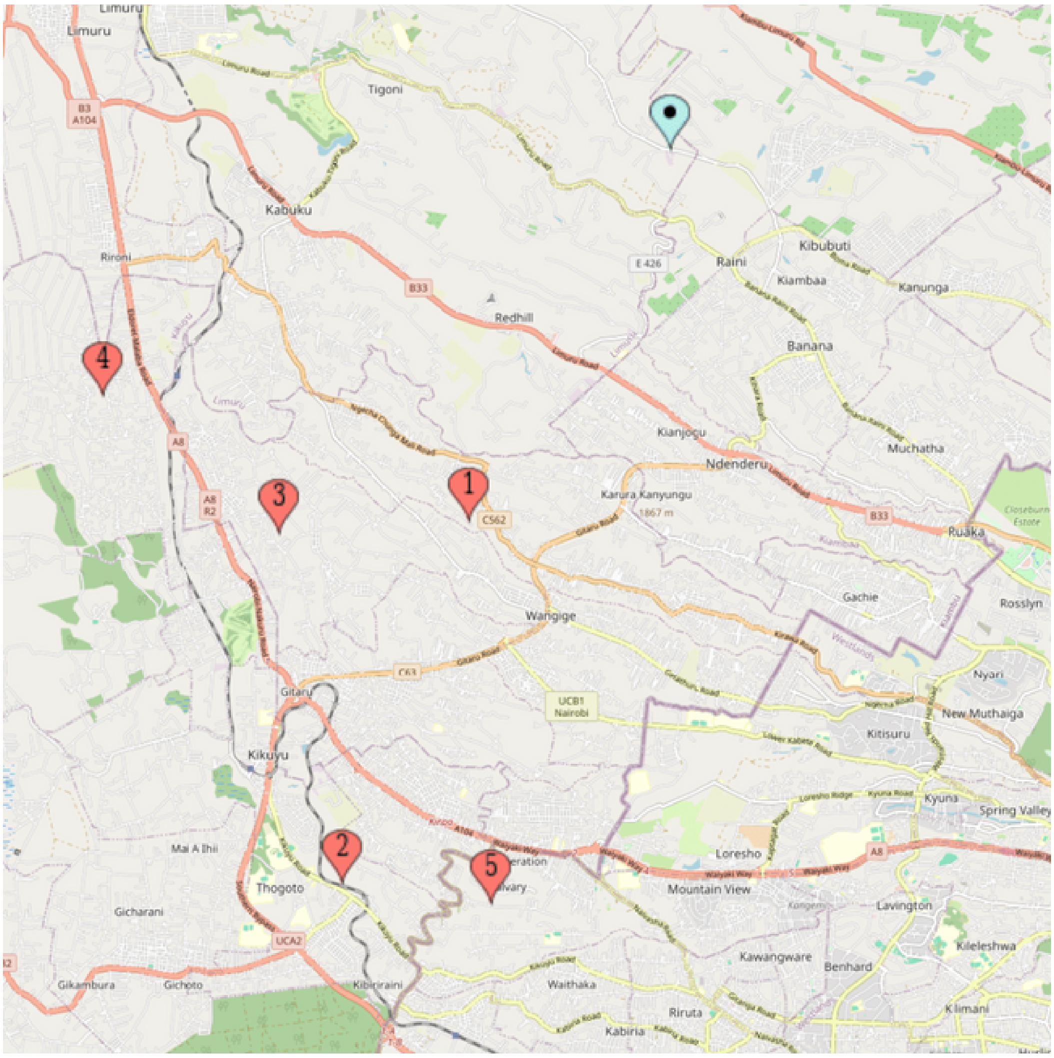


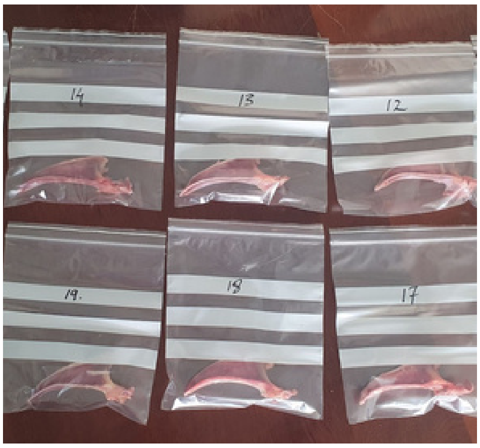
Figure 1. Map marking the farms, where the hens were intercepted and the slaughter facility. Kiambu county, Kenya.

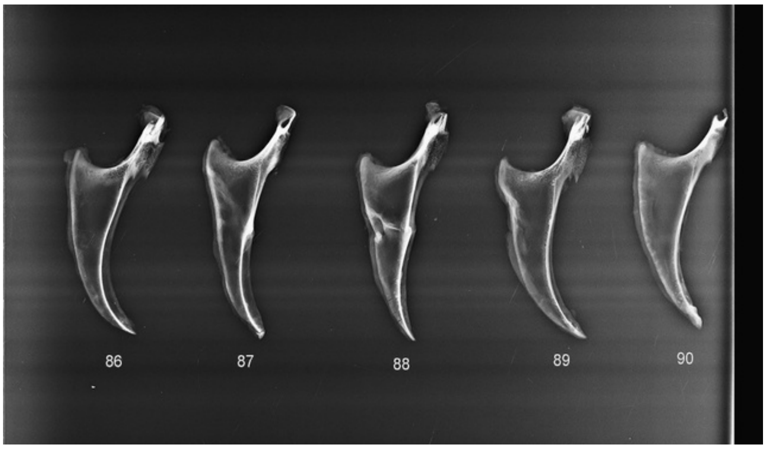
Sampling

The scope of the study involved recruiting 5 farms throughout Q4 of 2023. The criteria for farm selection included:

- Deep litter cage-free housing system
- End of lay hens - ages of at least 75 weeks of age (WoA)
- Small-medium sized commercially-active egg farms (at least 500 hens)
- Located in the vicinity of the slaughter facility.

Each flock was visited before depopulation to collect data via farmer interviews and confirm compliance with set criteria. Then, collection visits would occur, 20 hens would be selected via randomised, stratified sampling by veterinary professionals (4 hens from each side of the house and 4 from the centre of the flock). They were then separated and transported to the commercial slaughter facility. The observation should yield a result within ±20% of the real value at a 95% confidence level. Upon slaughter, KBs were extracted and stored frozen until radiography was performed within a week after extraction. The overall welfare and keel bone status of the hens used for the last two data collection exercises were also assessed in-vivo by two trained vet professionals, also followed by KB scoring post-mortem, as in the other exercises. The training these collaborators underwent was described previously [Healthier Hens, 2024].





Expected output

Data that can be used to supplement and compare with the figures reported in the Global North. The insights will generate interest and motivation to carry out more research into how widespread bone health issues are in hens kept cage-free in underrepresented regions and encourage investigations towards interventions tailored for local conditions and farming specifics.

Methodological limitations

- ISA Brown hens were assessed, this limits comparison as white strains are more prevalent in the Global North, where most of the published data originates from.
- A small sample size of farms (five).
- Despite training, inter-assessor variability was still high, making it difficult to compare the recorded KBF severity scores quantitatively.
- Uncertainties in the representativeness of the sampling - the personnel focused on distressing the hens as little as possible and finishing collection quickly, potentially yielding non-perfect sampling in the barns.
- A small sample of KBs was analysed from each farm: 20 out of 700 (500-1100) hen flocks.
- Sampling was done at the point of depopulation, suggesting that old, healed fractures might go unnoticed even upon radiographic scoring, potentially resulting in false negatives (suggesting we might risk underrepresenting the real values).
- Initially, slaughter facility staff were extracting the KBs, which could have caused some false positives via damages made to the bones upon extraction (suggesting we might risk overrepresenting the real values). Trained vet professionals carried out extraction during exercises 4 and 5 instead.

Results and discussion

On average, the hens were 92 WoA (76-112 WoA) at the time of interception (end of lay, voluntary depopulation by the farmers). Surprisingly, the productivity was still relatively high, averaging at 70% (60-76%). For context, we have recorded a low of 45% (68 WoA) and a high of 95% (60 WoA) among other interviewed Kenyan cage-free farmers (n = 33). The hens of the study flocks did not seem to suffer from significant underfeeding at the point of interception, having received 134 g/hen/day of feed, on average. However, 2 of the 5 farmers expressed dissatisfaction with the feed quality, pointing to low productivity and quality inconsistencies. Out of the larger sample of interviewed farmers, a quarter expressed experiencing feed issues, a fact we had previously observed to indeed be a risk factor in Kenya [Healthier Hens, 2023]. 2 of 5 farms provided ad libitum mineral supplements to the hens.

All of the farmers had vet professionals who helped them with on-farm health issues. None of the 5 farmers expressed having observed bone fractures on their farms. A caveat here is that farmers typically do not check for keel bone damage and a large majority are not aware of this welfare issue [Healthier Hens, 2023]. Similarly, only 33% of our surveyed vet professionals, actively working with farmers and visiting farms, said to have observed KB damage in the field. A caveat here: most were not familiar with palpation methodology and had not received the training needed to perform on-farm hen welfare assessments [Healthier Hens, 2024].

The effect of different KB assessment methods

The two trained vet professionals, who had scored KB status via palpation in #4 and #5 flock hens, believed that 65% and 100%, respectively, of the assessed hens had fractures, when assessed via palpation. These scores changed upon KB scoring post-mortem and resulted in them believing that 84% and 95%, respectively, had KBFs. These figures dropped significantly once the bones were assessed radiographically, yielding flock KBF prevalences of 35% and 30% in flock #4 and #5, respectively - see the figure below for an easier comparison. This confirms the high variability that can occur when comparing KBF data acquired using different methods, as per [Rufener and Makagon 2020]. Similarly, high variability was observed in terms of average KBF severity scores, when comparing assessments done using different methods. Here, palpation yielded averages of 1.9±1.2 and 2.9±0.9, post-mortem assessment: 2.4±1.3 and 3±1.3, and radiographic assessment: 1±0.7 and 0.9±0.7, respectively. The former two methods exhibited relatively high observer variability of 25% and 12% during #4 and #5 flock hen assessments, respectively, suggesting improvements might be possible with experience. Naturally, higher agreement was observed in post-mortem assessments.

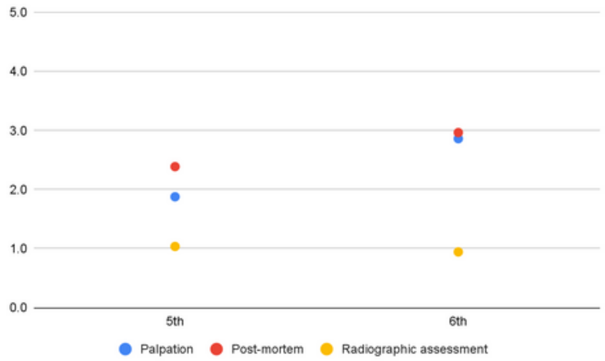


Figure 2: Determined KBF prevalences in #4 and #5 flock hens using different methods: in-vivo palpation (blue), post-mortem assessment (red) and radiographic assessment (yellow).

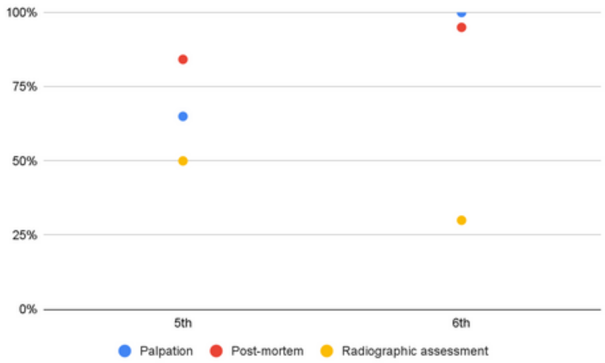


Figure 1. Map marking the farms, where the hens were intercepted and the slaughter facility. Kiambu county, Kenya.

Fracture locations were determined radiographically for all of the scored KBs, while the locations of #4 and #5 flock KBFs were also recorded via palpation and post-mortem assessments as per the same KB area template (see figures below), allowing for side-by-side comparison of scoring accuracy and consistency.

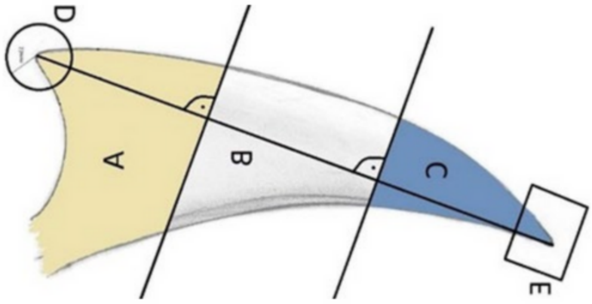


Figure 4: Keel bone damage scoring template, indicating specific bone areas.

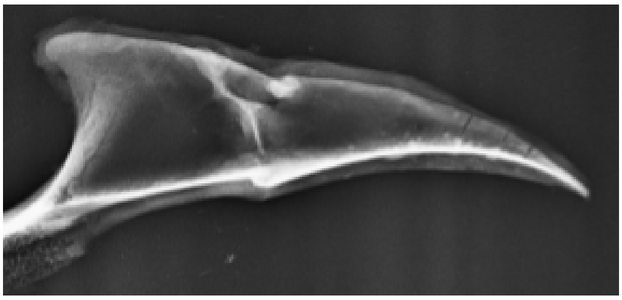


Figure 5: A radiograph of a fractured keel bone, exhibiting fractures in B and C areas.

In general, most fractures seemed to be positioned in the final third area of the bones (C), followed by the middle (B) and first (A) thirds (see table below). Surprisingly, relatively few fractures were observed in the tip of the KBs, which is typically a highly affected area together with the final third, as per Global North literature [Baur et al. 2020]. On the other hand, the high expected incidence of fractures in the first and second thirds, where the bone is typically the strongest, is also surprising, suggesting that the mode of fracture infliction might be different than in commercial flocks in the Global North.

When comparing across the different assessment methods, the determined numbers of fractures in specific bone areas generally followed the trend of palpation > post-mortem > radiographic assessments. The best agreement seemed to be in area A fractures. Overall, we consider the accuracy of radiographic assessments to be the highest as the method does not suffer from interference by external tissue and permits observing the full extent of hairline and old fractures, better revealing the extent of different injuries. The method also allows for a more accurate assessment of KB tip fractures.

Table 1: Overview of keel bone fracture locations in #4 and #5 flock hens as determined via palpation, post-mortem assessments, and radiographic assessments.

KBF 1	Fracture location				
	A	B	C	D	E
KBD assessment via palpation					
#4	**29%**	**55%**	**55%**	**0**	**0**
#5	**50%**	**85%**	**80%**	**0**	**50%**
Post-mortem KBD assessment					
#4	**75%**	**50%**	**70%**	**10%**	**0**
#5	**30%**	**40%**	**90%**	**0**	**0**
Radiographic KBD assessment					
#4	**35%**	**30%**	**35%**	**0**	**15%**
#5	**25%**	**30%**	**60%**	**0**	**5%**

Despite the observed variation in apparent prevalence, KBF severity and locations, our small sample sizes and high inter-observer variability do not permit us to draw any conclusions or present significant differences across the scores obtained via the three different methods. It does confirm, however, that care needs to be taken when comparing data acquired using different methods as the results may vary greatly. Assessments employing palpation and dissection are typically regarded to be at risk of underestimating KBF prevalence, as discussed, e.g., by Rufener and Makagon, 2020. However, in our case study involving two palpation and dissection assessments, there might have been bias among the assessors as the radiographically determined prevalence rates were significantly lower. We remain most confident in the results obtained via radiographic assessment and they will be used when discussing KBFs henceforth.

Keel bone deviations

Assessing KB damage also non-radiographically allowed us to get data on the potential prevalence and location of such types of damage. Both during palpation and post-mortem assessments, the two assessors were relatively consistent in their findings that there was a high prevalence of KB deviations (>80%) in #4 and #5 flocks. Most of the deviations were recorded in the middle third (B) area of the keel bone. Radiographs were not used in comparison as the method permits only two-dimensional assessment of KBs.

Although there is no reason to believe that deviations cause pain or suffering to the hens directly, some studies, e.g., Gebhardt-Henrich and Frohlich, 2015 showed that hens with KB deviations were often later diagnosed with KBFs, suggesting there might be a link between the two types of bone damage. Deviations potentially add to the overall pain and suffering experienced by hens throughout their lifespans, and are something that should be minimised in flocks. However, typically the proposed mechanism for KB deviation formation includes perching on poorly designed perches or prolonged perching, possibly in combination with low bone mineral density. Since many cage-free farms in Sub Saharan Africa do not have perches, we are unsure how these deviations evolve.

Previously published data shows that many hens are exposed to such KB deformations. Käppeli et al., 2011, for example, found that more than 50% of the hens had deformities (deviations and fractures), on average, in 39 commercial Swiss flocks. Similarly, Casey-Trott et al., 2017 observed 52% of hens with deviations in 4 experimental flocks. Heerkens et al., 2016 also found a comparable prevalence of 59% in Belgian flocks. On the other hand, Riber and Hinrichsen, 2016, observed significantly lower rates of prevalence reaching a maximum of 29% in Danish flocks. High variability was determined commonly across study flocks. Given that visual post-mortem assessment of KB deviations is a robust method of scoring such bone damage, we suspect that hens in Kenya might indeed be exposed to a high incidence rate of such deformities. However, more flocks should be assessed to get a better indication of whether the incidence rates are comparable or, potentially, higher than those observed in the Global North. Nonetheless, the seemingly high prevalence in KB deviations did not seem to have translated into high KBF prevalence as discussed below.

Keel bone fractures

The keel bones of hens from five different flocks were assessed radiographically (post-mortem) to identify fractures and score their severity. The table below provides an overview of how the KBs were distributed in terms of KBF severity and where, on the bone, the fractures occurred. 58% of the observed KBs had no significant fractures, whereas the remainder were mostly low-severity fractures. The overall average severity score of all scored KBs was 1.3±1, and 2±0.9 of only the fractures. Wilkins et al., 2011 determined an average corresponding severity score of 2.25, Rufener et al., 2019: 3.75, and Richards et al., 2011 observed more than half being low-severity fractures. All in all, our observations seem to be on the lower end of the spectrum, suggesting that the hens might be experiencing relatively less severe fractures. A possible explanation here could be the low spatial complexity of Kenyan deep litter farms. Wilkins et al., 2011 also assessed KBF severity scores of hens in aviaries with high perches, where the average score was significantly higher (3.25) and comparable to that reported by Rufener et al., 2019. If this is true, drastic intensification of cage-free housing systems, e.g., by installing high multi-tiered modules, could lead to more severe fractures. Here, it is also important to stress that as was in the cases of palpation and dissection, high inter-assessor variability was observed also in radiographic assessment, where our scores differed by 1.5 points, on average, preventing us from drawing strong conclusions on relative KBF severity.

Most fractures occurred in areas C (57%, final (caudal) third) and E (13%, tip) of the KBs, representing 58% of all identified fractures, which is in accordance with the findings in Global North flocks. Notably, however, there were significant fractions of fractures also in the first (A - cranial, 26%) and middle (B, 24%) thirds, which are rather unusual. Baur et al., 2020, for example, observed most fractures in C (61%) followed by E (15%) and A (12%) in Swiss commercial cage-free flocks. Thøfner et al., 2020 also found the most fractures in the caudal third (45%) but also a significant fraction across the caudal and middle thirds (31%). Given that the housing systems vary significantly from those used in the Global North, a contributing factor to KB damage, differences in fracture mechanics were expected.

Table 2: Overview of keel bone scores given via radiography (0-1: no fracture, 1-2: low severity fractures, 2-3: medium severity fractures, 3-5: high severity fractures) and identified keel bone areas of fracture occurrence (A-E).

Keel bone scores	0-1	1-2	2-3	3-4	4-5
Averages	58±18%	27±13%	8±7%	7±3%	0
Min	35%	15%	0	5%	0
Max	80%	45%	15%	10%	0
KBF locations	**A**	**B**	**C**	**D**	**E**
Averages	26±12%	24±11%	57±17%	1%	13±8%
Min	5%	10%	35%	0	5%
Max	35%	35%	75%	5%	25%

We observed a 4:1 ratio between low and high-severity fractures among the identified KBFs, as per the figure below, similar to the findings of Richards et al., 2011. On average, 42% (20-65%) of the hens had at least one keel bone fracture. This is comparable to published data from the Global North although slightly lower than expected. Eusemann et al., 2018, for example, observed 53%, Wilkins et al., 2011: 63%, while a large systematic review by Rufener and Makagon, 2020 found an average 55% prevalence, with mean data from different countries ranging widely from 12.6% to 84.5%. Similarly, the data reviewed throughout the EU Keel Bone Damage project also show significant variation 13.5-71%. It is also noteworthy that we used radiographic assessments. As published data often varies in methodology used, it makes it difficult to compare the results directly.

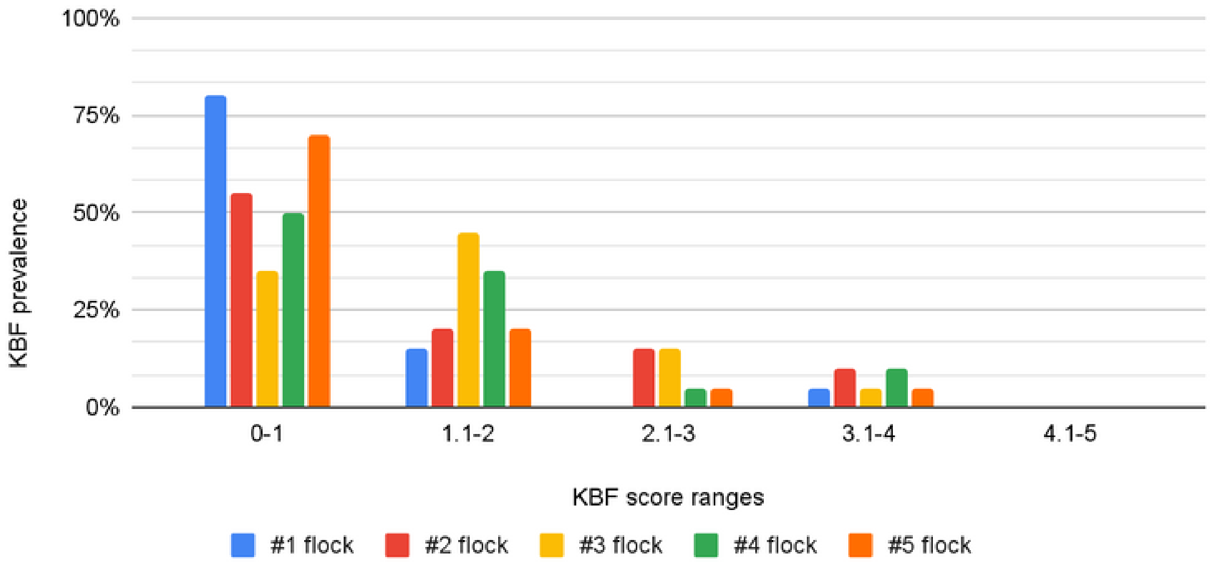


Figure 6: Overview of keel bone fracture score ranges as recorded in hen keel bone samples from 5 end-of-lay cage-free flocks. 0-1: no fracture, 1-2: low severity fractures, 2-3: medium severity fractures, 3-5: high severity fractures.

Of all the hens with fractures, 53% had experienced a single fracture, 38% - two fractures each, and 9% - more than two fractures each throughout their lifetimes. Thøfner et al., 2020 found 44% of the studied hens had multiple fractures. Similarly, Baur et al., 2020 observed that, on average, each hen had experienced three fractures, suggesting that our finding, where almost half of all hens with fractures had experienced multiple such injuries is reasonable. Once again, the results seem to be on the lower end of what is observed in the Global North.

Overall, the combined effects of feed quality, consistency issues and limited farmer awareness and knowledge would suggest that the hens might\ be at a higher risk of welfare issues. Although we have collected too little data to conclude, the consistent lower-end findings do add up and suggest that these overarching factors do not seem to have translated directly into significant differences in issues specific to the keel bone. There might be unexpected specific protective factors at play that prevent high incidences of KB damage to emerge. As per our farm visits and observations, these could include:

- later onset of lay,
- less complex housing design,
- lower rates of productivity.

Conclusions and recommendations

Significant variability was observed in KBF prevalence and severity scores among the different assessment methods, with radiographic assessment considered the most accurate. Non-radiographic assessments revealed a high prevalence (>80%) of keel bone deviations in two flocks, mainly in the middle third area of the KBs. Although the literature suggests there is a potential link between the incidence rates of KB deviations and fractures, we did not observe that.

Fracture locations were determined to mainly be in the final (caudal), followed by the first (cranial) and the middle thirds of the KBs, slightly deviating from initial expectations based on Global North literature, where most are observed in the final followed by the middle thirds. Radiographic assessments showed a relatively low average severity score of the studied KBs (1.3 using a scale of 0-5), with most fractures being of low severity. The true severity scores might be potentially lower than those reported in studies from the Global North, possibly influenced by differences in housing system complexity.

All findings recorded via radiographic KB assessments were on the lower end (42% (20-65%)) of what was expected based on the available literature and feed, management issues we observe at visited farms. However, it is difficult to quantitatively assess whether these differences are significant and robust. There might be a case for protective factors acting to mitigate the risks to hen KB health but uncertainty remains, especially as to how such factors might affect other welfare metrics and the net well-being of the hens kept cage-free in the region.

In summary, the case study provided valuable insights into the possible prevalence and severity of KB issues in end-of-lay hens kept in Kenyan cage-free farms, emphasizing the need for further research into potential preventative factors and possible interventions to mitigate this welfare issue.

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