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Keel Bone Damage in Laying Hens

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ABSTRACT

The use of alternative housing systems is increasing in response to the press of animal rights organisations and animal welfare-sensitive consumers. Pursuant to animal welfare legislation, it has become compulsory in the European Union member states to house laying hens in enriched cages or aviaries. However, one of the main problems associated with these housing systems is the frequent occurrence of skeletal damage, as a result of the reflexive movements of freely roaming animals. Owing to its protrusive anatomical structure, one of the most easily damaged skeletal parts is the sternum. Damage to the sternum is also referred to as keel bone damage. The term "keel bone damage" is used to describe bone deformities or fractures, which have long been named as bone anomalies in laying hens. Keel bone damage is a chronic disorder, which adversely affects the profitability of egg farms. Being a multifactorial disorder, it is difficult to identify the primary cause of keel bone damage, as many underlying reasons could be involved in its aetiology. Skilled and experienced practitioners can readily diagnose keel bone damage by palpating the sternal region. This study reviews the significance of keel bone damage for the egg sector and the welfare of laying hens.

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Introduction

The keel bone named *corpus sterni* in Latin, is the breast bone/chest bone of avian species, commonly referred to as the sternum. Keel bone damage is a major animal health and welfare problem encountered in the egg production. Poor animal welfare conditions cause chronic pain and suffering in laying hens, which are sentient beings. Keel bone damage is also known to have significant economic implications for laying hen holdings (Harlander-Matauschek et al., 2015). Keel bone damage is not comprised solely of fractures, but also encompasses other defects, such as deviation, haematoma and wounds (Petek, 2016). The occurrence of these defects is reported to range from 30% to 90% in laying hens (Anonim 1, 2020).

The keel bone plays an important role in the flight and perching of birds. The pectoral muscle, which moves the wings during flight, is attached to the keel bone. This muscle enables birds to display their natural behaviour and has a very important role in the perching of laying hens. The pectoral muscle also contributes to the respiration of birds by enabling the expansion of the thoracic cavity during the inhalation of air and the compression of the cavity during exhalation. Therefore, the sternum aids birds in successfully performing their basic daily activities, including flying and breathing. The thoracic cavity contains and protects the vital organs (Balkaya et al., 2016).

The ossification of the sternum occurs from the *cranial* end towards the *caudal* end. The bone structure of the sternum becomes more pointed towards the *caudal* end. While the skeletal structure is known to have fully formed in sexually mature chickens, ossification continues until the age of 40-50 weeks. From 50 weeks of age onwards, the egg yield of hens decreases, which eventually reduces the amount of calcium mobilized from the bones. For this reason, the incidence rate of keel bone damage progressively decreases as of the age of 50 weeks (Anonim 1, 2020; Casey-Trott et al., 2017; Donaldson et al., 2012; Kappeli et al., 2011; Petek, 2016; Stratmann et al., 2016; Toscano et al., 2013).

Young laying hens, which have newly started to lay, still have a cartilaginous *caudal* end of the sternum, and it has been determined that fractures of the *caudal* end cause more pain to the animal, when compared to fractures of the *cranial* end (Baur et al., 2020; Casey-Trott et al., 2017). Damage to the keel bone increases with the advance of age. In other words, the incidence of keel bone damage increases with the ageing of animals (Casey-Trott et al., 2017). In sexually mature animals, the hormone oestrogen contributes to osteoblastic activity (Özen and Haspolat, 2003). In hens that have started to lay eggs, approximately 10% of the required calcium is supplied from the body. The main source of calcium in the body is the long bones (Jung, 2019). As a result of the continuous supply of some of the calcium required for eggshell formation from the skeletal system, the bones become weaker and more prone to fractures. Among bones, the keel bone is particularly more sensitive to fracture (Rufener et al., 2019). Calcium deficit can be overcome by dietary programmes. Furthermore, wing beating, climbing ramps, and exercise systems positively affect bone development in fowl (Hardin et al., 2019; Jung, 2019) As keel bone damage causes pain and restricts the movements of animals, it eventually inflicts adverse effects on the daily activity of animals (Hardin et al., 2019).

Multiple predisposing factors are involved, including among others, the age of the bird, nutrition, genetic structure, environmental impact, and most importantly, the housing system. However, to date, the primary cause of keel bone damage has not been identified. Today, research on this topic mainly focusses on identifying the predisposing factors and decreasing the incidence of keel bone damage in animals (Anonim 1, 2020). This review presents information on the predisposing factors, clinical signs and diagnosis of keel bone damage.

Predisposing Factors

Keel bone damage, which is very common in laying hens, is a multifactorial defect. In other words, this defect does not result from a single cause, but rather occurs as a result of multiple reasons. Previous studies suggest that keel bone damage occurs upon trauma. Generally, such trauma occurs, when animals either run into each other or hit poultry house equipment (Baker et al., 2020; Harlander-Matauschek et al., 2015; Stratmann et al., 2016; Toscano et al., 2013).

Research has also shown that the skeletal part most affected by trauma is the sternum. This is attributed to the distinctly protrusive anatomical structure of the sternum, when compared to other bones. Thus, in the event of a collision, the body area, which is first affected by the impact, is the thoracic region (Donaldson et al., 2012; Riber et al., 2018; Saraiva et al., 2019). Predisposing factors involved in the occurrence of keel bone damage, include among others, housing systems, animal age, genetic structure, environmental effects, and nutrition.

Housing Systems

One of the main parameters deeply influential on animal welfare is the housing system. In Turkey the majority of commercial holdings operating in egg production use conventional battery cages for the housing of laying hens. In conventional battery cage systems, a high stocking density is applied, and as highly stocked birds cannot display their natural behaviour, they are exposed to extreme stress. In order to ensure favourable animal welfare conditions and meet consumer demands, the European Union has banned the use of conventional battery cages in egg production as of January 2012, and has shifted to the use of alternative housing systems instead (Anonim 2, 2020; Dukic-Stojcic, 2017; İpek and Sözcü, 2015). Thereby, animals have been granted the freedom to display their natural behaviour. In Turkey, it is planned to completely switch to the use of enriched cages in 2023. Therefore, studies in this field, are mainly aimed at a comparative assessment of different housing systems with respect to the level of animal welfare they offer. Conventional systems are opted for commercial production and the cleanliness of eggs. However, these systems are rather ineffective in providing favourable animal welfare conditions. Conventional systems prevent animals from displaying their natural behaviour and also restrict their motility. Immobility and restricted motility lead to disorders such as cage fatigue and osteoporosis. Enriched housing systems are reported to be more animal welfare-friendly (Ferrari et al., 2012; Saraiva et al., 2019; Vits et al., 2005). Given that these enriched systems allow birds to flap their wings, perch and scratch, among the alternative systems available for use, aviaries and enriched cages are more advantageous in terms of animal welfare. European Union member states use these alternative systems with an aim to ensure high animal welfare standards in animal production. Aviaries are multi-tier/multi-level systems, which give birds access to drinkers, feeders, nests and perches on each level. Housing systems, which enable animals to move freely and safely, are considered to be animal welfare-friendly. However, increased motility bears the risk of keel bone damage occurring. The use of low-quality litter on the ground of poultry houses accommodating highly active chickens, results in foot diseases. Furthermore, in multi-tier systems, animals may jump or fall from an upper level to a lower level. A common method used to prevent such risks is the ramp method (Hardin et al., 2019). Ramps are placed between tiers or are designed to extend from the lowest tier to the highest. Thereby, animals climb up and down the tiers in a more controlled and safe manner. Ramp systems reduce both the collision of animals with each other and the possibility of birds hitting poultry house equipment, and thereby, reduce the incidence of keel bone damage (Altan et al., 2018; Anonim 1, 2020; Anonim 2, 2020; Bayraktar et al., 2015; Stratmann et al., 2015). It is recommended to use rubber material as litter to prevent damage to the feet of birds (Heerkens et al., 2016). Foot health is closely linked to keel bone damage (Jung, 2019). Litter material, which is unfit for animal welfare, causes foot diseases such as dermatitis and hyperkeratosis of the foot pad, and bumblefoot. In alternative systems such as aviaries, which allow animals to move freely, diseases of the foot pad are observed at higher levels. This is because, in these systems, animals are not able to fully grip the perch, and therefore, slip and fall. Thereby, the incidence of keel bone damage increases (Heerkens et al., 2016). Previous studies have demonstrated that in alternative systems, such as aviaries, it is difficult to control the movements of animals, which poses a great risk for keel bone damage. Furthermore, the comparison of free-range systems with enriched systems has shown that a higher rate of keel bone damage occurs in the free-range systems, which allow animals to roam freely (Saraiva et al., 2019). On the other hand, free-range systems, which involve no cages, are associated with high levels of cannibalism among animals. Cannibalistic animals tend to be easily frightened and hide from other animals. Such animals, which display sudden and rapid movements, may repeatedly suffer from traumatic effects caused by colliding with each other and hitting poultry house equipment. Trauma may cause keel bone damage. In result, keel bone damage is more common in free-range systems, compared to cage systems (Petek, 2016). In general, studies have shown that the majority of keel bone damage cases are related to trauma. It is reported that equipment bearing the greatest risk for trauma is perches. Perching is a natural behaviour of laying hens. During daytime, birds spend most of their time resting on perches. Therefore, the design, material, diameter and height of the perches is important in terms of keel bone damage occurrence. Perches should be designed in a way to prevent the animals from slipping or falling off, and to enable them to take a strong grip. Generally, it is preferred to use metal perches in laying hen holdings. The risk of animals slipping and falling off is greater with the use of metal perches, compared to rubber perches. Therefore, it is recommended to use rubber/plastic perches to prevent laying hens from slipping or falling off (Anonim 2, 2020; Chargo et al., 2019; Hardin et al., 2019; Kappeli et al., 2011; Riber et al., 2018; Toscano et al., 2013).

When perching, birds apply their body pressure to the thorax (Saraiva et al., 2019). Rubber perches may prevent pressure-inflicted animal health problems (Hardin et al., 2019). The possibility of animals colliding with each other while climbing on and off perches or hitting equipment is known to be high. An imbalance of animals, while getting off perches, may also cause keel bone damage. In this respect, the height of perches bears importance for animal health (Anonim 2**,** 2020; Rufener et al., 2019). A high incidence of tibial and humeral fractures has been reported to be caused by the jumping or falling off of animals from perches (Donaldson et al., 2012).

Thus, the presence of perches is considered as a risk factor for keel bone damage (Saraiva et al., 2019). Furthermore, tibial and humeral fractures have been demonstrated to be positively correlated with the occurrence of keel bone damage (Fleming et al., 2004; Harlander-Matauschek et al., 2015). These disadvantages of perches can be overcome with use of ramp systems. Ramps enable birds to safely climb on and off perches, and thereby, reduce traumatic incidents (Anonim 1, 2020; Anonim 2, 2020; Hardin et al., 2019).

Age of Laying Hens

The rearing of laying hens covers two periods, namely, the growing and laying periods. The growing period is of particular importance in terms of ensuring the development of a strong and intact bone structure. While allowing animals to exercise and acquire a strong skeletal structure, the use of ramp systems starting from the early age of birds also prevents keel bone damage. The use of ramps in multi-tiered housing systems, such as aviaries, ensures the controlled and safe movement of animals within the poultry house and allows the development of a flexible and fracture-resistant bone structure in animals before they reach sexual maturity. The use of ramps offers benefits not only during the growing period, but also during the laying period. Ramp systems accelerate bone development in young animals. The placement of feeders and drinkers at different heights also has positive effects on bone development (Anonim 1, 2020).

The development of the basic skeletal structure of chickens is completed by 16-18 weeks of age. However, within this age range, the *caudal* end of the sternum is known to be still cartilaginous. The ossification of the sternum continues up to 40 weeks of age. Once they start to lay eggs, hens require a high level of calcium for eggshell formation. During the laying period, the blood levels of oestrogen, which increases osteoblast activity, are elevated (Hardin et al., 2019). The calcium needed for the ossification of the *caudal* sternum is used for eggshell formation, which results in the *caudal* end of the sternum remaining cartilaginous. As the calcium required for the formation of the eggshell is mobilised partly from the bones, this deficit needs to be corrected (i.e. by nutrition and exercise) (Anonim 1, 2020; Özen and Haspolat, 2003; Riber et al., 2018). It has been determined that the risk of keel bone damage emerges with the start of the laying period (26). The incidence of keel bone damage increases with advanced age, until the age of 50 weeks (Casey-Trott et al., 2017; Donaldson et al., 2012; Kappeli et al., 2011; Petek, 2016; Stratmann et al., 2016; Toscano et al., 2013)

Genetic Structure

One of the predisposing factors of keel bone damage is genetic structure. Previous research has generally focussed on the correlation of layer hen breed (white and brown lines) with keel bone damage. Results obtained suggest that keel bone damage is more common in brown lines, compared to white lines, owing to brown breeds being larger and heavier (Petek, 2016; Rufener et al., 2019). Higher body weight increases the impact of animals colliding with each other or hitting equipment. Furthermore, greater body weight increases the pressure exerted on the thorax during perching. Therefore, high body weight constitutes a risk factor for keel bone damage (Toscano et al., 2013).

When selecting layers for egg production, flocks should be composed of animals with a better genetic bone structure. Thereby, the risk of trauma-induced bone fractures can be reduced. The heritability of bone structure is predicted as 0.4. A genetic selection based on this parameter would reduce the incidence of keel bone damage (Andersson, 2017; Fleming et al., 2004; Saraiva et al., 2019).

Environmental Effect

Environmental factors, including the lighting schedule, staff and stocking density are also important predisposing factors for keel bone damage.

In animal husbandry, animals require adequate light in order to be able to display their natural behaviour, in line with the animal welfare approach. In the event of inadequate lighting, birds are observed to display anxiety while climbing on and off perches, which prevents them from maintaining balance and causes them to fall. These falls may cause fractures or other damage of the tibia, humerus and keel bone. Adequate lighting of the poultry house enables animals to freely display their natural behaviour, such that they feed, drink, rest, lay eggs and perch without suffering from any anxiety. It has been reported that while a light intensity of 0.8-1.5 lux reduces the motility of birds, a light intensity greater than 5 lux increases motility. Thus, these two light intensities pose a risk for keel bone damage. In order to ensure the controlled movement of animals in the poultry house, gradual transition from light to dark and from dark to light should be employed such that placing animals under stress is avoided (Anonim 1, 2020; Anonim 2, 2020). The lighting of the poultry house needs to be adjusted to the physiology of the animals. High levels of light intensity cause aggressiveness in birds (Anonim 1, 2020).

Another important environmental factor is staff. Staff should be trained. They should enter the poultry house with slow movements and increase their speed once the animals are accustomed to their presence. The walking around of staff in a poultry house, starting from an early age of the animals housed there, helps birds to become accustomed to both people and the regular visits of staff. The conduct of in-house checks by staff at different times of the day, in different corners of the poultry house with different clothes worn each day helps the process (Anonim 1, 2020).

Another major parameter influential on keel bone damage is stocking density, referring to the number of animals housed per unit area. Whether applied in a caged or cageless housing system, high stocking density has been shown to increase the incidence of keel bone damage (Jung, 2019).

Nutrition

Laying hens reach sexual maturity at 16-18 weeks of age. When laying eggs, layers mobilize part of the calcium required for eggshell formation from their bones (Eusemann et al., 2020). Therefore, the loss of calcium from bones needs to be replaced by nutrition. When the diet of laying hens is not supplemented with calcium, an increased rate of osteoporosis is observed. The osteoclastic activity in the bones needs to be reduced through tailored nutrition programmes (Hardin et al., 2019). The nutrient requirements of the layer flock should be determined by experts, and feed should be formulated based on these requirements (Anonim 1, 2020). Dietary supplementation with vitamin D_3 increases blood calcium levels and thereby, strengthens bones (Hardin et al., 2019; Kappeli et al., 2011). Furthermore, dietary supplementation with omega-3 increases bone resistance to fractures (Jung et al., 2019**;** Toscano et al., 2013). The inclusion of vitamin K in the diet increases calcium storage in the body, and thereby, bones tissue development (Anonim 1, 2020). Another important dietary aspect is the calcium and phosphorus ratio. A balanced calcium-phosphorus ratio improves egg yields (Bayraktar et al., 2018). Increased mineral concentrations in the bones are associated with decreased keel bone damage (Toscano et al., 2013).

Clinical Signs

Keel bone damage is a major animal welfare concern in commercial egg farms (Harlander-Matauschek et al., 2015). In fact, it is described as an injury with severe economic implications (Dukic-Stojcic et al., 2017). During daytime, laying hens spend most of their time perching. Birds suffering from keel bone damage have been observed to display anxiety when climbing on and off perches. In some cases, an animal with keel bone damage may refrain from climbing off the perch and prefer to remain on it for an extended time period. Under such conditions, animals cannot display their natural perching behaviour, which in result would lead to stress. Observations have shown that animals with keel bone damage tend to spend most of their time on the ground of the poultry house. Birds with this injury display both reluctance to move and reduced locomotor activity (Harlander-Matauschek et al., 2015; Riber et al., 2018; Rufener et al., 2019). Keel bone damage is known to cause pain, and it has been reported to adversely affect animal welfare (Jung et al 2019; Petek, 2016; Rufener et al., 2019; Saraiva et al., 2019; Thofner et al., 2020). In order to investigate the presence of pain in cases of keel bone damage, in previous research, animals suspected of having this type of injury were administered with analgesics, and their movements were observed afterwards. Observations showed that the activity of the suspect animals increased after the administration of analgesics (Hardin et al., 2019; Riber et al., 2018). The importance of keel bone damage for egg farms is also related to the significantly adverse effects of this injury on the reproductive performance of layers. Reports indicate that keel bone damage is associated with decreased egg yield and poor egg quality, particularly in terms of reduced eggshell resistance (Candelotto et al., 2017**;** Jung et al., 2019; Stratmann et al., 2015; Stratmann et al., 2016). Research has shown that the pain and stress caused by keel bone damage inhibits laying in hens (Armstrong et al., 2020; Candelotto et al., 2017; Rufener et al., 2019; Saraiva et al., 2019).

Apart from its effects on the locomotor system, keel bone damage has also been ascertained to affect the biological functions of birds. Thermoregulatory dysfunction may develop with this injury, due to the inadequate expansion and compression of the lungs during inhalation and exhalation. When exposed to high temperatures, avian species try to balance their body temperature by opening their mouth. As birds suffering from keel bone damage are incapable of the adequate expansion and compression of the thoracic cavity, their thermoregulatory system disrupts and eventually, animals develop heat stress (Riber et al., 2018).

Diagnosis

Several methods, including palpation, dissection, and radiography-tomography can be used for the diagnosis of keel bone damage. The most commonly used diagnostic method is palpation, as it is easy to apply, costless, and yields rapid results. This method is employed by trained and experienced practitioners by palpating the keel bone starting from its *cranial* end and extending towards its *caudal* end. If possible, diagnosis by palpation should be performed by more than one person. Thereby, the risk of misdiagnosis can be reduced. Collected data shows that fractures of the *caudal* end of the sternum are more common. Compared to those of the cranial and mid-part of the sternum, fractures of the caudal sternum have been reported to cause more pain (Andersson, 2017; Baur et al., 2020; Chargo et al., 2019; Gebhardt-Henrich et al., 2019; Toscano et al., 2013; Tracy et al., 2019). Diagnostic results have demonstrated that, when damaged, the keel bone may appear bent or curved or may resemble the letter C or S in shape. While some damages to the keel bone do not cause any clinical sign, some other damages may directly affect the movement of animals (Hardin et al., 2019). Another method used for the diagnosis of keel bone damage is radiography and tomography. This method enables the confirmation of cases initially diagnosed by palpation (Chargo et al., 2019). Radiographic techniques clearly display the severity of bone fractures. However, these techniques present with certain disadvantages, such as high cost and the requirement to restrain animals motionless in order to be employed (Sirovnik ve Toscano, 2017).

Dissection is considered to be the final resort. The animals are decapitated, and damages diagnosed by the palpation of the sternum are examined macroscopically. This process enables practitioners to test their skills. A comparative assessment of images taken of animals before and after dissection has proven to be very beneficial for practitioners (Toscano et al., 2013; Tracy et al., 2019).

In a previous study, the movements and gait of healthy animals and animals suspected of having keel bone damage were compared for a certain distance. It was observed that the healthy animals covered the distance within a shorter period of time (Riber et al., 2018).

Conclusion

Keel bone damage is described as one of the most important animal welfares- and economy-related problems encountered in laying hen holdings. This type of injury causes birds to show reluctance to move and decreases egg yields. Animals, which suffer pain are not able to display their natural behaviour, which exposes them to poor animal welfare conditions. Recent research has shown that, although alternative housing systems offer better animal welfare conditions, when compared to conventional systems, they are disadvantageous in terms of the risk of keel bone damage. It has been determined that the adjustment of lighting according to the physiological needs of animals enables their controlled movement, which in return reduces the risk of keel bone damage. The selection of laying hens with a genetically stronger bone structure would also reduce the risk of keel bone damage. Literature reports suggest that a balanced diet also has an important place in decreasing the risk of such damage. The most common method used for the diagnosis of keel bone damage is palpation. The employment of this method by trained and skilled persons reduces the possibility of misdiagnosis. To our knowledge, there is no prior study published on the investigation of keel bone damage in Turkey. In the future, it would be of use to make a comparison of the incidence of keel bone damage in local layer hybrids and foreign layer hybrids. New scientific data could contribute to reducing keel bone damage in laying hens.

References

Altan A., Erensayın C., Bayraktar H., Kutlu H. R., Türkoğlu M., Sarıca M., Arda M., Elibol O., Yetişir R., Yamak U. S. 2018. "Ed. M. Türkoğlu, M. Sarıca, Tavukçuluk Bilimi (Yetiştirme, Besleme, Hastalıklar), s. 218-220, Bey Ofset Ankara.

Andersson, B. (2017). Genetic aspects of keel bone deformities and fractures determined by palpation in laying hens. Lohmann Information, 51, 36-41.

Anonim 1. (2020). http://www.keelbonedamage.eu/ activities/ practical information-for-stakeholders (ET: 23.08.2018).

Anonim 2. (2020). https://www.compassioninfoodbusiness.com /media/7436221/additional-guidance on multitier systems for laying hens (ET: Ocak.2019).

Armstrong, E. A., Rufener, C., Toscano, M. J., Eastham, J. E., Guy, J. H., Sandilands, V., Smulders, T. V. (2020). Keel bone fractures induce a depressive-like state in laying hens. Scientific Reports, 10(1), 1-14.

Baker, S. L., Robison, C. I., Karcher, D. M., Toscano, M. J., Makagon, M. M. (2020). Keel impacts and associated behaviors in laying hens. Applied animal behaviour science, 222, 104886.

Balkaya, H., Özdemir, D., Özüdoğru, Z. (2016). Atmaca da Accipiter nisus Kanadın Superficial Kaslarının Makroanatomik Yapısı. Fırat Üniversitesi Sağlık Bilimleri Veteriner Dergisi, 30 (4), 23-28.

Baur, S., Rufener, C., Toscano, M. J., Geissbühler, U. (2020). Radiographic Evaluation of Keel Bone Damage in Laying Hens-Morphologic and Temporal Observations in a Longitudinal Study. Frontiers in Veterinary Science, 7, 129.

Bayraktar, B., Kılınç, B., Kılınç, A. A. 2018. Kanatlı Hayvan Beslemesinde Kalsiyum Fosfor Dengesinin Fizyolojik Rolü Ve Patolojik Etkilerinin İncelenmesi. II. Uluslararası Gevher Nesibe Sağlık Bilimleri Kongresi, 30 Kasım - 2 Aralık 2018, Ankara Türkiye, Bildiriler içinde (s.72-74).

Bayraktar, H., Yalçın, S., Özkan, S., 2015. Kanatlı Hayvan Yetiştiriciliğinde Değişimler Ve Yeni Arayışlar. Türkiye Ziraat Mühendisliği VIII. Teknik Kongresi Bildiriler Kitabı, 12-16 Ocak 2015, Ankara Türkiye, (s. 838-859).

Candelotto, L., Stratmann, A., Gebhardt-Henrich, S. G., Rufener, C., van de Braak, T., Toscano, M. J. (2017). Susceptibility to keel bone fractures in laying hens and the role of genetic variation. Poultry science, 96(10), 3517-3528

Casey-Trott, T. M., Guerin, M. T., Sandilands, V., Torrey, S., Widowski, T. M. (2017). Rearing system affects prevalence of keel-bone damage in laying hens: a longitudinal study of four consecutive flocks. Poultry science, 96 (7), 2029-2039.

Chargo, N. J., Robison, C. I., Baker, S. L., Toscano, M. J., Makagon, M. M., Karcher, D. M. (2019). Keel bone damage assessment: Consistency in enriched colony laying hens. Poultry science, 98(2), 1017-1022.

Donaldson, C. J., Ball, M. E. E., O'Connell, N. E. (2012). Aerial perches and free-range laying hens: The effect of access to aerial perches and of individual bird parameters on keel bone injuries in commercial free-range laying hens. Poultry science, 91(2), 304-315.

Dukic-Stojcic, M., Peric, L., Relic, R., Bozickovic, I., Rodic, V., Rezar, V. (2017). Keel bone damage in laying hens reared in different production systems in Serbia. Biotechnology in Animal Husbandry, 33(4), 487-492.

Eusemann, B. K., Patt, A., Schrader, L., Weigend, S., Thöne-Reineke, C., Petow, S. (2020). The role of egg production in the etiology of keel bone damage in laying hens. Frontiers in Veterinary Science, 7, 81.

Ferrari, L., Lolli, S., Ferrante, V. (2012). The effects of housing systems on laying hen welfare: Conventional vs. furnished cages. Zootecnıca ınternatıonal, 34(3), 32-37.

Fleming, R. H., McCormack, H. A., McTeir, L., Whitehead, C. C. (2004). Incidence, pathology and prevention of keel bone deformities in the laying hen. British poultry science, 45(3), 320-330.

Gebhardt-Henrich, S. G., Rufener, C., Stratmann, A. (2019). Improving intra-and inter-observer repeatability and accuracy of keel bone assessment by training with radiographs. Poultry science, 98(11), 5234-5240.

Hardin, E., Castro, F. L. S., Kim, W. K. (2019). Keel bone injury in laying hens: the prevalence of injuries in relation to different housing systems, implications, and potential solutions. World's Poultry Science Journal,75(2), 285-292.

Harlander-Matauschek, A., Rodenburg, T. B., Sandilands, V., Tobalske, B. W., Toscano, M. J. (2015). Causes of keel bone damage and their solutions in laying hens. World's Poultry Science Journal,71(3), 461-472.

Heerkens, J. L. T., Delezie, E., Rodenburg, T. B., Kempen, I., Zoons, J., Ampe, B., Tuyttens, F. A. M. (2016). Risk factors associated with keel bone and foot pad disorders in laying hens housed in aviary systems. Poultry science, 95 (3), 482-488.

İpek, A., Sözcü, A. (2015). Alternatif kanatlı yetiştirme sistemlerinde yetiştirme pratikleri ve refah standartları. U.Ü Ziraat Fak. Derg, 29, 133-146.

Jung, L. (2019). Laying hen welfare-The prevention of feather pecking and keel bone damage. Doktora Tezi. Kassel Üniversitesi, ALMANYA.

Jung, L., Niebuhr, K., Hinrichsen, L. K., Gunnarsson, S., Brenninkmeyer, C., Bestman, M., Knierim, U. (2019). Possible risk factors for keel bone damage in organic laying hens. animal, 13(10), 2356-2364.)

Kappeli, S., Gebhardt-Henrich, S. G., Fröhlich, E., Pfulg, A., Schaublin, H., Stoffel, M. H. (2011). Effects of housing, perches, genetics, and 25-hydroxycholecalciferol on keel bone deformities in laying hens. Poultry science, 90 (8), 1637-1644.

Özen, Ş., Haspolat, K. (2003). D Vitamini, Kalsiyum, Kemik Metabolizması ve Psikiyatrik Bozukluklar. Klinik Psikiyatri 2003; 6: 102, 113.

Petek, M. (2016). Non-cage housing systems and laying hen welfare: keel bone damage and feather pecking. Tropical Animal Science and Production (TASP 2016).

Riber, A. B., Casey-Trott, T. M., Herskin, M. S. (2018). The influence of keel bone damage on welfare of laying hens. Frontiers in veterinary science, 5, 6.

Rufener, C., Baur, S., Stratmann, A., Toscano, M. J. (2019). Keel bone fractures affect egg laying performance but not egg quality in laying hens housed in a commercial aviary system. Poultry science, 98(4), 1589-1600.

Saraiva, S., Esteves, A., Stilwell, G. (2019). Influence of different housing systems on prevalence of keel bone lesions in laying hens. Avian Pathology, 48(5), 454-459.

Sirovnik, J., Toscano, M. J. (2017). Restraining laying hens for radiographic diagnostics of keel bones. In Proceedings of the 10th European Symposium on Poultry Welfare. Ploufragan (p. 162).

Stratmann, A., Fröhlich, E. K. F., Gebhardt-Henrich, S. G., Harlander-Matauschek, A., Würbel, H., Toscano, M. J. (2015). Modification of aviary design reduces incidence of falls, collisions and keel bone damage in laying hens. Applied animal behaviour science, 165, 112-123.

Stratmann, A., Fröhlich, E. K. F., Gebhardt-Henrich, S. G., Harlander-Matauschek, A., Würbel, H., Toscano, M. J. (2016). Genetic selection to increase bone strength affects prevalence of keel bone damage and egg parameters in commercially housed laying hens. Poultry science, 95(5), 975-984.

Thofner, I., Hougen, H. P., Villa, C., Lynnerup, N., Christensen, J. P. (2020). Pathological characterization of keel bone fractures in laying hens does not support external trauma as the underlying cause. Plos one, 15(3).

Toscano, M. J., Wilkins, L. J., Millburn, G., Thorpe, K., Tarlton, J. F. (2013). Development of an ex vivo protocol to model bone fracture in laying hens resulting from collisions. Plos One, 8(6).

Tracy, L. M., Temple, S. M., Bennett, D. C., Sprayberry, K. A., Makagon, M. M., Blatchford, R. A. (2019). The Reliability and Accuracy of Palpation, Radiography, and Sonography for the Detection of Keel Bone Damage. Animals, 9(11), 894.

Vits, A., Weitzenbürger, D., Hamann, H., Distl, O. (2005). Production, egg quality, bone strength, claw length, and keel bone deformities of laying hens housed in furnished cages with different group sizes. Poultry science, 84(10), 1511-1519.