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Determination of hardness and mechanical properties of pig claws in three Greek swine herds

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Abstract

Lameness in pigs is a major welfare and economic issue for swine breeding herds. Claw lesions have been suggested to be a significant cause for lameness in sows. Housing conditions and nutrition management on the farm influence horn quality and may be associated with the development of claw lesions in pigs.

The current work examines the structure as well as hardness, fracture and mechanical properties of claws retrieved from housing sows. For the mechanical characterisation of pig claws, an experimental program that includes three point bending test in claws was performed in order to obtain the resistance of the tissue under bending forces. The study also includes hardness measurements through Vickers method as well as inspection of the structure through Scanning Electron Microscopy. Experimental measurements show that the claw specimen behaves as a linear viscoelastic material. Measurements of hardness were found to be affected by the moisture content of the claws.

Keywords: Claw horn; Elastic modulus; Hardness; Mechanical properties; Sow

1. Introduction

Claw lesions (CLs) are very common in sows [12, 14]. The high prevalence of CLs may be linked with the intensive farming of pigs on concrete floors, with minimal or no bedding [10]. The role of nutrition in sow foot health is also important [1, 11, 17].

The claw includes the distal phalanx, which is covered with a horn capsule. The horn capsule consists of a hard outside wall, a sole of hard horn, a soft heel, and a narrow white line joining the wall and sole [13]. Claw horn (CH) production is the result of proliferation, keratinisation (cellular differentiation) and cornification (cell death) of keratinising epidermal cells (keratinocytes) in the claw epidermis [15].

CH is a natural biological composite of keratinized material and behaves as a linear viscoelastic material [4, 5, 16]. Its mechanical properties such as hardness, viscoelasticity, stiffness, strength and toughness depend on the structure and the chemical composition of keratins that form the claw and horn moisture content [2, 3, 9, 18].

Formation of CH is a complex process which also depends on a balanced diet and a sufficient supply with the amino acids cystine and methionine, fatty acids, the minerals zinc, copper, selenium, manganese and vitamins A, D, E and biotin [1, 15, 17]. In general, chelated minerals have a beneficial effect on the health status of the majority of hoof anatomical sites and the severity of lesions [11].

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Despite a high prevalence of CLs in sows [7, 8, 12], we could not identify studies focusing on mechanical properties of claws in breeding sows.

The current study is established to our knowledge for first time measurements of mechanical properties of claws retrieved from housing sows. Those measurements include hardness measurements, through Vickers method and three point bending test in order to obtain the resistance of the tissue under bending forces. These values could be compared with future protocols of feed in order to investigate the effect of diet supplementation with chelated zinc, copper and manganese, vitamins and concentrated feeds on sow claw health and hoof horn quality.

2. Material and methods

2.1. Experimental Procedure and test conditions

The studied herds were indoor, farrow-to finish herds with 330 (Herd A), 160 (Herd B) and 800 sows (Herd C), respectively, with Danbred (herds A and B) and Hermitage (herd C) genotypes. The animals were loose housed in groups of eight to twelve on combinations of concrete and slatted flooring. Current farming of sows follows traditional - conventional breeding system without supplementation of organic complexes. The biomechanical properties of 79 samples of claws were tested. The horn samples were cut from the claws of freshly slaughtered sows by means of a band saw, model Metabo precision wnb bandsaw 0.9 kw, BAS 317. Mechanical testing was conducted using an Instron tensile machine (model 3382, INSTRON SA) equipped with a 3-point bending system and a 100 KN load sensor, with an error margin of ± 0.1 N. The samples were submitted to a compression test, the crosshead speed of test was 0.5 mm/min and the temperature condition was 25 °C.

The CH behaves as a viscoelastic material, combining elastic and viscous behavior, where the applied stress results in an instantaneous elastic strain followed by a viscous, time-dependent strain [4, 16].

Hardness is defined as the resistance of a material to permanent deformation by a harder object. The harder the material the smaller the degree of penetration by the indenter and the smaller the size of the indentation that remains [16].

The Vickers hardness test method consists of indenting the claw sample with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 100 KN load sensor. The full load is normally applied for 10 to 15 seconds.

The determination of Hardness was achieved with a Shimadzu model, micro hardness tester type -M. The equation for the calculation of hardness is given as:

$$H_v = 1854.4 * P / d^2, \text{ where} \quad \begin{array}{l} H_v: \text{Vickers hardness, P: testing load (gf),} \\ d: \text{length of diagonal line across indent } (\mu\text{m}) \end{array}$$

The elastic modulus E can be defined as the resistance of a material to deformation [9] and is calculating by dividing the tensile stress by tensile strain. The equation for the calculation of elastic modulus is given as:

$$E = \sigma / \varepsilon, \text{ where} \quad \begin{array}{l} \sigma: \text{tensile stress} = \text{Force} / \text{Area (N/m}^2 \text{ or Pa),} \\ \varepsilon: \text{tensile strain} = \text{extension} / \text{length} \end{array}$$

2.2. Moisture content

After testing, the samples were dried completely in an oven at 105 °C until their mass was constant. The moisture content was calculated as the difference between oven-dry and initial mass, divided by the dry mass.

2.3. Preparation of impact specimens

Specimens from retrieved claws were cut by diamond saw in small slabs (4 x 10 x 50 mm³) according to the ASTM D790 Standard test methods for flexural properties [19]. Claw samples prepared and cut into rectangular specimens for three point bending testing purposes using low velocity cutting to avoid any micro breakage of the specimens during the procedure. A special stainless-steel support (mount) was prepared for mounting the rectangular 3PB specimens. Each specimen was prepared to polishing procedure prior to mechanical testing in order to achieve smooth surfaces on all sides of the specimen. After the cutting procedure the specimens were stored in low temperature conditions (-5 up to -

20 °C) up to the time of mechanical testing. The claw samples were stored in small, sealed plastic containers to prevent dehydration.

3. Results

Values of Vickers hardness (Mean ± SEM) of the claw's samples, elastic modulus and claw lesion scoring in association with moisture content are listed in table 1, 2, 3, 4.

Value 0 of claw lesion scoring corresponds to non-significant lesions and value 2 corresponds to cracks or detachment of the horn section.



Figure 1 Instron 3382 Model.

Figure 2 Three point bending system procedure.

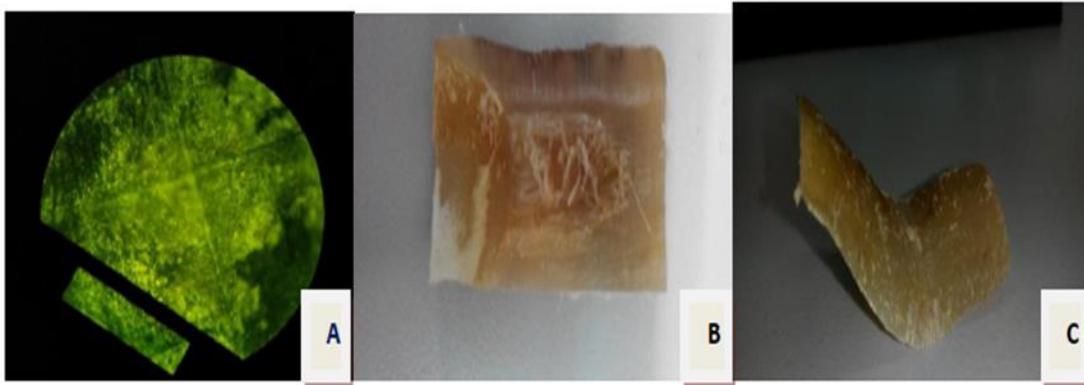


Figure 3 A) Representative traces of the Vickers tests in claws specimens (75x45x20 mm³) that were used in the study. The two diagonals of the indentation left in the surface of the sample after removal of the load are measured using a microscope and their average calculated.

B) Represents claw specimen before use of three - point bending system procedure.

C) Displays optical result after this procedure.

Table 1 Values of Vickers hardness (Hv) of the claws sample.

	Left front	Right front	Left back	Right back
Number of specimens	7	10	7	10
Vickers hardness Hv (kg/mm ²)	8,84 ± 0,54	9,73 ± 1,23	6,71 ± 0,44	10,174 ± 0,85

Table 2 Values of Elastic modulus (E) of the claws sample in association with moisture.

Number of specimens	4	19
Vickers hardness Hv (kg/mm ²)	26,42 ± 1,37	7,23 ± 1,56
Moisture content (%)	0 – 15	> 15

Table 3 Values of Vickers hardness (Hv) of the claws sample in association with moisture content.

Number of specimens	5	5
Claw lesion scoring	2	0
Vickers hardness Hv (kg/mm ²)	7,80 ± 0,99	8,51 ± 0,58
Moisture content (%)	> 15	> 15

Table 4 Values of Vickers hardness (Hv) of the claws samples and claw lesion scoring in association with moisture content.

Number of specimens	5	7
Elastic modulus E (GPa)	1,7 ± 0,40	0,44±0,09
Moisture content (%)	0 – 15	> 15

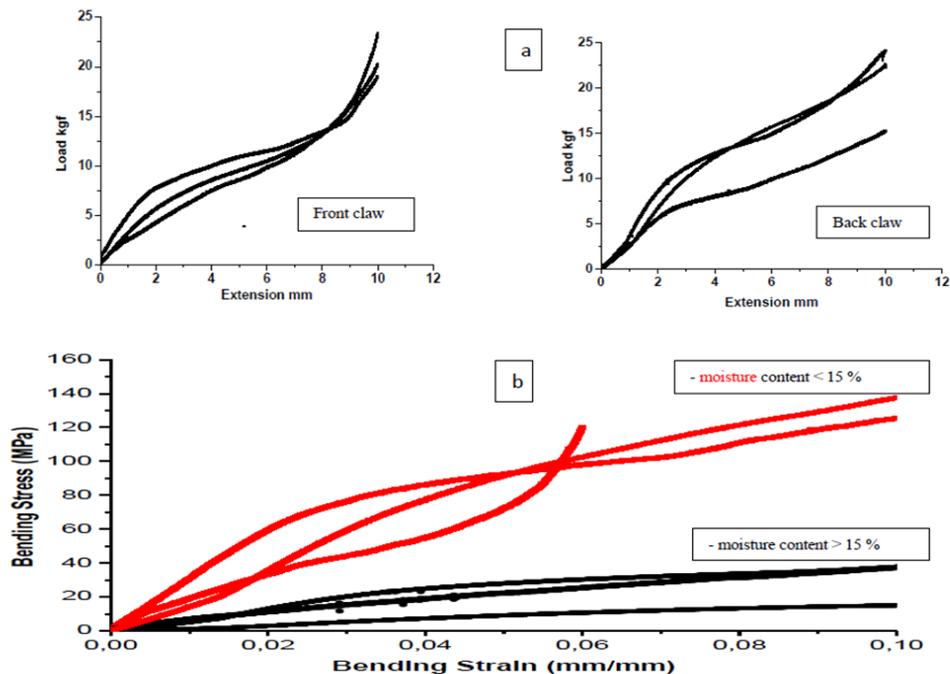


Figure 4 Plots a) of extension (mm) versus load (kgf) and b) of bending stress (Mpa) versus bending strain (mm/mm) occurring from three point bending tests in different claws collected from sows from central Greece.

4. Discussion

Our results indicate that the claw specimen behaves as a linear viscoelastic material and is consistent with other studies [9, 18]. The strain rate influences the measured values of elastic modulus and with increasing strain rates a transition from ductile to brittle behavior can occur.

As noted above, the elastic modulus of samples with low moisture content (0 – 15 %) was found to be higher than the elastic modulus of samples with moisture content greater than 15 %. Claw horn lesion (CHL) was found to affect the mechanical strength of CLs in sows. Elastic modulus decreased with increasing lesion score. Measurements of hardness were found to be affected by the moisture content of the claws; the hardness decreases with increasing moisture content. These results are consistent with the work of [4, 9]. The lower hardness values could indicate that the claws are more prone to injuries due to compressive pressures [6]. An increase in moisture values results in a decrease in the elasticity of the sample and an increase in the plastic deformation zone of the specimens.

Finally, there is a negative correlation between claw hardness and the severity of CLs, indicating that low values of CLs were related to increased values of hardness and vice versa.

5. Conclusion

The Vicker's hardness and the elastic modulus of claws retrieved from housing sows were determined in association to moisture content. The hardness Hv ranged from 6.71 to 10.17 kg/mm² while the elastic modulus ranged from 0.44 to 1.7 GPa. Based on the mechanical and fracture analysis and the results extracted it can be observed that there is a good agreement of the experimental data in all tested samples.

The claw specimen behaves as a linear viscoelastic material. Experimental measurements show that sows' claws exhibit fluid-elastic behavior (exhibit elasticity, then show deformation before being fractured). At the same time, the appearance of macroscopic lesions on the claws is associated with the recording of different hardness values. The current study is the first reported hardness and elasticity in sow's claws and is related to a conventional diet. It could be a reference point for future studies where specific diets of organic complexes of trace minerals are supplemented in sow diet in order to improve strength and functional integrity of horn quality.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors have no conflicts of interest to declare.

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