Meat Science 177 (2021) 108496

Contents lists available at ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Claw disorders as iceberg indicators of cattle welfare: Evidence-based on production system, severity, and associations with final muscle pH☆

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ARTICLE INFO

Keywords:
Cattle welfare
Claw disorders
Post-mortem assessment
Iceberg indicators
Meat quality

ABSTRACT

This study presents a novel approach to use claw disorders in cattle as a retrospective welfare indicator characterized at the abattoir. A total of 1040 cattle (2080 front and back left claws) were analyzed from 143 batches, originating from feedlots, free-range, and dairy systems. Our results indicate that abnormal claw shapes (>55%) and fissures of the claw wall (>25%) had the highest prevalence, regardless of the system of origin. For the seven types of lesions monitored, numerous associations were found between lesions in the front and rear limbs typical of each production system. Ultimate meat pH was higher in animals with white line disease and skin wounds in feedlot and free-range cattle. We conclude that claw disorders can be used as an iceberg indicator to provide valuable information about animal fitness, and the ability to cope with the husbandry and pre-slaughter environment. These indicators can be used to improve the level of welfare of the animals.

1. I. Introduction

In general, beef consumed around the world originates from animals fattened on feedlots, farms or grazing systems, or, to a lesser degree, from dairy systems either from cull cows or steers (Valadez-Noriega et al., 2020). Beef cattle is mostly fattened under intensive production systems that are normally restrictive in terms of access to valuable resources such as living space, freedom of movement and interaction with natural substrates (Miranda-De La Lama et al., 2013). These restrictions provide economic advantages for farmers but have considerable negative impacts on animal welfare since they do not meet the behavioral and biomechanical needs of cattle, especially with regards to their claw health (Platz, Ahrens, Bahrs, Nüske, & Erhard, 2007). In contrast, grazing systems and their variations offer freedom of movement, although interaction with geographic and climatic conditions can also affect claws (Baird, O'Connell, McCoy, Keady, & Kilpatrick, 2009). Regardless of the type of production system, cattle require robust and resilient limbs, feet and claws that allow them to withstand the gradual increase in weight they gain in a relatively short period of time. In a healthy animal the musculoskeletal system must also provide optimal locomotion. This optimum implies "natural gait and activity" and "good condition of the locomotor apparatus" in the long term (Alsaaod et al., 2017).

Lameness is one of the most important unsolved problems in dairy cattle production all over the world (Alvergnas, Strabel, Rzewuska, & Sell-Kubiak, 2019), and is characterized by gait abnormalities and discomfort emerging from the presence of painful claw, foot or limb lesions (Alsaaod, Fadul, & Steiner, 2019). The cost of lameness includes direct expenditures in the form of treatment (i.e., outside labour, producer labour, and therapeutics), indirect losses (i.e. non-sellable milk, reduced milk production, reduced reproductive performance, plus reduced weight gain, increased risk of culling and death, increased risk of foot disorder recurrence, increased risk of other diseases), besides causing pain and suffering, which reduces animal welfare (Dolecheck,

☆ This study was funded by the Mexican National Council for Science and Technology-CONACYT – (Project number *Ciencia Básica* CB-2015-259,327) in which the principal investigator was Genaro C. Miranda-de la Lama, thanks to the funding source.

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https://doi.org/10.1016/j.meatsci.2021.108496
Received 26 October 2020; Received in revised form 27 February 2021; Accepted 10 March 2021
Available online 17 March 2021
0309-1740/

Dwyer, Overton, & Bewley, 2018). In this context, claw disorders are implicated in 90% of lameness in cattle (Murray et al., 1996). In the past few years, a large number of risk factors at the herd and cow level have been identified, including factors related to nutrition, hygiene, access to pasture, purchase of animals, cow comfort, trimming and footbath routines, genetics, age, social rank, and body condition (Moreira et al., 2019). Also, claw disorders have traditionally been classified according to their aetiology and pathogenesis into infectious or partly infectious lesions (i.e., sole disorders and heel erosion), mostly related to environmental hygiene, and horn lesions (i.e., fissures of the claw wall; double sole, and white line disease), and caused by metabolic (i.e. abnormal claw shape) or mechanical factors (Chapinal et al., 2013). Most of the studies on risk factors and the aetiologies of claw disorders come from dairy cattle, although recent scientific evidence highlights the importance of these illnesses in beef cattle (Chamorro et al., 2019).

Nowadays, there is an increased international trend to incorporate welfare indicators during meat inspection at abattoirs as a voluntary retrospective monitoring tool for cattle welfare and health (Harley, More, Boyle, O'Connell, & Hanlon, 2012). Likewise, a relatively new idea has been proposed known as "iceberg" indicators. In their 2009 report, the Farm Animal Welfare Council (FAWC) suggested using iceberg indicators in abattoirs as a means of assessing and ensuring overall animal welfare (Van Staaveren et al., 2017). These indicators can give valuable information on two relevant aspects of the life of production animals: 1) welfare problems during growth and development while fattening of animals at farm level; and 2) acute or traumatic conditions of recent occurrence that are associated with pre-slaughter operations such as transport, lairage and slaughter (Grandin, 2017). Currently, it is widely accepted that lameness and chronic or acute claw injuries produce pain and suffering that, under conditions of transport and pre-slaughter handling, can cause accentuated stress in animals (Losada-Espinosa, Villarroel, Maria, & Miranda-de la Lama, 2018). The effects of pre-slaughter stress on muscle glycogen depletion and the consequent dark cutting condition have been well documented (Ferguson & Warner, 2008). In this context, it is possible that the effect of the production system on claw health and its possible contribution to increasing the ultimate muscle pH, has been underestimated. Therefore, the aims of this study were 1) to monitor prevalence of claw disorders according to animal origin (feedlot, free-range and dairy systems) through post-mortem inspection at the abattoir level, 2) identify associations of the disorders studied between severities and also between rear and front claws according to animal origin, and 3) to determine which claw disorders are related to animal origin and the risk for high ultimate muscle pH.

2. Material and methods

The study was carried out in the state of Durango (north of Mexico) during 2018 in an abattoir managed by Durango Regional Cattle Union (UGRD) and certified by Federal Inspected Type (TIF), located in Malaga (24°09′37.8"N 104°30′19.3"W). This area is characterized by having a semi-arid climate with a mean annual rainfall of 500 mm and a mean annual temperature of 19 °C, at approximately 1885 m above sea level. The abattoir was chosen for four main reasons: 1) the homogeneity in the type of animals slaughtered (at least 90% of the animals slaughtered were *Bos taurus*), 2) for having an infrastructure and operational quality similar to international standards, 3) meets the requirements of Federal Inspection System or TIF according the Official Mexican Standards (NOM-008-ZOO-1994; NOM-009-ZOO-1994; NOM-033-ZOO-1995; NOM-194-SSA1–2004), 4) for its strategic geographical position processing animals from different cattle production systems. Thus, the animals in our study were classified into three large groups based on origin: feedlot, free-range and dairy cattle. Feedlot cattle came from farms concentrated in the valley and semiarid zone (northeast, centre and southeast of the state of Durango), confined in open pens with continuous fencing panels of pipe or steel cable. Usually, feedlots have dirt pens with a strip of concrete along the feed bunk lines, a structure to provide shade, and waterers. Free range cattle came from extensive systems based on native scrubs and grasslands of the mountain areas (eastern slopes of the Sierra Madre Occidental) and semi-arid areas of the central valleys of the state de Durango. These animals usually graze freely over large areas of land, but usually with ad libitum access to water and mineralized salt. Finally, the dairy cattle came from the *Comarca Lagunera*, a region located between two states (Durango and Coahuila), with the largest concentration of dairy animals in Mexico (~ 423,000 head or 20% of all dairy animals in the country). These animals came from intensive dairy systems (tie stall), in open pens, with concrete floors, shaded areas, with ad libitum access to water and concentrated feed, forages and/or silage (Figueroa-Viramontes, Delgado, Sánchez-Duarte, Ochoa-Martínez, & Núñez-Hernández, 2016). The permission to conduct the study was approved by the Institutional Subcommittee for the Care and Use of Experimental Animals of the Faculty of Veterinary Medicine of the National Autonomous University of Mexico (Protocol Number DC-2018/2–11).

2.1. Study description

This post-mortem evaluation was implemented as a cross-sectional study in order to assess claw health and cleanliness in cattle that entered the slaughter chain through routine planning. Data were collected from 1040 commercial cattle with a live weight of 510.35 ± 14.98 kg, of which 362 came from feedlots (Hereford, Charolais, Limousine and Angus commercial crossbreds), 414 from free-range systems (Wagyu or British and Continental crossbred animals with up to one half *Bos indicus* influence) and 264 from intensive dairy systems (Holstein breed). Being a regional abattoir, it receives animals from large suppliers and from small family farms, the latter of which vary widely in terms of feeding strategies, facilities and management. Therefore, only animals from the large regular suppliers (UGRD members) were sampled. For each animal we evaluated the left claws from the front and rear extremities (totalling 2080 limbs). Animals was assessed without interfering with abattoir schedules on 15–20 sampling days each month in April, May and June (total 60 days). Each sampling day lasted from 09:00 h until 14:00 h with the goal of inspecting 2–5 batches per day. A batch was considered a group of cattle of the same origin coming from the same farm and belonging to the same slaughter group (same loading, transportation, unloading). Information on each shipment was obtained from the Veterinary Office of SENASICA at the abattoir (Mexican animal health authority), including the number assigned to each animal, animal origin (farm), commercial category, sex, transport and pre-slaughter conditions (including journey time) and type of livestock vehicle. With this information, a database was created that enabled us to identify and locate each animal in lairage, at the stunning box and in the cold chamber. It is important to note that the methodology used allowed to identify and locate the data of each individual animal from the farm to the refrigeration chamber, in order to analyse any predisposing factors for foot/claw injuries and/or quality defects in the meat.

2.2. Abattoir: operative conditions and facilities

The abattoir operated from Monday to Friday (0830–1500 h) with a slaughter capacity of 9000 heads/month. The concrete unloading ramps (19°) had nonslip floors that were as wide as the livestock trailers (6 m wide). They were connected through a metallic curved race (3 m wide) to a lairage area that consisted of 24 pens (6.5 m wide x 7 m long; 45.5 m^2) with suspended canopies roofing (white-painted galvanized) and galvanized sheet (16 and 8 pens, respectively), all with nonslip concrete floors. In the plant there was not mixing of animals from different livestock trucks, and each group of animals was housed in separate pens. During lairage, the animals had access to water ad-libitum while resting, no food was provided unless the owner requested it and only when the plant kept cattle in lairage overnight.

A metallic passageway led from the lairage area to three parallel single file races with a single file race in the last 10 m before the stun box. The floors were slatted concrete, with metal bars between the driving races. A stockperson drove the animals manually into the stun box using his body, hands, and various tools (mainly an electric goad) when required. The plant had a hydraulic vertically sliding tailgate at the entrance of the box. The stunning box (2 m long x 1.80 m high) had an automatic head fixation system, and its surface was made of stainless steel without a non-skid floor. One of the sides of the stun box had a guillotine door to make the animal fallout from the side of the box after stunning (for the same reason, the floor had a slight slope). The slaughter plant used a standard penetrating captive bolt gun pneumatically powered (model STUN-BP1, FREUND®, Paderborn, Germany), but when this did not work, stock-people used a one-handed pistol with a free bullet. During observations, the stockpersons always worked the animals from outside the race or box. Normally, only one person worked each animal in the stunning box. After being stunned, the cattle were suspended by a hind leg, bled out, and transferred to the production line to begin the process of removing the head, feet, skin, viscera, and the quartering of the carcass.

2.3. Claw assessment

An assessment protocol was developed to register the feet conditions of cattle after slaughter at the abattoir based on an exhaustive literature review and preliminary observations of the research team. According to the schematic division of the ICAR Claw Health Atlas (Egger-Danner et al., 2014), four assessment areas (wall, heel, sole and white line) were chosen, including one corresponding to the metacarpals and metatarsals for the evaluation of the integrity of the skin. The severity of the lesions was determined by their surface area (Table 1), as in the protocol developed by Greenough, Weaver, Broom, Esslemont, and Galindo (1997), in addition to the most prevalent injuries in dairy (Solano et al., 2016) and beef cattle (Magrin et al., 2018). We also integrated two cleaning measures for the limb and claw. The protocol was validated using 70 animals (those data were not used for subsequent statistical analyses). Given the practical problems of sampling four limbs for each animal due to the speed of the slaughter line and the order of amputation for each limb (a. front left, b. front right, c. rear left and d. rear right), it was decided to only sample the limbs from the left flank of each animal, which are the first and third to be severed. This made it possible to maintain the traceability of each limb and compare fore and hind limbs, since, based on a review of the scientific literature available for dairy and beef cattle, there can be important differences in the prevalence and severity of injuries between these limbs (Fjeldaas, Nafstad, Fredriksen, Ringdal, & Sogstad, 2007; Sogstad, Fjeldaas, Østerås, & Forshell, 2005).

Table 1
Classification criteria for assigning the degree of severity of cattle claw disorders during inspection at the abattoir level.

Claw disorders	Severity		
	No injury	Mild injury	Severe injury
Abnormal claw shapes (ACS)	0	Asymmetries or overgrowths less than or equal to 2 cm	Asymmetries or overgrowths are greater than 2 cm
Fissures of the claw wall (FCW)	0	Fissure length is less than or equal to 5 cm	Fissure length is greater than 5 cm
Skin wounds (SW)	0	Injury surface is less than or equal to 5 cm	Injury surface is greater than 5 cm
Sole disorders (SD)	0	The sole disorder surface is less than or equal to 5 cm	The sole disorder surface is greater than 5 cm
Heel erosion (HE)	0	The eroded surface is less than or equal to 5 cm	The eroded surface is greater than 5 cm
White line disease (WLD)	0	Injury surface is less than or equal to 5 cm	Injury surface is greater than 5 cm
Double sole (DS)	Present/absent		

The assessment protocol was applied in two stages, in the first stage each limb was measured in terms of general cleaning -GC- (clean or dirty) and interdigital cleaning -IC- (clean or dirty). After brushing and washing the limb, the second stage of the protocol (Fig. 1) began and included all abnormal claw shapes -ACS- (where 1 meant no abnormality, 2 mild abnormality, 3 serious abnormality), fissures of the claw wall -FCW- (where 1 meant no injury, 2 non-severe injury and 3 severe injury), skin wounds -SW- (where 1 was no injury, 2 non-severe injury, 3 severe injury), sole disorders -SD- (where 1 was no injury, 2 non-severe injury and 3 severe injury), heel erosion -HE- (where 1 was no injury, 2 non-severe injury and 3 severe injury), white line disease -WLD- (where 1 was no injury, 2 non-severe injury, 3 severe injury), and double sole -DS- (without or with). All lesions were identified, classified and scored by the same observer and in the same order.

Upon arrival of the animals to the abattoir, the official veterinarian designated a number for each animal. The personnel marked the bovine's back with a number, which was used to identify it in the stunning box. Once stunned, the animal was hoisted and bled; the time between stunning and bleeding was approximately 40 s. At 15 s immediately after starting the bleeding, the operating personnel removed the front left limb from the tarsal-metatarsal joint, then did the same with the rear left limb. One assistant collected the anatomical part between hock and claw of the left front and rear limbs from the animals, maintaining individual recognition and progressive order. In a room adjacent to the stunning box, the limbs of each animal were evaluated. Each leg was evaluated in terms of general and interdigital cleaning and later the limb was submerged in water and the organic matter was removed with a brush to be able to observe it. Subsequently, the claw was supported on a straight surface for inspection through the following steps: 1) verification of conformation (asymmetry or corkscrew claws, heel height, wall length, interdigital opening and presence of growth defects); 2) integrity of the skin in metatarsals and metacarpals (skin wounds above the coronary band); 3) inspection of the wall; 4) inspection of the sole; and 5) inspection of the heel and WLD.

2.4. pH measurements

To determine carcass pH 24 h post-mortem (pH^{ult}) of the *M. longissimus*, we used a digital pH meter with a penetration probe (Hanna Instruments, H199163, Woonsocket, Rhode Island, USA), which was inserted into a small incision in the left side of the carcass (12/13th rib interface). The pH meter was re-calibrated at the same temperature of the cold chamber (4 °C) after every five samples, using two standard buffer solutions at pH 7.0 and 4.0. The pH was measured as the average of readings taken at two sites. Carcasses showing pH 24 values greater than 6.0 were classified as dark cutting.

2.5. Statistical analysis

All statistical analyses were carried out using SPSS statistical package, version 22.0 (SPSS Inc., Chicago, IL, USA). Contingency tables were used to identify and describe associations between the variables included in the study and significance level was established at $P < 0.05$. Prevalence of the studied claw disorders were expressed as percentages, and the McNemar's χ^2 test was calculated to assess whether such prevalence differed between front and rear feet, both for all the animals studied and within each production system (feedlot, free range and dairy). In order to assess the association between the level of severity of each claw disorder (absent, non-severe and severe for CD, FCW, SL, SD, HE and WLD, or absent/present for DS) in front and rear feet and between different lesions in the same feet, Somers' D was calculated (Somers, 1962). The values of this ordinal–ordinal comparative test range from −1 to 1 with a value of 1 indicating a strong positive relationship, −1 a strong negative relationship and 0 no relationship.

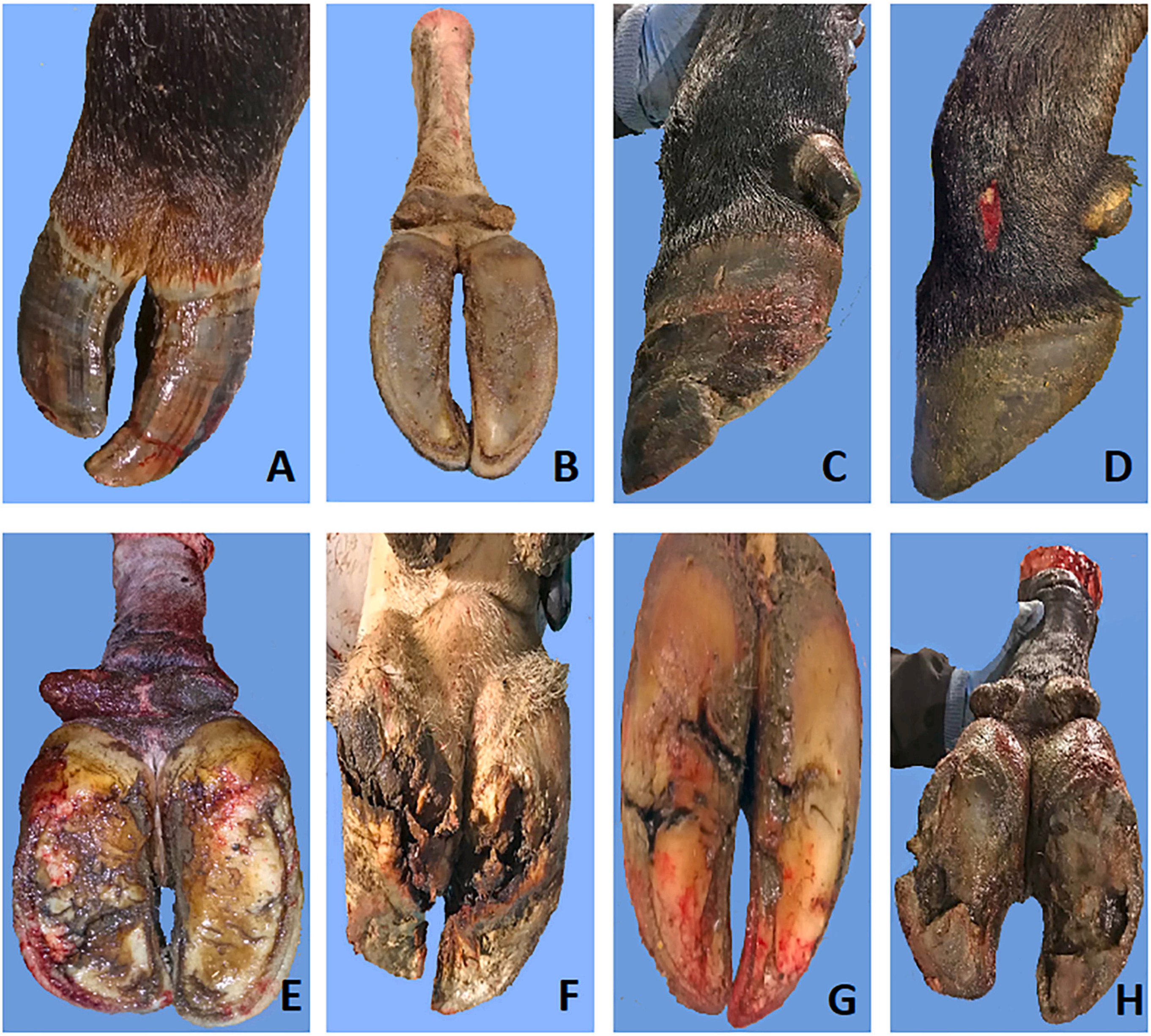

Fig. 1. Claw disorders evaluated in the study: Abnormal claw shapes -ACS- as asymmetric claws (A), and corkscrew claws (B); Fissures of the claw wall -FCW- (C); Skin wounds -SW- (D); Sole disorders -SD- (E); Heel erosion -HE- (F); White line disease -WLD- (G); Double sole -DS- (H).

Results were considered significant when Somers' D > 0.2 and $P < 0.05$. A multivariable logistic regression analysis was performed to identify claw disorders that represent risk factors for $pH_{24} \geq 6.0$ for each production system. The pH_{24} values were analyzed as a binomial response variable with values of $pH_{24} < 6.0$ and $pH_{24} \geq 6.0$. All claw disorders were included as predictor variables, considering the three levels of severity in front and in rear feet (absent/non-severe/severe and absent/present for double sole). Univariable logistic analyses were first performed for each independent variable with respect to the pH_{24}. The resulting significant variables, the claw disorders related to them according to the Somers D 'test, and the interactions between them were considered for the multivariable logistic analysis. Stepwise forward method was used to include significant variables, and the goodness of fit of the final model was tested using the Hosmer-Lemeshow statistic test.

3. Results

Overall, 34.8% of the cattle studied came from feedlots, 39.8% from free-range systems and 25.4% from dairy systems. Table 2 shows a detailed distribution of the animals according to their production system of origin, as well as sex, commercial category, journey distance, and vehicle type.

3.1. Prevalence of claw disorders

The prevalence of claw disorders in animals from feedlot, free range, and intensive dairy systems and their distribution in front and rear feet are presented in Table 3. Feedlot cattle showed a marked prevalence of ACS (61%), FCW (26%) and SD (17%) lesions. They were also found to have a significantly higher prevalence of ACS ($P < 0.01$) in the front claw (74%) compared to the hind claw (47%). However, for FCW and SW injuries the prevalence was higher in the hind claw ($P < 0.05$; 30% and 19%, respectively). The other four types of disorders evaluated were not significantly different between front and hind feet ($P \geq 0.05$). For animals from free range systems, the prevalence of claw disorders was mainly concentrated in ACS (55%), FCW (20%) and SW (17%).

Table 2
Distribution of the animals included in the current study ($n = 1040$).

Animals	Feedlot n = 362 (%)	Free-range n = 414 (%)	Dairy n = 264 (%)	Total n = 1040 (%)
Sex				
Male	310 (85.6)	193 (46.6)	40 (15.2)	543 (52.2)
Female	52 (14.4)	221 (53.4)	224 (84.8)	497 (47.8)
Commercial category				
Heifers	12 (3.3)	6 (1.4)	8 (3)	26 (2.5)
Cows	40 (11)	215 (51.9)	216 (81.8)	471 (45.3)
Young bulls	129 (35.6)	11 (2.7)	20 (7.6)	160 (15.4)
Bulls	181 (50)	182 (44)	20 (7.6)	383 (36.8)
Journey distance				
1–50 km	84 (23.2)	275 (66.4)	15 (5.7)	374 (36)
51–100 km	51 (14.1)	70 (16.9)	4 (1.5)	125 (12)
101–150 km	47 (13)	45 (10.9)	243 (92)	335 (32.2)
151–200 km	19 (5.2)	12 (2.9)	1 (0.4)	32 (3.1)
>200 km	161 (44.5)	12 (2.9)	1 (0.4)	174 (16.7)
Vehicle types				
Small trailers	61 (16.9)	369 (89.1)	40 (15.2)	470 (45.2)
Gooseneck trailer	94 (26)	40 (9.7)	121 (45.8)	255 (24.5)
Pot-belly trailer	207 (57.2)	5 (1.2)	103 (39)	315 (30.3)

Table 3
Prevalence of claw disorders according to production system (feedlot, free range and intensive dairy) and their distribution in front and rear limbs.

Variables	Cattle affected %	Feet: Front %	Feet: Rear %	P-value
Feedlot cattle (n = 362)				
Hygienic conditions				
Dirty feet	10.50	4.70	6.91	NS
Interdigital dirt	21.55	14.36	9.95	NS
Claw disorder				
Abnormal claw shape	60.90	74.30	47.50	<0.01
Fissures in claw wall	26.70	22.70	30.70	<0.05
Sole disorders	17.50	19.10	16.00	NS
Skin wounds	16.30	13.50	19.10	<0.05
Heel erosion	16.20	18.00	14.40	NS
White line disease	7.00	6.90	7.20	NS
Double sole	3.00	4.10	1.90	NS
Free range cattle (n = 414)				
Hygienic conditions				
Dirty feet	10.14	6.04	7.73	NS
Interdigital dirt	23.43	13.04	14.98	NS
Claw disorder				
Abnormal claw shape	55.10	64.70	45.40	<0.01
Fissures of the claw wall	20.40	16.20	24.60	<0.01
Skin wounds	17.10	15.70	18.60	NS
Sole disorders	12.20	12.10	12.30	NS
Heel erosion	10.90	10.90	10.90	NS
White line disease	5.40	5.60	5.30	NS
Double sole	1.30	1.40	1.20	NS
Dairy cattle (n = 264)				
Hygienic conditions				
Dirty feet	9.85	2.65	8.71	<0.01
Interdigital dirt	12.50	6.82	7.95	NS
Claw disorder				
Abnormal claw shape	55.50	69.30	41.70	<0.01
Fissures of the claw wall	26.10	23.50	28.80	NS
Sole disorders	19.30	18.60	20.10	NS
Skin wounds	16.50	12.90	20.10	<0.05
Heel erosion	15.00	14.80	15.20	NS
White line disease	6.30	6.80	5.70	NS
Double sole	1.30	1.10	1.50	NS

P-values correspond to McNemar χ^2 test. $P < 0.05$ denotes statistically significant differences. NS: No significant differences.

Regarding the prevalence of disorders between front and hind feet, significant differences were only found for ACS and FCW ($P < 0.01$). Where claw deformities were more prevalent in the front feet than the rear (64% vs 45%), FCW was more prevalent in the rear feet (16% vs 24%). Finally, animals from dairy systems showed a marked prevalence of ACS (55%), FWC (26%) and SD (19%) lesions. However, only ACS and SW injuries were significantly different ($P < 0.01$) between front and rear feet, where ACS had a higher prevalence in front feet than in rear (69% vs. 41%), while SW injuries had a higher prevalence in rear feet (13% vs. 20%).

3.2. Associations between front and rear claw conditions or disorders

Table 4 shows the degree of association between the variables of severity in the front claw and severity in the rear claw, determined individually in all animals and segmented by production system. The Somers' D value for ACS indicated a statistically significant association between the severity of the lesions of the front and rear claw both for all animals ($P < 0.001$) and in the three production systems ($P < 0.001$). The FCW lesion only presented a statistically significant association in dairy animals ($P < 0.001$). For heel erosion (HE), statistically significant D values were also observed in the three production systems ($P < 0.001$). The SD was significant only in feedlot and dairy cattle ($P < 0.001$). No significant associations were found for SW, WLD and DS disorders.

3.3. Associations between different types of claw conditions or disorders

In general, the associations established by Somers' D test, between claw conditions or disorders were related to the origin of the animals and due to differences between front and rear limbs (Table 5). This phenomenon was especially evident in animals from feedlots, where five significant associations ($P < 0.05$) found for the forelimbs (ACS-FCW; ACS-SD; SD-HE; SD-WLD; IC-GC) and five more in the hind limbs (ACS-FCW; WLD-ACS; WLD-HE; SD-HE; SD-WLD). Free-range animals showed six significant associations ($P < 0.05$) in the forelimb (WLD-FCW; SD-HE; SD-WLD; GC-WLD; IC-WLD; IC-SD) and only one in the rear limb (IC-GC). Finally, in dairy animals, three significant associations ($P < 0.05$) were found for the forelimbs (ACS-FCW; SD-ACS; SD-HE) and another three for the hind limbs (WLD-HE; SD-HE; IC- GC).

3.4. Claw disorders and high muscle pH

Recording of pH_{24} showed that 24.2% of the carcasses were found to have a ≥ 6.0, and no significant differences were found between different production systems (feedlot 24.0%, free range 21.0%, and dairy = 27.7%). Significant predictors for $pH_{24} > 6.0$, using univariable logistic regression for feedlot cattle, were SD and WLD in rear feet and SW in front feet. In all cases, severe disorders were associated with significantly greater odds of having $pH_{24} > 6.0$ relative to the absence of the disorder (severe SD in rear feet: OR = 3.47, 95% IC = 1.83–8.69, $P < 0.01$; severe WLD in rear feet: OR = 8.55, 95% IC =1.63–45.0, $P < 0.05$;

Table 4
Associations (Somers' D) between the level of severity of claw disorders in front and rear feet (n = 1040).

Variables	Total	Dairy	Feedlot	Free-range
Hygienic conditions				
Dirty feet	0.319***	–	–	0.493***
Interdigital dirt	–	0.253*	–	0.219**
Claw disorders				
Abnormal claw shape	0.338***	0.402***	0.306***	0.324***
Heel erosion	0.367***	0.428***	0.404***	0.262***
Sole disorders	0.341***	0.494***	0.327***	–
Fissures of the claw wall	–	0.233***	–	–

Statistically significant results when Somers' D > 0.2 and * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$).

Table 5
Associations (Somers' D) between different types of claw conditions or disorders in front and rear feet (n = 1040).

	Front							*Rear*						
	FCW	*ACS*	*HE*	*WLD*	*SD*	*GC*	*IC*	*FCW*	*ACS*	*HE*	*WLD*	*SD*	*GC*	*IC*
Feedlot														
FCW														
ACS	0.212***							0.279***						
HE	–	–						–	–					
WLD	–	–	–					–	0.226***	0.223**				
SD	–	0.211***	0.337***	0.238**				–	–	0.338***	0.280**			
GC	–	–	–	–	–			–	–	–	–	–		
IC	–	–	–	–	–	0.282**		–	–	–	–	–	–	
Free-range														
FCW														
ACS	–							–						
HE	–	–						–	–					
WLD	0.268**	–	–					–	–	–				
SD	–	–	0.227**	0.280**				–	–	–	–			
GC	–	–	–	0.209*	–			–	–	–	–	–		
IC	–	–	–	0.209*	0.220**	–		–	–	–	–	–	0.297***	
Dairy														
FCW														
ACS	0.243***							–						
HE	–	–						–	–					
WLD	–	–	–					–	–	0.202*				
SD	–	0.237***	0.440***	–				–	–	0.320***	–			
GC	–	–	–	–	–			–	–	–	–	–		
IC	–	–	–	–	–	–		–	–	–	–	–	0.356***	

Statistically significant results when Somers' D > 0.2 and * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.00$.

severe SW in front feet: OR = 2.86, 95% IC = 1.12–7.29, P < 0.05). For free range cattle, the only variable associated with pH >6.0 was SW in the front limb, where severe lesions were associated with significantly greater odds of high pH relative to the absence of the lesion (OR = 3.307, IC 95% = 1.44–7.61, P < 0.01). No significant associations were found between claw disorders and high pH in carcasses from dairy cattle. The results of multivariable regression model (Table 6) indicated that pH was affected significantly (P < 0.05) by WLD in front feet and SW in rear feet in feedlot cattle, where carcasses from animals with severe lesions had a greater risk of a pH > 6.0 compared with those without those lesions (severe WLD: OR = 7.62, P < 0.05; severe SL: OR = 2.758, P < 0.05). In free range cattle, severe SW in front feet was the only disorder that significantly increased the prevalence of pH > 6.0 (OR = 3.31, P < 0.01) compared with the absence of the lesion. In general, no effect of non-severe lesions on the pH (<6.0 or ≥ 6.0) was observed.

Table 6
Multivariable logistic regression analysis of claw disorders for the prevalence of pH ≥ 6.0 (n = 1040) in feedlot and free-range systems.

Variables	Categories	SE	OR	CI 95%	*P*
Feedlot					
SW in front limb	Absent				<0.05
	Non-severe	0.624	0.374	0.11–1.27	NS
	Severe	0.487	2.758	1.06–7.16	<0.05
WLD in rear claw	Absent				<0.05
	Non-severe	0.516	1.551	0.56–4.26	NS
	Severe	0.855	7.620	1.43–40.69	<0.05
Constant		0.140	0.292		<0.001
Free range					
SW in front limb	Absent				<0.05
	Non-severe	0.402	1.222	0.56–2.69	NS
	Severe	0.425	3.307	1.44–7.61	<0.01
Constant		0.136	0.238		<0.001

OR = odds ratios; SE = Standard error; CI = confidence intervals; Ref: variable considered as reference. Significance level at $P < 0.05$.

4. Discussion

Recurrently, animal welfare is a term used to express ethical concerns about the quality of life experienced by animals, particularly animals that are used by human beings in food production (Hansen & Østerås, 2019). However, from a scientific point of view this term refers to the ability of an individual to cope with any challenges generated by its environment (Broom, 2014). In this context, foot disorders are a source of discomfort, pain, fear, anxiety, and frustration that clearly produces accentuated stress and can affect individual biological fitness to cope with the productive environment. Thus, foot health and integrity should be an operational and ethical priority to improve cattle welfare in beef production. Although there is some previous work on the prevalence and risk factors associated with claw disorders in beef cattle, these studies are based on cattle from feedlots only (i.e. Magrin et al., 2018; Magrin et al., 2020). From a clinical point of view, sampling only two limbs per animal (front and rear left) could be seen as a limitation of our study, but in terms of an approach to assessing animal welfare indirectly, this methodology showed a good cost-benefit relationship, since it allowed sampling a large number of animals under commercial conditions and provided valuable information on how animals adapt (or not) to their productive environment. Our study is the first to analyse the influence of origin of the animals (feedlots, free-range and dairy) on prevalence and severity of claw disorders, as well as its effect on the final pH of beef. Finally, our study proposes the possibility of considering claw lesions as iceberg indicators of animal welfare in monitoring schemes at the abattoir-level.

4.1. Prevalence of claw disorders

In general, our results show a high prevalence of claw disorders in the cattle population studied, providing important information about aspects that affect the welfare of the animals throughout their lives, since each production system had different effects on claw health. Claw alterations are a multifactorial condition, and their prevalence can vary between regions, in addition to being highly influenced by production systems (Solano et al., 2016). The productive environment around the animals is a determining factor in the balance of the epidemiological triad. Factors such as type of housing, animal management and handling, feeding strategies, grades of physical restriction, type of floor and season predispose the appearance of lameness and claw disorders (Cook, 2003). Nonetheless, prevention methods such as additional claw trimming, proper feeding, floor hygiene, footbath, lying surface, rubber flooring, and stocking density could help reduce and keep the prevalence of claw disorders to a minimum (Bruijnis, Hogeveen, & Stassen, 2013). Our results suggest a marked effect of the production system of origin. For example, cattle from the feedlots showed a marked general prevalence of ACS, FCW and SD, although the former were present in 60% of the animals, while the remaining two disorders were present in 26% and 17% respectively. That group also had a significantly higher prevalence of ACS (74%) in the front claw, compared to hind claw (47%). However, for FCW and SW injuries the prevalence was higher in the hind claw. A possible explanation for these results may be due to diets high in carbohydrates that are used in the completion of fattening animals, and that are associated with laminitis, which can cause fissures in the wall and also injuries to the sole (Greenough, 2001).

Regarding the animals from free-range systems, we observed a distribution pattern similar to that observed in the other two systems assessed. However, proportionally the values in these animals were lower in all disorders, which is consistent with numerous studies in Latin America that have reported low percentages of claw alterations when cattle are produced in similar production systems (Tadich, Hettich, & Van Schaik, 2005; Tomasella et al., 2014). The prevalence of claw disorders was mainly concentrated in ACS (55%), followed by FCW (20%) and SW (17%). The high prevalence of ACS disorders underlines an important problem for this type of animals, possibly because they are reared and fattened extensively in difficult climatic and geographical conditions that make it difficult to establish routine claw inspections and trimming (Álvarez, Martínez, & Cardona, 2017). Finally, animals from intensive dairy systems showed a marked prevalence of ACS (55%), FWC (26%) and SD (19%) disorders. However, ACS had a higher prevalence in the front claw rather than the rear. The ACS prevalence in our study was high, although it is not usually mentioned in articles on dairy systems. That may be because the literature reports the prevalence of dairy production units where claw trimming is routine, which corrects and prevents conformation defects (Alvergnas et al., 2019), while in our study the post-mortem findings indicate that being at the end of their productive life and being discard animals, farmers often omit preventive claw care. The scarce attention given to the suffering of cull-cows in many Latin American countries puts them at high risk for poor welfare (Sánchez-Hidalgo, Rosenfeld, & Gallo, 2019). Although the farmer is usually thought to be the most interested in the health of his animals, especially when they are more productive, there is also evidence for a progressive loss of empathy towards sick and old animals because they involve economic and time losses (Losada-Espinosa, Miranda-De la Lama, & Estévez-Moreno, 2020). The type of care omission found in our study (whether deliberate or not) highlights the need to implement awareness and training programs for stockpeople.

4.2. Associations between front and rear claw severe conditions or disorders

Our study shows that the positive association between front and rear limb dirtiness was only significant for free-range animals. These animals come from woodlands grasslands and shrubland ecosystems where they are exposed to harsh environmental conditions and long periods of walking, which would explain why both limbs were dirty. During the cold season in semiarid environments, free-range cattle are exposed to cold, rainy, and windy conditions (Valadez-Noriega et al., 2020). This may cause dirtiness because of the formation and accumulation of mud on limbs, including the interdigital space. In the case of dairy animals, only a significant association was found for the CI variable, but not for CG. That may be since even when the extremities are clean, certain conditions can increase the amount of dirt in the interdigital space. It is possible that prolonged exposure to wet floors, slurry, poor quality or deteriorated floors, uncomfortable bedding and little physical exercise might alter the skin permeability and increase the risk of interdigital infection in animals from intensive dairy systems (Loberg, Telezhenko, Bergsten, & Lidfors, 2004; Palmer, Donnelly, Garland, Majithiya, & O'Connell, 2013). Frequent change and supplementation of litter might have a direct preventive effect on interdigital dirtiness and specially in infectious claw lesions (Fjeldaas et al., 2007).

Normally, it is assumed that most claw disorders tend to occur in the front and rear extremities (Alvergnas et al., 2019). However, Chapinal et al. (2013) found a genetic correlation of 0.55 between "any claw lesion" in front limbs and "any claw lesion" in rear limbs. This suggests that claw disorders in front and rear limbs are not exactly the same genetically, because there is a strong environmental influence that determines possible claw injuries in animals. In our study, the Somers' D test demonstrated a strong relationship for this effect (regardless of production system) only for ACS and HE disorders. The interaction between possible genetic and environmental effects could explain this high association for these two claw disorders. The bilaterality of ACS in hind limbs has been widely documented (Van Amstel, 2017), although some studies suggest certain correlations between these disorders in the right and left hind and front claws (Manske, Hultgren, & Bergsten, 2002). Our study shows that this claw disorder affects both claws (front and rear), even if they are on the same flank, regardless of the production system of origin. Heel erosion has also been reported as bilateral, and according to our results there is a high association of its presence in both hind and forelimbs in all animals. However, this association was significant but lower in free-range animals. The high prevalence of HE has been related to free-range systems, but also in complete housing systems with poor hygiene (Magrin et al., 2020). Although there is evidence that a cold-humid climate contributes to the appearance of this claw disorder (Correa-Valencia, Castaño-Aguilar, Shearer, Arango-Sabogal, & Fecteau, 2019), both conditions were present in the agroecosystems of our study. Heel erosion likely shares the same causal factors as digital and interdigital dermatitis, and an association between these diseases has been reported (Chapinal, Baird, Machado, Von Keyserlingk, & Weary, 2010).

In our study of disorders affecting the sole, only SD had an association between the presence of this lesion in the front and hind legs for feedlot and dairy animals, but not for free-range animals. These findings imply that these types of claw disorders are related to intensive cattle production systems, especially to the ingestion of high quantities of readily fermentable starchy cereals, which has secondary consequences of subacute or acute ruminal acidosis (Stokka et al., 2001). The FCW lesions were similar in fore and hind limbs only for dairy animals. This result may be related to ruminal acidosis, which is a recurrent problem in intensive dairy systems and exacerbated by prolonged locomotion on hard concrete floors (Van der Tol et al., 2003) or due to insufficient space allowance (Wechsler, 2011). Meanwhile, for WLD and DS, no association was observed between front and rear extremities. These types of disorders are characterized by being bilateral, therefore if they affect the left limb, they will also affect the right one (Magrin et al., 2020). Our protocol assessed the presence of front and rear claw disorders, indicating that that there was no association between the occurrence of WLD and DS claw lesions between front and rear left claws. Finally, there was no significant association between fore and hind limbs for SW. Skin wounds of the tarsal or carpal regions are acute lesions and quite common during pre-slaughter operations. They might have been produced by collisions, falls, rubbing, kicks and even entrapments in holes (installations, loading / unloading ramps, truck), wires or ropes (Agina & Ihedioha, 2017). Our results suggest that these wounds are random and do not always involve all the limbs. Overall, the data show how these wounds can be used as welfare indicators related with management problems and deficiencies in the maintenance of the facilities and/or livestock vehicles.

4.3. Associations between different types of claw conditions or disorders

Claw disorders are considered a multifactorial disease and seem to be closely associated with nutritional and metabolic disturbances and infectious diseases. Prevention is geared towards a combination of good animal husbandry, appropriate diet formulation, and especially claw trimming and care (Stokka et al., 2001). Claw trimming is quite feasible in dairy systems where animals are handled individually on a daily basis (Fjeldaas et al., 2007), while it is less feasible in practice on feedlots and free-range systems. Our results indicate a series of associations between severe disorders or conditions clearly related to the origin of the animals according to their production system. Cattle from feedlots showed significantly more associations than animals from the other two systems. A possible explanation could be related to their rapid increase in body weight which places pressure on the base of the developing claws. This asymmetry combined with low physical activity can affect claw health and may be an overlooked source of claw pathologies (Pauler, Isselstein, Berard, Braunbeck, & Schneider, 2020). We identify four patterns of associations; each one related to a disorder or condition and its association with other conditions: 1) SD, 2) WLD, 3) ACS, and 4) IC. The most common association for the three systems was SD-HE, although it was present in both limbs for feedlot and dairy animals (in free-range animals it was only significant for the forelimbs). Several studies in dairy cows have found similar associations, more commonly in housed systems and less frequently in free-range (Enevoldsen, Gröhn, & Thysen, 1991), where both injuries are associated with claw contact with manure slurry and abrasive floors (Chapinal et al., 2010).

The second most frequent association was that of WLD with different disorders in the three production systems evaluated. Although in the case of feedlot and dairy animals this association was only related with hind limbs, for free-range cattle is was only associated with the front limbs. Associations of WDL in the hind claws have been widely described in stabled and grazing dairy cows and are mainly due to the tendency for overgrowth and the effect of gait and bearing the weight of a large udder (Baird et al., 2009). WLD was associated with feedlot animals with ACS, HE and SD, secondary associations as a result of subacute or acute ruminal acidosis conditions (Magrin et al., 2020). However, in free-range animals these associations occurred in the front claws, which may be due to the compact soils and extreme climatic conditions of the region and the frequent lack of general and interdigital hygiene of the claws in these animals. Cattle abrade the soles and apical region of the white line of their hooves on hard coarse surfaces, such as compact soils (Shearer & Van Amstel, 2017). This abrasion compromises the integrity of the white line, leading to its separation and the subsequent colonization of the claw tissues with bacteria that cause associations with other claw disorders (Johnston, Eichhorn, Kontulainen, Noble, & Jelinski, 2019).

The third most frequent association found in our study was between ACS with SD and FCW. However, it was only observed in feedlot animals (both limbs) and dairy animals (only forelimbs). These abnormalities in the silhouette of the claw have been related with intensive systems due to genetic predisposition and especially with chronic laminitis (Alvergnas et al., 2019). The relative size and shape of the claw horn capsule is determined by the rate of horn growth versus wear. When the rate of horn growth exceeds the rate of wear, claws become overgrown, and weight bearing within and between the claws is adversely affected. This disparity in weight load is normally greatest for the lateral claw of rear feet and the medial claw of front feet, whereby pressure is concentrated on the sole and the wall of the claws (Shearer, Plummer, & Schleining, 2015). Finally, the association between dirty limbs and interdigital dirt was significant for the forelimbs of feedlot animals and the hind limbs for dairy cows and free-range animals. In dairy cows, dirt on floors and cubicles has been described as a predisposing factor for claw disorders (Ariza, Levallois, Bareille, Arnoult, & Guatteo, 2020), although the relationship between dirty feet and other disorders is not yet very clear (Sadiq, Ramanoon, Mossadeq, Mansor, & Syed-Hussain, 2020). However, this association was found in free-range animals, where IC was associated with SD and WLD in forelimbs. This result is important because it is usually assumed that grazing in beef cattle is practically a guarantee for good claw health (Armbrecht, Lambertz, Albers, & Gauly, 2018).

4.4. Claw disorders and the risk associated with high muscle pH

In beef, one of the most common meat quality problems is dark cutting beef. This condition is generally unacceptable for consumers because it is visually unappealing and its pH 24 $\geq$ 6.0 reduces shelf-life, causing significant losses for the meat industry in many countries (Jerez-Timaure et al., 2019). Dark cutting beef are generally linked to a low muscle glycogen content at slaughter caused by elevated glycogenolysis induced by on-farm nutrition, stress and exercise in the pre-slaughter period (Fuente-Garcia, Sentandreu, Aldai, Oliván, & Sentandreu, 2020). Our results show an incidence of 24% dark cutting, an intermediate value within the ranges between 8 and 48% reported and compiled in Mexico by Loredo-Osti et al. (2019). Moreover, we also found that production system origin and pre-slaughter conditions both had an important influence on the probability that certain claw injuries may be related to dark cutting. Although lameness has been reported as an important cause of culling dairy cows (Dahl-Pedersen, Foldager, Herskin, Houe, & Thomsen, 2018), surprisingly, our results indicate that in dairy animals sent to the abattoir, claw disorders did not increase the probability of high muscle pH. This effect may be due to animal age, as cull dairy cows are usually older than feedlot and free-ranging cattle, and their temperament might be calmer, leading to less effects on beef quality (Estévez-Moreno et al., 2021).

From our results, feedlot and free-range cattle with SW in the forelimbs showed a high probability of developing high pH. Excitable temperament has been reported among *Bos taurus* beef breeds, particularly in young animals on feedlots and cattle reared in extensive systems (Cooke, Bohnert, Cappellozza, Mueller, & Delcurto, 2012). Therefore, it is possible that our results are due to a complex interaction between the origin of the animals, temperament, genotype, reactivity to novel environments and handling that may increase the probability that animals suffer limb injuries, especially the front ones. This is because these legs are the first to come into contact with any new surroundings during handling and displacement during transport and at the abattoir. Acute skin wounds are painful lesions that may cause reactivity, restlessness, suffering, stress and may contribute to the condition of non-ambulatory animals (Miranda-de la Lama et al., 2020), and, based on our results, can also affect muscle pH_{24}.

Finally, the high probability found between the WLD lesion and high pH in hind legs in feedlot animals, may be due to the chronic pain caused by toe-tip necrosis, which is a common side effect of WLD and exacerbated by the pre-slaughter operations. The origin of WLD in fattening animals is related to the abrasion theory of Johnston et al. (2019), where presumably a hyperexcitable temperament, overcrowding or overly aggressive handling results in cattle forcing themselves against the animals ahead of them in alleyways and chute systems. As the force exerted by those cattle increases, they lose traction, especially in the hind limbs that are being used for propulsion, and this loss of traction results in abrasion of the solar horn and white line on the flooring. Paradoxically, to improve cattle footing and traction, the flooring of feedlot handling systems frequently consists of stamped or etched concrete or has metal cleats installed in it, which may be risk factors for WLD.

5. Conclusions

Our results show a high prevalence of claw disorders in the cattle population studied, while differences in claw health based on production system provide important retrospective information about aspects related to animal welfare. Thus, the most prevalent claw disorders observed were abnormal claw shape, fissures of the claw wall and skin wounds. We found associations of severity between forelimbs for all ACS, HE, SD and FCW disorders in dairy animals, ACS, HE, SD in feedlot animals and only ACS and HE in free-range animals. There were also four types of associations between disorders according to the affected claw. Severe disorders WLD and SW showed a predictive capacity for pH being greater than 6 in animals from feedlots and free range. We conclude that retrospective abattoir-level claw assessment is an important tool and source of information about how production systems can influence cattle health and welfare. These measures could be considered iceberg indicators and integrated into specialized protocols to assess post-mortem cattle welfare. Hence, the incorporation of the assessment of claw disorders as part of a monitoring scheme of animal welfare at the abattoir-level may provide a framework that not only enables the timely identification of hazards and threats, but can also help to suggest approaches that either support or drive different risk management strategies to be adopted by the farmers and beef industry.

CRediT authorship contribution statement

M. Bautista-Fernández: Conceptualization, Methodology, Validation, Investigation, Data curation. **L.X. Estevez-Moreno:** Conceptualization, Methodology, Validation, Data curation, Formal analysis, Writing - original draft. **N. Losada-Espinosa:** Validation, Investigation. **M. Villarroel:** Writing - original draft, Writing -review & editing, Visualization. **G.A. María:** Conceptualization, Resources. **I. De Blas:** Data curation, Formal analysis. **G.C. Miranda-de la Lama:** Conceptualization, Methodology, Validation, Investigation, Supervision, Resources, Project administration, Funding acquisition, Writing -Original Draft, Writing -Review & Editing, Visualization.

Declaration of Competing Interest

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

Acknowledgments

The authors are thankful to Paola Mares (*Campo Libre*), Rogelio Soto, Luis Morales (*Union Ganadera Regional de Durango-UGRD)*, Danilo Méndez (FMVZ-UNAM) and Patricia Mora (FESC-UNAM) by valuable support to conduct this study. Many thanks to the CONACyT for the Scholarship of Michelle Bautista-Fernández in the M.Sc. Program. Finally, we are also grateful to the anonymous referees for their insightful comments, which helped to improve the paper significantly.

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