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Risk factors for claw disorders in intensively finished Charolais beef cattle

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ABSTRACT

This cross-sectional study aimed at performing a risk factor analysis of on-farm housing and management factors associated with infectious and non-infectious claw disorders of intensively finished Charolais young bulls and heifers. Claws' health condition of a total of 1305 animals belonging to 88 batches finished in farms located in the Eastern Po Valley (Italy) was assessed at slaughterhouse. Batch prevalence of feet affected by sole hemorrhage (SH) and white line abscess (WLA) was calculated and foot condition was summarized by infectious lesion (ILS) and non-infectious lesion (NILS) scores according to diseases' etiology. Batch prevalence of feet with SH, WLA, and assigned to the worst score classes were the outcomes in the risk factor analysis. Information about rearing facilities and health management of the tested batches were gathered in each origin farm along with a dietary sample used for chemical and physical analyses. Five categorized factors and 30 continuous covariates were considered as independent predictors and a cluster analysis of the continuous covariates was performed to select the most representative ones. Percentage of feet/batch affected by SH was on average 57.0 ± 32.5 % (SD) and by WLA was 9.94 ± 12.7 %. Percentage of feet/batch with the worst ILS and NILS was 29.6 ± 32.8 % and 12.5 ± 14.1 %, respectively. Charolais bulls showed a higher risk of SH and WLA than heifers and an increasing dietary NDF content acted as preventive factor. Concrete slats increased the risk of SH. Animals slaughtered in winter had the highest risk of WLA and the increasing level of dietary water-soluble carbohydrates (WSC) was a further risk factor. The risk for the worst NILS was lowest in spring and in presence of ventilation systems. It increased for bulls and in those batches fed diets with higher WSC content. Batches for which the farmer reported a higher prevalence of urgently slaughtered animals during finishing showed a higher risk of WLA and infectious claw diseases. The risk for infectious claw diseases was reduced in animals slaughtered in summer, housed on deep litter and fed diet with increased NDF content. It increased in farms where diet formulation was not under the nutritionist control. As general outcomes of the study, benefits for the claw health of finishing Charolaise may come from the use of the deep litter and ventilation systems, the involvement of a nutritionist in diet formulation, and the provision of diets with reduced WSC and increased NDF contents.

1. Introduction

Severe lameness events in finishing beef cattle are becoming more and more a relevant health issue, since they are shown to impose the early culling of affected animals with negative consequences on beef farm economics (Brscic et al., 2015a; Magrin et al., 2019a, b). Bulls unlikely recover from a severe lameness event and their temporary housing on a sick bay implies additional costs related to extra time and labor for their handling, pharmaceutical therapies and laboratory analysis, loss of weight gain and depreciation of carcass value (Miskimins, 2002; Ahola et al., 2011).

Among different causes of lameness such as trauma, osteochondrosis, septic joint disease, physitis, etc., claw disorders are considered the major responsible, accounting for 70.0–84.7 % of all cases of lameness in feedlot cattle (Miskimins, 2002; Newcomer and Chamorro, 2016) and for 66.3 % of all cases in finishing beef cattle (Compiani et al., 2014). A recent *post-mortem* inspection carried out at slaughter (Magrin et al., 2018) allowed to detect the most frequent claw disorders

Abbreviations: ILS, infectious lesion score; NILS, non-infectious lesion score; RR, relative risk; SH, sole hemorrhage; TMR, total mixed ration; WLA, white line abscess; WSC, water-soluble carbohydrates

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affecting feet of finishing beef cattle and to highlight a high variability among different batches of cattle (from 0 to 100 % of feet affected by specific alterations). As earlier suggested by Fjeldaas et al. (2007), the wide variability observed for specific claw disorders among different beef herds suggests the existence of some potential predisposing factors on the farms of origin related to the housing and management quality.

Several factors on farms are known to affect claw condition of intensively finishing beef cattle. In particular, the ingestion of high quantities of readily fermentable starchy cereals is reported to predispose cattle to laminitis-related disorders including white line and sole hemorrhages, sole ulcers, white line fissures and double sole (Fjeldaas et al., 2007; Greenough, 2007), as secondary consequences of subacute or acute ruminal acidosis conditions (Nagaraja and Titgemeyer, 2007; Gonzàlez et al., 2012). Also the prolonged locomotion on hard concrete floors or an insufficient space allowance predispose beef cattle to non-infectious claw horn disruption, hemorrhages or white line diseases (Fjeldaas et al., 2007; Graunke et al., 2011; Wechsler, 2011) since the weight-bearing distribution on the claw capsule is unbalanced over time, increasing pressure concentrations in specific areas of the sole (Greenough, 2007; Telezhenko et al., 2008). Moreover, low hygiene condition of the farm environment (Graunke et al., 2011; Brscic et al., 2015b) and the cold-humid climate (Sogstad et al., 2005; Sanders et al., 2009) are the main direct predisposing factors for infectious claw disorders such as digital and interdigital dermatitis and heel horn erosion.

So far, associations between the occurrences of different claw disorders and some relevant cattle characteristics, farm management practices, or specific chemical and physical parameters of finishing diets adopted for intensively reared beef cattle have not been documented. The aim of this study was to perform a risk factor analysis of on-farm housing and management factors associated with infectious and non-infectious claw disorders of intensively finished Charolais young bulls and heifers.

2. Material and methods

2.1. Farm sample at the slaughterhouse

This cross-sectional study was part of a wider *post-mortem* evaluation of the health condition of finishing beef cattle (Magrin et al., 2018). Data were collected in 3 cattle slaughterhouses during 30 slaughter days in Northern Italy from April 2016 until March 2017 at 3 different assessments: 1) from April to June 2016, 2) from September to October 2016, and 3) from February to March 2017. During these days, all batches of cattle entering the slaughter chain through the ordinary planning were inspected for their claws' health condition. Only the number of cattle inspected was set *a priori*, but not gender nor breed (Magrin et al., 2018). As reported in detail in the previous cited paper, a total of 2146 animals and 4292 hind feet belonged to 153 different batches arriving from 80 farms were inspected. Out of these 153 batches, 88 were Charolaise, 28 Limousine, 11 other French meat crossbreds, 10 Italian crossbreds, and 16 minor beef breeds and crossbreds of beef cattle genotypes reared with a minor frequency in Italy.

The original dataset was restricted to Charolais breed only, being the main beef breed reared in Europe (Cozzi, 2007; Bouquet et al., 2009; Gallo et al., 2014) and one of the most imported in Italy to be finished in local specialized units. One given breed was also chosen to reduce the bias due to the breed effect, since each beef breed is generally reared under different housing, flooring and feeding systems. In particular, for the current risk factor analysis, a total of 1305 animals belonging to 88 batches of Charolais young bulls and heifers (88/153, 58 % of the total sample) finished in 43 commercial fattening units located in the lowland of Eastern Po Valley of Italy was used.

2.2. Post-mortem claw inspection

Claw health condition of the animals was assessed on both right and left feet by a veterinarian (professional hoof trimmer) following the method described by Magrin et al. (2018). In particular, after trimming of the sole horn with an electric grinder, the same fixed veterinarian evaluated the claw health status by looking for the specific claw disorders on the sole. Claw disorders registered were sole hemorrhage, white line abscess, toe and sole ulcer, and corkscrew among the non-infectious disorders; and heel horn erosion, interdigital and digital dermatitis, and interdigital phlegmon among the infectious disorders. As reported in the previous cited study, all animals inspected were regularly introduced in the ordinary slaughterhouse planning, assuming that they were able to move independently or walk unassisted during the loading on trucks with no signs of impaired locomotion or severe lameness within the European Council Regulation 1/2005 (European Council, 2005), and therefore, apparently healthy.

The prevalence of feet affected by specific types of claw disorders was calculated at batch level and the individual claw condition was summarized with two claw lesion scores according to the etiology of the diseases detected: infectious lesion score (ILS) and non-infectious lesion score (NILS). Per each score, the cut-off value below which the worst 15 % of feet may be found was identified using the 75th percentile of the score distribution, identifying the worst score classes: from 1 to 5 for the ILS and from 3 to 13 for the NILS. More details concerning the recording system for claw disorders and the calculation and distribution of claw lesion scores were reported in Magrin et al. (2018). Since right and left feet of the same animal showed similar clinical diagnoses, the dataset used for the risk factor analysis was reduced to the left feet only, which were graded the worst mean claw lesion scores (Magrin et al., 2018).

In the current study, (1) the batch prevalence of feet affected by sole hemorrhage (SH) and white line abscess (WLA) as the most frequent non-infectious claw disorders, and (2) the batch prevalence of feet felt within the worst claw lesion score classes (ILS 1–5, and NILS 3–13) were selected as response variables in the risk factors analysis.

2.3. On-farm questionnaire and feed sampling

Information about the farms from which each inspected batch came were gathered from the slaughterhouse records. A single trained assessor interviewed all farmers within the given time period of each of the three assessments (on average 6.61 ± 6.2 (mean ± SD) days after the slaughter sessions) using a standardized questionnaire containing information regarding characteristics and health management of the tested batches (% of animals urgency slaughtered, dead, and treated for lameness problems gathered from the farm books), and the features of their rearing facilities during the finishing period. A list of all information collected for the tested batches is reported in Tables 1 and 2. During the farm visit, the assessor collected a fresh total mixed ration (TMR) sample that according to the farmer was consumed by the inspected animals in the last part of their finishing. After collection, TMR samples were kept frozen at - 20 °C until chemical and physical analyses. After thawing, samples were assayed for dry matter (DM), ether extract (EE), crude protein (CP) and ash according to AOAC (2000). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were analyzed according to Van Soest et al. (1991). Starch content was determined by liquid chromatography (AOAC, 2000) and water-soluble carbohydrates (WSC) were assessed using the phenol-sulfuric acid method described by Hall (2014). Non-fiber carbohydrates (NFC) content was calculated as [100-(NDF + CP + EE + Ash)]. The mineral profile of TMR samples was determined using the energy dispersive X-ray fluorescence spectroscopy technique (Berzaghi et al., 2018). In order to estimate the fibrous portion mainly responsible for promoting cattle rumination, a TMR sample of 250 g was soaked in 6 l of water heated at 39 °C. The floating portion of the sample was recovered and its NDF content (low density-NDF) was determined and expressed as percentage of the total DM of the TMR.

Particle-size distribution of the dietary samples was assessed using

Table 1
The 5 categorized potential risk factors selected for claws disorders in finishing Charolais beef cattle fattened on 43 commercial farms.

Potential risk factor	Definition	Levels	Answer, %
Season and cattle characteristics			
Finishing season	Astronomical season occurs on the date of slaughter	1: Spring	39.8
		2: Summer	17.0
		3: Fall	18.2
		4: Winter	25.0
Cattle category	Gender	1: Bull	60.2
		2: Heifer	39.8
Related to rearing facilities			
Type of floor	Pen floor in which animals were housed during finishing	1: Concrete slats	30.7
		2: Deep litter	58.0
		Missing answer	11.3
Ventilation system	Presence of any automatic system for air ventilation	1: No	35.2
		2: Yes	53.4
		Missing answer	11.4
Feeding management			
Involvement of a nutritionist - diet analysis frequency/ year	Skilled practitioner in charge of cattle nutrition and number of chemical analyses of the diet per year	1: No - ≤ 2 times	20.5
		2: No - > 2 times	36.3
		3: Yes - ≤ 2 times	5.70
		4: Yes - > 2 times	17.0
		Missing answer	20.5

the Penn State Forage Particle Separator (3-Sieve Model with 4-mm Sieve, 2013; Nasco, Fort Atkinson, WI, USA). One portion of the samples was separated into four portions: particles > 19 mm in length retained by the top sieve, particles between 19 and 8 mm in length retained by the middle sieve, particles between 8 mm and 4 mm in length retained by the lower sieve and feed particles < 4 mm in length accumulated on the bottom pan (Heinrichs, 2013). Each portion was then weighed and divided by the total sample weight to calculate the proportion of the four fractions.

Table 2
All 30 continuous covariates collected through farmers' questionnaire or obtained by chemical and physical analyses of 58 samples of total mixed ration (TMR) to be tested for their association with claw disorders in Charolais beef cattle.

Potential risk factor	Mean	SD	Min	First quartile	Median	Third quartile	Max
Feed intake and animal body weight at slaughter							
DM intake, kg/bull/day	10.1	0.92	8.13	9.31	10.0	10.5	13.4
mean final body weight, kg	672	96.1	500	560	730	750	775
Cattle health information gathered from the farm book, % of animals							
urgency slaughter	0.81	1.73	0	0	0	1.13	12.0
mortality	0.87	1.22	0	0	0	1.38	5.71
treatment for lameness	4.72	8.67	0	0	0	5.56	46.7
Rearing facilities characteristics							
manger space, m/animal	0.55	0.14	0.22	0.45	0.53	0.64	0.98
space allowance, m^2/animal	4.37	1.89	2.29	3.54	4.14	4.59	14.5
TMR chemical composition							
dry matter (DM), %	59.1	7.15	44.9	54.3	58.4	61.5	82.1
crude protein (CP), %DM	13.5	1.00	11.1	13.1	13.8	14.3	15.0
ether extract (EE), %DM	3.61	0.53	2.42	3.36	3.64	3.89	4.87
ash, %DM	4.63	0.84	2.82	3.98	4.65	5.32	7.01
neutral detergent fiber (NDF), %DM	31.2	4.35	14.5	29.4	30.5	32.0	41.5
acid detergent fiber (ADF), %DM	19.6	2.82	13.5	18.0	19.0	20.7	27.3
acid detergent lignin (ADL), %DM	3.10	0.80	1.54	2.32	3.14	3.43	4.81
low density-NDF[1], %DM	20.2	7.5	7.5	16.4	19.3	22.6	41.9
starch, %DM	32.0	3.78	22.2	30.9	31.8	34.3	40.4
non-fiber carbohydrates[2] (NFC), %DM	46.9	3.38	38.9	45.6	47.6	48.6	53.1
water-soluble carbohydrates (WSC), %DM	5.48	0.84	4.00	4.79	5.45	6.11	8.16
calcium (Ca), %DM	0.49	0.11	0.24	0.45	0.49	0.57	0.76
phosphorus (P), %DM	0.34	0.05	0.34	0.32	0.34	0.37	0.56
magnesium (Mg), %DM	0.19	0.03	0.19	0.18	0.19	0.21	0.32
potassium (K), %DM	0.85	0.17	0.54	0.73	0.80	0.98	1.19
chlorine (Cl), %DM	0.48	0.18	0.12	0.38	0.44	0.54	0.93
sodium (Na), %DM	0.33	0.18	0.02	0.20	0.31	0.41	0.77
zinc (Zn), mg/kg	87.2	26.5	33.0	77.0	85.0	92.0	209.0
Particles separation through sieving and particles length							
upper sieve (19 mm), %TMR	5.37	7.50	0.29	1.37	2.42	5.41	39.3
middle sieve (8 mm), %TMR	25.6	7.40	11.6	21.1	24.8	31.7	46.3
lower sieve (4 mm), %TMR	22.1	4.70	14.1	18.1	22.6	25.7	34.4
bottom, %TMR	47.0	10.6	23.1	39.1	46.8	54.9	65.3
mean particle length, mm	4.25	1.10	2.87	3.63	4.00	4.58	7.85

[1] low density-NDF = fraction mainly responsible for promoting rumination referred to the NDF content of a floating portion obtained after soaking a dietary sample in water at 39 °C and expressed as percentage of the total DM.
[2] NFC = Non-Fiber Carbohydrates calculated as = [100-(NDF + CP + EE + Ash)].

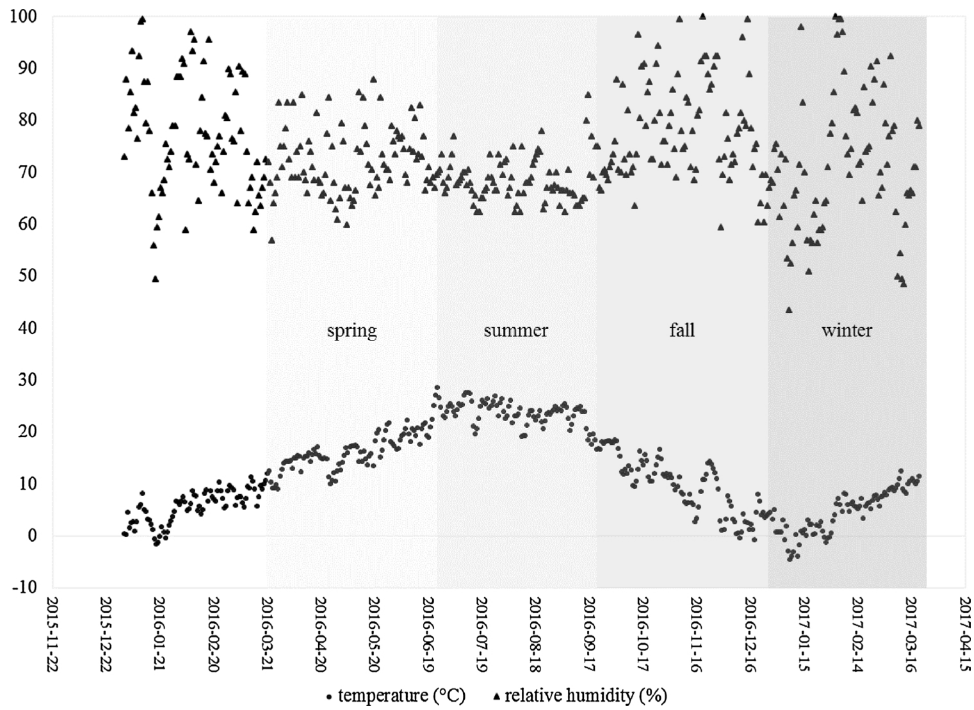

Fig. 1. Average temperature and humidity values for the study-period carried out from 2016–2017 gathered from a reference weather station (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto (ARAV), Padova, Italy) for the geographic area where the beef farms of origin of the inspected Charolais batches were mainly located.

2.4. A-posteriori categorization of season and climate data

According to the date of slaughter, each batch was allotted to a given finishing season (Season). Daily average values of temperature and relative humidity for the years 2016–2017 (Fig. 1) were gathered from a reference weather station for the geographic area where the beef farms were mainly located in order to describe the seasonal variations of these two parameters (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto (ARAV), Padova, Italy).

2.5. Statistical analysis

The batch prevalence of feet affected by SH and by WLA, and the batch prevalence of feet felt within the worst ILS and NILS classes served as dependent variables (response) in the risk factor analysis. Data gathered from farmers' questionnaire and TMR chemical and physical analyses were considered as independent predictors as they could represent potential risk factors for the development of claw disorders: 5 categorized factors (Table 1) and 30 continuous covariates (Table 2). To take into account the multicollinearity among the 30 continuous covariates, a preliminary cluster analysis was performed to select the variables that can better represent the associations among predictors. Variables clustering (based on correlations matrix) removed collinearity, decreased variables redundancy, and helped to reveal the underlying structure of the input variables. The variables-reduction was performed in Enterprise Miner 13.2 of SAS, using the Variable Clustering node. Within each group of predictors identified by the clustering process, the most correlated variables with the outcomes (response variables) were selected. All the categorized potential risk factors and the continuous covariates, as selected in the previous step, were included as predictors in a multivariable generalized linear model, using a Poisson distribution and logarithm link function (PROC GENMOD of SAS) as suggested by Zou (2004). Bonferroni correction was applied for *post-hoc* pairwise comparisons and relative risks (RR) for continuous and categorical predictors were estimated. The prevalence of feet affected by specific diseases according to the significant factors was calculated by least squares means. The assumptions of the linear model (homoscedasticity and independence of the residuals) were graphically assessed, and all variables met the model assumptions. Power of the analysis was assessed using Statistica 13.4.0.14 (TIBCO Software Inc.).

3. Results

A total of 1305 Charolais were inspected at the slaughterhouse, belonged to 88 different batches. Out of the total 88 batches, 29 were monitored at the first assessment arriving from 22 beef farms, 31 were monitored at the second assessment arriving from 24 beef farms, and 28 were monitored at the third assessment arriving from 19 beef farms. Since some batches arose from the same farm within assessments (12 batches from 5 farms at the first and at the second assessments, and 15 batches from 6 farms at the third assessment) and among assessments (31 batches from 6 farms monitored at every assessment) (**Table 1S**), some farmers were interviewed more times and a total of 58 samples of finishing TMR was collected.

The answers given by the farmers per each level of a specific categorized factor are reported in Table 1, whereas descriptive statistics for the continuous covariates are reported in Table 2.

The percentage of feet at batch level affected by SH ranged from 6.25–100 %, with a mean (± SD) of 57.0 ± 23.5 %; the percentage of feet at batch level affected by WLA ranged from 0 to 53.3 %, with a mean of 9.94 ± 12.7 %. The average prevalence of feet assigned an ILS 1–5 at batch level was 29.6 ± 32.8 %, ranging from 0 to 100 %, and that of those assigned a NILS 3–13 at batch level was 12.5 ± 14.1 %, ranging from 0 to 60 %.

3.1. Clustering procedure outcomes

The clustering process at batch level identified eight groups of variables, which explained the 66 % of the total variance (Fig. 1**S**; **Table 2S**). The first cluster included NDF, ADF, Starch and NFC. The average R^2 of these variables with the cluster was 86 %. Neutral detergent fiber was selected as potential main predictor of the group due to its significant correlation with the batch prevalence of WLA ($r = -0.36$, $P = 0.006$) and the batch prevalence of feet with NILS 3–13 ($r = -0.37$, $P = 0.004$). The second cluster included seven variables: Ash, ADL, CP, P, low density-NDF, space allowance (m^2/animal), and upper sieve (19 mm). The average R^2 of these variables with the cluster was 58 %. The low density-NDF was selected as potential main predictor of the cluster being correlated with the batch prevalence of feet with WLA (r = −0.31, P = 0.018) and with ILS 1–5 (r = 0.26, P = 0.49). The third cluster grouped together WSC content of the TMR, Cl, Na and the prevalence of urgency slaughters (% of animals). The average R^2 of these variables with the cluster was 61 %. Water-soluble carbohydrates content was selected as potential main predictor of the cluster, having r = 0.35, P = 0.008 with the batch prevalence of feet with WLA and r = 0.37, P = 0.005 with the batch prevalence of feet with NILS 3–13. Percentage of urgency slaughter was also selected for the significant correlation with the batch prevalence of feet with WLA (r = 0.23, P = 0.050) and with NILS 3–13 (r = 0.25, P = 0.046). Another cluster assembled EE, K, treatment for lameness (% of animals), DM intake (kg/head/day), and mean final body weight (BW) (kg). The mean R^2 of the variables with the cluster was 57 %. Mean final BW was the predictor selected for its significant correlation with the batch prevalence of feet with WLA (r = 0.28, P = 0.033) and with NILS 3–13 (r = 0.29, P = 0.030). The Mg and lower sieve (4 mm) (%TMR) were grouped in the fifth cluster (average R^2 with the group was 74 %). Lower sieve (4 mm) was the selected predictor due to the high correlation with the batch prevalence of feet with WLA (r = 0.28, P = 0.041). The sixth cluster collected two variables: Ca and Zn (mg/kg) (average R^2 was 74 %) and the latter was selected due to the correlation with the batch prevalence of feet with WLA (r = 0.35, P = 0.007). The seventh group consisted of middle sieve (8 mm), bottom sieve, mean particle length (mm), and DM (%) of the TMR. The average R^2 was 70 % and mean particle length was selected for its correlation (r = 0.23, P = 0.050) with the batch prevalence of feet with ILS 1–5. The last cluster included manger space (mm/head) and mortality (% of animals). Average R^2 of the grouped variables with cluster was 64 %. Manger space (m/animal) was chosen for its correlation with the batch prevalence of feet with SH (r = 0.24, P = 0.035).

3.2. Risk factor analysis

Charolais bulls showed a higher risk to develop both SH and WLA than heifers and an increasing NDF content of the TMR acted as preventive factor for the development of these disorders (Tables 3 and 4). The housing on concrete slatted floor was associated with a higher risk of SH (Table 3).

Season resulted a relevant risk factor for WLA, since animals slaughtered in spring had the lowest risk of WLA and those slaughtered in winter the highest risk (Table 4). The increasing level of WSC in TMR was a further risk factor for this pathology. Batches for which the farmer reported a higher prevalence of animals that were urgently slaughtered during finishing showed a higher risk of WLA (Table 4). The risk for feet to be assigned to the worst NILS (NILS 3–13) was lowest in spring compared to the other slaughter seasons; it was higher for bulls compared to heifers and it increased in batches fed a TMR with higher WSC content. The presence of ventilation systems was instead a preventive factor for this response variable (Table 5).

Animals slaughtered in summer had the lowest prevalence of feet with ILS 1–5, while the risk for infectious claw diseases was highest for batches slaughtered in fall and winter (Table 6). Regarding the housing systems, the concrete slatted floor resulted a predisposing factor for feet with ILS 1–5 compared to the deep litter. Regardless the frequency of chemical analyses on dietary samples, the prevalence of feet with ILS 1–5 increased in farms where TMR formulation was not under the control of a cattle nutritionist (Table 6). An increase of both total and low density-NDF content of TMR reduced the risk for ILS 1–5 and a similar trend was observed for the increasing percentage of particles retained by the lower sieve (4 mm) of the Particle Size Separator. The risk of feet assigned to ILS 1–5 increased in batches of animals fed TMR with longer particle length and in those with the higher frequency of urgency slaughters throughout the fattening cycle (Table 6). Zinc was the only mineral retained in the model, resulting a predisposing factor for the prevalence of feet affected by infectious claw diseases.

The power analysis tested on the most relevant claw disorders (SH and WLA) showed that 9 batches in each animal category have a 90 % power for detecting a difference of 40 % between the percentage of feet with SH of bulls and heifers with a P-value of 0.05; and 31 batches in each animal category have a 90 % power for detecting a difference of 11 % between the percentage of feet with WLA of bulls and heifers with a P-value of 0.05.

Table 3
Significant risk factors for the occurrence of sole hemorrhage at batch level by multivariable analysis using a generalized linear model with Poisson distribution and logarithm link function.

Independent variable (factor/covariate)	Factor levels	Ls-means (%)	Statistical outcome[1]			P-value
			RR	95 % CI	p-value	
Category	Bull	76.1	2.10	1.26 – 3.49	0.004	0.004
	Heifer	36.2	–	–	–	
Type of floor	Concrete slats	70.9	1.83	1.55 – 2.15	< 0.001	< 0.001
	Deep litter	38.9	–	–	–	
NDF[2], %DM			0.96	0.95 – 0.98	< 0.001	< 0.001

[1] RR = relative risk; 95 % CI = 95 % confidence interval.
[2] NDF = neutral detergent fiber.

4. Discussion

Charolaise is the main beef breed in Europe with more than 1,5 million cows reared only in France (Bouquet et al., 2009). Italy imports about 1 million of young bulls and beef heifers per year and Charolaise and Limousine are the most imported purebreds to be finished in beef farms mainly located in the Po Valley (Gallo et al., 2014). Italian beef farms operate under rather standardized management systems based on the group housing of cattle and the provision of TMR based on maize silage and concentrate feedstuffs (Cozzi, 2007). Beef cattle are housed indoors in pens with concrete fully slatted or deep littered floors for a finishing period of about seven months. Research outcomes by Brscic et al. (2015b) and Magrin et al. (2019a) showed that both types of floor could impair leg and claw condition of Charolais bulls. This breed seems prone to lameness events particularly during the final part of its fattening leading to the early culling of affected animals. All these findings suggested a deeper understanding of the risk factors to specific claw disorders for finishing Charolais cattle, and especially for those regularly introduced in the ordinary slaughterhouse planning, presumably with no signs of impaired locomotion or severe lameness. Severely lame bulls were excluded *a priori* from the *post-mortem* inspection since their early culling was imposed, either directly on the farm or at the abattoir entering the slaughter chain through a special planning. However, the batch prevalence of urgently slaughtered animals during finishing reported by the farmer might partially offset this lack.

Our sample size consisting of 88 Charolais batches inspected at slaughter was sufficient to guarantee a suitable power for the statistical approach adopted.

The gender of the animals was a risk factor for the occurrence of non-infectious disorders in bulls compared to heifers. The finishing period of Charolais beef heifers is usually shorter than that of young bulls in order to avoid an excessive carcass fatness due to their early maturity. Gallo et al. (2014) reported a significant difference in final BW between Charolais heifers and young bulls finished in Italian fattening units (527 *vs.* 703 kg). This difference could have prevented heifers from the risk of non-infectious claw disorders by reducing the weight load on the sole. Another explanation for the lower risk of SH and WLA on heifers' claws could arise from the lower energy content of

Table 4
Significant risk factors for the occurrence of white line abscess at batch level by multivariable analysis using a generalized linear model with Poisson distribution and logarithm link function.

Independent variable (factor/covariate)	Factor levels	Ls-means (%)	Statistical outcome[1]			*P*-value
			RR	95 % CI	*p*-value	
Season	Spring	3.30	–	–	–	< 0.001
	Summer	7.93	2.40	1.62 – 3.58	< 0.001	
	Fall	7.22	2.19	1.37 – 3.49	0.001	
	Winter	11.7	3.54	2.47 – 5.07	< 0.001	
Category	Bull	13.9	4.09	2.04 – 8.22	< 0.001	< 0.001
	Heifer	3.39	–	–	–	
WSC[2], %DM			1.33	1.01 – 1.76	0.044	0.043
NDF[3], %DM			0.90	0.85 – 0.95	< 0.001	< 0.001
Urgency slaughter, % of animals			1.10	1.01 – 1.20	0.031	0.031

[1] RR = relative risk; 95 % CI = 95 % confidence interval.
[2] WSC = water-soluble carbohydrates.
[3] NDF = neutral detergent fiber.

Table 5
Significant risk factors for the prevalence of feet at batch level with non-infectious lesion score from 3 to 13 by multivariable analysis using a generalized linear model with Poisson distribution and logarithm link function.

Independent variable (factor/covariate)	Factor levels	Ls-means (%)	Statistical outcome[1]			*P*-value
			RR	95 % CI	*p*-value	
Season	Spring	5.47	–	–	–	< 0.001
	Summer	12.1	2.22	1.58 – 3.11	< 0.001	
	Fall	10.5	1.91	1.29 – 2.84	0.001	
	Winter	17.2	3.14	2.31 – 4.28	< 0.001	
Category	Bull	19.9	3.64	1.92 – 6.88	< 0.001	< 0.001
	Heifer	5.48	–	–	–	
Ventilation system	No	14.8	2.01	1.59 – 2.54	< 0.001	< 0.001
	Yes	7.37	–	–	–	
WSC[2], %DM			1.49	1.19 – 1.88	0.001	0.001

[1] RR = relative risk; 95 % CI = 95 % confidence interval.
[2] WSC = water-soluble carbohydrates.

Table 6
Significant risk factors for the prevalence of feet at batch level with infectious lesion score from 1 to 5 by multivariable analysis using a generalized linear model with Poisson distribution and logarithm link function.

Independent variable (factor/covariate)	Factor levels	Ls-means (%)	Statistical outcome[1]			*P*-value
			RR	95 % CI	*p*-value	
Season	Spring	5.23	4.56	2.82 – 7.35	< 0.001	< 0.001
	Summer	1.15	–	–	–	
	Fall	17.8	15.5	8.91 – 26.9	< 0.001	
	Winter	18.0	15.7	9.63 – 25.5	< 0.001	
Type of floor	Concrete slats	8.87	1.79	1.41 – 2.28	< 0.001	< 0.001
	Deep litter	4.94	–	–	–	
Involvement of a nutritionist - diet analysis frequency/year	No - ≤ 2 times	34.2	67.0	38.9 - 116	< 0.001	< 0.001
	No - > 2 times	41.6	81.5	44.7 - 148	< 0.001	
	Yes - ≤ 2 times	0.51	–	–	–	
	Yes - > 2 times	2.63	5.16	3.19 – 8.32	< 0.001	
NDF[2], %DM			0.73	0.69 – 0.77	< 0.001	< 0.001
Low density-NDF[3], %DM			0.88	0.85 – 0.91	< 0.001	< 0.001
Zinc, %DM			1.07	1.05 – 1.08	< 0.001	< 0.001
Mean particle length, mm			3.79	2.98 – 4.81	< 0.001	< 0.001
Lower sieve (4 mm), %TMR[4]			0.80	0.76 – 0.85	< 0.001	< 0.001
Urgency slaughter, % of animals			1.37	1.27 – 1.48	< 0.001	< 0.001

[1] RR = relative risk; 95 % CI = 95 % confidence interval.
[2] NDF = neutral detergent fiber.
[3] Low density-NDF = fraction mainly responsible for promoting rumination referred to the NDF content of a floating portion obtained after soaking a dietary sample in water at 39 °C and expressed as percentage of the total DM.
[4] TMR = total mixed ration.

their diets. These two pathologies are known as laminitis-related claw lesions and they may develop in response to ruminal acidosis conditions promoted by diets with high energy density (Greenough, 2007; Plaizier et al., 2012). In this regard, this study confirmed the negative impact of feeding TMR with high content of readily degradable carbohydrates on the development of non-infectious claw disorders (NILS 3–13), and on WLA in particular, probably as consequence of an impaired rumen metabolism (Plaizier et al., 2012; Heinrichs, 2013). The EFSA Opinion (2012) on the welfare of cattle kept for intensive beef production recommended the inclusion of a certain amount of fiber on their diets to reduce the risk of sub-acute ruminal acidosis and its consequent laminitic condition. Our results clearly support the preventive role of providing TMR with an increased fiber content against the development of laminitis-related claw lesions. Therefore, the improvement of claw health condition in finishing beef cattle suggests a reduction in the ratio between readily fermentable carbohydrates and fibrous components of the TMR.

In this study, the risk of WLA and ILS was positively associated with the frequency of early culling events in the observed batches. Despite the lack of scientific knowledge as regards the association between specific claw disorders and culling rate for beef cattle, several authors reported high hazard ratios of culling for dairy cows affected by white line diseases (Cramer et al., 2009; Charfeddine and Pérez-Cabal, 2017) and infectious claw diseases such as severe dermatitis or interdigital phlegmon (Booth et al., 2004; Charfeddine and Pérez-Cabal, 2017).

Regarding the type of floor, the concrete slatted floor resulted a predisposing factor either for SH or infectious claw diseases. These results are consistent with previous findings by Graunke et al. (2011) who recorded on this type of floor a higher prevalence of bulls with hemorrhages diffused on the sole area and on white line zones, and with severe dermatitis. Although infectious claw diseases were more often recorded on deep litter pens with inadequate litter management (EFSA, 2012; Brscic et al., 2015b), they may also occur on concrete slats when not-well drained or not properly cleaned (Hultgren and Bergsten, 2001; Lowe et al., 2001).

Consistent with previous findings (Sogstad et al., 2005; Sanders et al., 2009), our risk factor analysis identified season as one of the main predisposing factors both for infectious and non-infectious claw disorders. The climate of the lowland in the Po Valley of Italy is mostly characterized by a humid subtropical climate with foggy, damp and cool weather and sudden bursts of frost in wintertime (Cfa zone for Köppen climate classification) that results in a wetter environment in the indoor cattle housing systems compared to the other seasons of the year. It has been reported how a prolonged exposure of the claws to wet environment increases the likelihood of the development of infectious and non-infectious claw disorders (Borderas et al., 2004; Cook et al., 2004). By looking at the reference environmental temperature and relative humidity recorded throughout the entire study-period, claws inspected in late winter were exposed during the last three months of finishing to the maximum values of humidity and to widest variation in temperatures (mean $\pm$ SD = 4.54 $\pm$ 4.08; min = -4.6; max = 12.4). On the contrary, feet inspected in spring and summer were exposed to drier conditions, thanks also to the contribution of the ventilation systems (Magrin et al., 2017), thus preventing the risk of non-infectious claw disorders observed in this study.

A lower prevalence of feet affected by infectious claw diseases occurred when a cattle nutritionist was involved in TMR formulation, pointing out the key role of a skilled person either in diet formulation or in its more frequent quality check.

Several authors identified zinc as one of the main minerals involved in the processes of keratinocyte proliferation that might improve claw integrity and the resistance of the interdigital skin against bacterial agents (Inoue et al., 2014). However, our results did not show any preventive effect of the dietary zinc content on the development of infectious claw diseases. This lack of positive response could be due to the source of zinc and/or to the presence of some zinc-antagonists in the TMR, since both have proven to affect the bioavailability of the mineral (NRC, 2001; Tomlinson et al., 2004). Unfortunately, information collected by the on-farm questionnaire did not addressed the feed ingredients of the TMR and their source and therefore it is not possible to prove the above assumptions.

Some physical characteristics of the diet related to the particles size were only retained by the multivariable model for infectious claw diseases. In particular, the increasing length of the dietary particles and the decreasing quantity of particles retained by the lower sieve (4-mm) resulted predisposing factors for the occurrence of infectious claw pathologies. Palmer and O'Connell (2015) identified different risk factors other than diet characteristics for infectious claw diseases, such as housing, biosecurity, management practices etc. However, we may hypothesize that highly fermentable diets with higher mean particle length, might have increased the risk of infectious claw diseases either through a more intense feed selection activity against the longer particles of the TMR and/or through an insufficient presence of small fibrous particles retained by the 4 mm sieve that are known to promote cattle ruminative activity and rumen buffering (Heinrichs, 2013).

5. Conclusion

The current study investigated potential on-farm risk factors associated to infectious and non-infectious claw disorders in finishing Charolais beef cattle reared under intensive production systems. The outcomes of the multivariable analyses identified for each claw disorder specific risk factors regarding the rearing facilities characteristics and some chemical and/or physical parameters of the diet. As general outcomes of the study, the claw health of finishing Charolaise may benefit from the housing on deep litter, the use of ventilation systems, the involvement of a nutritionist in diet formulation, and the provision of diets with reduced WSC level and increased NDF content.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.prevetmed.2019.104864.

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