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UNIVERSITÀ DEGLI STUDI DI PADOVA

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CICLO XXXI

HEALTH AND WELFARE PROBLEMS OF FINISHING BEEF CATTLE: LAMENESS AND POSSIBLE PREVENTING SOLUTIONS

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ABSTRACT

The general purpose of this PhD thesis was to analyse the impact on beef cattle health and welfare of some housing and flooring solutions mainly adopted in the intensive rearing systems. In particular, it aimed at investigating claws health status of intensively finished beef cattle belonged to different breeds (Charolaise, Limousine and Holsteins) and housed on different flooring systems (deep litter, fully concrete slatted floor and rubber covered slatted floor). A further aim was the testing of possible preventing solutions against lameness. The thesis was divided in 6 chapters:

A general introductive chapter (**Chapter 1**) focused on the beef cattle production system in Europe, and in Italy in particular way. Moreover, it identified the most relevant housing and management factors that could impair the welfare of finishing beef cattle.

In the light of the rare published research concerning the claw disorder distribution in finishing beef cattle, the first step consisted in a *post mortem* inspection at the slaughterhouse that allowed to assess the claw condition of a large number of finishing beef cattle batches (**Chapter 2**). In particular, we assessed after trimming the prevalence of specific claw disorders and their location on the sole in hind feet of beef cattle which arrived at slaughter with no signs of impaired locomotion. Non-infectious disorders resulted the most common diagnoses among batches, mainly on the lateral claws and in the heel-sole junction area.

The second research aimed at assessing the prevalence of lameness, its severity degree (mild or severe) and its time of onset during finishing. This study focused the most prevalent intensive beef production system operating in Italy that consists of Charolais bulls fattened in deep litter or fully slatted floor pens (**Chapter 3**). Severe lameness events were always recorded in the last part of the fattening. Fully slatted floor increased the prevalence of severe lameness and the relative risk of early culling compared to deep litter. An increased space allowance for bulls in fully slatted floor acted as preventive measure against both mild and severe lameness.

Considering alternative housing solutions to the concrete fully slatted floor, the third study aimed to assess whether growth performance, health, behaviour and claw condition of finishing bulls belonging to two beef breeds with different slaughter weight like Charolaise and Limousine, would be affected by their housing on a concrete or on a rubber covered

slatted floor (**Chapter 4**). On a perspective of the development of welfare friendly flooring systems tailor-made for specific beef cattle breeds, the use of rubber covered floor as an alternative to the concrete slatted floor should be advised only for bulls like Limousine that are finished at a final body weight (BW) around 600 kg. Despite the positive growth performance, health and welfare of Charolais bulls finished at a final BW above 700 kg were impaired by their housing on both concrete or rubberized slatted floors.

In order to prevent the negative impact of the new rubberized surfaces on the cleanliness of the animals, the last research was addressed to investigate the effects of an increased drainage area on hygiene, body condition, behaviour, claw- and leg health of fattening bulls kept in fully slatted pens equipped with rubber mats (**Chapter 5**). This 4%-unit increase was not enough to improve the hygiene of the floor, and thus of the animals even if it reduced the number of carcasses penalised at the slaughter for unacceptable hygiene. However, regardless of drainage area, several signs of good comfort on rubberized surfaces were recorded in any group of bulls such as few abnormal locomotor and transition movements, frequent social interactions and relaxing lying postures.

Successively, general discussion and conclusions focused the main outcomes (**Chapter 6**). Although our findings provide new insights about the relevant impact of lameness in beef cattle farms, additional investigations are need to identify other potential predisposing factors on farms for specific claw disorders and consequently the best housing, flooring and management solutions for bulls during their finishing.

RIASSUNTO

L'obiettivo generale di questa tesi di dottorato è stato quello di analizzare l'impatto sulla salute e sul benessere del vitellone da carne di alcune soluzioni di stabulazione e pavimentazione prevalentemente adottate nei sistemi intensivi. In particolare, mirava ad investigare lo stato di salute degli unghioni di bovini da carne in fase di finissaggio di diverse razze (Charolaise, Limousine and Holsteins) e allevati su diversi sistemi di pavimentazione (lettiera permanente, grigliato in cemento e rivestito in gomma). Mirava poi a testare possibili soluzioni preventive alla zoppia. La tesi è divisa in 6 capitoli:

Un capitolo introduttivo (**Capitolo 1**) è focalizzato sui sistemi di allevamento del vitellone da carne in Europa, con particolare interesse all'Italia. Vengono inoltre identificati i maggiori fattori di rischio per il benessere del vitellone legati alla stabulazione e al management.

Alla luce della scarsa conoscenza sulla distribuzione delle lesioni podali nel vitellone, il primo passo ha previsto un'ispezione *post mortem* al macello degli unghioni di un ampio numero di partite di vitelloni (**Capitolo 2**). Dopo il pareggio funzionale, è stata valutata la prevalenza di problemi podali e la loro posizione soleare in piedi posteriori di bovini da carne che arrivavano al macello senza segni evidenti di zoppia. Le alterazioni podali non-infettive risultavano le più comuni tra le partite, per lo più negli unghioni laterali e nell'area di giunzione bulbo-suola.

La seconda ricerca mirava alla valutazione della prevalenza di zoppia, la sua severità (lieve e grave) e il momento della comparsa durante il ciclo. Essa considerava il prevalente sistema di produzione in Italia che consiste nell'allevamento di vitelloni Charolaise su lettiera permanente o su grigliato in cemento (**Capitolo 3**). Eventi di zoppia grave sono sempre stati registrati nell'ultima parte del ciclo. La pavimentazione in grigliato ha aumentato la ricorrenza degli eventi gravi di zoppia e il relativo rischio di riforma precoce rispetto alla lettiera permanente. Un aumento della disponibilità spazio/capo sul grigliato ha ridotto l'incidenza di entrambe le zoppie, lievi e gravi.

Considerando soluzioni di pavimentazione alternative al grigliato in cemento, il terzo studio mirava a valutare se le performance di crescita, la salute, il comportamento e la condizione podale di vitelloni appartenenti a due razze da carne aventi differenti pesi di

macellazione come lo Charolaise e il Limousine possano essere influenzate dal sistema di stabulazione in grigliato con o senza gomma (**Capitolo 4**). Con la prospettiva di sviluppare sistemi di stabulazione welfare friendly adatti a specifiche razze da carne, l'uso del grigliato in gomma come alternativa al grigliato in cemento dovrebbe essere consigliato solamente per vitelloni come i Limousine che vengono macellati ad un peso finale di circa 600 kg. Nonostante le positive performance di crescita, la salute e il benessere di vitelloni di razza Charolaise macellati ad un peso finale superiore ai 700 kg risultavano compromessi in entrambi i sistemi di stabulazione, su grigliato cementato o su quello gommato.

Al fine di prevenire l'impatto negativo delle nuove superfici gommate sulla pulizia degli animali, l'ultimo studio ha testato gli effetti sull'igiene e sul benessere di vitelloni da carne di un certo incremento dell'area di drenaggio di una pavimentazione in grigliato con tappetini in gomma (**Capitolo 5**). Questo incremento del 4% non è risultato sufficiente a migliorare l'igiene del pavimento e degli animali, sebbene abbia ridotto il numero di carcasse penalizzate al macello per un livello di pulizia inaccettabile. Tuttavia, indipendentemente dall'area di drenaggio, sono stati registrati molteplici segni di benessere legati alla stabulazione su gomma come la ridotta frequenza di movimenti anomali durante la locomozione e le transizioni, frequenti interazioni sociali e posizioni rilassanti durante il decubito.

A seguire, una generale discussione è focalizzata sui maggiori risultati (**Capitolo 6**). Sebbene i nostri risultati abbiano apportato nuove conoscenze sull'impatto che la zoppia ha sugli allevamenti di bovini da carne, ulteriori studi sono necessari per identificare altri potenziali fattori predisponenti ai problemi podali a livello aziendale e di conseguenza le migliori soluzioni di stabulazione e management per i vitelloni durante la fase di finissaggio.

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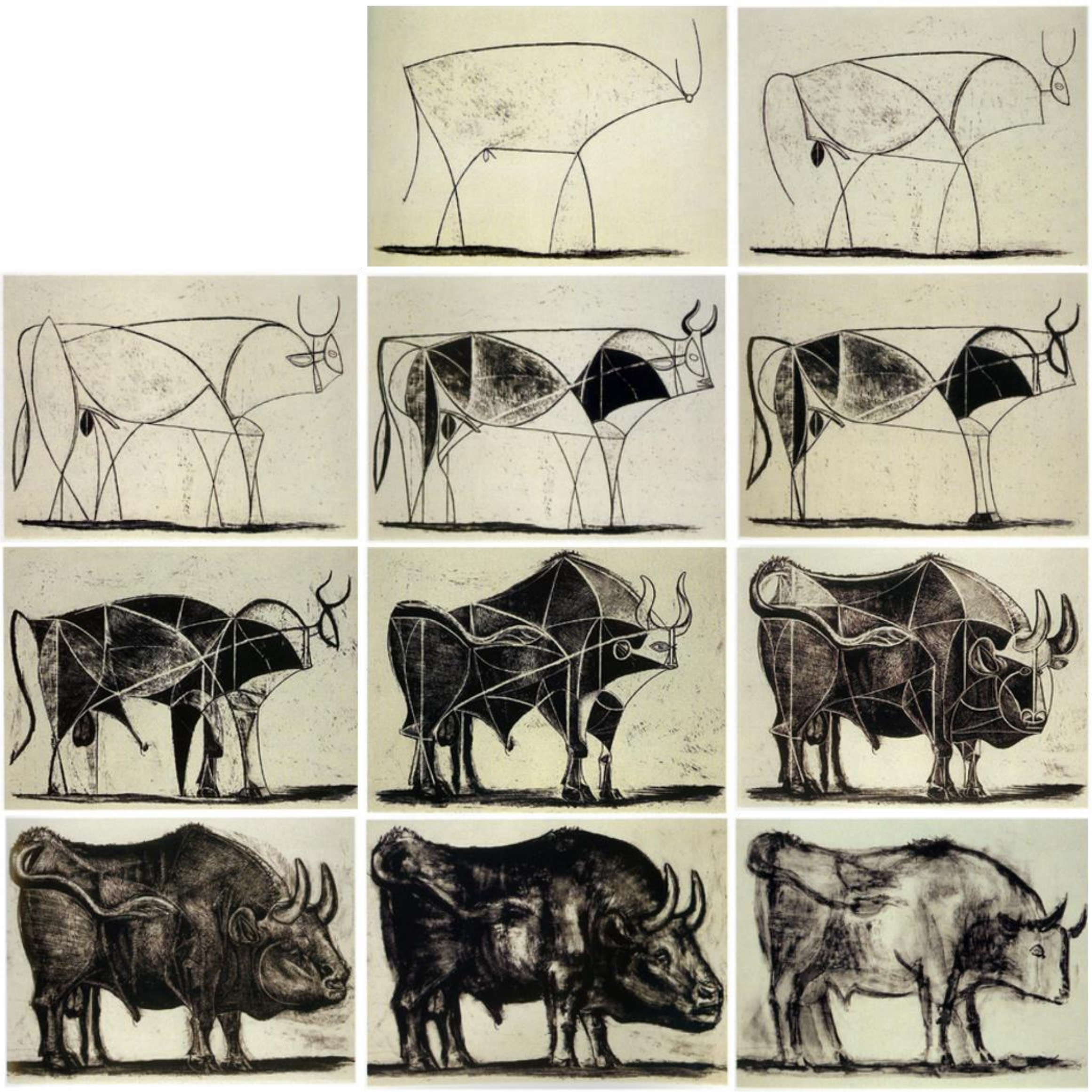
ABBREVIATIONS

ADG = Average Daily Gain
B = Breed
BW = Body Weight
CC = Corkscrew Claw
CH = Charolaise
CHD = Claw Horn Disruptions
CI = Confidence Interval
CP = crude protein
CS = Concrete Slatted floor
DD = Digital Dermatitis
DL = Deep Litter
DM = Dry Matter
FD = moment of Feed Delivery
FS = concrete Fully Slatted floor
GLS = Global Lesion Score
HHE = Heel Horn Erosion
HO = Hour of Observation
ID = Interdigital Dermatitis
ILS = Infectious Lesions Score
IP = Interdigital Phlegmon
LIM = Limousine
NDF = Neutral Detergent Fibre
NILS = Non-Infectious Lesion Score
OD = Observation Day
OR = Odd Ratio
RCS = Rubber Covered Slatted floor
RR = Relative Risk
SA = Space Allowance
SH = Sole Haemorrhage
TF = Type of Floor
TMR = Total Mixed Ration
U = Ulcer
WC = Weight Class
WLA = White Line Abscess

CHAPTER 1

General Introduction



BEEF CATTLE PRODUCTION

Beef Cattle Production in the EU-28

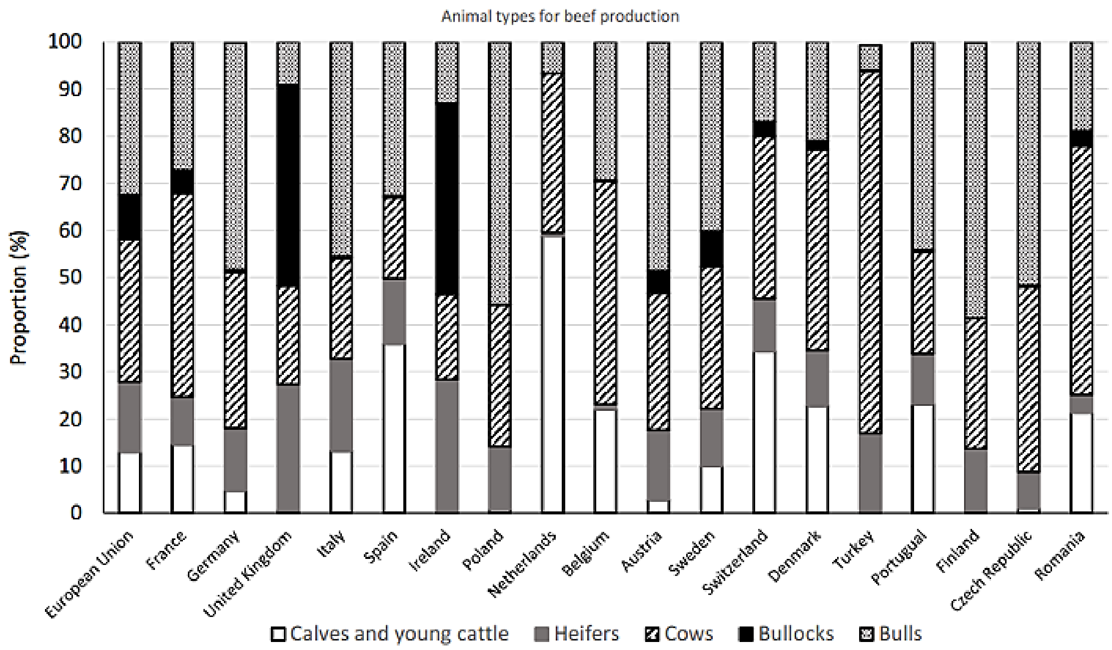
Almost 90 million of cattle were recorded and a total of 8 million tonnes of bovine meat were produced in the European Union (EU-28) in 2016 (Eurostat, 2017). The highest numbers of bovines and the highest productions of cattle meat were in France, Germany and United Kingdom. Together in fact they accounted for almost half (45.2 %) of the total EU-28 beef production (Eurostat, 2017). The major European Countries with their corresponding cattle population size and meat productions are shown in **Table 1**.

Table 1. Bovine population and meat production in 2016 (*Source*: Eurostat 2017).

	bovine population (million head)	meat production (thousand tons of carcass weight)
France	19.0	1,462
Germany	12.5	1,148
United Kingdom	9.81	912
Ireland	6.61	588
Italy	6.31	810
Spain	6.26	638
Poland	5.97	501
Netherlands	4.29	416
Belgium	2.50	278
Romania	2.05	58
Denmark	1.55	129
Sweden	1.44	131
EU-28	89.1	7,799

Beef production is characterized by a wide diversity across European countries depending on cattle genotypes reared (Hocquette et al., 2018). It mainly resulted from beef cattle breeds that were specifically fattened for their meat, but it can be derived from dairy cattle breeds. In general, almost 63% of the bovine meat produced in the EU-28 in 2016 derived from bulls or cows, but each European country is addressed to a specific type of cattle production (**Figure 1**). In particular, beef genotypes are late maturing animals (*i.e*. Charolaise, Limousine and Blonde d'Aquitane) and they are predominant in France. The majority of these male animals are fattened as young not-castrated bulls in mainland Europe, in particular in Finland, Poland, Czech Republic, Austria, Germany, and Italy. Dairy crossbreds mated to late maturing beef breeds are predominantly in United Kingdom and Ireland and they are reared as castrated steers or heifers. Calves and young cattle are mainly fattened in Netherlands, Spain, and Switzerland for the veal meat production (Hocquette et al., 2018). Depending on the type of genotype reared and on the climate conditions, each European country adopts a specific fattening system that can be diversified greatly from the most intensive to the most extensive one (European Food Safety Authority (EFSA), 2012). Intensive beef fattening systems are characterized by the indoor housing of the animals and high-concentrate diets, while extensive fattening systems consist in summer pasture, winter housing of the animals and grass-based diets (EFSA, 2012).

Figure 1. Beef production types for the major European Countries (*Source*: Hocquette et al. 2018).



Beef Cattle Production in Italy

As stated previously, 45.6% of the beef cattle production in Italy comes from the finishing of young (1-year-old or more) not-castrated bulls. The Italian production systems can be divided in two types, according to their location and breed reared (Cozzi, 2007). The intensive production system is predominant and it mainly located in the Po Valley (Northern Italy), where 70 - 75% of the beef cattle are reared in fattening units widely diversified in their size (from more than 1000 heads in Veneto region to less than 400 heads in Piedmont region). The extensive production system is predominant in the North-western and in the Central-Southern part of Italy, and it consists in cow-calf operations systems organized in small units of 20-25 heads (Cozzi, 2007).

The Italian production does not cover the national demand of meat and requires the import of live cattle and meat from abroad (Istituto di Servizi per il Mercato Agricolo ed Alimentare (ISMEA), 2006). The Italian beef production is indeed strictly dependent on the import of young cattle at an age of 10 to 14 months and an initial live weight of 300 to 400 kg, to be raised and finished in our national fattening units for about 7 months (ISMEA, 2006). The most common imported genotypes are Charolaise, Limousine and crossbreeds from France, and Polish Friesian and Simmental from Eastern Europe (Compiani et al., 2014; Gallo et al., 2014). In particular, purebred Charolaise and Limousine have obtained in our Country a great economic importance for their growth ability and meat quality, and they are also easily accessible due to the limited distance between production and fattening areas.

The intensive production systems generally consist in the indoor loose housing of the animals in specialized fattening units and their grouping in multiple pens equipped with fully slatted floor or permanent straw litter (Cozzi et al., 2005). For economical and practical reasons, the slatted floor is the most predominant solution in Italy and in other European countries. Littered pens indeed require the use of bedding materials and a higher labour cost for faces' removal than fully slatted pens. However, they are mostly adopted for heavy slaughtered bulls like Charolaise that are known to be more sensitive to lameness (Cozzi et al., 2005). The testing of alternative flooring solutions draws the attention towards a partial rubberization of the concrete floor or the use of rubber mats on the top of concrete slats that are spread in the last years all over the Europe (EFSA, 2012).

In order to achieve appropriate carcass weight, muscularity and fatness to meet the preference of the Italian retail chain, and to guarantee a certain level of rumination function, cattle are offered *ad libitum* a mixture of digestible fibre and starch from cereals characterized by high energy level and high amounts of fermentable carbohydrates (Cozzi et al., 2008; EFSA, 2012). According to an Italian research carried out on 406 commercial beef farms located in the Po Valley (Cozzi et al., 2008), beef cattle are generally finished using total mixed rations (TMR) based on maize silage and concentrate feedstuffs. Out of the total 406 farms, 194 farms used the maize silage as main constituent of the dietary dry matter (DM) representing on average 33.4% of the total DM (**Figure 2**). Depending on the level of inclusion of maize silage and its particles length, diets provided to beef cattle had an average DM content of 350 ± 38 (± SD) g/kg of fresh weight, a starch content of 310 ± 28 g/kg DM and an NDF content ranging from 307 to 331 g/kg DM.

Figure 2. Distribution of the farm population (406 Italian commercial farms) according to amount of maize silage included in the diet for finishing beef cattle (*Source*: Cozzi et al. 2008).

RISKS OF POOR WELFARE FOR BEEF CATTLE DURING THEIR FINISHING

The EFSA Panel on Animal Health and Welfare (2012) identified the most relevant *housing* and *management* factors that could impair the welfare of finishing beef cattle.

In particular, some characteristics of the *housing* system adopted such as microclimatic conditions, indoor confinement, type of flooring and space allowance could have a negative impact on the animal welfare.

Microclimatic Conditions

In mainland Europe where beef cattle are housed indoors on fully slatted floors or on deep litter (Scientific Committee on Animal Health and Animal Welfare (SCAHAW), 2001; Cozzi et al., 2009), they could experience heat stress when exposed to high temperature and humidity values with no possibility to maintain homeothermy by dissipating heat effectively (EFSA, 2012). In this scenario, animals' heat dissipation efficiency depends on barn micro-environmental conditions and the resources provided, such as water, feeding and manure management. Some heat mitigation strategies that farmers could adopt include changing the feeding regimen (Mader, 2003), providing additional drinking water points (Mazzenga et al., 2006) and using cooling systems, such as ventilation (Calegari et al., 2014; Magrin et al., 2018), and water sprinkling or misting (Mitlohner et al., 2001).

Type of Flooring

The type of floor is considered a relevant risk factor for cattle kept for beef production (EFSA, 2012). Among different types of flooring systems frequently adopted in intensive indoor systems, fully concrete slatted floor is not recommended considering results of previous studies addressed the negative effects of this type of floor on animal health and welfare.

Concrete Slatted Floor *vs*. Deep Litter

Effects on health. Fattening bulls kept on fully concrete slatted floors showed indeed an increased risk of early culling mainly due to locomotory problems such as lameness or musculoskeletal system pathologies (Murphy et al., 1987; Tessitore et al., 2009; Brscic et al., 2015a) and a higher risk of mortality compared to bulls kept on deep litter (Rumor et al., 2015). The exposure of the legs to hard and abrasive surfaces as the concrete floor was often associated to the presence of several lesions on legs (Platz et al., 2007; Schulze Westerath et al., 2007; Graunke et al., 2011) and at carpal and tarsal joints (Ruis-Heutinck et al., 2000; Persson et al., 2007) because it increased the probability of external traumatic trauma by heavy finishing bulls. Also, the claw tissue had a higher risk to be damaged on hard surface increasing the occurrence of claw injuries, specific sole disorders and white line haemorrhages (Ruis-Heutinck et al., 2000; Graunke et al., 2011). The abrasiveness of the concrete slatted floor affected claw horn growth and wear and claw conformation, arising the susceptibility to specific lesions (Telezhenko et al., 2008).

Effects on behaviour. Bulls' discomfort towards this type of floor was confirmed by several studies in which finishing beef cattle, when given a free choice, showed a clear preference for soft flooring in the lying area such as straw bedding or rubber-coated slats (Ruis-Heutinck et al., 2000; Lowe et al., 2001). Bulls housed on concrete slatted floor showed some behavioural alterations such as atypical standing/lying up and discomforting lying postures, reduced number of lying bouts and increased their duration (Ruis-Heutinck et al., 2000; Gygax et al., 2007a; Mayer et al., 2007; Platz et al., 2007; Absmanner et al., 2009; Rouha-Muelleder et al., 2012) and reduced social interactions with the other pen-mates (*i.e.* mounts and fights) (Absmanner et al., 2009; Brscic et al., 2015a). Moreover, Wechsler (2011) and Brscic et al. (2015a) reported that finishing cattle had a higher risk to slip when housed on concrete slats than on deep litter since their grip and skid resistance were limited. Considering these previous findings, deep litter flooring system has reported to be a preventive solution against bull's lameness, locomotory and integumental alterations, abnormal postures and behavioural activities, and claw disorders.

Effects on hygiene. An inadequate litter management could impair significantly the cleanliness of the bulls as reported in several studies (Gottardo et al., 2003; Tessitore et al., 2009; EFSA, 2012; Brscic et al., 2015a). The recommend requirement of a regular litter renewal with sufficient quantity of bedding material to ensure animal cleanliness had increased the labour and the costs by the beef farmers related to its proper management.

Concrete Slatted Floor *vs*. Rubberised Slatted Floor

These economical and practical reasons address to investigating flooring alternatives to improve animal health, welfare and cleanliness of finishing beef cattle at the same time. Nowadays, the mostly adopted alternative solution is the use of rubber mats on the top of the fully slatted concrete floor (Lenehan, 2003).

Effects on health. Positive outcomes for using rubber mats related to leg health and behaviour of beef bulls were reported in several recent studies. In particular, Elmore et al. (2015) observed a decrease in gait score and swelling at the knees and hocks in finishing beef steers housed on fully slatted rubber mats than those on fully slatted concrete. Other studies (Platz et al., 2007; Schulze Westerath et al., 2007; Graunke et al., 2011; Brscic et al., 2015b) proved that bulls on rubber slatted were less frequently treated for locomotor problems and showed less leg lesions (*i.e*. carpal bursitis) than those on concrete slatted.

Effects on behaviour. Lowe et al. (2001) observed bulls preferring rubber mattresses than concrete floor during lying. In accordance to the findings reported by Lowe et al. (2000) and Mayer et al. (2007), bulls on softer bedding were more frequently observed changing postures from lying down to getting up. Recently, other researchers (Cozzi et al., 2013; Brscic et al., 2015b; Elmore et al., 2015) confirmed the increasing of the frequency of transitions along with the number of social interactions (*i.e*. mounting events) in bulls housed on perforated floor coated with a rubber mattress or on fully slatted rubber mats. They observed also a decrease of abnormal lying down and unsuccessful attempts to lie down, and a reduction of the time spent resting and time required by bulls for lying down, in accordance with findings by Absmanner et al. (2009). These numerous results proved a general welfare improvement and a good level of confidence by finishing bulls to stand and lie down and to move when housed on rubber surfaces.

Effects on hygiene. However, some concerns were raised for bulls' cleanliness (EFSA, 2012) that appear impaired for bulls finished on rubber mats than for those on concrete slatted floors (Graunke et al., 2011; Brscic et al., 2015b; Elmore et al., 2015). In compliance with European Council Regulation 853/2004 (European Council, 2004) cattle's cleanliness at the slaughterhouse is mandatory in order to reduce risks of meat contamination. Results related to the hygiene condition of finishing bulls remains limited and conflicting considering findings by Lowe et al. (2001), Schulze Westerath et al. (2007) and Keane et al. (2015) that reported no differences in bull cleanliness between rubber or concrete flooring systems. On the contrary, Lenehan (2003) observed cleaner bulls on rubber mats than on concrete slats. The cleanliness of the animals is mainly influenced by the drainage area of the floor, which is less on floors equipped with rubber mats than on concrete slatted (Lowe et al., 2001; Platz et al., 2007; Graunke et al., 2011; Brscic et al., 2015b).

Effects on claw condition. Consequently, not-well drained floors could lead to the development of claw disorders. Kremer et al. (2007), Platz et al. (2007) and Keane et al. (2015) reported that finishing bulls on rubber mats had a higher incidence of hoof lesions than those on concrete slats. However, several researchers differentiated the type of claw disorders in relation to their origin, infectious or non-infectious (Claw Horn Disruptions (CHD)). Lower incidence of CHD such as sole and white line haemorrhages was detected on feet of bulls housed on rubber mats in comparison with concrete slats, either in beef and dairy cattle (Graunke et al., 2011; Hultgren and Bergsten, 2001; Bergsten et al., 2009). Telezhenko et al. (2008) showed that the weight bearing of the sole zone in cows kept on rubber flooring only was less than that of cows on hard surfaces, resulting in an increased weight-bearing role of the bulbs and on the claw walls' zones, the strongest parts of the claw capsule. This shift of the weight bearing point to the bulbs could be caused by the overgrowth of the claw horn due to the low abrasiveness of rubber floors (Toussaint Raven, 1989). It is likely that the reduced pressure exerted to the sole area could reduce the likelihood to develop severe lesions. Differently, heel horn erosion as an infectious alteration was more frequently observed on rubber mats by Graunke et al. (2011). The increasing of this claw alteration could find two reasons. The first one could be related to the poor hygienical condition of the rubber floor due to its smaller drainage capacity than concrete slatted floor (Hultgren and Bergsten, 2001; Manske et al., 2002). The second one could be due to the lower abrasiveness of the rubberized surface that limits the horn wearing at the heels, as Bergsten et al. (2009) observed for less-wearing deep straw bedding. Moreover, the lower abrasiveness that characterized rubber mats (Platz et al., 2007; Bergsten et al., 2009; Telezhenko et al., 2009), could lead claws to change their conformation. In particular, the development of toe overgrowth (longer dorsal wall and diagonal lengths) due to poor wear was observed when bulls housed on fully slatted floor pens covered with rubber mats (Platz et al., 2007; Rouha-Muelleder et al. 2012; Brscic et al., 2015b).

Effects on growth performance. Regarding the effects of the type of floor on growth performance of finishing beef cattle, Lowe et al. (2001) recorded similar production parameters such as weight and carcass gains and carcass composition between bulls housed on fully concrete slatted floors and those on rubber mats. Differently, recent studies reported improved growth performance of bulls housed on rubberized floors. In particular, these bulls were heavier at the end of the finishing period (Brscic et al., 2015b) with a higher average daily gain than bulls kept on concrete slatted (Cozzi et al., 2013; Brscic et al., 2015b). Moreover, Graunke et al. (2011) showed that bulls on rubber surfaces tended to be slaughtered at a lower age than bulls on concrete, with no variations on the dry matter intake in accordance with findings by Cozzi et al. (2013).

Space Allowance

As stated previously, space allowance is another important factor that affects health and welfare of finishing bulls reared under intensive conditions (EFSA, 2012; Rouha-Muelleder, 2012). No European Regulations impose exact standards dealing with the space allowance for fattening cattle, but they set a minimum space allowance of 3 m^2/head for animals until 500 kg, plus 0.5 m^2 per 100 kg for animals over 500 kg (SCAHAW, 2001). Only some recommendations have been published for the minimum space allowance for beef cattle and they are widely different among each other's. Considering the most frequent types of floor for fattening bulls, the fully slatted floor (**Table 2**) and the deep litter (**Table 3**), some of those recommendations are reported.

Regardless of the type of floor, an insufficient space allowance could force bulls to spend more time standing and performing abnormal lying-down and standing-up movements such as lying down sequence interruptions (Gygax et al., 2007b), and could increase their risks of trampling or stepping on lying pen-mates (Gupta et al., 2007). It could also affect the lying behaviours of bulls, reducing the number of lying bouts per day and their mean duration, and the time spent by bulls lying laterally on their side (Gygax et al., 2007b; Rouha-Muelleder, 2012). Improvements in the time spent lying were previously recorded by Kirchner (1987) and Ruis-Heutinck et al. (2000). These atypical behaviours due to the restricted space may result in higher stress levels of the animals firstly (Gupta et al., 2007), and in higher pressure and friction at the hocks secondary (Schulze Westerath et al., 2007). With regard to the sexual behaviour of finishing bulls, it has been observed that mounting behaviour seems not to be influenced by space allowance (Kirchner, 1987; Wierenga, 1987; Gygax et al., 2007b), even if EFSA (2012) suggested an increased occurrence of aggressive behaviours among pen-mats with restricted space allowance. There are conflicting results regarding the effect of space allowance on the hygiene condition of the animals. Hickey et al. (2003) and Gygax et al. (2007b) observed an improvement in animal cleanliness with larger space allowance, in contrast with past findings by Andreae et al. (1980).

Table 2. Recommendations dealing with the mean/minimum space allowance (m^2) for fattening cattle housed on fully slatted floors (*Source*: SCAHAW 2001).

Literature reference	Mean space allowance per animal (m^2)	Minimum space allowance (m^2) per specific class of weight (kg)				
		200	300	400	500	600
Dodd (1985)	-	-	1.4	-	2.0	2.2
Hardy and Meadowcroft (1986)	-	1.1	1.5	1.8	2.1	2.3
Jordbruhsinformation 2 (1998)	-	-	-		2.3	
Sundrum and Rubelowski (2000)	2.4	-	-	-	-	-

Table 3. Recommendations dealing with the minimum space allowance (m^2) for fattening cattle housed on solid floor like deep litter (*Source*: SCAHAW 2001).

Literature reference	Minimum space allowance (m^2) per specific class of weight (kg)				
	200	300	400	500	600
Hardy and Meadowcroft (1986)	3.0	3.4	3.8	4.2	4.6
Jordbruhsinformation 2 (1998)	-	-		4.5	
Sundrum and Rubelowski (2000)	-	-	-	-	4.6

Among numerous *management* factors affecting beef cattle welfare (*i.e*. mutilations, breeding and genetics, grouping of animals, human-animal interaction, etc.) the EFSA Panel (2012) emphasised the impact of the nutrition and feeding plans adopted.

Nutrition and Feeding Plans

In order to promote the maximum daily gain, beef cattle finished in specialized units are generally fed TMR based on maize silage and concentrate feedstuffs. Although a certain amount of long fibre roughages is provided to the maintenance of a certain degree of physiological ruminal function (Mazzenga et al., 2009), rations for beef cattle are particularly rich in rapidly fermentable carbohydrates derived from a mixture of digestible fibre and starch from cereals (EFSA, 2012). An excessively rapid fermentation of starchy cereals could result in decreasing of rumen pH that lead to destruction of many of the normal rumen bacteria and protozoa, destabilizing those microorganisms involved in regular fermentations (Nagaraja and Titgemeyer, 2007). This unstable rumen condition leads to subacute or acute acidosis that is identified as the primary disorder in cattle by SCAHAW (2001). Secondary disorders such as parakeratosis of the rumen epithelium, hepatic abscesses or laminitis in hoof horn might be associated with this pathology, even if their exact origin is unknown. It is likely that rumen acidosis causes the production of toxic factors like endotoxin that reach the portal circulation across the damaged rumen wall (SCAHAW, 2001).

MAIN CAUSES FOR LOSSES IN BEEF CATTLE

Respiratory Diseases

Bovine respiratory disease is considered the main cause for economic losses either in finishing beef (Buchanan et al., 2016) and in feedlot cattle (Taylor et al., 2010, Casas et al., 2011; Kuehn et al., 2011; Schaefer et al., 2012). It is a clinical condition characterized by multiple triggering factors such as bacterial pathogens or management or environmental influences (Edwards, 2010), that induces signs of discomfort, pain and distress, impaired breath, coughing, reduced appetite and weight loss. Economic losses are predominantly related to the costs for antibiotic therapies and for vaccination, and to the reduction in growth performance (Wittum et al., 1996; Buchanan et al., 2016). It was calculated that this economic loss is over $13.90 per bull reared in 1,000-feedlot cattle herd (Snowder et al., 2006). It was reported to be the main responsible for morbidity (75% of total diagnoses) and for mortality (40-50% of total mortality) in feedlot cattle (Edwards, 2010). The incidence of pulmonary lesions due to respiratory disease in published studies ranged from 43 to 72% (Wittum et al., 1996; Thompson et al., 2006; Schneider et al., 2009; Caucci et al., 2018).

Digestive Diseases

Intensive beef production systems are designed to maximize animal growth and profitability, generally by providing high-concentrate diets with small amounts of forage (Campbell et al., 1992), often as TMR in order to promote synchronized intake of concentrates and forages (Cozzi and Gottardo, 2005; Nagaraja and Lechtenberg, 2007). However, the scientific opinion on beef cattle welfare by EFSA (2012) suggested that beef cattle fed intensively on high energy rations (<15% physically effective fibre) are at a high risk of digestive disorders, representing a serious failure in management.

Ruminal Acidosis

As described in the previous paragraph, ingestion of high quantities of readily fermentable starchy cereals can lead to ruminal acidosis (Kleen et al., 2003; Calsamiglia et al., 2012). This pathological condition could develop in the early stage of fattening as a result of overly rapid transition from high-forage to high-concentrate diets (Bevans et al., 2005), or in the later stage of fattening due to excessive intake of non-structural carbohydrates (Nagaraja and Titgemeyer, 2007). Negative effects of ruminal acidosis on growth and health of beef cattle reared in intensive systems have been reported (González et al., 2012) and a high incidence of mortality has been diagnosed in cattle with severe case of acute acidosis (Nagaraja and Lechtenberg, 2007).

Locomotor Apparatus Diseases

The impact of lameness in cattle are gaining more attention because of reduced animal welfare and high economic losses both in dairy (Cha et al., 2010; Bruijnis et al., 2012) and beef cattle production systems (Compiani et al., 2014). Lameness resulted indeed one of the main causes for culling in dairy cattle after infertility and mastitis (Hernandez et al., 2011) and in beef cattle (Refaai et al., 2013). In past studies on feedlot cattle, the incidence of locomotor apparatus diseases was only second to that of respiratory diseases and it ranged between 16 to 22% of the total morbidity (**Table 4**).

Table 4. Total morbidity and incidence of respiratory and locomotory diseases in feedlot cattle (*Source:* Compiani et al. 2014).

	n of cattle	Total morbidity, %	Bovine respiratory diseases, %	Locomotor apparatus diseases, %
Church and Radostits (1981)	294.1	12.9	7.55	2.73
Edwards (1984)	250.5	9.0	6.03	1.98
Griffin et al. (1993)	1,843.7	13.1	-	2.1

ORIGIN OF LAMENESS IN BEEF CATTLE

Past studies identified different causes of lameness in beef cattle, such as trauma, osteochondrosis, septic joint disease, physitis and foot disorders (Murphy et al., 1975; Church and Radostits, 1981; Edwards, 1984; Griffin et al., 1993; Persson et al., 2007). Foot disorders, in particular, are responsible for approximately 70% of cases of lameness in feedlot cattle, being identified as the main cause of lameness (Church and Radostits, 1981; Edwards, 1984; Griffin et al., 1993; Murray et al., 1996; Miskimins, 2002). This result was recently confirmed by Newcomer and Chamorro (2016) who found foot diseases be the main cause of lameness in 84.7% cases in feedlot cattle. A study on intensive finishing bulls (Compiani et al., 2014) reported that lameness originated from foot diseases in approximately 66.3% of all cases and from specific arthropathies in 33.7% of all cases. With regard to the incidence of lameness in intensive finishing bull herds, Cozzi et al. (2013) and Brscic et al. (2015a) recorded on average 1 to 3% of lameness cases, respectively. In Norwegian beef-cow herds with different housing and feeding management, lameness was recorded in 1.1% of the animals (Fjeldaas et al., 2007). However, specific causes of lameness are still poor characterized for finishing beef cattle. Differently to dairy cattle where the routine inspection of feet through the functional claw trimming allows to identify and treat specific claw disorders at an early stage (Hultgren and Bergsten, 2001; Solano et al., 2016), investigations on the claw health through the functional trimming *in vivo* are rare in fattening bulls for economic reasons, for the shortness of fattening cycle and for the high risk of injuries for hoof trimmers. Moreover, the intensive management system adopted in beef farms, often characterized by reduced space per head, poor floor cleanliness, scarce human-animal interaction and not-trained stockmen (Compiani et al., 2014), could reduce the attention for the individual locomotion, underestimating lameness events.

Metabolic-mechanical Aetiology

Laminitis is defined as an inflammatory condition of the lamellae of the hoof (Nocek, 1996) and it is considered the most important claw disease in dairy cattle (Smilie et al., 1999; van Amstel and Shearer, 2006; Newcomer and Chamorro, 2016). It was reported to be the main cause of foot disorders both in dairy and feedlot cattle (Stokka et al., 2011). Specific foot disorders indeed are known as laminitis-related claw lesions such as sole haemorrhages, white line disruptions, sole and toe ulcers and double soles (Smilie et al., 1999; Sogstad et al., 2005; Greenough, 2007). Other clinical manifestations are poor horn quality and horn growth abnormalities (Compiani et al., 2014). In dairy cattle, it has been demonstrated that the primary cause of these claw disorders involves the disruption of claw horn synthesis leading to the reduction in the supportive capacity of its connective tissue (Ossent and Lischer, 1998). This condition increases the internal pressure on the sole from the third phalanx or pedal bone, transmitting greater forces to the sole area (Ossent and Lischer, 1998). However, the exact aetiology of such claw horn lesions remains obscure, being either associated to the magnitude and duration of external forces by the housing environment acting on the sole (Webster, 2001), and to the feeding plans adopted for the animals (Greenough, 2007).

External Forces by the Housing Environment

Claw-horn disruption, haemorrhages or white line diseases could be due to external mechanical forces from the environment (Mülling, 2002; Sogstad et al., 2005; Compiani et al., 2014). These mechanical influences include uneven forces arisen from the floor type and/or quality such as bad, hard, abrasive or slippery slats, or from the farm management such as narrow movement alleys or reduced space allowance. On one hand, uncomfortable environment and facilities could increase the aggressiveness of the animals and their competition among each other, predisposing them to the risk of traumatic injuries causing lameness (Greenough, 2007; Telezhenko et al., 2009; Compiani et al., 2014). On the other hand, a prolonged locomotion on hard concrete floors could increase the magnitude of external forces on the sole, unbalancing the weight-bearing distribution on the claw capsule (Greenough, 2007; Telezhenko et al., 2008). An improper weight-bearing balance on the sole of feet exposed to hard concrete floors could increase pressure concentrations in specific areas resulting in claw horn damages and lameness (van der Tol et al., 2002; Greenough, 2007). These areas of the sole might be more susceptible to alterations of the vascular system and to subsequent metabolic claw disorders. In particular, heel-sole junction area is firstly compressed at each stride of the animal by the expansion of the digital cushion on the wall above, being easily subjected to the development of disorders (Greenough, 2007; Shearer and van Amstel, 2013). Moreover, the weight distribution is uneven between lateral and medial lateral claws, with the latter one bearing more weight (van Amstel and Shearer, 2006). This is the reason why most of the lesions were recorded in the lateral claws than in the medial ones (Murray et al., 1996; Vermunt and Greenough, 1996; Fjeldaas et al., 2007; Newcomer and Chamorro, 2016). Movement and shifting of weight during locomotion could make the hind feet more predisposed to claw disorders than the front one (Fjeldaas et al., 2007; Newcomer and Chamorro, 2016). This uneven weight-bearing could be corrected by the routine functional claw trimming (Toussaint Raven, 1989) that consider the above assumptions as basic principles. However, as affirmed previously, this practice is not used in beef cattle during their finishing for economic and feasibility reasons.

Feeding Plans

The feeding regimen adopted on the intensive beef cattle production systems could be considered another important risk factor for claw horn lesions. Differently to dairy cattle, bulls are fed diets with high-nutritional level, high-energy and high quantity of fermentable carbohydrates, that could predispose them to the development of ruminal acidosis (Greenough, 2007). It is likely that the rumen flora during acidosis produce toxin, endotoxin and/or inflammation products (*i.e*. histamine) that could directly or indirectly affect the vascularization of the claws, leading to laminitic conditions (Plaizier et al., 2008).

Infectious Aetiology

Some claw disorders causing lameness could have an infectious origin. The main predisposing factor for the infectious disorders such as digital and interdigital dermatitis and heel horn erosion is the hygiene condition of the farm environment (Hultgren and Bergsten, 2001; Cook et al., 2004). Animal and floor cleanliness could be easily impaired by insufficient drained and scraped alleys (Graunke et al., 2011) or by bad quality of bedding materials (Brscic et al., 2015a). Moreover, seasonal effect was observed to be the second direct predisposing factor after dirtiness for infectious disorders (Sogstad et al., 2005; Sanders et al., 2009). In temperate climate conditions like in Italy, the farm environment is supposed to be wetter in winter that is the worrier season exposing claws to higher moisture (Cook et al., 2004; Espejo et al., 2006). It has been reported that claws that are continuously exposed to moisture become softer and more disposed to disorders (Borderas et al., 2004), both infectious and non-infectious ones.

Animal-related Factors

In addition to nutrition, external forces and hygienic farm conditions, other animal-related factors could predispose the animal to specific claw disorders causing lameness or complicate existing ones (Fjeldaas et al., 2007; Compiani et al., 2014). Townsend et al. (1989) reported that the probability to develop lameness in beef bulls is 7 times greater for bulls with the heaviest initial body weight than for those with the lightest one. Similarly, Stanek et al. (2004) found that the claw condition of fattening bulls become worse over time with an increase of animal body weight. Other studies instead reported a direct relation between claw disorders and age of the animals. In particular, Fjeldaas et al. (2007) found more infectious and non-infectious disorders with increasing age of bulls inspected. Some breeds seem to be more sensitive to lameness than others (Fjeldaas et al., 2007; Compiani et al., 2014). In particular, Charolaise has been considered a sensitive breed to lameness, especially after a long-term housing on concrete slatted floor (Refaai et al., 2013; Brscic et al., 2015b). However, it is likely that intrinsic characteristics of the genotype such as growth rate attitude or feed intake capacity and specific marketing choices such as feeding plan, slaughter weight or duration of the finishing could predispose them to it.

Conformation and dimension of the claws could also predispose animals to claw disorders and lameness (Vermunt, 2004). Abnormal claw shapes such as corkscrew claws were demonstrated to be frequently affected by haemorrhages of the white line and the sole, white line separations and sole ulcers (van Amstel et al., 2002), suggesting that any torsion of either the lateral or medial claw might increase the probability of lameness. Moreover, greater toe length as the result of overgrown claws along with a higher live weight could increase the load on the sole, predisposing claws to severe claw disorders and clinical lameness (Keane et al., 2015). Boettcher et al. (1998) found a negative correlation between toe angles' values and the appearance of clinical lameness. In particular, they showed that cows with sharper toe angles were genetically predisposed to clinical lameness.

Social interactions performed by fattening bulls such as mounting and fighting activities are necessary to establish the inner hierarchy among pen-mates (Phillips, 1993).

However, inadequate management or housing choices (type of floor, space allowance, etc.) impose animals to change their natural behaviour (Gupta et al., 2007; Gygax et al., 2007a) increasing the frequency and/or the magnitude of social interactions that could become more intense and powerful (EFSA, 2012). Increasing mounting activity, the risk to incur in traumatic injuries become higher especially for heavy animals and the hind feet could be subjected to frequent transitory loads that could impair their horn production (Vermunt and Greenough, 1996; Brscic et al., 2015a).

PREVALENCE OF CLAW DISORDERS IN BEEF CATTLE

Results available in literature regarding the distribution of lameness lesions in beef cattle are rare and widely conflicting. They refer to different beef cattle production systems, from the American feedlots (Miskimins, 2002), from commercial cow-calf operations (Newcomer and Chamorro, 2016) or from beef-cow herds (Fjeldaas et al., 2007). Moreover, the collection of claw disorders data was differently performed, for example analysing all medical records collected over a specific period on an experimental centre, or through *in vivo* functional claw trimming practice. Another relevant weakness is the lack of a specific claw recording scheme for beef cattle. The re-adaptation of existing protocols for dairy cattle could lead to the use of an improper nomenclature to identify specific claw disorders. All these observations justify the complexity of direct comparisons between new and existing data, either between dairy and beef cattle, and among different beef cattle production systems. In the light of the above considerations, one recent study observed that most cases of lameness in beef cattle from calf-cows operations had non-infectious aetiology (79.5% of all diagnoses). In particular, the most common disorders were corkscrew (25.6%) and vertical fissures (21.2%), followed by sole ulcers (14.2%), abscesses (11.1%), double soles (6.8%), white line disease (3.7%) and laminitis (3.7%) and were mainly detected on the hind limbs, and on the lateral claws in particular (Newcomer and Chamorro, 2016). Over the total diagnoses, 13.8% of cases had an infectious origin. Digital dermatitis was diagnosed in 6.0% and heel horn erosion in 5.8% of the cases, prevalently in hind feet. Claw lesion distribution was investigated in another study that considered a total of 362 Norwegian beef cows belonged to 12 herds

(Fjeldaas et al., 2007). Laminitis-related claw lesions were detected in 18.0% while infectious lesions in 16.6% of the total animals. Among the first category, the prevalence of white line fissures was the highest (8.3% in the hind claws; 0.8% in the front claws), followed by haemorrhages of the sole (7.8% in the hind claws; 0.6% in the front claws), haemorrhages of the white line (3.0% and 0.8% in the hind and front claws respectively), sole ulcers and double sole. Among the latter category, heel horn erosion was found in 16.1% of the animals in the hind claws and in 1.7% in the front claws and digital dermatitis in 2.2% of the animals only in the hind claws. Asymmetric and corkscrew claws were separately considered and were diagnosed with a higher frequency in the hind claws compared to the front claws. It interesting to notice that Fjeldaas et al. (2007) tested the variability of specific claw disorder among batches, resulting in herds with a high prevalence of animals affected by a given claw lesion and in herds with all healthy animals. This last result suggests the existence of possible associations between some management factors and specific claw disorders.

FINANCIAL IMPLICATIONS AND CURRENT RECOMMANDATIONS

In dairy farms, lameness has major financial and welfare implications (Esslemont and Kossaibati, 1997; Enting et al., 1997; Bruijnis et al., 2010, 2012). In particular, economic losses include direct costs for veterinary treatments but also indirect costs associated to the reduction of milk yield (Warnick et al., 2001; Amory et al., 2008) and of reproduction performance (*i.e.* prolonged calving intervals) (Hernandez et al., 2001). Moreover, lameness has considered the third main cause for early culling after infertility and mastitis (Collick et al., 1989; Refaai et al., 2013), becoming a serious economic concern for dairy farmers. From a recent survey on financial losses caused by lameness in intensive dairy herds made by Ózsvári (2017), the economic loss due to lameness in dairy units resulted very similar in different countries (United Kingdom, Hungary, The Netherlands) mostly ranging between €40 - 50 per head and €100 - 300 per lameness event.

Concerning in particular beef cattle production, lameness become a relevant economic issue also for the beef industry. In addition to the risk of culling of the lame animal, further economic losses for beef farmers arise from the additional time and labour for handling lame bulls on farm, antibiotic therapies, laboratory analysis, reduction of weight gain and, in most severe cases, the death of the animals which do not react to treatments (Miskimins, 2002). A survey conducted in the Western United States quantified a mean loss of the income of $4.23 per each 45.5 kg of body weight of lame bulls depending on the severity of lameness (Ahola et al., 2011). Regarding the losses associated to the growth performance, Griffin et al. (1993) reported that feedlot cattle showing lameness reduced their daily gain of 53 g compared to the healthy animals and their carcasses value depreciated by 50%.

As stated previously, farm management adopted in EU and national intensive beef production systems does not allow an accurate knowledge of the prevalence of lameness events (due to reduced space per head, poor floor cleanliness, scarce human-animal interaction, etc.). Consequently, estimations of the real economic losses related to this pathology are hardly performed. An Italian research group from the University of Milan (unpublished data) estimated a total loss of daily gain of 150 - 200 g during the entire cycle with a reduction of the carcass value by 20% and a total economic loss of €240 per animal in case of claw disorder. In case of severe lameness, the daily gain loss could reach up to 500 - 700 g with a reduction of the carcass value by 70%.

As cited previously throughout the introductory chapter, nowadays the EFSA is the most significant international organization concerning welfare of cattle. Following strictly the guidelines of the European Scientific Committee on Animal Health and Animal Welfare (2001), the EFSA (2012) Opinion on the welfare of cattle kept for intensive beef production reported some recommendations for the best farm management, feeding and housing solutions to prevent laminitis and lameness diseases, taking into account the wide scientific literature published. The main precautions involve the frequency of animal inspection, the diet and feeding management and the housing and flooring systems, and they could be summarized as follow. At least once daily inspection of the finishing bulls could be enough to detect lameness and treat it in a timely manner, consequently. In order to reduce the risk of bloat, sub-acute ruminal acidosis and its sequelae *(i.e.* rumen parakeratosis, liver abscesses and laminitis), diets for finishing cattle should include at least 15% physically effective fiber. Concerning the type of flooring system, the use of straw or sloped straw-bedded floors, partial rubberization or rubber mats on the top of concrete floors is suggested to reduce the prevalence of claws and legs lesions. Regardless of the floor type, the minimum space allowance should be 3 m^2 for an animal expected to reach 500 kg plus 0.5 m^2 for each 100 kg from 400 to 800 kg.

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CHAPTER 1

Aims of the Thesis

The general purpose of this PhD thesis was to analyse the impact on beef cattle health and welfare of some housing and flooring solutions mainly adopted in the intensive rearing systems. In particular, it aimed at investigating claws health status of intensively finished beef cattle belonged to different breeds and housed on different flooring systems (deep litter, fully concrete slatted floor and rubber covered slatted floor). A further aim was the testing of possible preventing solutions against lameness.

The studies were described in 4 chapters:

- In the light of the rare published research concerning the claw disorder distribution in finishing beef cattle, the first step consisted in a *post mortem* inspection at the slaughterhouse that allowed to assess the claw condition of a large number of finishing beef cattle batches (**Chapter 2**).
- The second research aimed at assessing the prevalence of lameness, its severity degree (mild or severe) and its time of onset during finishing. This study focused the most prevalent intensive beef production system operating in Italy that consists of Charolaise bulls fattened in deep litter or fully slatted floor pens (**Chapter 3**).
- Considering alternative housing solutions to the concrete fully slatted floor, the third study aimed to assess whether growth performance, health, behaviour and claw condition of finishing bulls belonging to two beef breeds with different slaughter weight like Charolaise and Limousine, would be affected by their housing on a concrete or on a rubber covered slatted floor (**Chapter 4**).
- In order to prevent the negative impact of the new rubberized surfaces on the cleanliness of the animals, the last study was addressed to investigate the effects of an increased drainage area on hygiene, body condition, behaviour, claw- and leg health of fattening bulls kept in fully slatted pens equipped with rubber mats (**Chapter 5**).

CHAPTER 2

An overview of claw disorders at slaughter in finishing beef cattle reared in intensive indoor systems through a cross-sectional study

An overview of claw disorders at slaughter in finishing beef cattle reared in intensive indoor systems through a cross-sectional study

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ABSTRACT

This cross-sectional study aimed to assess in *post mortem* the prevalence of specific claw disorders and their location on the sole in hind feet of finishing beef cattle reared indoors under intensive production systems. Evaluation was made on animals that were introduced in the ordinary slaughterhouse planning, presumably with no signs of impaired locomotion or severe lameness. A total of 4292 hind feet (right and left) belonging to 153 batches were collected (average feet/batch 28.1 ± 5.62 (SD)) in 3 abattoirs in Northern Italy at three time points (April-June and September-October 2016; February-March 2017). One veterinarian performed the claw trimming first and then scored the presence of specific claw disorders and their position on the sole considering seven zones (in the digital and interdigital areas). All claw disorders in a specific zone were recorded as binary (presence/absence). Infectious (ILS), non-infectious (NILS), and global (GLS) scores were calculated considering both the type of claw disorder detected and the number of zones affected. Non-infectious disorders were the most common diagnoses among batches, mainly on the lateral claws and in the heel-sole junction area. In particular, white line abscesses and ulcers (sole and toe ulcers) were also found as two of the most debilitating and painful lesions with a non-negligible frequency. Infectious diseases, when occurring in a batch, spread to almost all feet. As expected, GLS distribution on the total feet inspected showed a non-harmful condition, given that the worst scores from 3 to 13 were assigned to a restricted sample of feet (15%) and were far from the maximum potential value of 50. However, the GLS of all batches monitored revealed 10 critical batches having no healthy feet or more than 50% of feet graded with the worst scores.

Since right and left feet of the same animal showed similar clinical diagnoses, a more efficient claw health evaluation system should consider only one foot.

Although all cattle inspected were supposed to have no evident locomotory problems before slaughter, the detection of several foot disorders and the considerable distribution in some batches might suggest poor conditions on farms affecting finishing beef cattle health, behaviour, and welfare. It is therefore advisable that possible predisposing factors of specific claw disorders on the farms of origin be investigated more deeply.

Key words: beef cattle, claw disorder, intensive system, lesion score, *post mortem* evaluation, welfare.

INTRODUCTION

In dairy cattle, where the study of lameness has been often focused, more than 80% of lameness events are caused by claw disorders (Shearer and Van Amstel, 2013). Claw lesions that result in lameness are considered a crucial welfare problem in dairy cattle and a serious economic concern by farmers (Bruijnis et al., 2012). The impact of lameness in terms of reduced animal welfare and high economic losses is becoming harmful also in beef herds reared in intensive production systems. A survey conducted in the Western United States quantified a mean loss of income of $4.23 per 45.5 kg of lame bull body weight depending on the severity of lameness (Ahola et al., 2011). Further economic losses for beef farmers arise from the additional time and labour for handling lame bulls on farms, antibiotic therapies, reduced weight gain, early culling and, in the most severe cases, the death of animals that do not react to treatment (Miskimins, 2002). Although it has been reported that herd-level prevalence of severe lameness in beef cattle reared indoors ranges from 1 to 3% (Cozzi et al., 2013; Brscic et al., 2015), the prevalence of specific claw disorders causing lameness is still poorly investigated.

Numerous studies on dairy cattle identified the main claw disorders affecting foot health with different impact on locomotion (Sogstad et al., 2005; Tadich et al., 2010; Egger-Danner et al., 2015; Solano et al., 2016). Among non-infectious disorders, the most frequent lesions are sole haemorrhages (SH), white line abscesses (WLA), toe and sole ulcers (U), and corkscrew claw (CC). Among infectious disorders, the most frequently detected are heel horn erosion (HHE), interdigital (ID) and digital (DD) dermatitis, and interdigital phlegmon (IP). Despite the fact that most of these claw disorders do not directly lead to severe lameness conditions, they predispose to other claw disorders, resulting in evident signs of impaired locomotion (Manske et al., 2002; Sogstad et al., 2005).

In dairy farms, the routine inspection of feet through functional claw trimming allows specific claw disorders to be identified and treated at an early stage, whereas this practice is not adopted for beef cattle due to the shortness of the fattening cycle and the high risk of injury for the trimmers. Moreover, the less attention given to individual locomotion under beef farm management systems, which provide reduced space per head, poor floor cleanliness, and scarce human-animal interaction associated with untrained stockmen (Compiani et al., 2014) might result in underestimating lameness events. This may account for the lack of information on the general health status of the claws in beef herds reared indoors under intensive production systems. Considering the unfeasibility of checking claw health conditions at farm level, collecting data at abattoir guarantees a more cost-effective opportunity for animal health monitoring and disease surveillance. In some countries, this approach has already been adopted for pigs (Scollo et al., 2017) and cattle (Losada-Espinosa et al., 2018).

The aim of this study was to monitor claw health status in intensively finished beef cattle through *post mortem* inspection at the slaughterhouse. In particular, after trimming, we assessed the prevalence of specific claw disorders and their location on the sole in hind feet of beef cattle arriving at the slaughterhouse and regularly introduced in the ordinary slaughterhouse planning. In parallel, the study aimed at creating an index capable of summarizing the information collected and describing the overall claw health status.

MATERIALS AND METHODS

Geographical scenario

The study was conducted in Northern Italy, the core area of the intensive beef cattle production that accounts for 70-75% of the total animals in the Country (ISMEA, 2016). The farms of origin of the animals adopted indoor housing in multiple pens and provided high-concentrate diets to promote maximum daily gain as described by Cozzi et al. (2009) and Compiani et al. (2014).

Collection of data

This *post mortem* evaluation was implemented as a cross-sectional study in order to assess claw health conditions in finishing beef cattle that entered the slaughter chain through the ordinary planning. Data was collected in 3 cattle slaughterhouses in Northern Italy from April 2016 until March 2017. Batches of cattle arriving at the slaughterhouses were inspected without interfering with slaughterhouse schedules at 3 different time points (assessments). The first assessment was made from April to June 2016 (10 sampling days), the second from September to October 2016 (11 sampling days), the third from February to March 2017 (9 sampling days). Each sampling day lasted from 06:00 h until 13:00 h with a target of inspecting six or seven batches per day. A batch was considered a group of cattle of the same breed and category (bulls or heifers) coming from the same farm and belonging to the same slaughter group (same loading, transportation, unloading, lairage time, and slaughtering process). In compliance with European Council Regulation 1/2005 (European Council, 2005), all bulls 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. Furthermore, during unloading, the veterinarian in charge of controlling animal welfare checked the general status of the animals to evaluate the correctness of their handling and transport.

Claw disorders assessment and measurements

A priori, the number of animals inspected was set at the first 15 for batches of more than 15 animals or all the animals in smaller batches. One assessor collected the anatomical part between hock and claw of the hind limbs from the animals maintaining individual recognition and progressive order. Limbs collected were tied onto a handmade support before being trimmed (**Figure S1**). The trimming of the sole horn was performed by the same veterinarian with an electric grinder following the basic principle of functional claw trimming described by Toussaint Raven (1989) that considers an adequate dorsal wall length of 75 mm and a minimum sole thickness of 5 mm for adult Holstein Friesian cows. After trimming, the veterinarian evaluated claw health conditions by looking for the specific claw disorders described in the International Committee for Animal Recording (ICAR) Claw Health Atlas (Egger-Danner et al., 2015) and noting their position on the sole considering seven zones identified by specific numbers for digital zones (from 1 to 6) and interdigital zones (10) (Shearer et al., 2004) (**Figure S2**). Each disorder in a specific area of the sole was recorded as a binary measure (presence/absence).

Claw lesion scores

In order to summarize overall claw condition, two specific weighted scores were calculated per foot, considering non-infectious and infectious claw disorder aetiology separately. For lesions that can affect more than 1 zone, such as sole haemorrhage (SH), white line abscess (WLA), and ulcer (U), different classes were created considering the potential number of zones affected on the sole, and a specific severity score was associated to each class (**Table 1**). For disorders that can affect only one specific zone, such as corkscrew and infectious lesions, a specific severity score was assigned whenever they occurred (**Table 1**). Analyses of literature published on the origin and severity of specific claw lesions in dairy and beef cattle were used to establish the scores assigned (**Table 1**). A non-infectious lesion score (NILS) was calculated per foot as the sum of the scores assigned to non-infectious lesions as follows: {[SH(0, 1 or 3) + WLA(0, 3 or 6) + U(0, 5 or 10) + CC(0, 1)] × 2} and ranged from 0 (no lesions) to a maximum of 40 (20 for the lateral claw and 20 for the medial claw). An infectious lesion score (ILS) was calculated per foot by summing the scores assigned to infectious disorders as follows: [HHE(0, 1) + ID(0, 2) + DD(0, 3) + IP(0, 4)], and ranged from 0 (no lesions) to a maximum of 10. Finally, a global lesion score (GLS) was calculated as the sum of the two previous scores and ranged from 0 (no lesions) to a maximum of 50.

Statistical analysis

All statistical analyses were carried out using SAS/STAT (Inst. Inc., Cary, NC) and XLSTAT (Addinsoft, New York, NY). For multi-zone lesions (≥1 zone), a new variable was created considering a single occurrence of the same lesion. In order to provide an overview of claw disorder distribution, preliminary descriptive statistics were compiled of all claw disorders detected at the slaughterhouse. The prevalence of batches affected and the prevalence of feet within batch affected per disorder was calculated using a Proc UNIVARIATE (SAS 9.3; SAS Institute Inc.). The cut-off value for the three claw lesion scores below which the worst 15% of feet may be found was identified using the 75th percentile of the score distribution. The overall prevalence of feet per score class and the partition in right and left feet were calculated subsequently. The difference between the proportions of feet in a given score class of the right and left feet was evaluated using a Z-test. The effect of the time point on the non-normally distributed claw lesion scores was assessed using the non-parametric Mann-Whitney test. The minimum threshold of statistical significance was set at $P<0.05$.

RESULTS

A total of 2146 animals and 4292 hind feet (for 15 of which data is lacking) were inspected *post mortem* during 30 slaughter days at 3 time points. Animals belonged to 153 different batches from 80 farms ranging from 1 to 7 batches per farm. The number of batches observed was 47, 58, and 48 at the first, second, and third time point, respectively. The average number of animals monitored per batch was 14.0 ± 2.81 (SD) and the average number of feet inspected per batch was 28.1 ± 5.62 (SD). The overall herd level prevalence of claw disorders in specific sole zones is reported in **Table 2**. Regardless of lesion site, the overall prevalence of batches with at least one SH was 98.7%, those with one WLA was 54.9%, those with one U was 22.2%, and those with one infectious claw disorder was 83.7%. The prevalence of feet affected by at least one claw disorder varied greatly within batch from 0 to 100%. The most frequent lesion, SH, was observed in up to 96% of all batches monitored. The average within batch prevalence of feet affected by SH was higher in lateral claws than medial claws (50.2 vs. 25.9% of feet, respectively). Sole haemorrhage was more frequently recorded (in both higher number of batches and feet/batch) in zone 3 of both lateral and medial claws, and in zone 4, secondly (**Table 2**). In particular, the presence of SH in zone 3 on the lateral claws could be recorded in all claws evaluated within batch. A decreasing prevalence of batches with SH in lateral claw zones 5, 6, 2 and 1, and in medial claw zones 6, 2, 5 and 1 was recorded. A similar trend was observed in the average prevalence of feet with SH in these specific zones within batch. Lateral claw zones 5 and 6 could present SH in 70% and 90% of the feet evaluated within batch, respectively.

At least one WLA in the lateral claws was recorded in 52.3% of all batches monitored and the maximum prevalence within batch of feet affected by this disorder was 50%. The proportion of WLA in medial claws was lower than that in lateral ones considering both prevalence of batches and feet within batch. In particular, lateral claw zone 3 was the most affected by WLA, and was observed in almost 50% of all batches and in 50% of all feet evaluated within batch. A decreasing number of batches affected by WLA was progressively recorded in lateral claw zones 2, 5, 4 and 6, with an average prevalence of feet affected within batch equal to or less than 1%. Medial claws were affected by WLA only in zones 2 and 3, with the latter showing higher prevalence of affected batches and feet within batch. Ulcers were recorded in more than 10% of batches, with a higher prevalence of feet affected in lateral claws than medial claws. Ulcers affecting the toe (zone 1) were more frequently recorded than ulcers affecting the sole (zone 3 and 4), especially in lateral claws. The prevalence of feet within batch affected by ulcers reached a maximum 14% of all feet. Heel horn erosion was the most frequently recorded infectious disorder (**Table 2**), affecting lateral and medial claws equally in more than 50% of batches and an average of 17% of feet within batch. The within batch prevalence of feet showing this disorder varied from 0 to 100%. Interdigital dermatitis was detected in almost 30% of all batches and could affect up to 73% of all feet within batch. Although digital dermatitis was detected in a lower number of batches than ID, it could be found in nearly all feet within batch (92.9%). Interdigital phlegmon affected less than 1% of batches, reaching a maximum of 3.33% of feet affected within batch. Corkscrewed claws were detected in almost 6% of batches, and were observed in a maximum 10% of feet evaluated within batch (**Table 2**).

Figure 1 shows the distribution of the GLS on the total feet inspected: 31.4% of feet were completely healthy and 50.8% of feet were classified with GLS of 1 or 2. The maximum GLS value assigned was 13, a quarter of the potential value of 50, and 15% of all feet were classified over the GLS range of 3 to 13. **Table 3** shows the distribution of feet among different score classes. No differences in the percentage of feet within a given score class (**Table 3**) were observed for left and right feet.

Considering the infectious and non-infectious scores, 57 and 22 out of the total 153 batches inspected had more than 20% of feet with ILS ≥ 1 and NILS ≥ 3, respectively (**Table 4**). In 49 out of the total 153 batches inspected, more than 20% of feet were graded with a GLS ≥ 3 (**Table 4**; **Figure 1**). **Figure 2** presents the prevalence of healthy feet (with GLS = 0) and feet with GLS ≥ 3 for each batch monitored. Although none of the 153 batches had all feet completely healthy, the best batches (8 out of 153) had at least 80% of feet with GLS = 0. Another group of 8 batches showed healthy feet, 3 with more than 20% of feet having GLS ≥ 3 and 3 with more than 50% of feet having GLS ≥ 3. The worst condition was recorded in 10 batches (**Table 4**) that had 67.0% ± 13.4 of feet (mean ± SD) with GLS ≥ 3 and only 7.45% ± 9.21 of feet with GLS = 0. Feet conditions of these 10 batches is shown in **Figure 3** in greater detail. Eight out of 10 had feet with ILS ≥ 1, whereas the remaining 2 had no or few feet with infectious disorder and more than 50% of feet had NILS ≥ 3.

Variation in lesion scores (mean ± SD) at 3-time points is reported in **Table 5**. Average ILS resulted higher for claws evaluated during the third assessment, lower for those evaluated during the second assessment, and intermediate for those evaluated during the first assessment. Higher NILS were assigned to claws inspected during the second and third assessments compared to those inspected during the first assessment. Global lesion scores resulted higher for claws at the third assessment, lower for those at the first assessment, and intermediate for those at the second assessment.

DISCUSSION

The present study offers a large sample of feet monitored at the slaughterhouse for an evaluation of the prevalence of claw disorders in intensively finished beef cattle and their distribution by claw zone. The choice to monitor hind feet only stems from results of previous studies in which a higher frequency of disorders was reported in hind claws than in front claws in both dairy and beef cows (Sogstad et al., 2005; Fjeldaas et al., 2007).

Most claw disorders of non-infectious origin (SH, WLA and U) affected the lateral claws, mainly sole zones 3 and 4. These zones are in the heel-sole junction area and the first to be compressed by the expansion of the digital cushion on the wall above with every stride the animal takes (Greenough, 2007; Shearer and Val Amstel, 2013). Moreover, given that the horn at the abaxial end of the white line in zone 3 is the softest horn of all zones, it is likely that these zones are more susceptible to alterations of the vascular system and subsequent metabolic claw disorders (Greenough, 2007). Sole haemorrhage was detected in almost all feet monitored and showed a higher prevalence than in studies on dairy herds (Solano et al., 2016). This difference suggests that cattle genotypes and management systems (such as feeding plans and housing solutions) used in beef and dairy farms might influence the occurrence of this disorder. A review on intensive beef cattle rearing systems in Italy (Cozzi et al., 2009) showed that fattening bulls and heifers are generally housed indoors in multiple pens and fed high amounts of concentrates. It is precisely these characteristics related to the intensification of both dairy and beef production systems that are primarily associated with SH (Bergsten, 2003; Sogstad et al., 2005). We could not exclude slight appearances of SH during functional *in vivo* trimming that do not directly lead to severe lameness events from being underreported, however. Conflicting findings from several studies on dairy cows raise issues about the impact of SH on animal locomotion. Some researchers associated more extended and severe SH with acute or sub-acute clinical signs of lameness (Bergsten, 1993; Manske et al., 2002), and with poor locomotion scores (Chapinal et al., 2009), whereas others did not find any difference in locomotion between cows having SH or not (Flower et al., 2005).

White line disease was considered one of the main causes of lameness in dairy cows (Manske et al., 2002; Tadich et al., 2010). The prevalence of WLA in the present study was lower than as reported for dairy and beef cattle in previous studies (Newcomer and Chamorro, 2016; Solano et al., 2016). Our finding of zone 3 as the zone most frequently affected by WLA was, however, confirmed by Greenough (2007). Poor farm management practices in dairy and beef farms seem to be the main cause of WLA risk. These include the adoption of suboptimal organization of animal traffic or loading on trucks, the choice to enlarge herd/group size and interrupt the social hierarchy that may lead to more inaccurate movements and abnormal foot loading, and the presence of wet and dirty floors that may increase the softness of the sole horn and its wear (Fjeldaas et al., 2007; Barker et al., 2009; Keane et al., 2015). Detailed information on housing and floor type, hygiene level, and the animal handling solutions adopted on the farms of origin would provide stronger evidence for the associations hypothesized above. As with WLA, the occurrence of infectious diseases detected in this study was lower than as reported by Newcomer and Chamorro (2016) and Solano et al., (2016) for beef and dairy cattle, respectively. The infectious aetiology of HHE, DD and ID is proved by the high prevalence of feet affected within batch, which could reach up to 100% of total feet inspected. Predisposing factors for these infectious disorders mainly include farm environment hygiene conditions easily impaired by insufficiently drained and scraped alleys or bad quality of bedding materials (Hultgren and Bergsten, 2001; Cook et al., 2004). Although information on the flooring systems at the farms of origin is unavailable, a recent survey on beef cattle housing systems set fully slatted floors as the dominant flooring solution due to their effectiveness in allowing animal body cleanliness and lack of costs for bedding material (Cozzi et al., 2009). Although this might explain why the occurrences of WLA and infectious diseases were lower than those of previous studies, its impact on foot health is no less alarming. Prevalence of U in the sole and toe zones were comparable to those reported in previous dairy and beef studies (Fjeldaas et al., 2007; Sanders et al., 2009). Some authors have suggested that these could be the results of sole haemorrhages (Lischer and Ossent, 2002) and this assumption could justify their frequent and exclusive presence in sole zones 3 and 4. Moreover, other authors have reported a strong relation between ulcers and metabolic and hormonal factors in dairy cows (Sogstad et al., 2005) but our data was insufficient to confirm this. Although the recorded prevalence of ulcers was lower compared to the other disorders, they should be given particular attention since they are considered the most common cause of lameness (Manske et al., 2002).

The lack of difference between the claw lesion scores assigned to left and right feet indicates the similar overall health condition of the two hind feet. This finding would support a *post mortem* foot inspection protocol with the analysis of only a single hind foot that enables a more detailed assessment of animal foot condition. Considering our severity scoring system, it should be emphasized that the maximum score assigned to 0.05% of feet was included within the first quarter of the entire GLS scale distribution and that only 15% of feet fell within the worst GLS class (from 3 to 13). The distribution of the overall feet condition among score classes and the herd-level prevalence of healthy feet show claw conditions in finishing beef cattle to be not very harmful. Despite the legal requirement that only sound cattle must be transported and enter the ordinary slaughter chain, with a limited reliability we could state that there was no evidence that impaired locomotion or severely lame cattle were introduced into the chain. However, the good condition of the inspected feet could support the general healthy status of bulls' locomotory apparatus and claws. It is likely that feet subjected to more severe laminitic conditions would be potentially identified with higher GLS than the maximum censored scores in this study.

One unexpected finding was instead the negative condition that showed a high prevalence in some batches of feet classified within the worst score classes, or no healthy feet. Analysing claw disorder aetiology in these critical batches reveals that most animals had predominant infectious diseases with secondary non-infectious problems while the others had a high prevalence of severe non-infectious diseases only. This evidence suggests the existence of specific critical points related to feeding, housing and management systems at beef farms capable of impairing feet conditions in different ways.

In this study, we decided to test the effect of the time point on claw health status, given that the three assessments were made in three periods of the year with different climate and environmental conditions. A confounding assessment time point/batch effect may likely exist because except for certain repetitions, different batches were monitored at the three points. However, the number of batches was sizeable within time point and similar among time points. The worst ILS and NILS were given to feet analysed during the third assessment, which was characterized by the cold, humid weather typical of winter in Northern Italy. In a temperate climate, farm environments are wetter in winter, and therefore claws are exposed to higher moisture (Cook et al., 2004; Espejo et al., 2006). Studies on dairy cattle report that claws continuously exposed to moisture become softer and more vulnerable to severe infectious and non-infectious lesions (Borderas et al., 2004). Seasonal effect is reported as being one of the main direct predisposing factors for infectious disorders after dirtiness

(Sogstad et al., 2005; Sanders et al., 2009), and it might be an indirect factor behind non-infectious lesions by making the horn weaker.

CONCLUSIONS

This *post mortem* inspection carried out at slaughter permitted the assessment of claw conditions in a high number of finishing beef cattle that belonged to different batches. Although animals were supposed to not have any evident signs of impaired locomotion or severe lameness when they arrived at the slaughterhouse, several infectious and non-infectious disorders were detected. Non-infectious disorders, mainly on the lateral claws and in the heel-sole junction area, were the most common diagnoses among batches. In particular, white line abscesses and ulcers, two of the most debilitating and painful lesions, were also found with non-negligible frequency. Calculating the foot GLS considering both the type of disorders detected and the number of zones affected might be a convenient way to assess overall claw health condition. As expected, GLS distribution on the total feet inspected showed a non-harmful condition for beef cattle, given that the worst scores were assigned to a restricted sample (15%) of feet and were far from the maximum potential value. Considering GLS distribution among batches permitted the identification of a few critical batches having from 50% to 100% of feet graded with the worst scores. Right and left feet of the same animal showed similar clinical diagnoses, thus presenting the possibility of considering only one foot when monitoring claw health conditions, in such way making this inspection system at slaughter more efficient.

Although the prevalence of these claw disorders was not high enough to cause evident signs of locomotory problems during loading and unloading, we cannot exclude the possibility that specific claw disorders could still affect the health, behaviour and welfare of finishing beef cattle, especially in some critical batches with frequent feet diseases. This finding recommends further investigations of possible predisposing factors on farms to prevent these pathologies.

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Table 1. Claw disorder descriptions along with proper references and specific weighted coefficients assigned to each level of claw disorder for the calculation of the foot claw lesion scores.

Claw disorder (Abbreviation)	Description	References	Level	Score
Non-infectious disorders				
Sole haemorrhage (SH)	The most common non-infectious claw disorder, suggesting that SH could be the first symptom after an inflammatory condition in the corium that arises during subclinical laminitis events	Bergsten, 1993; Sogstad et al. 2005; Solano et al. 2016; Miguel-Pacheco et al. 2017	none	0
			1 ≤ n of SH ≤ 3	1
			n of SH > 3	3
White line abscess (WLA)	Separation of the white line with necro-purulent inflammation of the corium due to the weakening of the suspensory apparatus, haemorrhages, accumulation of exudates and impaired horn production	Mülling, 2002; Egger-Danner et al. 2015	none	0
			n of WLA = 1	3
			n of WLA > 1	6
Toe and sole ulcer (U)	Ulcers, occurring in the apex of the toe or at the heel-sole junction are assessed in case of penetration through the sole horn. They are the result of haemorrhages and contusions in the corium, and associated with clear pain responses by the animals and with severe lameness events	Lischer and Ossent, 2002; Manske et al. 2002; Tadich et al. 2010; Wilhelm et al. 2017	none	0
			n of U = 1	5
			n of U > 1	10
Corkscrew (CC)	Any torsion of either the lateral or medial claw. Abnormal claw shapes such as CC often occur independently of most claw lesions but depend on stall/flooring systems or trimming practice frequency	Fjeldaas et al. (2007); Egger-Danner et al. 2015	no	0
			yes	1
Infectious disorders				
Heel horn erosion (HHE)	Characterized by fissures or craters of the heel that possibly extend to the corium	Egger-Danner et al. 2015	no	0
			yes	1
Interdigital dermatitis (ID)	Every type of superficial and mild dermatitis around the claws	Egger-Danner et al. 2015	no	0
			yes	2
Digital dermatitis (DD)	Painful infection of the digital and/or interdigital skin with erosion and ulcerations	Egger-Danner et al. 2015	no	0
			yes	3
Interdigital phlegmon (IP)	Generalized swelling of the foot accompanied by a painful necrotic lesion in the interdigital skin and severe lameness	Shearer and Van Amstel, 2013	no	0
			yes	4

Table 2. Prevalence of claw disorders detected in 153 batches of finishing cattle slaughtered in Northern Italy, calculated as the number of affected batches divided by the total number of batches monitored and within batch as the number of affected feet divided by the total number of feet evaluated (min - max).

	Lateral claw		Medial claw		Interdigital area	
	% of affected		% of affected		% of affected	
	batches	feet	Batches	feet	batches	feet
Non-infectious disorders						
Sole haemorrhage						
≥1 zone	96.1	50.2 (0 - 100)	86.9	25.9 (0 - 93.8)		
zone 1	7.19	0.41 (0 - 18.8)	5.23	0.20 (0 - 6.67)		
zone 2	45.1	5.02 (0 - 43.8)	28.8	2.61 (0 - 56.7)		
zone 3	93.5	33.6 (0 - 100)	79.1	17.6 (0 - 87.5)		
zone 4	87.6	16.4 (0 - 59.4)	54.9	5.56 (0 - 30.0)		
zone 5	57.5	12.2 (0 - 70.0)	24.8	2.41 (0 - 43.3)		
zone 6	52.9	7.58 (0 - 90.0)	30.7	3.51 (0 - 45.0)		
White line abscess						
≥1 zone	52.3	6.74 (0 - 50.0)	13.7	0.76 (0 - 16.7)		
zone 2	18.3	1.19 (0 - 20.0)	5.23	0.25 (0 - 11.1)		
zone 3	49.0	5.90 (0 - 50.0)	11.1	0.51 (0 - 6.67)		
zone 4	0.65	0.04 (0 - 6.67)	-	-		
zone 5	1.31	0.04 (0 - 3.33)	-	-		
zone 6	0.65	0.04 (0 - 6.67)	-	-		
Ulcer						
≥1 zone	13.7	0.72 (0 - 14.3)	11.8	0.61 (0 - 10.0)		
zone 1 (toe ulcer)	12.4	0.69 (0 - 14.3)	11.1	0.60 (0 - 10.0)		
zone 3 (sole ulcer)	0.65	0.02 (0 - 3.13)	-	-		
zone 4 (sole ulcer)	1.31	0.04 (0 - 3.33)	0.65	0.01 (0 - 2.27)		
Corkscrew claw	5.88	0.36 (0 - 10.0)	-	-		
Infectious disorder						
Heel horn erosion	51.0	17.2 (0 - 100)	51.6	17.9 (0 - 100)		
Digital dermatitis					5.88	3.16 (0 - 92.9)

Interdigital dermatitis	25.5	4.40 (0 - 72.7)
Interdigital phlegmon	0.65	0.02 (0 - 3.33)

Table 3. Number and percentage of feet classified in a given score class (0 = no lesions) of the infectious, non-infectious and global score, and their pairwise comparison between proportions (%) of right and left feet belonged to 153 batches of finishing beef cattle slaughtered in Northern Italy.

Claw score	Class	n of feet (%[a])	n of feet (%[b])		*P*-value
			left	right	
Infectious lesion score	0	3314 (77.5)	1650 (77.0)	1664 (77.9)	0.500
	1 -5	963 (22.5)	492 (23.0)	471 (22.1)	0.500
Non-infectious lesion score	0	1764 (41.2)	902 (42.1)	862 (40.4)	0.262
	1	1246 (29.1)	614 (28.7)	632 (29.6)	0.522
	2	842 (19.7)	399 (18.6)	443 (20.7)	0.088
	3 - 13	425 (9.94)	227 (10.6)	198 (9.27)	0.163
Global lesion score	0	1341 (31.4)	693 (32.4)	648 (30.4)	0.168
	1	1279 (29.9)	623 (29.1)	656 (30.7)	0.255
	2	894 (20.9)	428 (20.0)	466 (21.8)	0.148
	3 - 13	763 (17.8)	398 (18.6)	365 (17.1)	0.219

[a] prevalence of feet assigned to a given score class over the total feet inspected at slaughter (No. 4277); [b] prevalence of right and left feet assigned to a given score class over the total left (No. 2142) and right (No. 2135) feet inspected at slaughter.

Table 4. Number of batches with different prevalence of feet (≤ 20%, 21 - 50%, and > 50%) having infectious lesion score ≥ 1, and non-infectious and global lesion scores ≥ 3, belonged to finishing beef cattle slaughtered in Northern Italy.

Claw score	Class	n of batch with			Total
		≤ 20% of feet	21 – 50% of feet	> 50 of feet	
Infectious lesion score	1 – 5	96	30	27	153
Non-infectious lesion score	3 – 13	131	19	3	153
Global lesion score	3 – 13	104	39	10	153

Table 5. Claw lesion scores (mean ± SD) assigned to feet of finishing beef cattle slaughtered in Northern Italy according to the effect of the time point.

Claw score	Time point			Significance
	Apr - Jun 16	Sep - Oct 16	Feb - Mar 17	
Infectious lesion score	$0.29^{b} \pm 0.75$	$0.17^{c} \pm 0.47$	$0.68^{a} \pm 1.10$	***
Non-infectious lesion score	$0.85^{b} \pm 1.24$	$1.25^{a} \pm 1.56$	$1.23^{a} \pm 1.36$	***
Global lesion score	$1.15^{c} \pm 1.39$	$1.42^{b} \pm 1.63$	$1.91^{a} \pm 1.77$	***

****P*<0.001.

Figure 1. The proportional frequencies (expressed as percentages) of beef cattle feet assigned a given score over the complete global lesion score scale (from a minimum of 0, to a potential maximum of 50) during the *post mortem* evaluation carried out in Northern Italy.

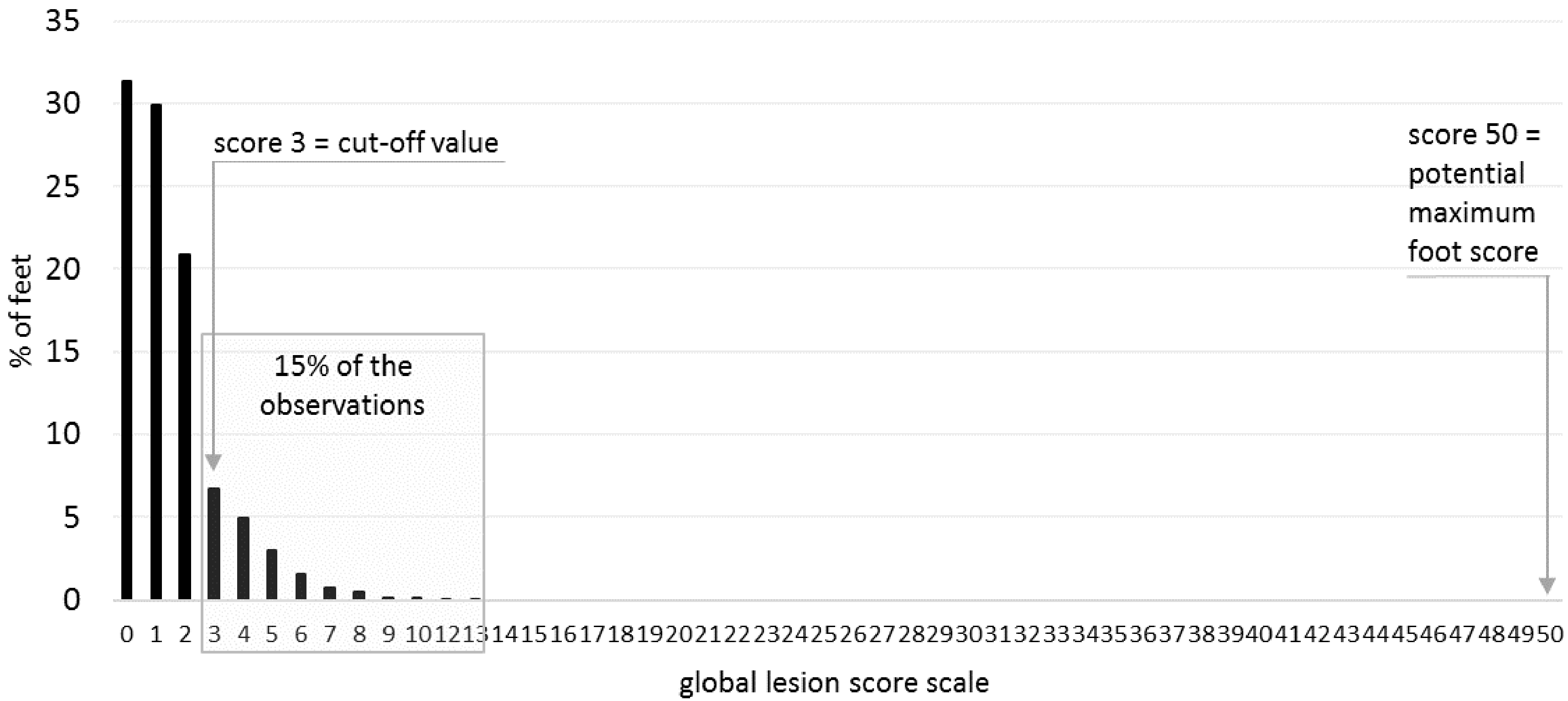

Figure 2. Prevalence of healthy feet (global lesion score = 0) and affected feet (global lesion score ≥ 3) per each of the total 153 batches monitored in Northern Italy.

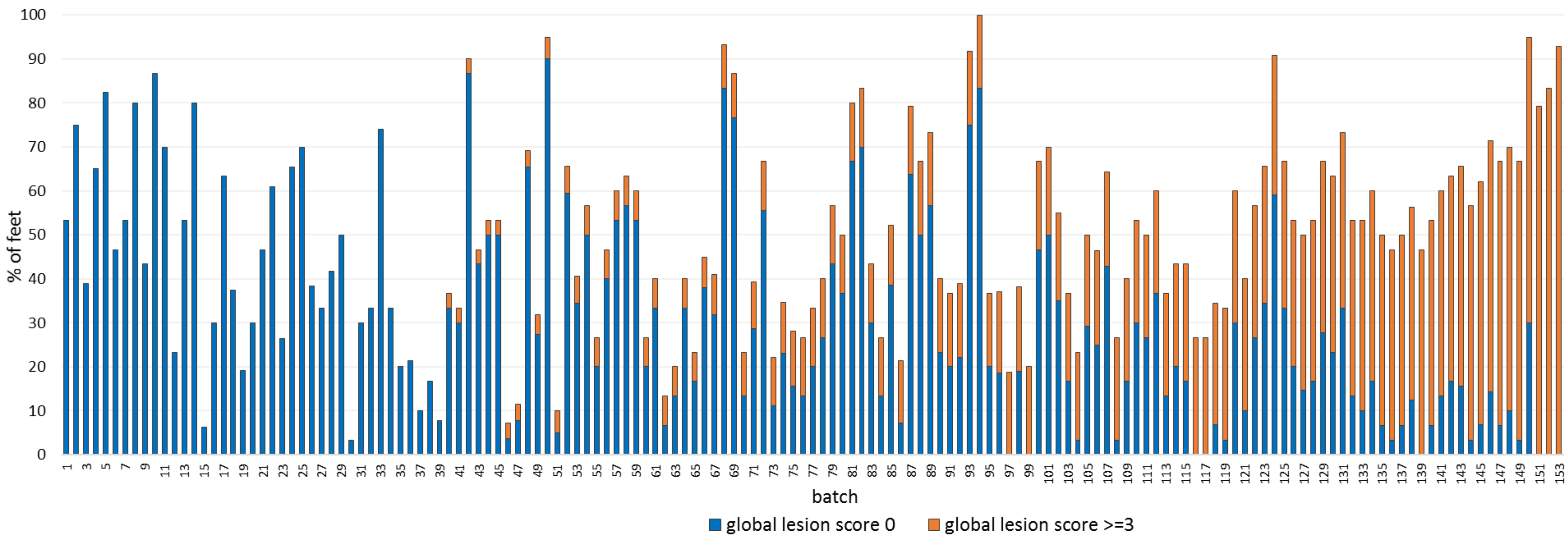

Figure 3. Discrimination of claw disorder aetiology (expressed as percentages of feet within a given score class) of the worst 10 batches inspected during a *post mortem* evaluation in Northern Italy having more than 50% of feet with global lesion score ≥ 3.

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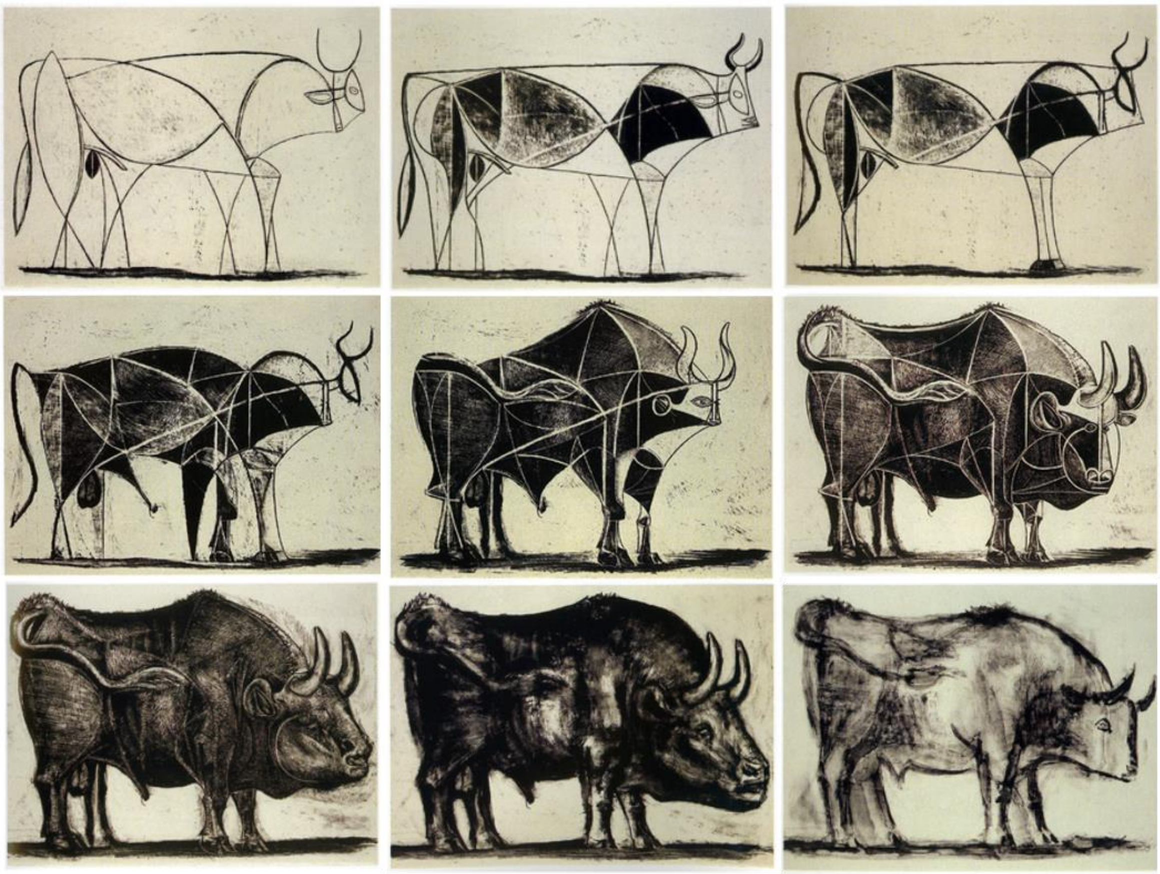
CHAPTER 3

Short communication: Time of occurrence and prevalence of severe lameness in fattening Charolais bulls: impact of type of floor and space allowance



Short communication: Time of occurrence and prevalence of severe lameness in fattening Charolais bulls: impact of type of floor and space allowance

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ABSTRACT

This study aimed at assessing the prevalence of lameness in a large number of batches of Charolais bulls housed in deep litter (DL) or concrete fully slatted (FS) floor pens with different space allowance. Data were recorded during 18 months from eight Italian intensive beef farms. Five farms housed bulls in DL pens, with space allowance of 5.0 m^2/head (two farms) and of 5.5 m^2/head (three farms), respectively. Three farms housed bulls in FS floor pens, with space allowance of 3.5 m^2/head (two farms) and of 4.0 m^2/head (one farm), respectively. Lameness events were recorded by a trained veterinarian and then categorized as: mild when they did not impair the regular conclusion of the fattening cycle of the affected bull; or severe when they imposed the early culling of the animal. Date and average body weight of each batch of bulls at arrival on farm and at slaughter were collected as well as those of severely lame bulls at the time of culling. The study analysed data of 314 batches for a total of 7201 bulls. Prevalence of bulls showing mild lameness was 1.23% and it was similar between types of floor. Severe lameness had a higher prevalence in bulls housed on FS than on DL floor (1.86 *vs*. 0.56%; P<0.001), and the relative risk of early culling in FS pens was more than three times higher than in DL pens. An increased space allowance from 3.5 to 4.0 m^2/head in FS floor pens acted as a preventive measure against both mild and severe lameness. A wider space allowance from 5.0 to 5.5 m^2/head in DL pens did not reduce the prevalence of severe lameness that however was always below 1%. Regardless of type of floor, severe lameness events were always recorded in the last part of the fattening cycle (178 $\pm$ 28 (SEM) days of fattening) and their occurrence was not affected by the space allowance within type of floor.

Key words: beef cattle, deep litter, mild lameness, severe lameness, slatted floor, space allowance.

INTRODUCTION

In Europe beef production is mainly carried out in specialized farms where cattle are intensively fattened in multiple pens with different types of floor. Beef farm's economics and production efficiency are negatively affected by both mortality and early culling rates. Type of floor and limited space allowances are considered relevant risk factors for beef cattle health by the EFSA Panel on Animal Health and Welfare (2012). The use of a fully slatted floor (FS) is not recommended for its slipperiness and for the risk of foot injuries (Ruis-Heutinck et al., 2000). Compared to the deep litter floor (DL), FS increased early culling rate due to musculoskeletal system pathologies/lameness (Brscic et al., 2015) and mortality of fattening bulls (Rumor et al., 2015). An insufficient space allowance could be also a main risk factor for lameness in fattening cattle since it could force bulls to spend more time standing and performing abnormal lying-down and standing-up movements (Gygax et al., 2007). Aiming at preventing leg and claw disorders in beef cattle, this study assessed the prevalence of lameness in a large sample of fattening Charolais bulls housed in DL or FS floor pens with different space allowance. Further aim of this research was to detect the time of the fattening cycle when a severe lameness event is more likely to occur in cattle housed on these two types of floor and to estimate the related production losses.

MATERIALS AND METHODS

Farms management and housing systems

The study was carried out in eight beef farms located in the Eastern Po Valley (Italy) that fattened Charolais bulls imported from France. According to the size of farm, batches of animals were regularly introduced to each fattening unit with a weekly or biweekly frequency. According to the farm biosecurity procedures, bulls were progressively acclimatized to the new rearing environment and management in dedicated barns that were separated from the fattening barns. At the end of this adaptation period that lasted 20 - 30 days, bulls were transferred to fattening barns and housed in small groups in multiple pens. All the farms considered in the study had a similar feeding management and cattle health supervision was in charge of the same veterinarian. During the fattening period, bulls were fed diets based on corn silage, cereal grains, soybean meal and cereal straw (mean protein 12.5 - 13.5% DM;

starch 32.0 - 38.0% DM and NDF 28.0 - 32.0% DM contents) that were provided *ad libitum* as total mixed ration with a single daily delivery in the morning.

The monitored farm sample differed for the type of floor and for the space allowance within a given flooring system as follows: 1) five farms had DL pens; two of them (farms A and B) had a space allowance of 5.0 m^2/head and three of them (farms C; D and E) had a space allowance of 5.5 m^2/head; 2) three farms had FS pens; two of them (farms F and G) had a space allowance of 3.5 m^2/head, and farm H had a space allowance of 4.0 m^2/head.

Data about the space allowance/head provided for each batch of bulls monitored were calculated dividing the total dimension of the pen by the number of bulls allotted, and then used for the farm sample categorisation.

Lame bulls recording

The study considered a period of 18 months, starting from June 2016. In all farms, all bulls were weekly inspected for their leg and claw health condition and the number of bulls showing a lameness problem during the fattening was recorded by the same veterinarian. The veterinarian gathered carefully all information about lame bulls in the farm book (*i.e.* treatment, time for healing, movements among pens, transport to the slaughterhouse, etc.). Successively, a trained assessor collected these data from all farms and categorized each lameness event according to two classes: 1) mild lameness that did not impair the completion of the fattening cycle requiring only a temporary removal of the affected bull from the fattening pen to a sick bay until healing; 2) severe lameness that imposed the early culling of the animal at the abattoir or at the farm, in urgent cases.

Growth performance

Data about date and average BW at arrival of each batch of bulls were gathered from the recording system of each farm. The same recording system provided information about date of slaughter and average slaughter BW of the same batches. Individual days of fattening and BW at the time of culling of each severely lame bull were recorded on farm.

Statistical analysis

Prevalence of mild and severe lame bulls recorded for each inspected batch were analysed using a GLM assuming a Poisson distribution (Proc Genmod of SAS 9.3; SAS Institute

Inc., Cary, NC, USA). The model included the fixed effects of type of floor (DL *vs.* FS), space allowance within type of floor (5.0 *vs*. 5.5 m^2/head for DL and 3.5 *vs*. 4.0 m^2/head for FS floor) and farm as random effect. Ls-means and relative risk (RR) with 95% confidence interval (CI) were calculated. Average batch BW at arrival and at the time of slaughter and batch fattening days were submitted to a mixed model (PROC MIXED of SAS 9.3; SAS Institute Inc., Cary, NC, USA) to test the effect of type of floor, space allowance within type of floor and farm as random effect. The same model was used to process BW and days of fattening at culling of severely lame bulls. Data were reported as Ls-means ± SEM. *Post-hoc* pairwise comparisons among Ls-means were corrected using the Bonferroni adjustment.

RESULTS

The study gathered data from 314 batches of Charolais bulls for a total of 7201 animals. Sixty-one batches (2388 bulls) were monitored in farms A and B where animals were housed in DL pens with a space allowance of 5.0 m^2/head; 188 batches (2262 bulls) were observed in farms C, D and E that had pens with the same flooring systems but a space allowance of 5.5 m^2/head. Data from 37 batches of animals (1407 bulls) housed in FS floor pens with a space allowance of 3.5 m^2/head were gathered in farms G and F and 28 batches (1144 bulls) were monitored in farm H in which bulls were housed in FS floor pens with a space allowance of 4.0 m^2/head. The prevalence of bulls showing signs of mild lameness was on average 1.23% and there was no difference due to the type of floor (**Table 1**). Bulls housed on FS floor had a higher prevalence of severe lameness compared to bulls on DL and the RR of occurrence of a severe lameness event was more than three times higher for bulls kept in FS than in DL floor pens (**Table 1**). A greater space allowance tended to be a preventive measure against the occurrence of mild lameness events for bulls housed on DL (P=0.08). In case of FS pens, an increase of space allowance from 3.5 to 4.0 m^2/head acted as a significant preventive measure against mild lameness events (**Table 2**). In case of severe lameness events, an increased space allowance was a preventive measure, only for bulls kept in FS floor pens (**Table 2**). The average BW at arrival was similar between type of floor and space allowance within type of floor (**Table 3**). There was no difference due to type of floor and space allowance within type of floor for the duration of the fattening cycle. However, for both types of floor the batches of bulls housed with a higher space allowance were sent to the abattoir at a higher BW (**Table 3**).

Severe lameness events were recorded in the last part of the fattening (178 ± 28 d) and their occurrence was not affected by type of floor and space allowance within type of floor (**Table 3**). The culling BW of severely lame bulls was on average 637.2 ± 42 kg and it did not differ between treatments (**Table 3**).

DISCUSSION

The Italian beef sector accounts over 1.5 million cattle produced per year, nearly one third of the total beef cattle fattened in Europe. Beef farms are mainly located in the Po Valley and they operate according to a rather standardized housing and management system based on the finishing of animals imported from abroad at an age of 10 to 14 months and an initial BW of 350 to 450 kg. Charolais is the main breed fattened in the Italian beef farms and batches of bulls are regularly imported from France throughout the year for a finishing period of about seven months (Gallo et al., 2014). Animals are fattened in dedicated barns where they are group housed in FS or DL pens.

In this scenario, FS floor confirmed to be a risk factor for leg and claw health of finishing Charolais bulls by increasing the frequency of severe lameness events that imposed an earlier culling of the affected bulls. It has been reported that claw tissue damages are more severe on a hard surface like the concrete slats because bulls may develop carpal and tarsal lesions, experience traumatic injuries during social interactions (*i.e*. mounts and fights) or suffer the over-wear of the claw horn resulting in white line diseases (Schulze Westerath et al., 2007; Tessitore et al., 2009). Bulls' discomfort towards this type of floor was confirmed by further studies in which finishing beef cattle, when given a free choice, showed a clear preference for soft flooring in the lying area such as straw bedding or rubber-coated slats (Ruis-Heutinck et al., 2000; Lowe et al., 2001).

Our results indicate that the risk of both mild and severe lameness events can be lowered on FS by a larger space allowance. As reported by Gupta et al. (2007), a limiting space on a hard and uncomfortable floor increases the risks of bull trampling or stepping on a lying pen-mate as well as the stress level of the animals.

As in previous studies (Tessitore et al., 2009; Brscic et al., 2015), DL floor confirmed to be a preventive solution against bull's lameness. However, the increasing prevalence recorded in the present study for mild lameness events in bulls kept on DL pens at 5.0 m^2/head suggests to provide a space allowance above this threshold. Some authors reported that cattle' activity could be affected by the total physical dimension of the pens rather than the individual space allowance (Telezhenko et al., 2012). In particular, they showed that, being equal the pen density, cows housed on larger pens are more active than those on narrower pens having access more free space, but using our data it is not possible to test these comparisons since pen density changes among farms.

Brscic et al. (2015) observed relevant signs of leg lesions after a long-term housing of beef cattle in finishing pens and in FS ones, in particular. Consistent with these findings, in this study, severe lameness events that imposed the early culling of bulls always arose in the last part of their cycle fattening. It is interesting to note that the time when a severe lameness event was more likely to occur did not differ according to the type of floor, but the type of floor affected the prevalence of the problem.

Our recording data aimed at assessing the production losses imposed by the severe lameness in beef cattle. Regardless of both type of floor and space within type of floor, the BW difference between the average batch slaughter weight and the average weight of a culled bull was always above 80 kg. However, it is likely that this loss was not only the result of the shorter fattening cycle imposed by the urgent slaughter of the lame animal. To support this hypothesis, we estimated for a healthy bull that regularly completed the fattening cycle, the average BW at the day of fattening in which a culling event due to a severe lameness frequently occurred. This value (679.1 ± 17.2 kg) was more than 40 kg higher than the average BW of a culled bull.

CONCLUSIONS

Lameness is a relevant health problem for beef cattle fattened in intensive systems that in the most severe cases imposes the early culling of affected animals with negative impact on farm's efficiency and economics. This study showed that severe lameness events mainly occur during the last part of the fattening, resulting in a body weight loss around 80 kg when compared to the slaughter weight of a healthy (not lame) bull. The risk to be culled due to a severe lameness has shown to triple for bulls housed in slatted floor than in deep littered pens.

Table 1. Effect of type of floor on the prevalence of mild and severe lameness (Ls-means) in fattening Charolais bulls.

	Type of floor		RR (95% CI)[a]	Significance
	deep litter	fully slatted		
Lameness (% of bulls)				
mild	1.34	1.05	0.78 (0.26-2.39)	ns
severe	0.56	1.86	3.29 (3.00-3.61)	***

[a] Relative risk (RR) and 95% confidence interval (CI) with deep litter as term of comparison; ns P>0.10; ***P<0.001.

Table 2. Effect of space allowance within type of floor on the prevalence of mild and severe lameness (Ls-means) in fattening Charolais bulls.

Type of floor:	Deep litter		RR (95% CI)[a]	Significance	Slatted floor		RR (95% CI)[b]	Significance
Space allowance (m^2/head)	5.0	5.5			3.5	4.0		
Lameness (% of bulls)								
mild	3.12	0.57	0.18 (0.03-1.25)	†	4.45	1.43	0.06 (0.02-0.17)	***
severe	0.61	0.53	0.87 (0.72-1.04)	ns	2.24	1.54	0.69 (0.67-0.71)	***

[a] Relative risk (RR) and 95% confidence interval (CI) with 5.0 m^2/head as term of comparison for deep litter; [b] Relative risk (RR) and 95% confidence interval (CI) with 3.5 m^2/head as term of comparison for slatted floor; ns P>0.10; †P<0.10; ***P<0.001.

Table 3. Effect of type of floor and space allowance within type of floor on the average body weight at arrival and at the slaughter and on the days of fattening of batches of Charolais bulls, and on body weight and days of fattening of early culled bulls due to a severe lameness event.

Type of floor (TF)	Deep litter		Slatted floor		SEM	Significance	
Space allowance (SA) (m^2/head)	5.0	5.5	3.5	4.0		TF	SA
Batch of bulls							
Body weight (kg)							
at arrival	424.2	401.5	391.7	406.1	23.8	ns	ns
at slaughter	724.2	770.2	722.8	753.4	17.1	ns	*
Days of fattening	209	240	216	210	27	ns	ns
Severely lame bulls							
Body weight at culling (kg)	634.3	633.7	641.2	639.7	40.9	ns	ns
Days of fattening at culling	179	186	183	162	27.8	ns	ns

ns P>0.10; *P<0.05.

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CHAPTER 4

Health, behaviour and growth performance of Charolais and Limousin bulls fattened on different types of floor

Health, behaviour and growth performance of Charolais and Limousin bulls fattened on different types of floor

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ABSTRACT

This study aimed at assessing whether growth performance, health, behaviour and claw condition of finishing bulls belonging to Charolaise (CH) and Limousine (LIM) breeds, would be affected by their housing on concrete (CS) or rubber covered (RCS) fully slatted floor. A total of 228 CH (116 on CS and 112 on RCS) and 115 LIM (57 on CS and 58 on RCS) bulls were housed in groups of 9.0 ± 2.1 (SD) animals/pen with an average individual space allowance of 3.1 ± 0.2 m^2. The draining gaps of CS and RCS pens were 16.9 ± 1.7% and 11.6 ± 1.2% of the total floor surface, respectively. Bulls of both breeds had similar initial BW and they were slaughtered at the achievement of a suitable finishing. Charolaise had a higher final BW than LIM (750.8 ± 8.6 *vs*. 613.7 ± 10.9 kg; $P<0.01$), and bulls of both breeds kept in RCS pens had higher average daily gain than in CS pens (1.47 ± 0.02 *vs*. 1.39 ± 0.02 kg/d; $P<0.05$). The percentage of bulls that were early culled ($P<0.10$) or treated for locomotor disorders ($P<0.05$) was reduced by RCS floor only for LIM, while RCS floor tended to prevent the occurrence of bursitis for both breeds. Proportion of bulls lying with one front limb extended was higher for CH than LIM bulls ($P<0.05$), and for bulls on CS than for those on RCS floor ($P<0.01$). Bulls on RCS performed more head butt/displacements and chases than those on CS floor ($P<0.05$), and they reduced also the frequency of unsuccessful lie down attempts ($P<0.05$) and of abnormal lying down events ($P<0.01$). The use of RCS floor increased the frequency of mounts only in LIM bulls ($P<0.05$), while its reduced drainage capacity impaired only the cleanliness of CH bulls ($P<0.001$). *Post mortem* hoof inspection at the abattoir showed a longer claw dorsal wall and diagonal lengths, and sharper toe angles for CH bulls kept on RCS floor than LIM bulls. The outcomes of the study should advise the use of RCS as alternative to CS floor only for bulls like LIM that are slaughtered at a final BW around 600 kg. Regardless of the rubber covering, the use of fully slatted floor pens should instead be discouraged for the finishing of heavy bulls like CH because of the negative impact on their health and welfare.

Key words: Charolaise, Limousine, health, type of floor, welfare.

IMPLICATIONS

Intensive fattening of late maturing breeds is the predominant beef production system in mainland Europe. These animals are often kept on concrete slatted floor during finishing but recently, positive effects on their welfare were reported for rubberized slatted floors. However, research on these two flooring solutions has never investigated the response of specific beef cattle genotypes with different slaughter weight like Charolaise and Limousine. This study suggested the use of rubber covered slats only for Limousine. Alternative flooring systems to the slatted floor must be tested for heavier bulls like Charolaise to prevent detrimental effects on their health and welfare.

INTRODUCTION

The European beef cattle production accounts for almost 8 million tons of meat with France and Germany as main producing countries, followed by United Kingdom and Italy (Hocquette et al., 2018). There is a wide diversity among beef producing systems across Europe depending on cattle genotypes, feeding and management solutions (EFSA, 2012). Dual purpose genotypes and crossbreds between dairy cows and late maturing beef bulls are largely reared in UK, Ireland and the Scandinavian countries. Late maturing beef cattle breeds are predominantly fattened in mainland Europe. Young stocks belonging to these beef genotypes are reared in their country of origin (France, Ireland and Eastern European countries) for 10 to 14 months of age and then they are transferred to the country of destination to be finished for 6 to 7 months in specialized fattening units (Gallo et al., 2014).

Italy imports about 1 million heads per year including young bulls and beef heifers, mostly from France and their fattening is mainly carried out in specialized farms located in the Po Valley (Cozzi, 2007). As reported by Gallo et al. (2014), Charolaise and Limousine are the most numerous imported French purebreds fattened in Italy. Charolaise is generally finished at a heavy slaughter weight due to its well-known growth potential, feed efficiency and carcass quality (Alberti et al., 2008; Clarke et al., 2009). Limousine is slaughtered at a lower final weight than CH and it is appreciated by the retail chain for its high dressing percentage, carcass (Alberti et al., 2008).

During the finishing period, beef cattle are group housed indoors in pens with different types of floor. The fully slatted concrete floor is the most frequent flooring system used in the European fattening units because it requires low space demands and it allows an efficient manure drainage without any bedding material and labour (Fallon and Lenehan, 2002; Cozzi et al., 2005). However, concerns about health and welfare of beef cattle kept on fully slatted concrete floors were raised by the EFSA Panel on Animal Health and Welfare, (2012). Findings by Platz et al. (2007) and Absmanner et al. (2009) showed a higher incidence of slipping events and abnormal movements when standing up and lying down for bulls kept on concrete slatted floors than for those housed on alternative flooring solutions like the deep litter or different rubber surfaces. Moreover, covering concrete slats with rubber mats improved bulls' daily gain, claw health and locomotion by decreasing the occurrence of swelling in the leg joints and of white line haemorrhages in the sole (Graunke et al., 2011; Elmore et al., 2015; Keane et al., 2015). However, the scientific research on housing solutions for fattening beef cattle has never investigated the response of specific cattle genotypes to different flooring systems.

The aim of the present study was to assess whether growth performance, health, behaviour and claw condition of finishing bulls belonging to two beef breeds with different slaughter weight like CH and LIM, would be affected by their housing on a concrete or on a rubber covered slatted floor.

MATERIALS AND METHODS

Farms, housing and management

The study was carried out on six commercial beef cattle farms located in the Po Valley, Italy. Farms belonged to the same beef producers' association that was in charge of cattle feeding and health management. In each farm, half of the experimental pens had a fully slatted concrete floor (CS) made of slats 100 cm long, 12.5 cm thick and a 3 cm gap with draining gaps of 16.9 ± 1.7 (SD) % of the total surface. In the second half of the experimental pens, concrete slats were covered with 30-mm of synthetic rubber (RCS) (Riverstick Industries Ltd, Cork, Ireland), designed to match the gap profile of the slats underneath and to allow the drainage of the manure with draining gaps of 11.6 ± 1.2% of the total surface.

A total of 343 finishing beef bulls (228 CH and 115 LIM) were included in the study as follows: 66 CH bulls (four CS and four RCS pens) in farm A, 47 CH bulls (four CS and four RCS pens) in farm B, 72 LIM bulls (three CS and three RCS pens) in farm C, 60 CH bulls (three CS and three RCS pens) in farm D, 55 CH bulls in farm E (three CS and three RCS pens) and 43 LIM bulls (two CS and two RCS pens) in farm F. In all farms, bulls were housed in groups of 9.0 ± 2.1 animals/pen, balanced according to their initial BW and the average individual space allowance was 3.1 ± 0.2 m^2. All pens were equipped with two pressure water bowls for the provision of drinking water. In all farms, bulls were fed a finishing total mixed ratio based on maize silage delivered ad libitum once a day in the morning (between 09:00 and 10:00 h). Diets offered to CH bulls had an average DM content of 58.6 ± 6.9%, a CP content of 13.5 ± 1.0% DM, a starch content of 31.5 ± 4.4% DM and an NDF content of 31.4 ± 4.4% DM. Diets provided to LIM bulls had an average DM content of 58.5 ± 5.4%, a CP content of 14.0 ± 1.2% DM, a starch content of 32.9 ± 2.4% DM and an NDF content of 29.6 ± 3.7% DM.

Growth performance and health status

Bulls of each experimental pen were weighed in group at the beginning of the finishing period and they were weighed again at the end of it that was set by a beef cattle market expert according to the achievement of a suitable finishing. Initial and final BW were used to calculate pen average daily gain (ADG). The same veterinarian belonging to the producers' association was in charge of bulls' health in all farms. Individual health status of the animals was daily checked throughout the finishing period. Visually sick/lame animals were temporary removed from the fattening pens to a sick bay to receive pharmaceutical treatment until healing (less than one week). The number of bulls that were treated for respiratory and locomotor disorders was recorded as well as the number of bulls that was early culled due to fatal or traumatic events or lameness. A trained veterinarian performed an individual bull's health check the last month of finishing. Each bull was visually inspected from the feeding alley, and the occurrence of front and hind leg problems such as bursitis (swelling), alopecia and lesion/wound were recorded as binary variables (presence/absence) according to the Welfare Quality® Assessment protocol for cattle (Welfare Quality®, 2009). The individual cleanliness of the animals, as sign of comfort around resting, was assessed according to same protocol for cattle (Welfare Quality®, 2009).

Behaviour

In each farm, two 8-h behavioural observation sessions were carried out during the study period by a fixed team of four trained assessors. The first observation session was carried out 1 month after the housing of the bulls in the experimental pens, whereas the second one was carried out 2 weeks before the expected slaughter day. Two assessors per each type of floor were in charge of the behavioural observations starting right after feed distribution: one assessor recorded the continuous behaviours and the other the events. Position and type of data recorded by each assessor changed in a rotational manner every 2 h to reduce the bias due to the observer effect. Standing/lying postures and eating, ruminating, inactive, resting and other activities of the bulls were recorded as continuous behaviours using the scan-sampling technique with a 5-min interval between two consecutive scans (96 scans/pen/observation session) (Martin and Bateson, 2007). At each scan, the number of bulls performing each continuous behaviour was recorded. Mounting, chasing, head butt/displacement, slipping, unsuccessful attempts to lie down and abnormal lying down were recorded as events whenever they occurred at pen level using the behaviour-sampling technique (Martin and Bateson, 2007). A fifth assessor was in charge of measuring durations of the lying down sequences according to the Welfare Quality® Assessment protocol for cattle (Welfare Quality®, 2009).

Post mortem claw measurements

All the animals were slaughtered in the same abattoir owned and managed by the producers' association. Front and hind feet of a minimum of nine bulls/type of floor/farm were randomly chosen and inspected *post mortem* by the same trained veterinarian. Similarly to the study of Platz et al. (2007), dorsal wall length, diagonal length and toe angle of lateral claws on the left feet and of medial claws on the right feet were measured.

Statistical analysis

Pen was the experimental unit for bulls' growth performance, continuous behavioural data and events. Initial and final BW, ADG and days of fattening were analysed using a mixed model that considered the fixed effect of breed, type of floor and their interaction, with farm as random effect and the Bonferroni adjustment option. Continuous behavioural data gathered using the scan-sampling technique were expressed as percentage of bulls performing each behavioural activity, while events were expressed as number of each event performed per bull during the 8-h observation session. These data were processed using a mixed model that considered breed, observation session, type of floor and breed × type of floor interaction as fixed effects, considering farm as a random effect, the observation session as repeated option and the Bonferroni adjustment option. Statistical analyses of variables expressed as proportions regarding treated and early culled bulls were performed using $\chi 2$ tests (with the Marascuilo procedure) to verify their association with the type of floor within breed. Variables gathered as binary regarding bulls' cleanliness and health were expressed as percentages of bulls. When the prevalence resulted ≥ 1%, they were tested for association with the type of floor within breed using the one-way logistic regression analysis, and the odds ratio and 95% confidence intervals were calculated using RCS as term of comparison. Claw measurements were analysed using a mixed model that considered the effect of breed, type of floor and their interaction as fixed and of farm as random effects, with the Bonferroni adjustment option. All data were processed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA).

RESULTS

Regardless of breed and type of floor bulls had similar initial BW at the onset of the finishing period (**Table 1**). Bulls were slaughtered when they reached a suitable finishing and their final BW differed according to breed and type of floor (**Table 1**). In particular, CH bulls were heavier at the end of the fattening period compared to LIM bulls (750.8 ± 8.6 *vs*. 613.7 ± 10.9 kg; $P<0.01$), and bulls kept in RCS pens had higher BW than those kept in CS pens (691.5 ± 8.0 *vs*. 673.0 ± 8.0 kg; $P<0.05$). There were no breed and type of floor effects on the duration of the fattening. Average daily gain tended to be higher for CH than LIM bulls (1.50 ± 0.03 *vs*. 1.36 ± 0.03 kg/d; $P=0.068$) and it was significantly higher for bulls housed on RCS than for those on CS floor (1.47 ± 0.02 *vs*. 1.39 ± 0.02 kg/d; $P<0.05$). No breed × type of floor interactions were observed for bulls growth performance (**Table 1**). Type of floor did not affect the percentage of CH bulls treated for respiratory and locomotor disorders, nor the percentage of CH bulls that were early culled due to traumatic events or lameness (**Table 2**). In case of LIM, RCS floor significantly reduced the percentage of bulls treated for locomotor disorders and tended to lower the number of early culled bulls (**Table 2**). Odds ratio values indicated that RCS floor tended to be a preventive measure against the occurrence of bursitis for both breeds (**Table 3**). The type of floor did not affect the prevalence of CH bulls showing lesion/wound or alopecia. Lesion/wound were detected in 1.2% of LIM bulls on RCS floor and in none on CS floor. No signs of alopecia were found in LIM bulls housed on both flooring systems. The risk to be dirty was higher for CH bulls kept in RCS pens than for those kept in CS pens, but it did not differ for LIM bulls housed on the same floors (**Table 3**).

Observation of continuous behaviour showed a similar proportion of CH and LIM bulls standing and there was no type of floor effect on standing behaviour (**Table 4**). Sternal recumbency with all four limbs folded underneath the body was the most frequent lying postures of all bulls and its recorded frequency did not vary between types of floor, nor between genotypes. The proportion of bulls lying with one front limb extended was higher for CH than LIM bulls (18.2 ± 0.9 *vs*. 13.0 ± 1.5%; $P<0.05$), and for bulls housed on CS than for those housed on RCS floor (20.0 ± 1.2 *vs*. 11.1 ± 1.3%; $P<0.01$). Breed and type of floor had no effect on the proportion of bulls lying with two limbs extended or with lateral recumbency, or resting. Both breeds performed eating and ruminating activities with a similar frequency and the type of floor did not affect them (**Table 4**). Bulls performed rumination predominantly during lying. Breed × type of floor interactions for the occurrence of events are shown in **Figure 1**. A significant type of floor effect ($P<0.05$) was observed for head butt/displacement and chasing events, that were recorded with a higher frequency in bulls of both breeds on RCS compared to CS floor (0.89 ± 0.10 *vs*. 0.55 ± 0.10 for head butts/displacements; 0.08 ± 0.01 *vs*. 0.03 ± 0.01 for chases). The use of RCS floor increased the frequency of mounting events only in LIM bulls while slipping events did not differ according to both breed and type of floor. Regardless of breed, bulls kept in CS pens had a higher frequency of unsuccessful lie down attempts (0.08 ± 0.01 *vs*. 0.03 ± 0.01; $P<0.05$) and of abnormal lied down events (0.02 ± 0.004 *vs*. 0.01 ± 0.004; $P<0.01$) than bulls in RCS pens. A significant breed × type of floor interaction (**Figure 2**) was recorded for the time required by bulls to lie down ($P<0.05$). In particular, lying down duration was longer for LIM bulls housed on CS floor, lower for CH and LIM bulls on RCS floor and intermediate for CH bulls on CS floor.

A total of 121 bulls were inspected at the slaughterhouse recording front and hind claw measurements (n = 480 claw measurements) (**Table 5**). Charolais bulls housed on RCS floor had longer dorsal wall lengths of both front and hind claws compared to CH bulls on CS floor and LIM bulls on both floors. Diagonal lengths of both front and hind claws were longer for CH bulls housed on RCS floor, shorter for LIM bulls housed on CS floor and intermediate for the others. Toe angles measured on both front and hind claws resulted greater for LIM bulls kept in RCS pens, intermediate for LIM and CH bulls kept in CS pens and lower for CH bulls kept in RCS pens (**Table 5**).

DISCUSSION

Supporting the previous findings of Alberti et al. (2008), the great growth potential of CH bulls resulted in a heavier slaughter weight than LIM bulls. Bulls of both breeds improved growth performance on RCS floor confirming the positive effect of rubberized concrete floors coverings reported by Brscic et al. (2015a) and Cozzi et al. (2013). In literature, Charolaise has been considered a sensitive breed to lameness, especially after a long-term housing on CS floor (Refaai et al., 2013; Brscic et al., 2015b). In the present study, the rubber covering of concrete slats did not reduce the number of CH bulls that were early culled but it tended only to lower the occurrence of bursitis. Results of our study showed that also LIM bulls suffered of the housing on hard surface like the CS floor, increasing the occurrence of bursitis and the prevalence of animals treated for locomotor disorders. In beef cattle, leg lesions have been associated to the exposure of the limbs to hard and abrasive surfaces (Platz et al., 2007; Schulze Westerath et al., 2007), and the increased prevalence of bursitis observed in our study for both genotypes on CS floor fully supports this finding. The occurrence of further integumental alterations such as lesion/wounds and hairless patches observed only in CH bulls might instead arise from additional stressors to their joints due to the heavier body weight which narrowed space allowance over time (Graunke et al., 2011; Wechsler et al., 2011; Elmore et al., 2015). Support to this assumption comes from Brscic et al. (2015b) who reported a higher occurrence of hairless patches and lesions/swellings in heavy bulls at the end of their finishing period. Absmanner et al. (2009) considered the extension of one front limb as a possible strategy to get some relief in the leg joints during lying. The reduced frequency of this lying posture observed in both genotypes when kept in RCS pens could be a sign of their better comfort. The additional stress coming from the heavy BW of CH bulls might explain the significant breed effect observed for this lying posture. Several authors (Platz et al., 2007; Graunke et al., 2011) hypothesized that the slippery surface of the concrete slatted floor was an explanation for the inhibition of social interactions involving powerful movements in beef cattle. Rubber covering has been proposed as an alternative solution to concrete floors capable to increase bulls' confidence to perform natural behaviours and forceful social interactions such as head butt/displacements, chases and mounts (Gygax et al., 2007b; Absmanner et al., 2009). In the present study, the number of all these types of pen-mates interactions increased when LIM bulls were housed on the RCS floors. Charolais bulls showed a similar trend, except for the mounting events that did not change according to the type of floor. Mounting is a sexual behaviour performed by fattening bulls to establish the inner hierarchy among pen-mates (Phillips, 1993). The breed × type of floor interaction observed for this behaviour might have several explanations. When housed on a floor like RCS that provides a satisfactory hoof grip, the aggressive temperament of LIM breed (Pochas et al., 2006) could have encouraged mounting events in an attempt to stabilize hierarchy among pen-mates. However, since it was demonstrated that finishing bulls change their behaviour in relation to space allowance (Gupta et al., 2007; Gygax et al., 2007a), we cannot exclude that the lower space allowance for CH bulls caused by their heavy BW might have inhibited the performing of extreme and more powerful social interaction.

It has been demonstrated that fattening bulls perform transitions more cautiously when kept on a hard and slippery floor like CS because they are painful and potentially traumatic (Platz et al., 2007). Consistent with Gygax et al. (2007b), in our study, all bulls housed in RCS floor pens had a lower frequency either of unsuccessful attempts to lie down and of abnormal lying down events, both well-known indicators of housing discomfort. The increased confidence towards the RCS floor was furtherly supported by the shortest lying down duration recorded on this type of floor. Bull cleanliness is an important hygienic and economic issue at slaughter, as extremely dirty animals could increase the risk of microbial contamination of carcass and meat (Lowe et al., 2001; Schulze Westerath et al., 2007). Research on flooring systems identified the drainage area and the floor material as the main factors affecting beef cattle cleanliness (Graunke et al., 2011). In our study, rubber covering reduced of 31% the drainage area of RCS pens but only the cleanliness of CH bulls was impaired. Based on the literature (Gygax et al., 2007a; Zerbe et al., 2008), we hypothesize that the increased faecal output as consequence of the heavy BW was the main responsible for the worsened cleanliness of these animals. Moreover, since a dirty and wet coat might cause bull discomfort increasing the risk of skin lesions (Bosilevac et al., 2005), the impaired cleanliness of CH bulls could explain the prevalence of integumental alterations recorded on RCS floor.

It has been reported that, regardless of the type of flooring system, the claw condition of fattening bulls becomes worse according to the increase of bulls' BW (Stanek et al., 2004) and age (Fjeldaas et al., 2007). Moreover, the low abrasiveness of rubber flooring has shown to increase the occurrence of greater claws at the toe level resulting in longer dorsal wall and diagonal lengths compared to concrete flooring (Zerbe et al., 2008, Telezhenko et al., 2009). Our *post mortem* claw inspection clearly confirmed these findings suggesting further interesting outcomes. All bulls increased claws length when kept in RCS pens however, a significant sharpening of the toe angle was observed only in the claws of CH bulls. These animals completed their finishing at a higher BW than LIM bulls and the sharpening of their toe angle might have been a way to bear a greater weight load over a longer period. This growth-wear unbalance of the claw horn would cause the shifting of the weight bearing point to the bulbs area (Toussaint Raven, 1985), predisposing the claws to develop specific disorders on the sole (Kremer et al., 2007). On the other hand, even a prolonged housing of CH bulls on concrete slatted floor is supposed to lead their claws to the development of sole and white line lesions, since abrasive and hard surfaces provoke an extreme wear of the claw horn (Graunke et al., 2011; Telezhenko et al., 2008).

CONCLUSIONS

On a perspective of the development of welfare friendly flooring systems tailor-made for specific beef cattle breeds, the use of RCS floor as an alternative to the CS floor should be advised only for bulls like LIM that are finished at a final BW around 600 kg. As in dairy cows, the problem of hoof overgrowth recorded on RCS floor for these animals might be prevented by introducing a certain percentage of a more abrasive surface in the floor pen. Results of this study show that, despite the positive growth performance, health and welfare of CH bulls finished at a final BW above 700 kg were impaired by their housing on both concrete or rubberized slatted floors. Therefore, alternative flooring systems to the fully slatted floor should be tested by future studies in order to improve health and welfare of these heavy animals.

Table 1. Growth performance of Charolais and Limousin bulls housed on different types of floor during the finishing period (Ls-means).

Breed (B)	Charolaise		Limousine			Significance		
Type of floor (TF)	CS	RCS	CS	RCS	SEM	B	TF	B×TF
Number of bulls	116	112	57	58				
Live weight (kg)								
Initial	427.2	431.7	370.5	368.7	32.2	ns	ns	ns
Final	739.6	762.0	606.4	621.1	11.2	**	*	ns
Days of fattening	222.5	221.0	179.2	180.4	21.0	ns	ns	ns
Average daily gain (kg/day)	1.46	1.53	1.32	1.40	0.03	†	*	ns

CS = concrete slatted floor; RCS = rubber covered slatted floor; ns *P*>0.10; †*P*<0.10; **P*<0.05; ***P*<0.01.

Table 2. Effect of the type of floor on the percentage of treated (for locomotor or respiratory disorders) and early culled Charolais and Limousin bulls during the finishing period.

Breed	Charolaise		Significance	Limousine		Significance
Type of floor	CS	RCS		CS	RCS	
Treated bulls (% of bulls)						
For respiratory disorders	4.31	4.46	ns	10.5	8.62	ns
For locomotor disorders	4.31	1.79	ns	15.8	1.72	*
Early culled (% of bulls)	6.03	3.57	ns	3.51	0.00	†

CS = concrete slatted floor; RCS = rubber covered slatted floor; ns *P*>0.10; †*P*<0.10; **P*<0.05.

Table 3. Effect of the type of floor on the prevalence (%) of Charolais and Limousin bulls showing a given health problem at *in vivo* health check 1 month before the end of the finishing period.

Breed	Charolaise				Limousine			
Type of floor	CS	RCS	OR (95% CI)[a]	Significance	CS	RCS	OR (95% CI)[a]	Significance
Bursitis	22.5	13.5	1.87 (0.90–3.88)	†	34.5	19.0	2.26 (0.95–5.33)	†
Lesion/wound	7.8	2.9	2.87 (0.74–11.1)	ns	0.0	1.2	-	-
Alopecia	9.8	8.6	1.15 (0.45–2.95)	ns	0.0	0.0	-	-
Dirtiness	43.5	67.6	0.37 (0.25–0.55)	***	37.0	44.8	0.724 (0.42–1.24)	ns

CS = concrete slatted floor; RCS = rubber covered slatted floor; [a] Estimated odd ratios (OR) and 95% confidence intervals (CI) using RCS within breed as term of comparison; ns P>0.10; †P<0.10; ***P<0.001.

Table 4. Effect of the type of floor on behavioural parameters of Charolais and Limousin bulls recorded during the 8-h observation sessions starting right after feed delivery at 1 month after the beginning and at 2 weeks before the expected end of their finishing period (Ls-means).

Breed (B)	Charolaise		Limousine			Significance		
Type of floor (TF)	CS	RCS	CS	RCS	SEM	B	TF	B×TF
Continuous behaviour (% of bulls)								
Standing	53.1	55.5	53.2	55.6	5.25	ns	ns	ns
Lying posture								
Sternal recumbency	32.6	34.3	34.1	36.5	3.34	ns	ns	ns
Sternal with one front limb extended	22.2	14.1	17.8	8.19	1.70	*	**	ns
Sternal with two front limbs extended	1.36	1.24	0.71	0.75	0.38	ns	ns	ns
Lateral recumbency	5.38	5.40	6.80	4.14	1.31	ns	ns	ns
Resting	35.6	31.6	34.1	31.9	3.93	ns	ns	ns
Eating	13.5	17.7	18.2	17.5	2.75	ns	ns	ns
Ruminating								
While standing	5.14	4.62	3.97	3.44	0.76	ns	ns	ns
While lying	11.3	12.9	12.8	12.5	1.96	ns	ns	ns

CS = concrete slatted floor; RCS = rubber covered slatted floor; ns P>0.10; *P<0.05; **P<0.01.

Table 5. Effect of the type of floor on front and hind claw measurements of Charolais and Limousin bulls at *post mortem* inspection (Ls-means).

Breed (B)	Charolaise		Limousine			Significance		
Type of floor (TF)	CS	RCS	CS	RCS	SEM	B	TF	B×TF
Number of bulls	37	36	24	24				
Front claws								
Dorsal wall length (cm)	7.58^{c}	8.78^{a}	7.68^{c}	8.27^{b}	0.11	†	***	**
Diagonal length (cm)	17.6^{b}	19.3^{a}	16.5^{c}	17.2^{b}	0.16	***	***	**
Toe angle (°)	59.6^{ab}	50.0^{c}	55.0^{b}	60.9^{a}	1.46	†	ns	***
Hind claws								
Dorsal wall length (cm)	7.59^{b}	8.86^{a}	7.55^{b}	8.01^{b}	0.13	**	***	**
Diagonal length (cm)	16.0^{b}	17.4^{a}	14.8^{c}	15.4^{bc}	0.17	***	***	*
Toe angle (°)	58.7^{ab}	49.5^{c}	54.5^{b}	60.4^{a}	1.20	*	ns	***

CS = concrete slatted floor; RCS = rubber covered slatted floor; ^{a,b} values within a row with different superscripts differ for P<0.05; ns P>0.10; †P<0.10; *P<0.05; **P<0.01; P<0.001

Figure 1. Effect of the type of floor × breed interaction on the number of events performed by bulls during the 8-h observation sessions (Ls-means). Different letters indicate significant differences within a given event (a,b: $P<0.05$; x,y: $P<0.10$).

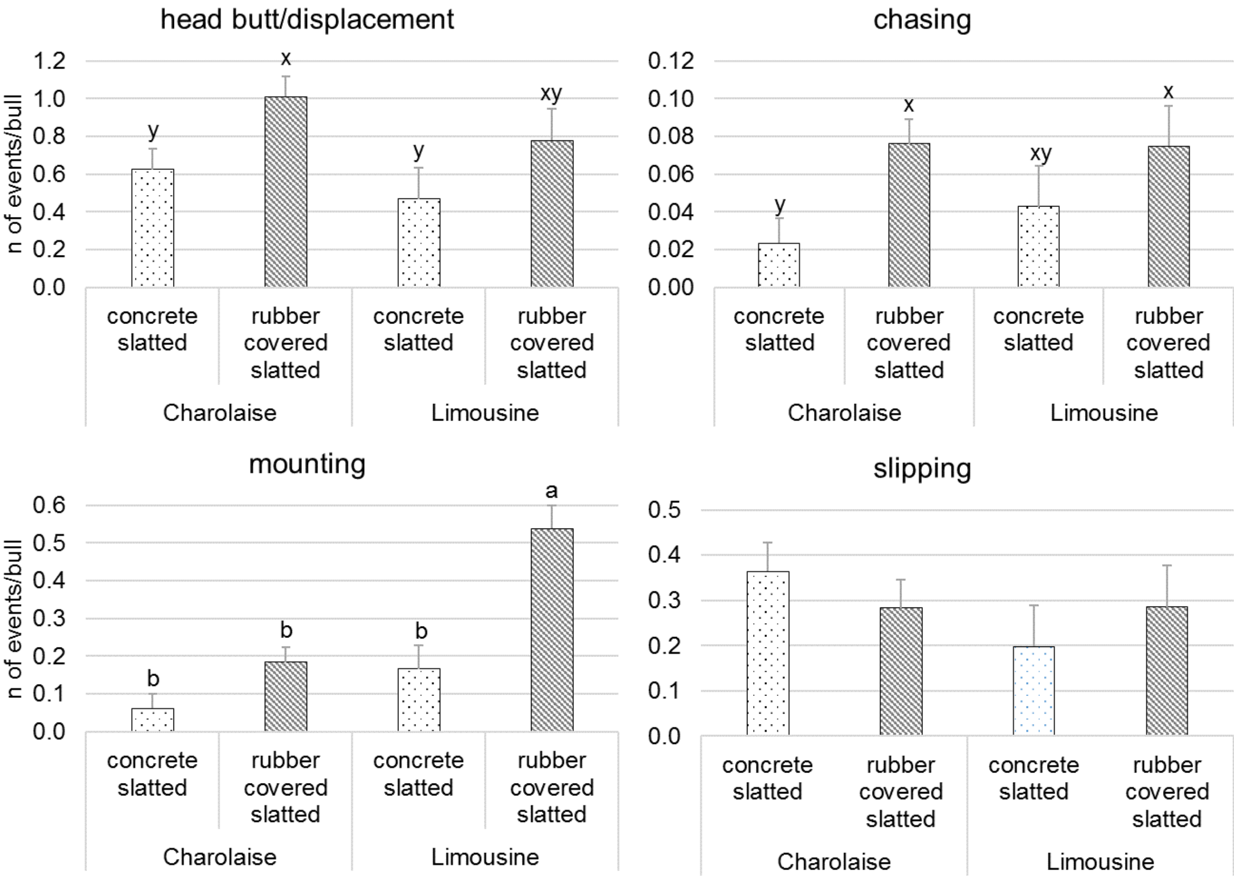
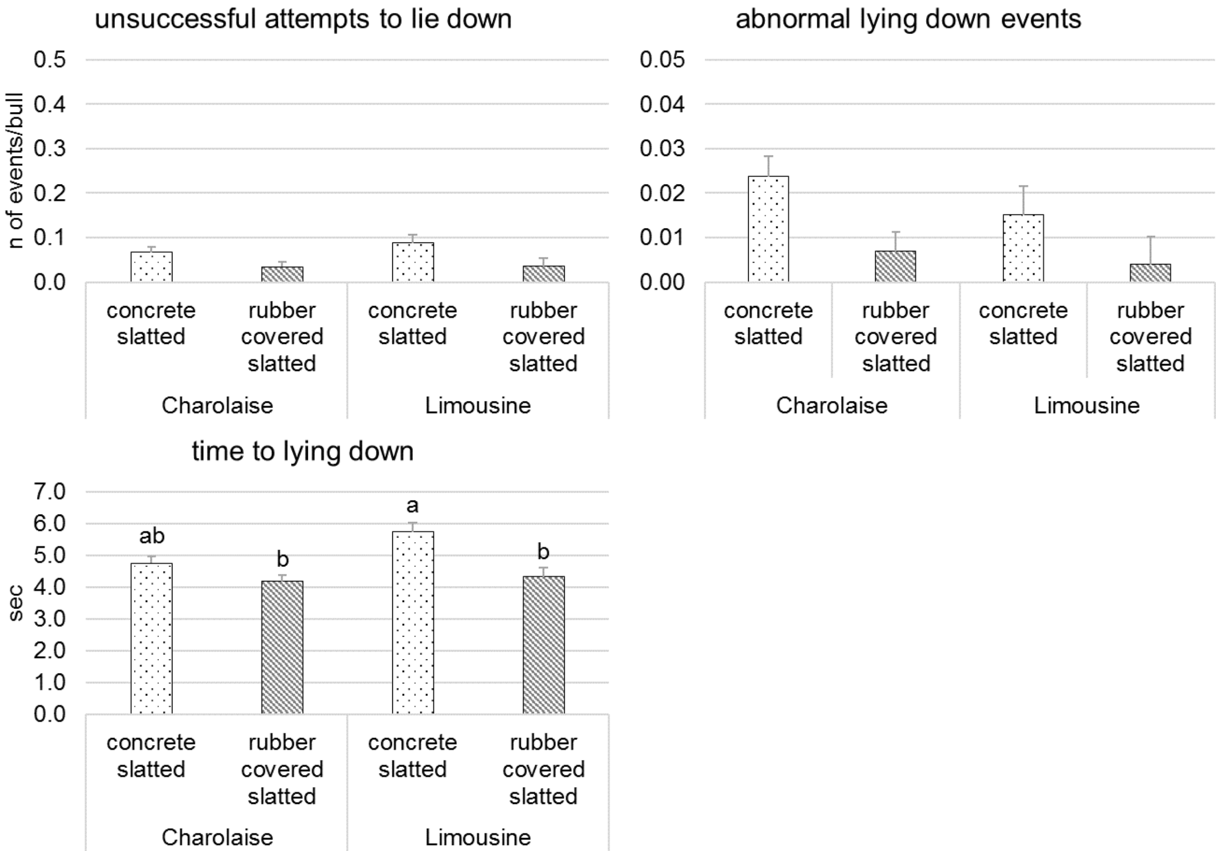


Figure 2. Effect of the type of floor × breed interaction on the lying down behaviour performed by bulls during the 8-h observation sessions (Ls-means). Different letters indicate significant differences within a given lying down behaviour for *P*<0.05.



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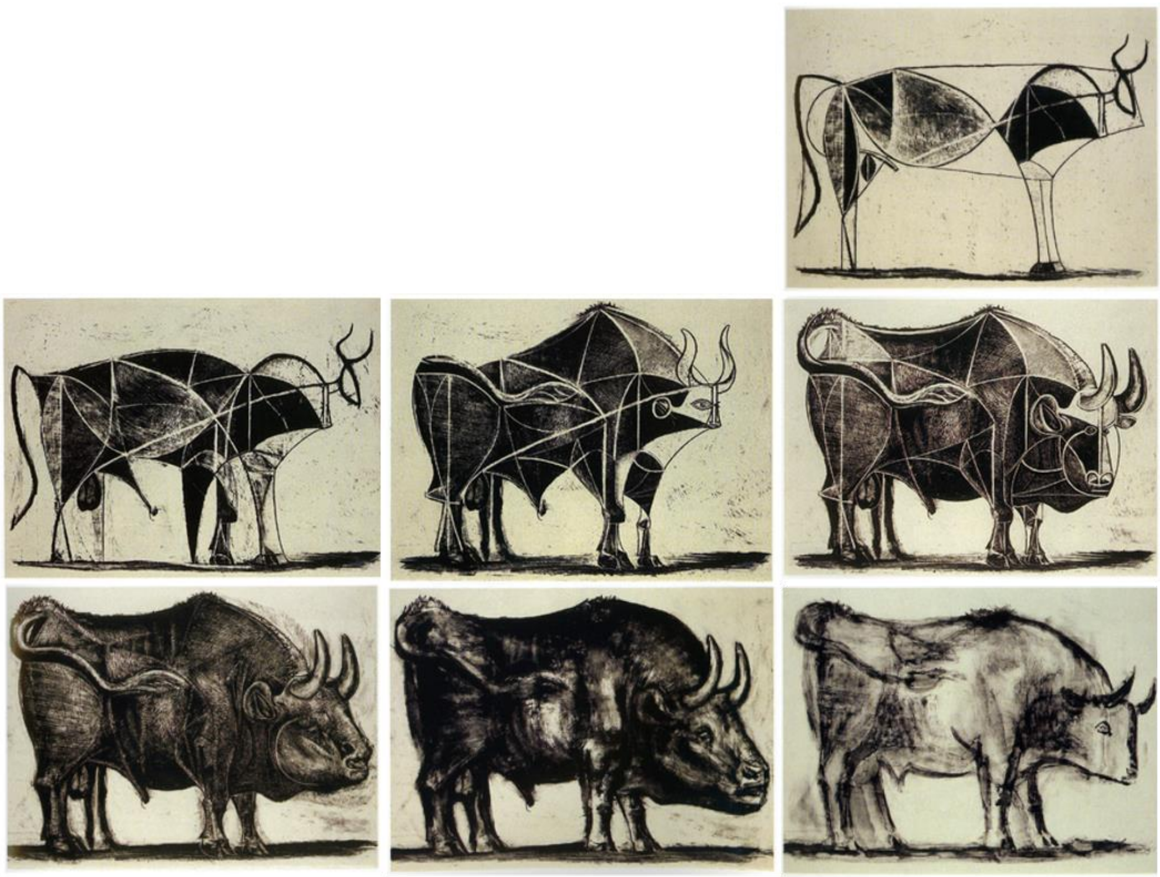
CHAPTER 5

Wider slots in fattening bull pens with fully slatted rubber mats to increase drainage area: Effects on animal hygiene, health and welfare



Wider slots in fattening bull pens with fully slatted rubber mats to increase drainage area: Effects on animal hygiene, health and welfare

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ABSTRACT

This study investigated the effects of increased drainage area by allowing wider slots in pens with fully slatted rubber mats on hygiene, body condition, behaviour, locomotion and leg and claw health in fattening bulls in Sweden. Bulls weighing less than 400 kg (Young) or more than 400 kg (Old) were housed (six per pen) in six fully slatted pens with 30 mm or 35 mm slot openings (Control), respectively. In three pens of each weight class (Young and Old), slot openings were increased to 35 mm and 40 mm (Test), respectively. All floors had rubber mats on top of the concrete slats and total drainage area was 14% for Control floors and 18% for Test floors. Animal body condition, hygiene level, hock lesions (swelling, hair loss and ulceration) and locomotion were assessed on eight observation days over a two-year study period. Two pens per floor type (Control and Test) were filmed for 14 hours during two sessions, to monitor animal behavioural activities, social interactions, lying postures and abnormal transitions. At slaughter, hind feet of bulls were measured, trimmed, photographed and evaluated for claw disorders by a veterinarian. Apart from body condition, all variables were binary. Wider slots did not affect animal hygiene, although three Control bulls and one Test bull were penalised at slaughter for poor hygiene. Young bulls were dirtier than Old bulls, especially on thigh/flank areas. Multivariate regression showed a higher risk of bulls becoming dirtier during winter months. The percentage of bulls showing locomotor or leg problems was generally very low and was not affected by the wider slots, although Test bulls showed a tendency to develop some swelling on hock and carpus. The Test floor did not impair bull behaviour, since few signs of poor comfort or abnormal movements were recorded and social interactions and transitions were similar between experimental floors. Test bulls were observed more frequently lying with one limb stretched out, likely a sign of good comfort. The Test floor reduced the frequency of asymmetric claws, but not the development of corkscrew or scissor claws. However, it did not cause relevant toe overgrowth. The wider slots of fully slatted Test floors with rubber mats did not affect the welfare of the bulls, but the 4%-unit increase in drainage area was not enough to achieve significant improvements in their hygiene.

Keywords: growing bulls, rubber mat, drainage area, hygiene, behaviour, claw disorders.

INTRODUCTION

Swedish welfare legislation issued in 2010 by the Swedish Board of Agriculture (SBA) requires the use of rubber or other resilient material on floors in fully slatted pens in newly built cattle barns. The mostly common solution at present is to install a rubber mat on top of a fully slatted concrete floor. Studies on slatted floors with rubber mats have shown increased comfort for lying, walking and standing cows (Telezhenko and Bergsten, 2005; Platz et al., 2007; Telezhenko et al., 2007) and improved leg and claw health (Kremer et al., 2007; Platz et al., 2007; Schulze Westerath et al., 2007; Graunke et al., 2011). For welfare reasons, slot width has been regulated by law and reduced from 40 mm to 35 mm for animals weighing more than 400 kg, and from 35 mm to 30 mm for animals weighing less than 400 kg. However, farmers claim that there has been a deterioration in animal hygiene following the change in the legislation on house flooring. A negative effect has been confirmed by studies reporting dirtier animals on concrete slats with slotted rubber mats than those on concrete slats alone (Lowe et al., 2001; Graunke et al., 2011). Animal cleanliness is an important welfare concern, since a dirty body can increase animal discomfort and skin lesions and poses a significant problem for food safety in terms of meat contamination at the slaughterhouse (Bosilevac et al., 2005; Hulsen, 2008). According to European Directive 2004/853/EC (European Council, 2004), animals that enter the slaughterhouse must be clean and must be evaluated for their carcass hygiene level using a four-point scale. Based on their cleanliness score, carcasses can be subjected to a payment penalty (Kött and Charkföretagen, 2008). Impaired cleanliness can be related to the limited drainage area of slatted floors, which is less with rubber mats than without any mats (Lowe et al., 2001; Fallon and Lenehan, 2002). Rubber mats indeed require a large surface for attachment to the underlying slats and to each other. The attachments reduce slot width openings and consequently the drainage effectiveness of the floor. Unfortunately, this problem has been exacerbated by the new legislation on resilient flooring materials, since the maximum slot width permitted between rubber slats remains the same as for concrete slats. Another point to be considered regarding this type of floor is the increased thickness of rubber slats through which manure drains.

Since the width of the slot openings between slats is regulated by the law and since the width of the slats themselves cannot be too narrow for reasons of material strength, the drainage area in rubber mat floors has become a rigid constraint. Although the maximum drainage area permitted by law for slatted floors in housing for young bulls is 28%, in practice it may be only 14% with slotted rubber mats (Graunke et al., 2011). Beside the drainage requirement, the choice of material and design of the floor should carefully consider the issue of leg and claws health, which can be impaired by handling fattening bulls, especially at the end of their finishing cycle. In particular, Graunke et al. (2011) observed a reduction in infectious claw disorders such as interdigital dermatitis and heel horn erosion on well-drained floors, whether bare concrete or covered with rubber.

The main objective of the present study was to investigate possible negative consequences of wider slots on the welfare (*i.e*. poor body condition, abnormal behaviour and locomotion, claw and leg problems) of fattening bulls housed in fully slatted pens with rubber mats. Another aim was to investigate whether increasing the drainage area from 14% to 18% improved animal hygiene.

MATERIALS AND METHODS

Experimental floors, animals and management

The study was carried out on a private farm located in southern Sweden, in a barn built in 2014 for housing fattening bulls. The barn has 12 pens, the dimensions of which comply with the current legislation regarding minimum area per animal at maximum weight (SBA, 2017). In the study, young bulls weighing <400 kg (Young) were housed in six pens (six bulls per pen) with a surface area of 12.09 m^2, which allowed 2.02 m^2 per bull. Bulls weighing >400 kg (Old) were allotted to the remaining six pens (six bulls per pen) which had a surface area of 13.95 m^2, allowing 2.33 m^2 per bull. There were also two sick pens, each with a surface area of 8.40 m^2. All pens had a fully slatted floor with rubber mats installed on top of each concrete slat element. The floor in the smaller pens for Young bulls had 30 mm slot openings and 100 mm slat width, while the floor in the larger pens for heavier bulls had 35 mm slot openings and 100 mm slat width. In three pens of Young bulls, the floor was changed from having 30 slot openings and 100 mm slat width (Control) to having 35 mm slot openings and 90 mm slat width (Test), Similarly, in three pens of Old bulls, the floor was changed from having 35 slot openings and 100 mm slat width (Control) to having 40 mm slot openings and 100 mm slat width (Test). Rubber mats were fitted on top of the concrete slats in all cases, creating a total drainage area of 14% for Control floors and 18% for Test floors. The Control floors were made by TCT (Thisted-Fjerritslev, Thisted, Denmark) and came topped with tailor-made mats in terms of opening size and slat width (30/100 mm or 35/100 mm). The Test floors were made by Nagl-floor (Martin Nagl Betonwerk GmbH, Wurmannsquick, Germany), also with tailor-made mats attached (35/90 mm and 40/100 mm). The mats were all made by Kraiburg Elastics (LOSPA Swiss, Tittmoning, Germany).

The barn is insulated and has natural ventilation. Air enters through adjustable light flaps along both long sides of the barn and is expelled from exhaust air ducts in the roof ridge. Underneath the slats, there is a culvert with automatic scrapers programmed to remove the manure twice a day.

Almost all animals (90%) included in the study were Holsteins, while the remaining 10% were Swedish Red cattle. On arrival, the animals were on average 4-5 months old and weighed 90 to 190 kg. Because of poor availability of calves, animals were gathered in the same pen until it was completely full. Young bulls were allotted to Control/Test pens with 30/35 mm slot openings. When these bulls reached 400 kg, they were moved to larger Control/Test pens with 35/40 mm slot openings. All animals received the same diet throughout the entire fattening period. The daily ration for each bull consisted of 2.5 kg of concentrate (Galant Fast, Lantmännen, Stockholm) and free access to grass silage (not analysed). The diet was provided manually twice a day, in the morning at 05:30 h and in the evening at 17:30 h. In the early afternoon (14:00-14:30 h), the farmer checked the amounts of residues in the feed gate and pushed them closer to the animals.

Bulls were slaughtered when they reached the required standard weight of about 600 kg after 17-22 months of fattening and 22-26 months of age. A person from the slaughterhouse selected mature bulls few weeks before slaughter. After each slaughter session, Young bulls were moved to the empty Test pens and new calves were recruited. During some periods of the year, some pens could not be filled because of poor market availability of calves.

During the experimental period, a total of 119 young bulls were assessed. Of these, 71 bulls were housed in Test pens and 48 in Control pens.

Animal health and hygiene

Throughout the experimental period, the body condition, hygiene and health status of the animals were assessed during eight observation days (OD), in April (OD 1), July (OD 2), August (OD 3), October (OD 4), December (OD 5) in 2016, and January (OD 6), May (OD 7) and July (OD 8) in 2017. It is likely that, during the eight observation days, some bulls were observed several times and a few only once. During each OD, a trained veterinarian visually inspected each bull from the movement alley and recorded the number of bulls in each pen showing signs of leg lesions (swelling, hair loss and wounds) and abnormal locomotion, scored on with a 3-point scale (Hulsen, 2008). The hygiene of hind parts of the animal body was assessed with a 3-point scoring system described by Sandgren et al. (2009). Moreover, the cleanliness of the animals was assessed in detail with a modified version of the 4-point scale proposed by Hulsen (2008), by evaluating separately the cleanliness in two areas of the body: 1) abdomen and hind legs and 2) thigh and flank on both sides. The body condition of bulls was also evaluated using a modified version of the 5-point scale suggested by Hulsen (2008). All parameters evaluated along with each scale point are explained in **Table 1**. In total, 401 individual observations were carried out for evaluation of body condition, health status and hygiene.

Animal behaviour

Two pens per floor type were continuously filmed with a video camera (Time Lapse HDR; TLC200 Pro, Brinno, Taipei City, Taiwan) attached to the beams in the roof in the feeding alley (height 3.0 m). The cameras, recording one image per 2 s, were run from 05:00 h to 19:00 h, during two observation sessions in April and in July 2017. Each hour of observation (HO) was coded according to the clock time, as HO 5 (05:00–06:00), HO 6 (06:00–07:00), HO 7 (07:00–08:00) etc. Using the recorded images, behavioural assessments of postures (standing/lying) and activities (eating, grooming, exploring, resting, and other activities) of each bull were made using the scan-sampling technique (Martin and Bateson, 2007), with a 5-min interval between two consecutive scans. Lying posture was recorded as sternal recumbency when all four limbs were folded underneath the body; extended limbs when one, two or three limbs were stretched out; and lateral recumbency when all four limbs were stretched out. Mounting, fighting, stereotypical behaviours and visits to the water bowl were recorded as events at pen level, using the behaviour sampling technique (Martin and Bateson, 2007). Using the same technique, the number of normal transitions, abnormal transitions (atypical lying down with hind legs first) and interruptions of lie-down pattern (sniffing and investigating the lying area, stepping forwards and backwards, kneeling on the carpal joints then standing up again) were also recorded, in order to obtain information about bull confidence in transitioning from standing to lying and vice versa (modified from Absmanner et al., 2009).

Claw measurements and health

At the slaughterhouse, the hind feet of bulls were collected and subsequently measured, trimmed, photographed and evaluated by one veterinarian. Dorsal wall length of inner and outer claws of each foot was measured using a vernier calliper. Claw disorders and alterations in conformation were recorded as a binary measure (0/1; absence/presence) according to the Nordic Claw Atlas (Bergsten et al., 2013).

Statistical analysis

Except for body condition, all variables were transformed as dichotomous (0/1; absence/presence) at individual level to simplify the original scoring systems. In particular, for cleanliness evaluation made in two separate parts of the body, 0 (absence) was given to assigned scores ranging from 1 to 2, while 1 (presence) to assigned score ≥3. For cleanliness evaluation made in the whole body, 1 (presence) was given to assigned scores ≥1.

Pen was taken as the experimental unit for data regarding cleanliness, health status and behaviour, and data were expressed as percentage of bulls (least squares (Ls)-means ± standard error of the mean (SEM)) scored dirty, having a given health problem or performing a given behavioural activity. All variables were normally distributed, except data regarding animal and claw health condition (Shapiro-Wilk $W<0.90$). Body condition score and cleanliness of abdomen/legs and thigh/flank were analysed with a mixed model (Proc Mixed of SAS 9.3; SAS Institute Inc., Cary, NC, USA) that considered the fixed effects of floor type (TF), weight class (WC), observation day (OD) and TF × OD and WC × OD interactions, with the repeated effect of OD and the nested effect of pen within (TF × WC) and the Bonferroni adjustment. Individual cleanliness of the whole body of bulls was analysed by a multivariate logistic regression procedure (Proc Logistic of SAS 9.3) using the Wald χ^2 test to assess potential risk factors. For each risk factor retained in the final model, odds ratio (OR) and 95% confidence intervals were computed. Because of the low prevalence of clinical signs recorded, a Z test was made to test the main effects of TF and WC only when the prevalence of a given health problem was ≥ 1. Behavioural activities and events were analysed with a mixed model that considered the fixed effects of TF, HO and their interaction. This model included the repeated effect of HO and the nested effect of Pen within TF, and the Bonferroni adjustment. The effect of WC was not tested for health and behavioural data. Regarding claw health recorded at the slaughterhouse, claw disorders and shape alterations showing a prevalence ≥1% were analysed with a Z test to compare floor types. Dorsal wall lengths were submitted to one-way ANOVA with a general linear model (Proc GLM of SAS 9.3) considering the fixed effect of TF, with batch as block effect. The minimum threshold of statistical significance was set at $P<0.05$ and a trend for a significant difference at $0.05<P<0.10$ for all parameters.

RESULTS

The multivariate regression for animal hygiene of the whole body showed no significant effect of floor type. A significantly higher OR for dirtiness was found in Young bulls than in Old bulls (**Table 2**). The risk of bulls becoming dirty was higher in particular at OD 5 and OD 6 than at OD 2, when they had the lowest risk of being dirty (**Table 2**). The percentage of bulls scored dirty on the upper part of the body (thigh/flank) was not affected by flooring, but it tended ($P=0.06$) to be higher for Young than for Old bulls (**Table 3**). This prevalence varied with OD, being higher at OD 4, OD 5 and OD 6 (in Oct-16, Dec-16 and Jan-17, respectively) than on the other observation days (**Table 3**; **Figure 1**). The percentage of bulls scored dirty on the lower part of the body (abdomen/legs) was not affected by TF or WC, but it varied with OD (**Table 3**). In particular, more bulls were scored dirty at OD 5, OD 6, and OD 7 (in Dec-16, Jan-17 and May-17, respectively) than on the other observation days (**Table 3**; **Figure 1**). Interactions between TF and OD or WC were not significantly different for the hygiene evaluation of either upper or lower body. Four bulls, of which three belonged to Control pens and one to a Test pen, were penalised at slaughter for poor body hygiene.

Bull body condition score did not differ between Control and Test pens, but it was higher for Old bulls than for Young bulls (**Table 2**). Although average body condition score did not fall below 2.85, a higher mean score was recorded at OD 8. There were no significant TF × OD and TF × WC interactions for bull body condition score (**Table 2**).

All bulls included in the trial completed their fattening cycle without relevant health problems. No bulls were observed with signs of hair loss or wounds. There was no significant difference between pen types in terms of the percentage of bulls showing abnormal locomotion. However, bulls housed in Test pens tended to develop more swelling on hock and carpus than bulls in Control pens (**Table 3**).

Behavioural activities and events performed by bulls were not affected by increasing the slot width (**Table 4**). However, there was a significant effect of hour of the day for activities such as eating (P<0.001) and grooming (P=0.03). A higher proportion of bulls eating was observed during HO 5, HO 14, and HO 18 (41.9 ± 3.5%, 41.3 ± 3.4% and 48.4 ± 3.5%, respectively), *i.e.* immediately after feed distribution or pushing-up in the manger. Grooming activity was performed more frequently by bulls during HO 6 and HO 15 (5.7 ± 0.9% and 3.3 ± 1.0%, respectively). A significant TF × HO interaction was found for the proportion of bulls standing (or lying), exploring, resting and performing other activities (**Table 3**; **Figure 2**). Pairwise comparisons between floor types within a given hour of observation showed a significantly higher proportion of Control bulls than Test bulls standing and exploring pen structures during HO 7 and HO 10. During the same hours, there was a higher proportion of bulls resting in Test pens. During HO 11, higher proportions of bulls were recorded resting in Control pens and performing other activities in Test pens.

Regarding the average number of events performed by bulls, the frequency of fights and visits to the water bowl was affected by the hour of the day (**Table 4**). In particular, for both events the highest peaks were recorded during HO 9 (1.0 ± 0.2 and 1.7 ± 0.3 for fights and visits to the water bowl, respectively), HO 15 (1.0 ± 0.2 and 1.5 ± 0.3) and HO 18 (1.3 ± 0.2 and 2.2 ± 0.3). There was no significant TF × HO interaction for any events recorded (**Table 4**). Lying postures were not affected by floor type (**Table 4**). However, the percentage of bulls lying on their belly (sternal recumbency) and with one or two limbs stretched out changed significantly according to the effect of the TF × HO interaction (**Table 4**; **Figure 3**). During four out of 14 hours of observation (HO 7, 10, 14, and 16), the percentage of bulls lying on their belly was higher for Control bulls than for Test bulls. In Test pens, a higher frequency of bulls lying with one limb stretched out was recorded during five out of 14 hours of observation (HO 7, 9, 10, 14, and 16). The percentage of bulls lying with two limbs stretched out differed between floor types during six out of 14 hours of observation, with a higher prevalence of Control bulls during HO 9, 11, 13, and 17 and of Test bulls during HO 7 (**Figure 3**). Regardless of floor type, bulls tended to lie down more frequently with three limbs extended right before feed delivery, *i.e*. during HO 5, 16 and 17 (P=0.09).

Results from the investigation of claw disorders are presented in **Table 5**. The percentage of feet affected by interdigital dermatitis and sole haemorrhage did not vary between types of flooring. Interdigital hyperplasia and white line lesions were detected in 2.56% of the claws from Control bulls, but in none of the claws from Test bulls. Corkscrew and scissor claws were only found in Test bulls, with an occurrence rate of 6.67% and 10.0%, respectively. However, a higher frequency of asymmetric claws was found in Control bulls. Length of the dorsal wall of both inner and outer claws was similar for Test and Control bulls (**Table 5**).

DISCUSSION

In the present study, the small difference in terms of drainage area between the two types of fully slatted rubber floor did not affect the hygiene of fattening bulls. It is likely that the 4%-unit increase in drainage area was not enough to improve the hygiene of the floor, and thus of the animals. Several studies have shown that floor properties, such as the drainage area, affect hygiene aspects of the animals that strictly relate to the hygiene condition of the floor (Lowe et al., 2001; Graunke et al., 2011). However, those studies compared concrete and rubber fully slatted floors and the difference in drainage area was greater than in our study. A drainage area of 18% was the maximum that could be achieved for the new type of floor with rubber mats in our study. In further investigations, it could be possible to increase the drainage area by reducing the slat width, taking into account the strength of the materials and animal welfare. Despite the lack of difference in animal hygiene between Control and Test bulls, based on the deduction in carcass payments imposed due to hygiene below the acceptable level, we could speculate that bulls housed on Control floors had worse hygiene. It is likely that the grading system adopted *post mortem* might be more rigorous than that adopted on-farm during the study. On farm, bulls weighing up to 450 kg showed a three-fold higher risk of becoming dirty than bulls weighing up to 650 kg. Since incidents of manure burn can damage the skin permanently, this should prompt farmers to maintain good hygiene of the floor and the animals early in the fattening cycle.

A higher percentage of bulls were scored dirty in December than in January, pointing to a clear effect of season on hygiene. Similarly, Swedish Animal Health Care and Taurus (2008) reported that animals entering the slaughterhouse in winter months are dirtier than those entering in other months of the year. A predisposing factor could be the higher environmental relative humidity during the winter season in Sweden (Wern, 2013), forcing animals to cope with wet surfaces. Wet floors can also increase slipperiness and the risk of injuries, especially for bulls housed on slatted flooring systems, impair coat cleanliness and limit the ability of animals to regulate their body temperature, leading to a higher incidence of respiratory diseases (Wechsler, 2011; Brscic et al., 2015a). However, in the present study health problems such as abnormal locomotion or swelling at the leg joints did not increase during winter months. The low occurrence of hock and carpus lesions in bulls housed on rubber floors is in line with results in previous studies on dairy cows testing the effects of harder and softer lying surfaces on animal health (Livesey et al., 2002; Rutherford et al., 2008). Softer lying surfaces, such as rubber mats or straw/sand bedding, do not have the hard, abrasive surface that increases the probability of external trauma such as carpal and tarsal lesions with concrete floors (Persson et al., 2007; Schlulze Westerath et al., 2007). In our study, the presence of abnormal locomotion and swelling was limited to the heavier bulls (up to 650 kg), and could be a result of powerful social interactions among pen-mates with increasing body size and therefore declining space allowance, over time (Brscic et al., 2015a). However, Test bulls tended to develop more swellings on hock and carpus than Control bulls. Schulze Westerath et al. (2007) suggest that development of superficial lesions at the hocks may be due to the size of the contact area and friction between the animal body and the surface. The increase in slot openings and the slight reduction in slat width of Test floors could have decreased the contact area between bull joints and the ground, increasing the pressure and friction at the hock level. Moreover, as Test pens were provided with newly manufactured rubber mats, it is more likely that the friction/abrasion of these mats was greater than that of mats in the Control pens, which were installed some years earlier. The larger slot width did not affect claw health and the prevalence of claw disorders was very low in all Test and Control bulls. These findings confirm that both rubber flooring systems allowed good claw health. The finding of some cases of interdigital dermatitis in Test bulls as well as Control bulls could be a result of low capacity of the new floor to improve bull hygiene. The few cases of claw shape alterations such as asymmetrical, scissor or corkscrew claws could be due to slight overgrowth of the claw horn, which is likely associated with the rubber flooring (Telezhenko et al., 2009; Brscic et al., 2015b). However, it is difficult to find an explanation for the specific shape alterations of the claws on the two types of floor. The dimensions of the claws inspected at the slaughterhouse were close to the ranges recorded by Platz et al. (2007) for group-housed fattening bulls kept in rubber-coated slatted floor pens and slaughtered at 21 months of age, and did not exceed the standards suggested by Dirksen (2002).

Behavioural observations showed that both floor types generally provided bulls with good comfort, since the frequency of atypical transitions and lying down interruptions was zero or very low. The low recorded frequency of interruptions of lying down is in line with results reported by Absmanner et al. (2009). Those authors found that all behavioural variables showing discomfort and atypical movements were less frequent in bulls housed on rubber-coated slatted floor pens than in bulls housed on fully concrete slatted floor pens. It has been widely reported that rubber mats for slatted floors improve the comfort of housed animals, reducing abnormal standing up and lying down movements and incomplete lying down transitions (Graunke et al., 2011; Cozzi et al., 2013). Ease of movement of bulls kept on both floor types (Test, Control) in the present study was also supported by the lack of difference in the number of transitions and in the percentage of standing/lying during the two 14-h observation sessions. Haley et al. (2000) suggest that animals feeling pain in carpal joints during lying periods avoid frequent getting up and lying down. The percentage of bulls we recorded standing up during 14-h observation sessions was similar to that recorded by Brscic et al. (2005b) during 8-h observation sessions on finishing beef cattle. There was no effect of floor type on bull behavioural activities, similarly to results reported by Elmore et al. (2015). However, the behavioural pattern of bulls varied over time in relation to the feed delivery. Most bull activities were similar between floor types within hour of observations, but during some observation sessions bulls housed on Control floors were more frequently observed standing up and more active (exploring pen structures and performing other activities) than bulls housed on Test floors. However, the number of social and sexual events, often characterised by extreme, powerful movements, were similar between floor treatments. These findings suggest that bulls performed their natural behaviours and were self-confident during the movement and the social interaction with other pen-mates. It can thus be argued that the 5 mm widening of slat openings did not impair the skid resistance of rubber floors and still provided good foot grip. As well as bull behavioural patterns, lying postures varied over time. During the observation sessions, Test bulls were more often observed lying down with one limb stretched out, while Control bulls lying down often had more than one limb stretched out. Considering the results of previous studies (Absmanner et al., 2009; Cozzi et al., 2013), an increase in number of outstretched lying positions could be considered a necessity to relief carpal and tarsal joints particularly compressed on cubicles with mattresses or hard concrete floors. The lower frequency of bulls housed on Test floors using outstretched lying positions with more limbs might be an indication of comfortable status of these bulls during lying. Moreover, regardless of floor type, more than half the bulls were generally observed to be lying with all four limbs folded underneath their body, probably a sign of them being confident in this posture.

CONCLUSIONS

This study found that a 4%-unit increase in drainage area of fully rubber slatted flooring did not seem to improve the hygiene of fattening bulls, although it reduced the number of carcasses penalised at the slaughterhouse for unacceptable hygiene level. However, in this study the narrower slot openings required by current animal welfare legislation in Sweden is unlikely to impair animal hygiene. Season of the year had the greatest influence on the hygiene of the bulls, which were dirtiest during the winter months. The behaviour of bulls on wider slots floor did not differ from that of bulls in the Control group. In particular, very few discomfort or abnormal movements were recorded and the frequency of social interactions was not reduced in any group of bulls. The most frequent lying posture with one limb stretched out adopted by the observed bulls might be a sign of good comfort. The wider slots did not affect the locomotion of bulls, but tended to increase the occurrence of swelling on hock and carpus. Although the new floor did not prevent the development of shape alterations such as corkscrew or scissor claws, it did not cause relevant toe overgrowth. Diagnosis of some cases of interdigital dermatitis indicated limited capacity of the new floor to improve bull hygiene.

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Table 1. Descriptive list of each score given to the recorded parameters.

Parameter Score	Description
Cleanliness of the whole body	
0	The animal is clean or some manure on the back and flanks
1	More areas (at least 3 portions) with dry manure, >10 cm in diameter on the back and flanks
2	Manure areas covering more than one-third of the back and flanks
Cleanliness of abdomen and hind legs	
1	No or very little manure area on hoof and lower leg/abdomen
2	Little manure area covering the lower leg/abdomen
3	Manure on the lower legs, but hair coat still visible
4	Legs mostly covered with manure, forming scabs on the thigh
Cleanliness of thighs and flanks	
1	No manure on thighs and flanks
2	Little manure area covering thighs and flanks
3	Manure on thighs and flanks, but hair coat is still visible
4	Thighs and flanks mostly covered with manure, forming scabs
Swelling on hock and carpus	
0	No swelling
1	Distinct and visible swelling
2	Swelling area >10 cm^2
Hair loss on hock and carpus	
0	No hair loss
1	Hair loss area <10 cm^2
2	Hair loss area >10 cm^2
Wounds on hock and carpus	
0	No wounds
1	Wound with blood area <2 cm^2
2	Wound with blood area >2 cm^2
Locomotion	
0	Normal
1	Normal standing posture but animal showing a curved back
2	Standing and walking with curved back, not loading one or more feet
Body condition	
1	Tail head: deep cavity with no fatty tissue under skin. Skin fairly supple but coat condition often rough: Loin-spine: prominent and horizontal processes sharp
2	Tail head: shallow cavity but pin bones prominent; some fat under skin. Skin supple; Loin: horizontal processes identifiable individually, with ends rounded
3	Tail head: fat cover over whole area and skin smooth, but pelvis can be felt; Loin: end of horizontal process can only be felt with pressure and only slight depression in loin
4	Tail head: completely filled and folds and patches of fat evident; Loin: processes cannot be felt, completely rounded appearance
5	Tail head: buried in fatty tissue, pelvis not palpable even with firm pressure

Table 2. Multivariate regression model for the prevalence of bulls scored dirty (Ls-mean ± SE) on the whole body, with Control floor, Young weight class and Observation day 2 as the basis for comparison.

Risk factor	Level	Prevalence of dirty bulls	OR (95% CI)[a]	Significance
Floor type	Control	51.1 ± 6.2	0.79 (0.49-1.26)	ns
	Test	52.2 ± 5.5	-	-
Weight class	Young	60.5 ± 6.5	2.59 (1.61-4.16)	***
	Old	42.8 ± 6.1	-	-
Observation day (OD)	OD 1	47.8 ± 11.1	3.61 (1.40-9.31)	**
	OD 2	20.7 ± 9.4	-	-
	OD 3	32.1 ± 8.6	1.90 (0.77-4.69)	ns
	OD 4	53.6 ± 10.2	5.73 (2.20-14.9)	**
	OD 5	93.4 ± 10.1	68.7 (17.1-276)	***
	OD 6	80.0 ± 8.5	21.9 (8.13-59.3)	***
	OD 7	50.9 ± 8.9	4.35 (1.77-10.7)	**
	OD 8	34.9 ± 8.7	2.40 (0.96-5.99)	†

[a] OR = Odds ratio, CI = confidence interval; ns P>0.10; †P<0.10; **P<0.01; ***P<0.001.

Table 3. Body condition, hygiene, locomotion and swelling at the leg joints of 119 bulls in 401 individual observations during eight observation days according to floor type, weight class and observation day.

	Type of floor (TF)		SEM	Weight class (WC)		SEM	Observation day[c] (OD)								SEM	Significance		
	Control	Test		Young	Old		1	2	3	4	5	6	7	8		TF	WC	OD
Dirtiness[a] (% of bulls)																		
thighs/flanks	38.6	39.8	5.6	47.5[a]	30.9[b]	5.5	39.1[bcd]	2.99[d]	9.90[d]	55.2[abc]	90.4[a]	67.3[ab]	33.3[cd]	15.5[d]	8.8	ns	†	***
abdomen/leg	40.0	36.6	7.9	45.6	30.9	7.8	31.0[b]	11.5[b]	6.33[b]	11.5[b]	86.0[a]	76.1[a]	51.9[ab]	31.6[b]	11.1	ns	ns	***
Body condition score[a]	3.07	3.05	0.1	2.96[b]	3.16[a]	0.1	2.98[b]	3.00[b]	3.11[b]	2.89[b]	2.85[b]	3.03[b]	3.12[b]	3.51[a]	0.1	ns	*	***
Clinical signs[b] (% of bulls)																		
abnormal locomotion	1.09	0.91	0.81	0.00	2.21	0.0	0.00	0.00	0.00	2.38	0.00	0.00	3.70	1.89	0.0	ns	-	-
swelling	0.55[b]	3.18[a]	0.91	1.35	2.76	0.0	4.88	3.77	1.69	0.00	0.00	0.00	1.85	1.89	0.1	†	ns	-

[a] Data processed using a mixed model; [b] Data processed using a Z-test considering only the main effects of floor type and weight class; [c] Observation day 1, 2, 3, 4, 5, 6 ,7 and 8 was in April, July, August, October, December 2016, and in January, May, and July 2017, respectively; Different letters indicate a significant difference among means in the same row within floor type (TF), weight class (WC) and observation day (OD) for P<0.10; ns P>0.10; †P<0.10; *P<0.05; ***P<0.001.

Table 4. Effect of type of floor (TF), hour of observation (HO) and their interaction on bull activities, events and lying postures recorded during the two 14-h behavioural observation sessions.

	Type of floor (TF)			Significance		
	Control	Test	SEM	TF	HO	TF ×HO
No. of pens assessed pens	2	2				
Behavioural activities (% of bulls)						
Standing	59.6	54.6	5.21	ns	***	***
Lying	40.4	45.4	5.21	ns	***	***
Eating	28.6	29.3	1.98	ns	***	ns
Grooming	1.85	2.14	0.56	ns	*	ns
Exploring	7.14	10.0	1.72	ns	**	***
Resting	38.4	44.6	8.51	ns	***	**
Other activities	22.6	18.1	5.02	ns	***	**
Events (no./bull)						
Normal transition	1.22	1.09	0.26	ns	ns	ns
Atypical lying down/standing up	0.00	0.00	-	-	-	-
Interruption of lying down[a]	0.05 (0-0.33)	0.03 (0-0.83)	-	-	-	-
Mounts	0.69	0.30	0.21	ns	ns	ns
Fights	0.59	0.49	0.09	ns	*	ns
Stereotypes	0.43	0.25	0.13	ns	ns	ns
Visits at the water bowl	1.24	1.16	0.15	ns	**	ns
Lying posture (% of bulls)						
Sternal recumbency	58.2	50.1	4.40	ns	**	*
Sternal with 1 limb extended	30.6	41.3	3.25	ns	†	†
Sternal with 2 limbs extended	10.1	5.75	2.28	ns	*	*
Sternal with 3 limbs extended	2.47	1.20	1.48	ns	†	ns
Lateral recumbency	0.53	0.39	0.24	ns	ns	ns

[a] A low number of bulls knelt on the carpal joints and then stood up again, so it was not possible to perform the statistical mixed model used for other behavioural measures. Expressed as mean and range; ns $P>0.10$; †$P<0.10$; *$P<0.05$; **$P<0.01$; ***$P<0.001$.

Table 5. Prevalence of claw disorders and shape alterations, and measurements of dorsal wall length according to the main effect of floor type.

	Floor type		Significance
	Control	Test	
No. of feet analysed	39	60	
Claw disorder (% of affected feet)			
Interdigital dermatitis	7.69	16.7	ns
Interdigital hyperplasia	2.56	0.00	-
Sole haemorrhage	20.5	33.3	ns
White line lesion	2.56	0.00	-
Shape alteration			
Corkscrew claws	0.00	6.67	-
Asymmetric claws	38.5	13.3	*
Scissor claws	0.00	10.0	-
Dorsal wall length[a] (mm)			
Inner claw	86.3 ± 2.0	82.6 ± 2.7	ns
Outer claw	86.7 ± 1.2	88.2 ± 1.2	ns

[a] Significant block effect of slaughter batch ($P<0.001$); ns $P>0.10$; *$P<0.05$.

Figure 1. Prevalence of bulls (Ls-means ± SEM) scored dirty on the upper (thigh/flanks) and lower (abdomen/legs), and on the whole body on different observation days during the study period.

Figure 2. Percentage of bulls in Test and Control pens (Ls-means ± SEM) observed standing, exploring, resting and performing other activities during the two 14-h behavioural observation sessions (from 05:00 h to 19:00 h). Different symbols indicate significant differences (†*P*<0.10; **P*<0.05; ***P*<0.01; ****P*<0.001) within a given hour of observation. FD = moment of feed delivery.

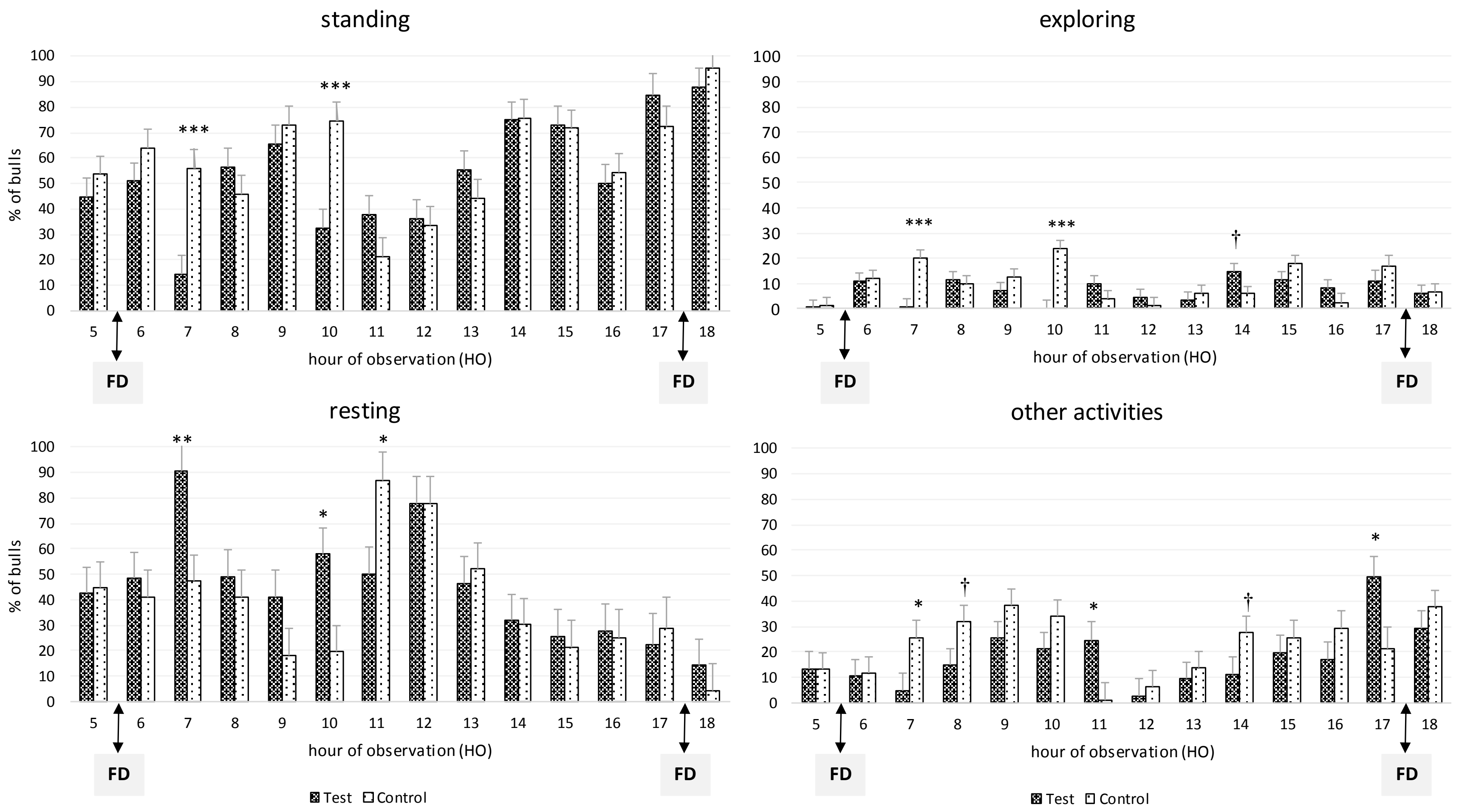
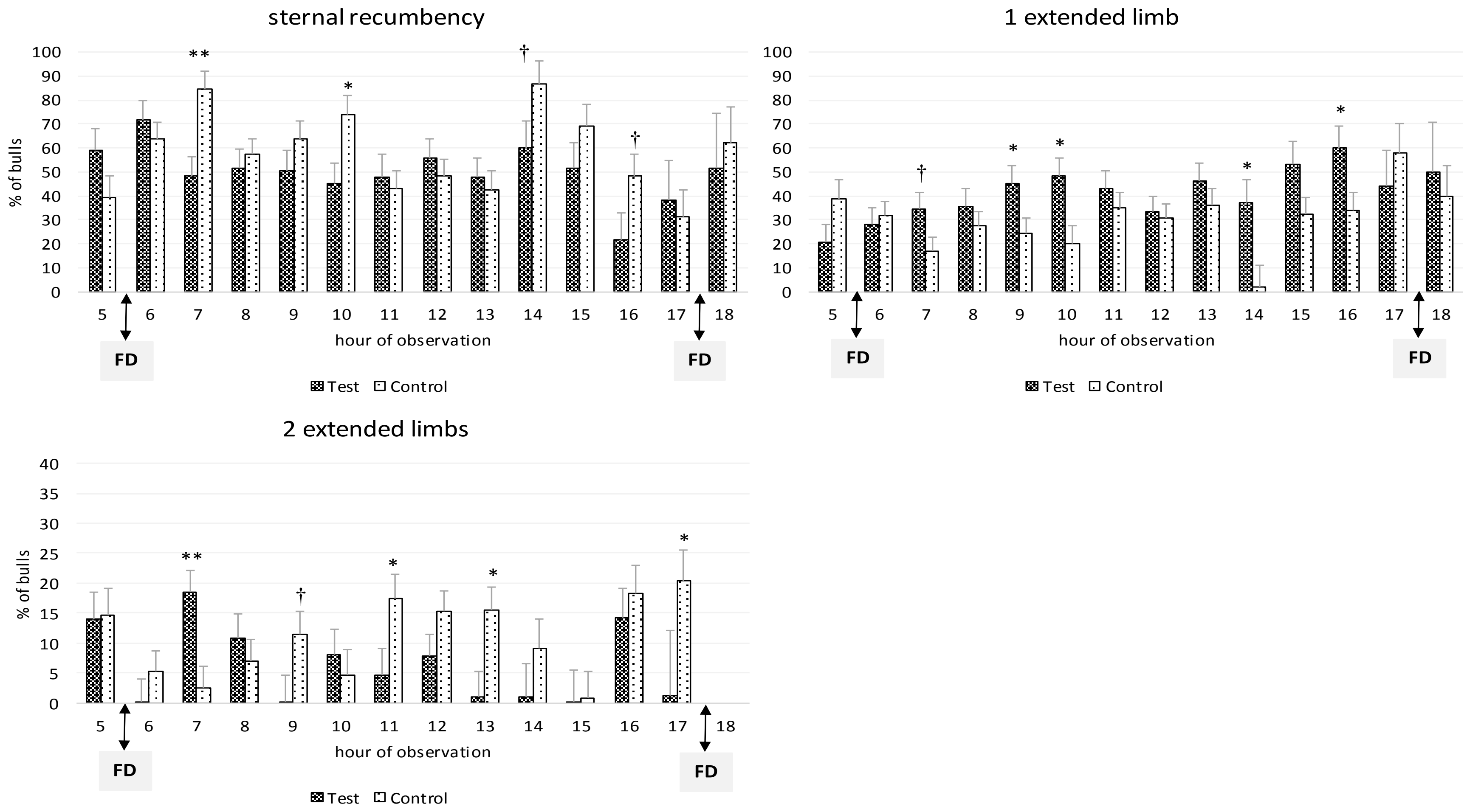


Figure 3. Percentage of bulls in Test and Control pens (Ls-means ± SEM) observed lying in sternal recumbency, with one or two extended limbs, during the two 14-h behavioural observation sessions (from 05:00 h to 19:00 h). Different symbols indicate significant differences (†*P*<0.10; **P*<0.05; ***P*<0.01; ****P*<0.001) within a given hour of observation. FD = moment of feed delivery.



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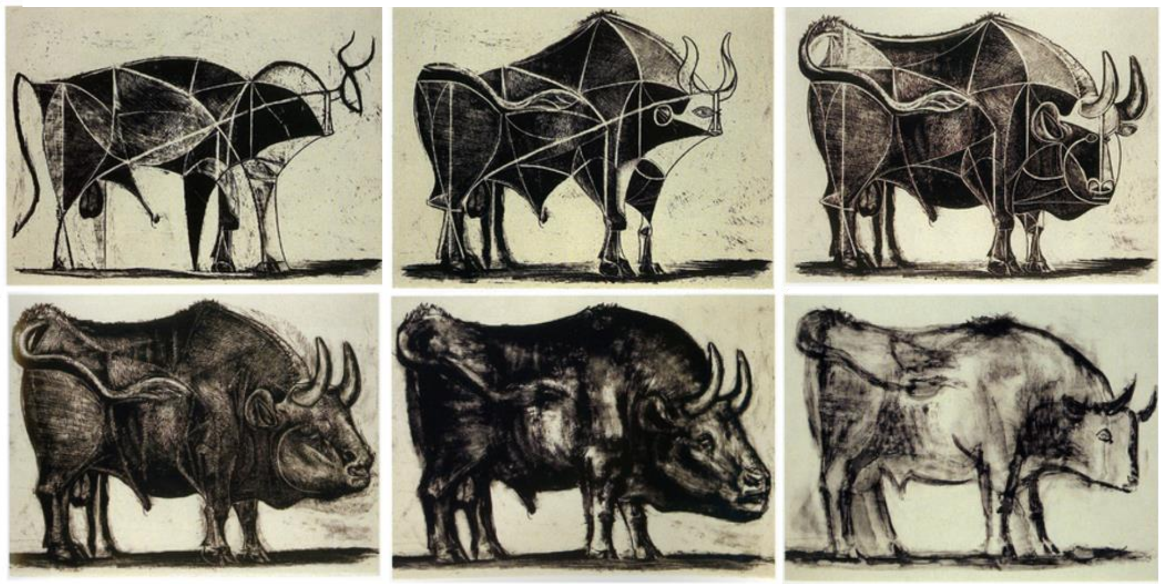
CHAPTER 6

General Discussion and Conclusions



This PhD project has provided new information concerning the claws condition of beef cattle finished in intensive indoor systems. It has proposed a more efficient inspection system at slaughter for claw health condition and tested different flooring systems for specific beef cattle breeds on a welfare friendly perspective.

As previously stated in the introductory chapter, the routine inspection of feet through the functional claw trimming *in vivo* on finishing bulls is unfeasible and not generally performed for economic reasons, for the shortness of fattening cycle and for the high riskiness by hoof trimmers. The proposed p*ost mortem* approach carried out at slaughter to check the claws health status can be considered a useful alternative to the routine functional trimming since it could guarantee a more cost-effective opportunity for claws health monitoring and disease surveillance. Moreover, considering the lack of published researches on the claw condition of finishing bulls, the inspection at the slaughterhouse allowed to collect data on a huge number of cattle that belonged to different batches, reflecting the predominant realities of the intensive beef production systems in Italy.

The high variability detected among batches of the prevalence of specific claw disorders on feet of not-apparently lame bulls suggest possible failures in farm management. In the future, indeed, this approach could address to benchmarking purposes with an *a posteriori* differentiation of the farms of origin in terms of management quality and animal welfare. Our attempt to create a global foot score that considers together different types of claw alterations (in terms of aetiological origin), their severity and their extent on the sole or on the interdigital area, should simplify possible associations with potential predisposing factors on farm.

The monitoring of an 18-months finishing period in eight Italian beef farms showed that lameness could have serious economic and welfare implications, as in dairy farms. The most severe cases of lameness impose the early culling of affected animals with negative impact on farm’s efficiency and economics. It has been also demonstrated that lameness events generally arise during the last part of the fattening resulting in bulls with reduced growth performance. The estimated body weight loss around 80 kg of a lame bull when compared to the slaughter weight of a healthy (not lame) bull is, in line with previous findings on feedlot cattle, but even more significant. This result points out the need to take preventive measures against lameness acting on the housing and flooring systems, since clinical signs of lameness events appeared when the economic loss is probably already unsustainable to maintain the affected bulls on farm. However, future researches should be addressed to estimate the total economic loss by beef farmers (including all costs related to pharmacological treatments, time to handling animals among pens, urgency slaughter etc.) in case of lameness with different aetiological origin and severity degree.

Our findings from the fourth and fifth studies confirmed that the occurrence of lameness in beef cattle is strictly associated to the type of flooring system adopted. In particular, we recorded the negative impact of the concrete slats on the occurrence of lameness events compared to softer flooring such as deep littered or rubberized slatted floors. Beyond the improvement in the occurrence of lameness, alternative rubberized surfaces to the concrete slatted flooring showed positive effects on bull behavioural activities, social interactions with pen-mates and lying comfort.

In addition to these findings, considering the main beef breeds fattened in Italy, Charolaise and Limousine, our results point out other interesting effects of the housing duration and of the final slaughter weight on the health and welfare of these heavy animals. The use of rubberized covered floor as an alternative to the concrete floor should be advised only for bulls like Limousine that are finished at a final body weight around 600 kg, lighter than Charolaise. Despite the positive growth performance, indeed, health and welfare of Charolaise finished at a final body weight above 700 kg were impaired by their housing on both concrete or rubberized slatted floors. It is likely that other important factors related to the type of production system chosen by the farmers, such as the type of breed, the duration of the finishing period to reach the desired growth performance etc. could affect the general health condition of the animals and their claw status, in particular.

However, this thesis highlights also several negative impacts of these alternative rubberized solutions on the hygiene of finishing bulls and on the overgrowth of claw horn, still remaining real concerns for economic and welfare points of view. From a forward-looking perspective, the impairment in bull hygiene could be overcame considering all together our findings on floor type, drainage area on slatted floor, breed and housing characteristics. The problem of hoof overgrowth recorded on rubber slatted floor due to its low abrasiveness might be prevented by introducing a certain percentage of a more abrasive surface in the floor pen.

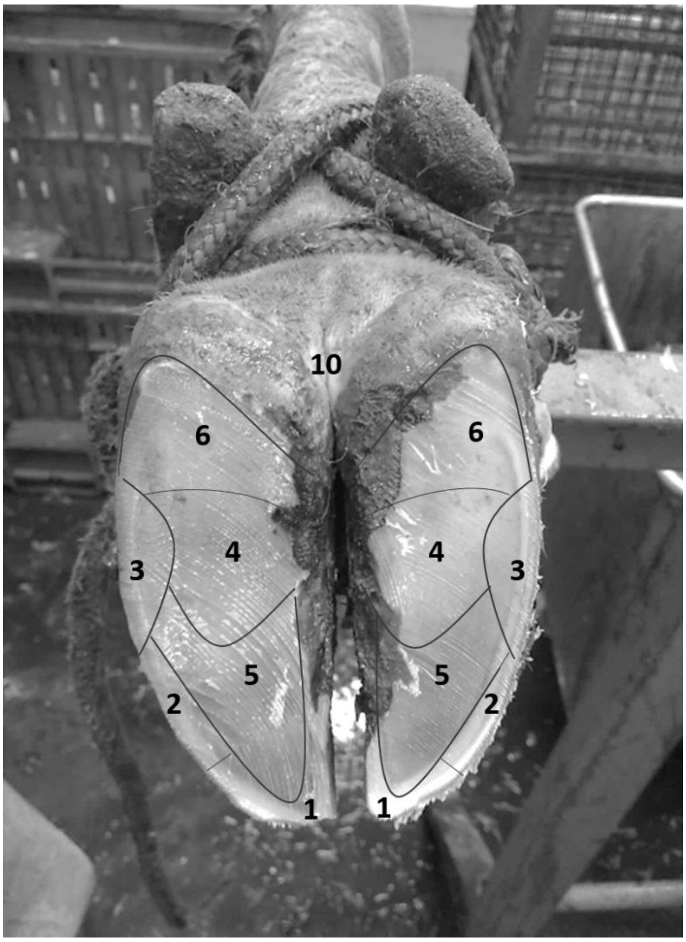
Although our findings provide new insights about the significant impact of lameness in beef cattle farms, further investigations are need to analyse additional potential predisposing factors on farms (*i.e.* feeding etc.) to lameness and to specific claw disorders, and consequently to identify the best housing, flooring and management solutions to be adopted during the finishing phase of these heavy animals.

SUPPLEMENTARY MATERIAL

CHAPTER 2. An overview of claw disorders at slaughter in finishing beef cattle reared in intensive indoor systems through a cross-sectional study.

Figure S1. Description of the handmade support used for the hind limbs of finishing beef cattle during *post mortem* evaluation carried out in Northern Italy (left) and detailed pictures of claws before (middle) and after (right) being trimmed by the veterinarian with an electric grinder.

Figure S2. Schematic view of the repartition in 7 zones of the sole of the claws (numbers 1 to 6 for sole areas and 10 for interdigital areas) used for the *post mortem* evaluation of hind limbs of beef cattle carried out in Northern Italy.



PUBLICATIONS AND ORAL PRESENTATIONS

Brscic, M., **Magrin, L**., Lora, I., Cozzi, G., Gottardo, F., 2018. *Post-mortem* rumen mucosa, lung and liver alterations in intensively finished beef cattle. Book of Abstracts of the 69th Annual Meeting of the European Federation of Animal Science, Dubrovnik, Croatia, 27-31 August 2018. Vol 24, pp. 242. ISBN: 978-90-8686-323-5; doi: 10.3920/978-90-8686-871-1.

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