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VIGILANCIA Y EVALUACIÓN *POST MORTEM* DEL BIENESTAR BOVINO: INTEGRACIÓN, VALIDACIÓN Y ASOCIACIONES ENTRE INDICADORES CONOCIDOS Y EMERGENTES EN CONDICIONES COMERCIALES

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NATYIELI LOSADA ESPINOSA

TUTOR:

GENARO C. MIRANDA DE LA LAMA

Facultad de Veterinaria

Universidad de Zaragoza

COMITÉ TUTOR

FRANCISCO A. GALINDO MALDONADO

Facultad de Medicina Veterinaria y Zootecnia

Universidad Nacional Autónoma de México

ABDEL-FATTAH ZEIDAN MOHAMED SALEM

Facultad de Medicina Veterinaria y Zootecnia

Universidad Autónoma del Estado de México

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Resumen

La comprensión actual del bienestar animal como un constructo multidimensional señala la necesidad de desarrollar métodos de evaluación que tengan un alcance integrador y que, al mismo tiempo, faciliten la identificación de perfiles de riesgo en los animales. En México, sin embargo, el tema ha recibido una atención muy limitada. En ese sentido, el presente proyecto de investigación estuvo conformado por tres etapas, encaminadas a incrementar el conocimiento sobre las implicaciones potenciales que las operaciones previas al sacrificio pueden tener sobre el bienestar del ganado. En la primera etapa (Capítulo 1), se llevó a cabo una revisión sistemática en la que se identificaron 72 indicadores de bienestar bovino que fueron clasificados en cuatro categorías (fisiológicos, morfométricos, conductuales y de calidad de la carne). Al mismo tiempo, se evaluó su validez y factibilidad de uso en rastro, y se seleccionaron los indicadores que se analizarían posteriormente. La segunda etapa (Capítulo 2) tuvo por objetivo evaluar el comportamiento de dichos indicadores a nivel rastro e identificar perfiles de riesgo integrados basados en el origen del animal, la logística previa al sacrificio e indicadores basados en el animal. Para caracterizar las prácticas operativas y logísticas desde la granja hasta el rastro, se aplicó un análisis de conglomerados (clúster) a las variables registradas (sistema de producción, categoría comercial, tamaño de cuernos, distancia de viaje, tipo de vehículo), que identificó cuatro perfiles logísticos. Nuestros resultados mostraron que cada sistema de producción tuvo efectos particulares sobre los animales. El estudio proporcionó datos que se pueden incluir en métodos de evaluación del bienestar del ganado para sacrificio, los cuales pueden adaptarse a sistemas de producción específicos. Por último (Capítulo 3), se investigaron los factores de riesgo asociados al decomiso de órganos (hígado), lesiones podales severas, hematomas y la calidad de las canales bovinas (pH). Se registraron datos para 143 viajes que abarcaron 1040 bovinos comerciales, provenientes de corrales de engorda, sistemas extensivos y sistemas de producción lecheros. Los detalles sobre la distancia del viaje, el tipo de vehículo, el tipo de ganado y el origen de los animales se obtuvieron de los informes del rastro. Los modelos multivariantes mostraron que el origen de los animales era un factor de riesgo potencial para hematomas severos y pH muscular elevado, siendo las vacas lecheras de descarte una de las categorías comerciales más afectadas. En general, las condiciones de transporte del ganado fueron factores que mostraron interacciones con tres de los indicadores evaluados (lesiones podales severas, hematomas en la canal, pH24). El conocimiento generado en este proyecto puede proporcionar una mejor comprensión de las condiciones bajo las cuales opera la cadena productiva de carne de res mexicana. Asimismo, puede ayudar a identificar los factores que influyen en el nivel de riesgo y, por lo tanto, en la implementación de enfoques basados en el riesgo. Finalmente, el proyecto propone la posibilidad de considerar los indicadores evaluados como indicadores 'Iceberg' del bienestar animal en esquemas de monitoreo a nivel rastro.

Palabras clave: Indicadores Iceberg; Rastro; Calidad de la carne; Perfiles de riesgo; Factores de riesgo

Abstract

The current understanding of animal welfare as a multidimensional construct emphasizes the need to develop an assessment method that has an integrative scope and, simultaneously, facilitates the identification of risk profiles in animals. In Mexico, however, the subject has received very limited attention. For that reason, the general purpose of the present project was to increase knowledge of potential welfare implications that pre-slaughter logistics might have on cattle. In the first stage (Chapter 1), a systematic review was carried out, which identified 72 cattle welfare indicators that were classified into four categories (physiological, morphometric, behavioural and meat quality). At the same time, their validity and feasibility for use in abattoirs were evaluated. The aim of the second stage (Chapter 2) was to evaluate the suitability of these indicators for assessments at commercial abattoir level and to identify integrated risk profiles based on the animal's origin, pre-slaughter logistics, and animal-based indicators. To characterize operational and logistic practices from the farm to the slaughterhouse, a two-step cluster analysis was applied to the registered variables (production system, cattle type, horn size, journey distance, vehicle type), which identified four logistics profiles. Our results reflected a marked effect of the production system of origin on the animals. The study provided data that can be included into assessment methods for the welfare of slaughter cattle, which can be tailored to specific production systems. Finally (Chapter 3), risk factors associated with organ condemnations (liver), severe hoof disorders, bruises prevalence, and the quality of beef carcasses (pH) were investigated. Data were recorded for 143 journeys encompassing 1,040 commercial cattle, originating from feedlots, free-range and dairy production systems. Details on journey distance, vehicle type, cattle type, and animals' origin were gathered from abattoir reports. Multivariate models showed that animals' origin was a potential risk factor for severe bruising and high muscle pH, with cull dairy cows as one of the most affected commercial categories. In general, cattle transport conditions were factors that showed interactions with three of the evaluated indicators (severe hoof injuries, carcass bruising, meat pH24). The knowledge generated in this project might provide a better understanding of the Mexican beef production chain, and aid in the identification of the factors that influence the level of risk and, therefore, the implementation of risk-based approaches. Finally, the project proposes the possibility of considering the evaluated indicators as 'Iceberg' indicators of animal welfare in monitoring schemes at the abattoir-level.

Keywords: Iceberg Indicators; Abattoir; Meat quality; Risk profiles; Risk factors

Contenido

Introducción

El bienestar animal se ha convertido en una preocupación social, un atributo dentro de un amplio concepto de calidad de la carne (María, 2006; Schnettler *et al*., 2007). Esta situación se refleja en el aumento de la cantidad de estándares públicos y privados introducidos en muchas empresas que desarrollan sistemas de monitoreo voluntarios del bienestar (Clark *et al*., 2017), incluyendo rastros comerciales. Durante las últimas décadas, se han reconocido las ventajas potenciales de las evaluaciones del bienestar animal a nivel rastro (Harley *et al*., 2012). En general, los rastros tienen una posición estratégica que permite la evaluación de un elevado número de animales (de diferentes orígenes) en poco tiempo y con un costo relativamente menor en comparación con las evaluaciones en granja (Carroll *et al*., 2018). Por otra parte, la inspección *post mortem* de la carne tiene el potencial de detectar enfermedades y ciertas condiciones de bienestar que pueden no ser evidentes durante la inspección *ante mortem* de los animales al llegar al rastro (Vial y Reist, 2014; Grandin, 2017). En ese sentido, distintos países europeos han adoptado sistemas basados en inspecciones *post mortem* en rastros a nivel nacional como una herramienta para monitorear la salud y el bienestar de porcinos (De Luca *et al*., 2021), bovinos (Antunovic *et al*., 2021) y aves (Allain *et al*., 2013).

Por otro lado, distintas autoridades y organizaciones internacionales han señalado la necesidad de una revisión radical a los procedimientos que han servido a la salud pública y animal durante más de un siglo (Antunovic *et al*., 2021). En consecuencia, la Autoridad Europea de Seguridad Alimentaria (EFSA, por sus siglas en inglés) recibió el mandato de evaluar los efectos en la vigilancia de la salud y el bienestar de los animales si se llegase a implementar un enfoque de inspección de la carne basado en el riesgo (Stärk *et al*., 2014). En un programa de inspección de la carne con evaluación del riesgo, donde se conoce el origen y el estado de salud del ganado procesado, los hatos de alto riesgo recibirían atención adicional en el rastro, a un costo mayor para el productor. En teoría, esta estrategia podría alentar a los productores a mejorar el estado general de salud y bienestar de sus animales (Edwards *et al*., 1997). Además, se facilitaría la recopilación y manejo de datos esenciales para un programa de aseguramiento de la calidad integrado longitudinalmente, al mismo tiempo que se familiarizaría a la industria con los beneficios que se obtienen de un mayor conocimiento del estado de salud y bienestar de los hatos.

La comprensión actual del bienestar como un fenómeno multidimensional plantea la necesidad de considerar una amplia gama de grupos de indicadores al interpretar las respuestas de los animales a las variaciones en su entorno, incluidos los indirectos relacionados con la calidad del producto (Losada-Espinosa *et al*., 2018). En ese contexto, es fundamental contar con indicadores válidos, factibles y fáciles de evaluar, para ayudar a que sea más verificable para los productores y más transparente para los consumidores (Miranda-de la Lama *et al*., 2017). Sin embargo, es importante tener en cuenta tanto el costo como la sencillez de los protocolos de evaluación. A nivel rastro, la recolección de una gran cantidad de mediciones representa un desafío (debido a la alta velocidad de procesamiento), por lo que es necesario detectar aquellas medidas (indicadores) que permitan identificar una mayor cantidad de riesgos potenciales (Wigham *et al*., 2018). En octubre de 2009, el Consejo para el Bienestar de los Animales de Granja (FAWC, por sus siglas en inglés) publicó un nuevo informe en el que abogó por el uso de indicadores de bienestar 'Iceberg' (FAWC, 2009). Hipotéticamente, dichos indicadores deben tener la capacidad de resumir de manera efectiva diferentes medidas alternativas de bienestar.

Los indicadores 'Iceberg' pueden brindar información valiosa sobre dos aspectos importantes de la vida de los animales de producción: los problemas de bienestar que ocurren durante el crecimiento de éstos en la granja; y condiciones agudas o traumáticas recientes asociadas con operaciones previas al sacrificio, como el transporte, la espera y el mismo sacrificio (FAWC, 2009; Grandin, 2017). Si se confirma que dichos indicadores tienen el potencial de proporcionar información valiosa sobre el estado del bienestar animal durante las distintas etapas de la crianza, su incorporación en los protocolos de evaluación podría limitarse a esas mediciones específicas, lo que reduciría el tiempo necesario para una evaluación (Heath *et al*., 2014). Sin embargo, aunque el concepto es intuitivamente atractivo, en la actualidad todavía es en gran parte teórico y poco probado dentro de la evaluación del bienestar animal (Collins *et al*., 2015). Tanto a nivel internacional (van Staaveren *et al*., 2017; Carroll *et al*., 2018; Hernandez *et al*., 2020; Friedrich *et al*., 2020) como a nivel nacional (Losada-Espinosa *et al*., 2021a; Losada-Espinosa *et al*., 2021b), la información es limitada.

Considerando lo anterior, el presente proyecto se dividió en tres etapas. La primera etapa (Capítulo 1) se encaminó a revisar el conocimiento actual sobre indicadores de bienestar bovino mientras se evaluó su validez y factibilidad de uso en rastros. Los indicadores se clasificaron en cuatro categorías (fisiológicos, morfométricos, conductuales y de calidad del producto) y se evaluaron cualitativamente con base en la literatura. A partir de esta revisión sistemática, y tomando en cuenta tanto las características del lugar de estudio (rastro comercial) como los recursos (humanos, financieros, materiales y tecnológicos), se seleccionaron seis indicadores para evaluar su potencial como indicadores tipo 'Iceberg' y su capacidad de inferencia sobre las condiciones de las diferentes etapas dentro de la cadena logística de producción del país.

Aunque los efectos de esos indicadores se han reportado individualmente, las interacciones entre ellos no son muy conocidas, especialmente las que involucran el manejo del sistema de producción (origen) y las prácticas logísticas. En ese sentido, se realizó la segunda etapa del proyecto (Capítulo 2) para probar la hipótesis de que podrían existir interacciones y patrones de agrupamiento entre el origen del animal y los indicadores de bienestar tipo 'Iceberg'. Específicamente, los objetivos de esta etapa fueron identificar indicadores de bienestar que fueran adecuados para evaluaciones a nivel rastro; cuantificar la probabilidad de ocurrencia de vocalizaciones, disparos de aturdimiento, lesiones podales severas, hematomas en la canal, decomisos parciales y pH de la carne durante el sacrificio entre animales de diferentes orígenes (sistemas feedlot, extensivos y lecheros) a través de la inspección *post mortem*; y por último, identificar perfiles de riesgo integrados basados en el origen de los animales, la logística previa al sacrificio e indicadores basados en el animal. Finalmente, la última etapa del proyecto (Capítulo 3), tuvo por objetivo reconocer las prácticas actuales de transporte comercial y logística previa al sacrificio de ganado sacrificado en México y su relación con los factores de riesgo asociados al decomiso de órganos (hígado), lesiones podales severas, hematomas y la calidad de las canales bovinas (pH).

Capítulo 1

Indicadores pre sacrificio de bienestar bovino para su uso en rastros comerciales con sistemas de monitoreo voluntario: Una revisión sistemática

Versión adaptada al español del artículo original:

Losada-Espinosa, N., Villarroel, M., María, G.A. y G.C. Miranda-de la Lama (2018): “Pre-slaughter cattle welfare indicators for use in commercial abattoirs with voluntary monitoring systems: A systematic review”, *Meat Science*, 138, pp. 34-48. Disponible en: https://doi.org/10.1016/j.meatsci.2017.12.004

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Indicadores pre sacrificio de bienestar bovino para su uso en rastros comerciales con sistemas de monitoreo voluntario: Una revisión sistemática

N. Losada-Espinosa [a] , M. Villarroel [b] , GA María [c] , GC Miranda-de la Lama [d]

[a] Programa de Posgrado en Ciencias de la Salud y la Producción Animal, Facultad de Medicina Veterinaria, Universidad Nacional Autónoma de México, UNAM, México
[b] Departamento de Ciencia Animal, E.T.S.I.A. Universidad Politécnica de Madrid, Madrid, España
[c] Departamento de Producción Animal y Ciencia de los Alimentos, Instituto Agroalimentario de Aragón (IA2), Universidad de Zaragoza, Zaragoza, España
[d] Departamento de Ciencia de los Alimentos, Universidad Autónoma Metropolitana, UAM-Lerma, Estado de México, México

Resumen

El bienestar animal se ha convertido en un tema importante de preocupación pública, económica y política, lo que lleva a la necesidad de validar indicadores de uso factible en los rastros. Se realizó una revisión sistemática, en la que se identificaron 72 indicadores de bienestar bovino que se clasificaron en cuatro categorías (fisiológicos, morfométricos, conductuales y de calidad de la carne). Se evaluó su validez y factibilidad de uso en rastros como medidas potenciales del bienestar del ganado durante el transporte al rastro y en el rastro mismo. Se identificaron varios indicadores altamente válidos que son útiles para evaluar el bienestar en los rastros, incluida la escala de condición corporal, las interacciones entre humanos y animales, las vocalizaciones, las caídas, los hematomas en la canal y el pH de la carne. Además, algunos indicadores con validez intermedia son útiles y deben investigarse más a fondo. La información a lo largo de la cadena productiva podría usarse de manera sistemática para proporcionar la base para una inspección de la carne con mayor énfasis en el riesgo. Se podría implementar un sistema integrado basado en el uso de indicadores clave definidos para cada etapa de inspección con el establecimiento de umbrales de alarma.

Palabras clave: Indicadores de bienestar bovino; Sistemas de monitoreo voluntario; Estrés pre sacrificio; Calidad de la carne; Rastro

1. Introducción

A lo largo de las operaciones previas al sacrificio, los animales pueden verse desafiados por situaciones que les provocan estrés, es decir, cuando no pueden adaptarse fisiológica o conductualmente a los desafíos ambientales o físicos (Terlouw, 2015). Estos desafíos perturban la homeostasis y se activa una respuesta adaptativa en un intento por restablecer el equilibrio (King et al., 2006). En primer lugar, se desencadenan respuestas fisiológicas asociadas a la reactividad emocional (frecuencia cardíaca y frecuencia respiratoria), seguidas de cambios conductuales (Van de Water, Verjans, & Geers, 2003; Averós, Martín, Riu, Serratosa, & Gosálvez, 2008; Bourguet et al., 2010; Pighin et al., 2013). Luego, la activación del eje hipotalámico-pituitario-adrenal (HPA) y la liberación de la hormona liberadora de corticotropina (CRH) activan el componente simpático-suprarrenal de la respuesta autonómica aumentando los niveles de cortisol (Ferguson & Warner, 2008; Hemsworth et al., 2011; Romero, Uribe-Velásquez, Sánchez, Rayas-Amor, & Miranda-de la Lama, 2017). El proceso de adaptación redirige la energía de la producción a la misma. La liberación de catecolaminas induce hipofagia y pérdida de peso por sus efectos sobre el hígado y sobre el tejido adiposo blanco y pardo (Rabasa & Dickson, 2016). En consecuencia, si la respuesta al estrés es lo suficientemente fuerte, la producción y la calidad de la carne se verán afectadas (Grandin & Shivley, 2015), causando importantes pérdidas económicas a la industria. En general, cuanto más pobre sea el bienestar de los animales, mayores serán las pérdidas económicas (Ingenbleek et al., 2013).

El agotamiento significativo de las reservas de glucógeno muscular antes del sacrificio tiene un efecto profundo y bien documentado en varios atributos clave de la calidad de la carne, como el pH final, la terneza, el color, la capacidad de retención de agua y los indicadores sensoriales (Van de Water et al., 2003; María, Villarroel, Sañudo, Olleta & Gebresenbet, 2003; Mounier, Dubroeucq, Andanson & Veissier, 2006; Tadich, Gallo, Bustamante, Schwerter & van Schaik, 2005). Además, Rostagno (2009) muestra que el estrés puede tener un efecto nocivo significativo en la seguridad alimentaria (un aspecto de máxima preocupación para el consumidor), proporcionando evidencia que vincula el estrés con la carga y eliminación de patógenos en animales de granja, aunque los mecanismos subyacentes a este efecto no han sido completamente dilucidados. Una extensa investigación, tanto en condiciones experimentales como comerciales, ha demostrado que el manejo del ganado puede afectar notablemente su fisiología del estrés y su productividad (Hemsworth et al., 2011). Para comprender las causas y consecuencias del estrés en el sacrificio, se han realizado varios estudios en condiciones controladas para evaluar las reacciones a procedimientos específicos (Bourguet, Deiss, Cohen Tannugi, & Terlouw, 2011). Los estudios de campo brindan información útil sobre el efecto de los ambientes comerciales y son particularmente valiosos cuando no es posible simular todos los factores presentes en el ambiente dentro de un experimento controlado (Jarvis, Harrington, & Cockram, 1996). Ambos enfoques son necesarios para comprender cómo reaccionan los animales a los diferentes aspectos de los procedimientos previos al sacrificio (Bourguet et al., 2011). La fase previa al sacrificio incluye las condiciones y prácticas entre la granja y el cajón de aturdimiento en el rastro (Ferguson & Warner, 2008). Durante este período, los animales pueden estar expuestos a una variedad de estímulos desafiantes (Ljungberg, Gebresenbet & Aradom, 2007), lo que dificulta determinar qué procedimientos contribuyen significativamente a su estado de estrés (Bourguet et al., 2010). Las mediciones del deterioro del funcionamiento biológico, en particular las relacionadas con la disminución de la salud y el aumento de las respuestas fisiológicas al estrés, pueden proporcionar una buena evidencia que corrobore que el bienestar está comprometido (Duncan, 2005). En este contexto, indicadores válidos, factibles y fáciles de evaluar son fundamentales para ayudar a que sea más verificable para los productores y más transparente para los consumidores.

Tradicionalmente, la legislación gubernamental ha sido el principal método para asegurar o mejorar el bienestar de los animales de granja (Bennett, 1997). Sin embargo, se cree que los sistemas de producción animal que promueven estándares más altos de bienestar animal conducen a mayores costos ambientales y financieros, que en última instancia, se trasladarán al consumidor a menos que se establezcan subsidios o exenciones fiscales para los productores. Las soluciones basadas en el mercado se reflejan en el aumento de la cantidad de estándares privados introducidos en muchas empresas que desarrollan sistemas de monitoreo voluntarios del bienestar, que aseguran que los productores y consumidores no tengan un precio fuera del mercado si se transmiten costos adicionales a través de la cadena de suministro (Clark, Stewart, Panzone, Kyriazakis & Frewer, 2017). Los sistemas de monitoreo voluntario pueden definirse como la medición, recopilación, cotejo, análisis, interpretación y difusión oportuna sistemática (continua o repetida) de datos sobre salud y bienestar animal de poblaciones definidas (Correia-Gomes et al., 2017). Para dicho seguimiento, los indicadores de bienestar basados en el animal se consideran los más válidos, porque se evalúa a los animales en sí (Llonch, King, Clarke, Downes, & Green, 2015). Pero se debe considerar una amplia gama de indicadores al interpretar las respuestas de los animales a las variaciones en su entorno, incluidos los indirectos relacionados con la calidad del producto. Las evaluaciones de bienestar a nivel granja son el principal método para evaluar el bienestar del ganado, pero esas evaluaciones requieren mucho trabajo, consumen mucho tiempo e incluso pueden aumentar la transmisión de enfermedades dentro y entre granjas (Dalmau, Temple, Rodríguez, Llonch, & Velarde, 2009). La inspección *post mortem* de la carne tiene el potencial de detectar más fácilmente enfermedades y ciertas condiciones de bienestar que pueden no ser evidentes durante la inspección *ante mortem* del animal al llegar al rastro (Vial & Reist, 2014; Grandin, 2017). En el pasado, las auditorías de bienestar se han desarrollado y probado como instrumentos de investigación o requisitos comerciales para documentar el bienestar animal a nivel rastro. Sin embargo, estas auditorías no están destinadas a ser utilizadas de forma rutinaria en la mayoría de los sistemas de vigilancia veterinaria de todo el mundo (Kristensen, Stoier, Würtz, & Hinrichsen, 2014). Por lo tanto, existe una creciente tendencia internacional a incorporar indicadores de bienestar durante la inspección de la carne en los rastros como una herramienta de monitoreo voluntario de la salud del ganado (Harley, More, Boyle, O' Connell & Hanlon, 2012; van Staaveren et al., 2017). Asimismo, se ha propuesto una idea relativamente nueva conocida como indicadores “iceberg” o “clave”. En su informe de 2009, el Farm Animal Welfare Council (FAWC) sugirió el uso de indicadores iceberg en los rastros como un medio para evaluar y garantizar el bienestar general de los animales, desde la granja de origen hasta el rastro (van Staaveren et al., 2017). El objetivo de este artículo es revisar el conocimiento actual sobre los indicadores de bienestar del ganado mientras se evalúa su validez (que miden lo que pretenden medir) y factibilidad (en términos de velocidad, costo y efecto en los procedimientos operativos normales) de uso a nivel rastro. Los indicadores se clasificaron en cuatro categorías (fisiológicos, morfométricos, conductuales y de calidad del producto) y se evaluaron cualitativamente con base en la literatura publicada.

2. Materiales y métodos

El objetivo principal de esta revisión es evaluar los indicadores que los científicos y otros profesionales utilizan actualmente para medir el bienestar del ganado y su posible aplicación en los rastros. La mayoría de las inspecciones en los rastros se centran en la calidad de la carne *peri* o *post mortem* para proteger la salud pública al garantizar la inocuidad de los alimentos. Sin embargo, existe un creciente interés en incorporar indicadores de bienestar bovino *pre mortem* que podrían indicar problemas subyacentes (van Staaveren et al., 2017).

2.1 Criterios y estrategia de búsqueda

Realizamos una revisión sistemática de la literatura científica publicada entre enero de 1995 y octubre de 2016 con base en la metodología desarrollada por Llonch et al. (2015), que solo incluye artículos de revistas publicados y revisados por pares sobre la evaluación del bienestar del ganado (terneros, novillos, novillas, vacas y toros). Las búsquedas se realizaron utilizando los mismos términos de búsqueda en cuatro motores de búsqueda: (1) PubMed; (2) ScienceDirect; (3) Scopus; y (4) Scielo. Los términos de búsqueda utilizados (incluidos todos los títulos, resúmenes y palabras clave) fueron: cattle OR beef cattle AND welfare OR 'animal welfare' AND transport OR lairage OR stun OR slaughter OR abattoir AND 'meat quality' AND PUBYEAR> 1994. Los registros de las bases de datos se exportaron directamente a EndNote, incluidos los artículos en inglés y en español. Se eliminaron los duplicados y documentos no relacionados directamente con el bienestar del ganado.

2.2 Criterios para la selección de indicadores de bienestar animal

Se recuperó y leyó un total de 85 artículos para identificar indicadores basados en los animales y en la calidad del producto asociados con el bienestar del ganado. Los indicadores relacionados que evalúan el mismo problema de bienestar se combinaron para dar 72 indicadores separados (Tablas 1 a 4). Luego, cada indicador se asignó a una categoría de medición (fisiológica, morfométrica, conductual y de calidad del producto). La validez y factibilidad de medir cada indicador en un rastro se categorizó como alta, intermedia o baja, según Llonch et al. (2015). Los indicadores de alta validez fueron aquellos validados en investigaciones previas a través de un gran número de artículos que, a su vez, tenían validez interna (p. ej., muestreo, medidas y procedimientos) y externa (inferencias), haciéndolos propensos a ser considerados como indicadores válidos. Los indicadores de validez intermedia fueron aquellos que no necesariamente indicaron un bienestar deficiente (p. ej., escala de condición corporal). Se sugirieron indicadores de baja validez, pero no poseen evidencia de que realmente evalúen el bienestar. Los indicadores con factibilidad alta fueron aquellos que podían registrarse en los rastros, independientemente del número de animales, el espacio disponible para los animales o la velocidad de la línea de procesamiento. Los indicadores de factibilidad media eran aquellos que requerían requisitos especiales (p. ej., espacio o tiempo extra) para una evaluación adecuada. Los indicadores de factibilidad baja eran aquellos que no podían evaluarse de manera rutinaria en los rastros comerciales. Cuando un indicador se definió como de alta validez en su entorno original, pero no parecía probable que fuera válido o factible cuando se midió en un rastro, consideramos el posible uso de indicadores de validez intermedia con alta factibilidad o tecnologías alternativas novedosas.

3. Resultados

La evaluación de la literatura científica actual proporcionó 72 indicadores de bienestar del ganado, separados por categoría y factibilidad en las Tablas 1 a 4, para un total de 22 indicadores fisiológicos, 2 morfométricos, 32 de comportamiento y 15 de calidad del producto. La mayoría de los estudios (85%) se realizaron en condiciones comerciales, con solo unos pocos experimentales (Apple, 1999; Apple et al., 1999; Lensink et al., 2000; María et al., 2003; King et al., 2006; Schwartzkopf-Genswein et al., 2007; Bourguet et al., 2010; Burdick et al., 2010; del Campo, Brito, Soares de Lima, Hernández, & Montossi, 2010; Alende et al., 2014; Emenheiser et al., 2014).

La tabla 1 muestra todos los indicadores fisiológicos. De las 10 subcategorías que componían esta clasificación, indicadores de deshidratación y/o hemoconcentración (volumen de células empaquetadas, proteína sérica total, hematocrito, glóbulos rojos y osmolaridad), índices de esfuerzo físico (CK, lactato, lactato deshidrogenasa y proteínas de fase aguda), y marcadores de miedo/excitación y reactividad emocional (frecuencia cardíaca, frecuencia respiratoria, temperatura rectal y proteínas de choque térmico), se destacaron en el número de indicadores utilizados para medir estas subcategorías (23%, 18% y 18% del total de indicadores, respectivamente). Sin embargo, las concentraciones plasmáticas de cortisol (medida endocrina), glucosa (índice de miedo/excitación y también relacionado con la liberación de catecolaminas) y lactato (índice de esfuerzo físico) fueron los indicadores más utilizados entre los autores correspondientes a esta categoría (83%). Con respecto a la categoría morfométrica, el 73% de las publicaciones (sobre esta categoría) utilizaron el peso vivo como principal indicador morfométrico (Tabla 2).

Entre los indicadores de comportamiento (Tabla 3), el 63% correspondió a la subcategoría presacrificio, el 28% a la subcategoría sacrificio y solo el 9% a la subcategoría respuestas al dolor. Las interacciones humano-animal y las vocalizaciones fueron los indicadores más comunes durante el presacrificio (48% y 44% de los autores correspondientes a esta categoría, respectivamente), y la actividad respiratoria y el reflejo corneal positivo en la subcategoría de sacrificio (78% de los autores correspondientes a esta categoría). Finalmente, de todos los indicadores de calidad del producto (Tabla 4), el 64% fueron instrumentales, el 29% sensoriales y el 7% relacionados con la calidad de la canal. Los indicadores más utilizados por los autores de esta categoría fueron pH, color y hematomas (68%, 47% y 34%, respectivamente).

Tabla 1
Indicadores fisiológicos de bienestar bovino, clasificados según su validez y factibilidad para su uso en rastros para evaluar el bienestar previo del ganado.

Categoría	Subcategoría	Indicador	Observación **(**transporte T; espera E; manejo pre-sacrificio MPS; sacrificio y desangrado SD**)**	Categorías comerciales de ganado (terneros machos Mt; novillos No; terneras hembras Ht; novillas Na; Vacas; Toros)	Validez (alta A; intermedia I; baja B)	Factibilidad en rastro (alta A; media M; baja B)	Referencias (primer autor y año de publicación)
Fisiológica	Medidas endócrinas	Concentración plasmática de cortisol	T, E, MPS, SD	Mt, No, Ht, Na, Vacas, Toros	A	B	Lensink, 2000; Lensink, 2001; Jacobsen, 2003; Van de Wader, 2003; María, 2004; Tadich, 2005; Amtmann, 2006; King, 2006; Mounier, 2006; Averós, 2008; Bourguet, 2010; Burdick, 2010; Bourguet, 2011; Hemsworth, 2011; Miranda-de la Lama, 2013; Pighin, 2013; Werner, 2013; Alende, 2014; Probst, 2014; Francisco, 2015; Chulayo, 2016; Romero, 2017
		Catecolaminas	T, E, MPS	Mt, No, Vacas	B	B	Bourguet, 2010; Burdick, 2010; O'Neill, 2012; Alende, 2014
	Índice de miedo/excitación y liberación de catecolaminas	Glucosa	T, E, MPS	Mt, No, Ht, Na, Vacas, Toros	A	B	Jarvis, 1996; Van de Wader, 2003; María, 2004; Tadich, 2005; Amtmann, 2006; Averós, 2008; Bourguet, 2010; Pighin, 2013; Alende, 2014; Probst, 2014; Chulayo, 2016
	Índice de privación de alimentos	B-hidroxibutirato	T, E	Mt, No, Na, Vacas	A	B	Jarvis, 1996; Tadich, 2005; Amtmann, 2006; Werner, 2013

	Ácidos grasos no esterificados (NEFA)	T, E	Mt, Ht	A	B	Van de Wader, 2003
Indicadores de ayuno	Ácidos grasos libres	E	Mt, No, Na, Vacas	A	B	Jarvis, 1996
	Glucógeno	T, E	No	A	B	Amtmann, 2006; Pighin, 2013; Alende, 2014
Índice de esfuerzo físico	Creatina quinasa (CK)	T, E, MPS	Mt, No, Ht	A	B	Van de Wader, 2003; María, 2004; Tadich, 2005; Amtmann, 2006; Averós, 2008; Werner, 2013; Mpakama, 2014; Francisco, 2015
	Lactato	T, E, MPS	Mt, No, Ht, Na, Vacas	A	B	Van de Wader, 2003; María, 2004; Averós, 2008; Bourguet, 2010; Miranda-de la Lama, 2013; Alende, 2014; Probst, 2014; Boles, 2015; Francisco, 2015; Hayes, 2015
	Lactato deshidrogenasa	MPS	Mt	A	B	Francisco, 2015
Indicadores de deshidratación y/o hemoconcentración Índice de miedo/excitación y liberación de catecolaminas	Volumen del paquete celular	T, E, MPS	Mt, No, Na, Vacas	A	B	Jarvis, 1996; Tadich, 2005; Amtmann, 2006; Pighin, 2013; Werner, 2013
Indicadores de deshidratación y/o hemoconcentración	Proteína sérica total	T, E, MPS	Mt, No, Na, Vacas	A	B	Jarvis, 1996; Averós, 2008; Pighin, 2013; Werner, 2013; Alende, 2014; Francisco, 2015
	Hematocrito	T, E, MPS	Mt, Vacas, Toros	A	B	Averós, 2008; Bourguet, 2011; Miranda-de la Lama, 2013
	Glóbulos rojos	T, MPS	Mt	A	B	Averós, 2008; Miranda-de la Lama, 2013
	Osmolaridad	E	Mt, No, Na, Vacas	A	B	Jarvis, 1996

Indicadores de inmunosupresión	Glóbulos blancos	T, E, MPS	Mt	A	B	Averós, 2008; Giannetto, 2011; Jacobsen, 2003; Miranda-de la Lama, 2013; Werner, 2013
Respuesta inmune	IgA	MPS	Mt	A	B	Francisco, 2015
Indicadores de procesos inflamatorios Índice de esfuerzo físico intenso	Proteínas de fase aguda (haptoglobina, amiloide A sérico, fibrinógeno)	T, E, MPS	Mt	I	B	Jacobsen, 2003; Averós, 2008; Giannetto, 2011; Werner, 2013; Francisco, 2015
Marcadores de miedo/excitación – Reactividad emocional	Frecuencia cardíaca	T, E	Mt, Ht, Vacas	B	B	Lensink, 2001; Van de Wader, 2003; Schwartzkopf, 2007; Bourguet, 2010; Giannetto, 2011
	Frecuencia respiratoria	T, E	Mt	I	M	Giannetto, 2011
	Temperatura rectal	T, E	Mt	B	B	Burdick, 2010; Giannetto, 2011
	Proteínas de choque térmico	T, E, MPS	Na, Vacas, Toros	I	B	Chulayo, 2016

Tabla 2

Indicadores morfométricos de bienestar bovino, clasificados según su validez y factibilidad para su uso en rastros para evaluar el bienestar previo del ganado.

Categoría	Subcategoría	Indicador	Observación (transporte T; espera E; manejo pre-sacrificio MPS; sacrificio y desangrado SD)	Categorías comerciales de ganado (terneros machos Mt; novillos No; terneros hembras Ht; novillas Na; Vacas; Toros)	Validez (alta A; intermedia I; baja B)	Factibilidad en rastro (alta A; media M; baja B)	Referencias (primer autor y año de publicación)
Morfométrica		Condición corporal	MPS	Vacas, Toros	A	A	Apple, 1999; Apple et al., 1999; Emenheiser, 2014
		Peso corporal	T, MPS	Mt, No, Na	A	M	Lensink, 2000; Gallo, 2001; Schwartzkopf, 2007; Ribeiro, 2012; Miranda-de la Lama, 2013; Werner, 2013; Boles, 2015; Francisco, 2015

Tabla 3

Indicadores de comportamiento de bienestar bovino, clasificados según su validez y factibilidad para su uso en rastros para evaluar el bienestar previo del ganado.

Categoría	Subcategoría	Indicador	Observación (transporte T; espera E; manejo pre-sacrificio MPS; sacrificio y desangrado SD)	Categorías comerciales de ganado (terneros machos Mt; novillos No; terneras hembras Ht; novillas Na; Vacas; Toros)	Validez (alta A; intermedia I; baja B)	Factibilidad en rastro (alta A; media M; baja B)	Referencias (primer autor y año de publicación)
Conductual	Pre sacrificio	Interacciones humano-animal	T, E, MPS, SD	Mt, No, Na, Toros, Vacas	A	A	Lensink, 2000; María, 2004; Bourguet, 2010; Hemsworth, 2011; Miranda-de la Lama, 2012; Muñoz, 2012; Hultgren, 2014; Probst, 2014; Hayes, 2015; Doyle, 2016; Grandin, 2017; Romero, 2017
		Vocalizaciones	T, E, MPS, SD	Mt, No, Na, Toros	A	A	Grandin, 1998; Grandin, 2001; María, 2004; Nanni, 2006; Sandstrom, 2009; Bourguet, 2011; Miranda-de la Lama, 2012; Muñoz, 2012; Hultgren, 2014; Probst, 2014; Hayes, 2015; Romero, 2017
		Correr	T, MPS	Mt, No, Na, Toros	A	A	Lensink, 2001; Sandstrom, 2009; Hultgren, 2014
		Deslizarse	T, E, MPS, SD	Mt, No, Ht, Na, Toros, Vacas	A	A	Lensink, 2001; Van de Wader, 2003; María, 2004; Nanni, 2006; Minka, 2007; Sandstrom, 2009; Bourguet, 2011; Miranda-de la Lama, 2012; Hultgren, 2014; Romero, 2017
		Caídas	T, E, MPS, SE	Mt, No, Ht, Na, Toros, Vacas	A	A	Van de Wader, 2003; María, 2004; Nanni, 2006; Minka, 2007; Sandstrom, 2009; Bourguet, 2011; Miranda-de la Lama, 2012; Muñoz, 2012; Hultgren, 2014; Romero, 2017

	Moverse hacia atrás	T, MPS	Mt, No, Ht, Na, Toros	A	A	Van de Wader, 2003; Sandstrom, 2009; Bourguet, 2011; Muñoz, 2012; Hultgren, 2014
	Saltar	T, E, MPS, SD	Mt, No, Na, Toros, Vacas	A	A	Nanni, 2006; Minka, 2007; Sandstrom, 2009; Muñoz, 2012; Hultgren, 2014; Romero, 2017
	Patear	T, MPS	Mt, No, Na, Toros	A	A	Lensink, 2001; Bourguet, 2011; Hultgren, 2014
	Agresión	T, MPS	Mt, No, Na, Toros, Vacas	A	A	María, 2004; Minka, 2007; Miranda-de la Lama, 2013; Hultgren, 2014; Romero, 2017
	Paralizarse	MPS	No, Na, Toros	A	A	Sandstrom, 2009; Hultgren, 2014
	Explorar	MPS	No, Na, Toros	A	A	Hultgren, 2014
	Movimientos de cabeza	E, MPS		I	M	Bourguet, 2011; Doyle, 2016
	Beber	T, E	Mt, No, Na, Vacas	A	A	Jarvis, 1996; Gallo, 2001; Schwartzkopf, 2007
	Rumia	T	No	A	B	Schwartzkopf, 2007
	Echarse	T, E	Mt, No, Na, Vacas	A	M	Jarvis, 1996; Gallo, 2001; Lensink, 2001; Schwartzkopf, 2007
	Pararse	T, E	Mt, No, Na, Vacas	A	A	Schwartzkopf, 2007;
	Moverse	T, E	Mt, No, Na, Vacas	A	A	Jarvis, 1996; Schwartzkopf, 2007
	Reactividad	T, E, MPS	Mt, No, Vacas	A	A	Lensink, 2000; King, 2006; Bourguet, 2010; Burdick, 2010
	Separación social	E, MPS	Vacas	A	M	Bourguet, 2010
	Score de marcha	T, E	Mt, No, Ht, Na, Vacas, Toros	I	M	Grandin, 2015; NAMI, 2016; Zinpro, 2016; Edwards-Callaway, 2017; Grandin, 2017
Sacrificio	Actividad respiratoria	SD	Mt, No, Na, Toros	A	A	Gallo, 2003; Gregory, 2007; Sandstrom, 2009; Atkinson, 2013; Mpamhanga, 2015; Pérez-Linares, 2015; Neves, 2016
	Movimiento de extremidades	SD	No, Na, Toros	A	A	Atkinson, 2013; Mpamhanga, 2015

	Tono muscular	SD	No, Na, Toros	A	A	Atkinson, 2013; Mpamhanga, 2015; Neves, 2016
	Ojos en blanco	SD	Mt, No, Na, Vacas, Toros	A	A	Gallo, 2003; Gregory, 2007; Sandstrom, 2009; Atkinson, 2013; Gibson, 2015; Mpamhanga, 2015
	Reflejo palpebral positivo	SD	No, Na, Toros	A	A	Atkinson, 2013; Mpamhanga, 2015; Neves, 2016
	Reflejo corneal positivo	SD	Mt, No, Na, Toros	A	A	Gallo, 2003; Gregory, 2007; Sandstrom, 2009; Atkinson, 2013; Mpamhanga, 2015; Pérez-Linares, 2015; Neves, 2016
	Parpadeo espontáneo	SD	Toros	I	M	Sandstrom, 2009; Atkinson, 2013; Neves, 2016
	Tiempo en colapsar	SD	Mt, No, Na, Vacas, Toros	A	A	Gregory, 2007; Gibson, 2015
	Postura recuperada	SD	Mt, No, Na, Vacas, Toros	A	A	Gallo, 2003; Atkinson, 2013; Gibson, 2015; Pérez-Linares, 2015
Respuestas al dolor	Respuesta a estimulación de fosas nasales	SD	Toros	I	M	Neves, 2016
	Respuesta a pellizco de lengua	SD	Toros	I	M	Neves, 2016
	Respuesta general al dolor	SD	Mt, No, Ht, Na, Vacas, Toros	I	M	Sandstrom, 2009; Atkinson, 2013

Tabla 4

Indicadores de calidad del producto y post-mortem de bienestar bovino, clasificados según su validez y factibilidad para su uso en rastros para evaluar el bienestar previo del ganado.

Categoría	Subcategoría	Indicador	Observación (transporte T; espera E; manejo pre-sacrificio MPS; sacrificio y desangrado SD)	Categorías comerciales de ganado (terneros machos Mt; novillos No; terneras hembras Ht; novillas Na; Vacas; Toros)	Validez (alta H; intermedia I; baja B)	Factibilidad en rastro (alta A; media M; baja B)	Referencias (primer autor y año de publicación)
Calidad del producto	Calidad de la canal	Hematomas		Mt, No, Na, Vacas, Toros	A	A	Jarvis, 1995; McNally, 1996; Gallo, 2001; Lensink, 2001; Nanni, 2006; Minka, 2007; Sandstrom, 2009; Huertas, 2010; Strappini, 2010; Hoffman, 2012; Miranda-de la Lama, 2012; Romero, 2013; Vimiso, 2013; Mpakama, 2014; Francisco, 2015; Cruz-Monterrosa, 2017
	Calidad instrumental	pH		Mt, No, Ht, Na, Vacas, Toros	A	A	McNally, 1996; Lensink, 2000; Gallo, 2001; Lensink, 2001; María, 2003; María, 2004; Onenc, 2004; Amtmann, 2006; King, 2006; Mounier, 2006; Jelenikova, 2008; Mach, 2008; Pérez-Linares, 2008; Bourguet, 2010; Del Campo, 2010; Strappini, 2010; Bourguet, 2011; Duarte, 2011; Ribeiro, 2012; Kim, 2013; Miranda-de la Lama, 2013; Pérez-Linares, 2013; Pighin, 2013; Romero, 2013; Vimiso, 2013; Hou, 2014; Mpakama, 2014; Peña, 2014; Teke, 2014; Francisco, 2015; Chulayo, 2016; Romero, 2017

Temperatura	Mt, No, Na, Vacas, Toros	B	B	Onenc, 2004; Ferreira, 2006; King, 2006; Bourguet, 2010; Del Campo, 2010; Bourguet, 2011; Chulayo, 2016
Color	Mt, No, Ht, Na, Vacas	A	B	Lensink, 2000; Gallo, 2001; Lensink, 2001; María, 2003; Van de Wader, 2003; Onenc, 2004; Ferreira, 2006; Panjono, 2009; Del Campo, 2010; Duarte, 2011; Ribeiro, 2012; Kim, 2013; Miranda-de la Lama, 2013; Pighin, 2013; Vimiso, 2013; Alende, 2014; Hou, 2014; Mpakama, 2014; Peña, 2014; Teke, 2014; Francisco, 2015; Chulayo, 2016
Huesos rotos	No, Na, Toros	I	M	Mpamhanga, 2015
Hemorragias petequiales	No, Na, Toros	I	M	Mpamhanga, 2015
Capacidad de retención de agua	Mt, No, Na, Vacas, Toros	A	B	Lensink, 2001; Onenc, 2004; Del Campo, 2010; Duarte, 2011; Ribeiro, 2012; Kim, 2013; Miranda-de la Lama, 2013; Alende, 2014; Hou, 2014; Kamatara, 2014; Peña, 2014; Teke, 2014; Francisco, 2015
Textura	Mt, No, Na, Vacas, Toros	A	B	Voisinet, 1997; Lensink, 2001; María, 2003; Onenc, 2004; Ferreira, 2006; King, 2006; Jelenikova, 2008; Panjono, 2009; Del Campo, 2010; Duarte, 2011; Ribeiro, 2012; Miranda-de la Lama, 2013; Alende, 2014; Hou, 2014; Kamatara, 2014; Peña, 2014; Teke, 2014; Boles, 2015; Francisco, 2015; Hayes, 2015; Chulayo, 2016
Marmoleo	Mt, No, Na	I	M	Panjono, 2009; Del Campo, 2010; Francisco, 2015; Hayes, 2015

		DFD	No, Na	I	M	Voisinet, 1997; Kreikemeier, 1998; Scanga, 1998; Van de Water, 2003; Ferreira, 2006; Pérez-Linares, 2008; Pérez-Linares, 2013; Romero, 2013; Chulayo, 2016; Romero, 2017
	Calidad sensorial	Terneza	Mt, No	A	No aplica	Lensink, 2001; Villarroel, 2003; Onenc, 2004; Miranda-de la Lama, 2013; Alende, 2014
		Madurez	Mt, No, Na	A	No aplica	Panjono, 2009; Miranda-de la Lama, 2013; Hayes, 2015
		Olor	Mt, No	I	No aplica	Villarroel, 2003; Onenc, 2004; Miranda-de la Lama, 2013; Alende, 2014
		Sabor	Mt	A	No aplica	Lensink, 2001; Villarroel, 2003; Onenc, 2004; Miranda-de la Lama, 2013
Post mortem		Score de lesión ruminal y abscesos hepáticos	Mt, No, Ht, Na, Vacas, Toros	A	A	Brown, 1975; Rezac, 2014; Amachawadi, 2016

4. Discusión

Esta revisión se centró en identificar los principales indicadores de bienestar bovino utilizados en la investigación internacional, especialmente en condiciones comerciales, y en evaluar su validez y factibilidad para promover su uso en los rastros. Los datos recopilados sistemáticamente son esenciales para la descripción precisa de la contingencia de peligros para la salud y pueden contribuir a la planificación, implementación y evaluación de acciones de mitigación de riesgos (Hoinville et al., 2013). Por lo tanto, las actividades de vigilancia del bienestar animal pueden proporcionar un marco que no solo permita la identificación oportuna de peligros y amenazas, sino que también sugiera enfoques que respalden o impulsen diferentes estrategias de gestión de riesgos para ser adoptadas por los sectores público y privado. Por ejemplo, éstos pueden comprender la internalización del riesgo por parte del sector privado, iniciativas establecidas de mitigación y gestión del riesgo, o enfoques de asociación complementarios (Irivine, 2015).

4.1 Indicadores fisiológicos

Diferentes autores han utilizado parámetros sanguíneos para evaluar la respuesta de estrés del ganado al manejo y transporte (Villarroel et al., 2003; Tadich, Gallo, Brito, & Broom, 2009). El cortisol, a pesar de su variabilidad y vida media corta, sigue siendo uno de los indicadores más utilizados, seguido del volumen de células empaquetadas (Jarvis et al., 1996; Tadich et al., 2005; Pighin et al., 2013), glucosa (Van de Water et al., 2003; Averós et al., 2008; Bourguet et al., 2010; Alende et al., 2014), lactato deshidrogenasa (LDH), insulina, ácidos grasos libres (Jarvis et al., 1996), actividad plasmática de creatina quinasa (CK), B-hidroxibutirato (Broom, 2003; Tadich et al., 2005). Más recientemente, la haptoglobina y el pig-map, una de las principales proteínas de fase aguda, también se han utilizado como indicadores de un bienestar deficiente (Piñeiro et al., 2007; Averós et al., 2008; Giannetto et al., 2011; Werner et al., 2013; Francisco et al., 2015). Es un principio básico de la ciencia (a menudo pasado por alto) que las medidas deben validarse adecuadamente antes de su uso. Esto no se ha hecho en muchas de las medidas conductuales, fisiológicas e inmunitarias que se utilizan (Rushen, 2003).

En algunos países, los gobiernos han encargado pequeñas inspecciones periódicas utilizando indicadores como cortisol, lactato y glucosa (Romero et al., 2017). Sin embargo, no siempre es fácil interpretar los niveles de cortisol como un indicador de la respuesta de los animales a los desafíos a corto y largo plazo.

La actividad de la corteza suprarrenal no se limita a condiciones adversas, ya que ocurre durante el cortejo, el apareamiento y la adquisición activa de alimentos, ninguno de los cuales podría describirse como actividades con efectos adversos en el individuo (Broom, 1988). Además, otros factores como la toma de muestras, la restricción de movimientos, la lactancia, el ordeño, el grado de habituación, las hormonas, las infecciones, así como las endotoxinas, también pueden afectar los niveles de cortisol (Sapolsky, Romero, & Munck, 2000; Trevisi & Bertoni, 2009; Blanco, Casasus, & Palacio, 2009). Normalmente se requieren varias muestras a lo largo del tiempo para tener en cuenta los picos y mesetas y la variación diurna (Broom, 1988; Shaw & Tume, 1992). Una enzima generalmente utilizada como indicador de estrés físico y/o daño muscular en la producción animal es la creatina quinasa (CK) (Minka & Ayo, 2009; Mpakama, Chulayo, & Muchenje, 2014; Simova, Voslarova, Vecerek, Passantino, & Bedanova, 2016). La actividad de CK aumenta aparentemente como resultado de un incremento en la permeabilidad de las membranas musculares inducido por la captura, carga y transporte (Mpakama et al., 2014). El transporte durante varias horas es un factor de exigencia física; los animales tienen que mantener el equilibrio y el contacto entre sí produce fatiga y hematomas, afectando la permeabilidad de las membranas y la liberación de las enzimas a la sangre. En algunos experimentos en los que se respetó la orden de transporte de bienestar animal, el aumento de la concentración de CK en la sangre fue mínimo o completamente ausente, lo que significa un bajo nivel de daño tisular (Hill, McManus, Brown, Playford & Noble, 2000; Minka & Ayo, 2009). Aunque es una enzima muy utilizada en investigación, también tiene limitaciones (que se mencionarán más adelante). Cada animal individual tiene métodos alternativos para hacer frente a la adversidad, por lo que usar solo una medida fisiológica de respuesta puede dar la impresión de que la mayoría de los animales no están estresados (Broom, 1988; Dawkins, 1998; Galindo & Manteca, 2012). Los indicadores fisiológicos no se utilizan de manera consistente en los rastros porque son costosos, invasivos y requieren un manejo adicional de las muestras (Llonch et al., 2015). Por otro lado, los indicadores fisiológicos pueden no ser siempre indicadores precisos del bienestar animal; también se debe considerar el metabolismo para la síntesis de algunas hormonas (p. ej., catecolaminas) y el estado fisiológico de los animales *per se* (O'Neill, Webb, Frylinck, & Strydom, 2012; Chulayo & Muchenje, 2015).

Está claro que todos los criterios utilizados para evaluar el bienestar se basan en mostrar alguna evidencia de cambio. El cambio *per se* no es un indicador de alteración en el bienestar ya que los animales ajustan continuamente su fisiología para mantener la homeostasis. Obviamente, su bienestar tampoco está en un estado de flujo continuo, debido a estos ajustes continuos. La pregunta importante para la investigación del bienestar en ambas disciplinas es "¿A qué nivel de cambio está en riesgo el bienestar?" (Barnett & Hemsworth, 1990). Creemos que es importante establecer valores de corte claros para cada criterio por cada especie de ganado. Además, en el pasado ha habido una tendencia a confiar demasiado en medidas fisiológicas, inmunológicas y conductuales de bienestar que no han sido adecuadamente validadas, y no consideran los problemas de salud, que son algunas de las principales amenazas para el bienestar de los animales de granja (Rushen, 2003). Por otro lado, los indicadores extremadamente sensibles al estrés pueden no ser útiles en la práctica, como ha sido el caso de ciertos indicadores como las enzimas de fase aguda (p. ej., Pig-Map o Haptoglobine) desencadenadas por situaciones estresantes debido a prácticas de manejo absolutamente normales o por programas rutinarios de vacunación en granjas. La sensibilidad de un indicador debe ser tal que sea posible detectar de forma fiable situaciones estresantes que supongan un sufrimiento significativo para los animales, evitando alarmas innecesarias basadas en cambios metabólicos normales.

Parece lógico que los veterinarios deban estar muy involucrados en el bienestar animal, pero históricamente han estado subrepresentados, particularmente en la parte del mundo de habla inglesa (Rushen, 2003). Esto ha llevado a una subestimación de la importancia de los problemas de salud como fuente de problemas de bienestar animal y a una subutilización de la incidencia de los problemas de salud como indicadores de bienestar, a pesar del reconocimiento temprano de la importancia de los problemas de salud para el bienestar animal, según lo informado por Broom (1986). Está claro que evaluar el bienestar animal es una tarea compleja y que no existe una medida simple y única (Rushen, 2003). En consecuencia, su evaluación debe abordarse desde múltiples perspectivas, que abarquen tanto el entorno donde vive el animal, el animal mismo y su producción. Al elegir qué variables fisiológicas miden mejor el bienestar, no debemos confiar demasiado en las "hormonas del estrés", ya que pueden no ser tan específicas de los estados de “motivación desagradable” como podríamos haber pensado (Dawkins, 1998). Como se mencionó anteriormente, los cambios fisiológicos también se pueden medir a través de la frecuencia cardíaca y respiratoria, así como la temperatura corporal, que puede cambiar según el nivel de actividad y la preparación para la acción de emergencia. En ambas situaciones, esas variables brindan información sobre qué tan duro está trabajando el animal para hacer frente a una situación (Broom, 1991) y se han utilizado a menudo al analizar los efectos del transporte y la espera (Lensink, Fernandez, Cozzi, Florand & Veissier, 2001; Van de Water et al., 2003; Schwartzkopf-Genswein et al., 2007; Bourguet et al., 2010; Burdick et al., 2010; Giannetto et al., 2011). En el momento del sacrificio, sin embargo, no es factible medir la frecuencia cardíaca o respiratoria, aunque esta última podría calcularse indirectamente en función de la temperatura corporal (utilizando una cámara termográfica, por ejemplo). Los factores estresantes pueden provocar un aumento de corta duración en la temperatura corporal central en los rumiantes, que es posible medir fácilmente (Pascual-Alonso et al., 2017). Hay una serie de estudios recientes que utilizan termografía infrarroja (IRT) para la vigilancia de enfermedades y bienestar del ganado. La termografía infrarroja consiste en usar una cámara infrarroja en los animales de un corral y luego identificar la temperatura de la superficie de alguna parte del animal a partir de las longitudes de onda detectadas (Yazdanbakhsh, Zhou, & Dick, 2017). El uso de la superficie del ojo es una opción común para la vigilancia de la fiebre; anatómicamente, debe correlacionarse bien con la temperatura central del animal y verse menos afectada por la temperatura ambiente (Okada, Takemura, & Sato, 2013). En esa línea, Burdick et al. (2010) encontraron que los toros 'temperamentales' pueden exhibir una respuesta más elevada (temperatura y frecuencia respiratoria) a los factores estresantes en comparación con los toros 'tranquilos' e 'intermedios'.

4.2 Indicadores morfométricos

En el ganado bovino, los indicadores comunes de desnutrición son el peso corporal o la escala de condición corporal (BCS, por sus siglas en inglés), aunque su uso a nivel rastro es limitado ya que varían en términos de edad, sexo y raza del animal, madurez, etapa de preñez o llenado intestinal (Nicholson & Sayers, 1987; Morris, Kenyon, & Burnham, 2002; Coopman, De Smet, Laevens, Van Zeveren, & Duchateau, 2009; Tebug, et al., 2016; Wangchuk, Wangdi, & Mindu, 2017). A nivel rastro, normalmente, la pérdida de peso se calcula por grupos o lotes, no individualmente. En consecuencia, generalmente la BCS se utiliza como una medida del estado nutricional. Aunque la BCS no indica el estado actual de apetito, proporciona información sobre el estado nutricional a largo plazo (Phythian, Hughes, Michalopoulou, Cripps, & Duncan, 2012). Por lo general, la BCS estima la movilización de las reservas de energía del ganado o el grado de gordura o delgadez utilizando una escala de 5 puntos (0 = más delgado, 5 = más gordo). Otros rangos de puntuación utilizan la escala 1-9, en EE. UU., y la escala 0-2 propuesta por Welfare Quality Project (Corah, 1989; Welfare Quality, 2009).

Según Morris et al. (2002), la técnica de escala de condición corporal se aprende fácilmente, no requiere equipo y, aunque algo subjetiva, brinda resultados confiables cuando se relaciona con la cobertura de grasa subcutánea. Apple (1999) mencionó que la BCS puede ser útil tanto para los productores de vacas y terneros como para las procesadoras de bovinos sacrificados al tomar decisiones de mercado. Medir la BCS puede considerarse altamente factible, sin embargo, algunos puntajes tienen demasiadas categorías y sufren de variabilidad entre observadores (Grandin, 2017). Halachmi, Klopcic, Polak, Roberts y Bewley (2013) informan que los resultados dependen de la persona que evalúa, la familiaridad con las vacas y la consistencia entre los períodos de evaluación, sugiriendo el uso de un dispositivo para el monitoreo automático (objetivo) de la condición corporal, como como cámaras termográficas o ecografías. Sin embargo, los costos del equipo y los consultores solo pueden hacerlo factible para hatos comerciales grandes, programas de selección genética y sistemas de producción donde los atributos de la canal son importantes en la clasificación (McGregor, 2017). En las economías en desarrollo y en las regiones remotas donde no se dispone de nuevas tecnologías, los métodos de evaluación subjetiva de bajo costo, como la BCS subjetiva, son la única alternativa. La escala de condición corporal también puede sufrir cambios repentinos, por ejemplo, durante el ciclo productivo de la vaca. Eso puede producir un estado metabólico de alto riesgo (balance energético negativo) ya que grandes cantidades de reservas corporales son movilizadas por el animal y deben ser metabolizadas, haciéndolo más propenso a la aparición de enfermedades metabólicas.

4.3 Indicadores de comportamiento

Las plantas de sacrificio se diseñan con base a criterios arquitectónicos convencionales, como la optimización del espacio o la facilitación de las actividades humanas, pero generalmente no consideran las necesidades de comportamiento de los animales (Miranda-de la Lama et al., 2012). Las mediciones completas del bienestar animal requieren observaciones desde la descarga hasta la inconsciencia, incluyendo la rampa de descarga, durante el tiempo de espera, el traslado del ganado al cajón de aturdimiento y el desangrado (Hultgren, Wiberg, Berg, Cvek, & Lunner Kolstrup, 2014). Las reacciones a ciertos aspectos de los procedimientos de sacrificio podrían tener consecuencias en etapas posteriores del sacrificio, por lo que mejorar una etapa puede tener efectos positivos en etapas posteriores (Bourguet et al., 2011). Para el ganado, la carga y descarga suele ser más estresante que el propio viaje; sin embargo, no existe una normatividad que defina las condiciones apropiadas o límites de tiempo para estos procedimientos (María, Villarroel, Chacón, & Gebresenbet, 2004). Por otro lado, se debe tener en cuenta que tanto las instalaciones disponibles durante esas etapas, como el manejo por parte del personal, también influirán el comportamiento animal. Varios autores sugieren la medición de caídas, agresiones/peleas, resbalones, saltos, tropezones, retrocesos, montas y vocalizaciones (Van de Water et al., 2003; Minka & Ayo, 2007; Bourguet et al., 2011; Hultgren et al., 2014), ya que son indicadores (eventos) asociados a respuestas conductuales relacionadas con el miedo y podrían reflejar la eficiencia con la que se maneja a los animales al llegar a la planta de sacrificio (Hemsworth et al., 2011; Miranda-de la Lama et al., 2012). Las condiciones de carga y descarga influirán en la calidad del tiempo de espera; sin embargo, la espera en malas condiciones también afectará el comportamiento animal.

Grandin (2017) menciona la extensa variación entre el comportamiento del ganado durante el tiempo de espera, con base en informes del personal del rastro; el ganado puede ser difícil o fácil de mover y es más probable que se maltrate al primero. Esto puede explicarse por diferencias en la reactividad emocional, es decir, la tendencia a mostrar reacciones pronunciadas ante diferentes situaciones que inducen miedo (Bourguet et al., 2010). Las pruebas utilizadas para evaluar el miedo animal, en la relación humano-animal (HAR, por sus siglas en inglés), se pueden dividir en tres categorías: 1) evaluación de las reacciones ante la presencia de una persona estacionaria, 2) evaluación de las reacciones ante una persona en movimiento, y 3) reacciones al manejo (Lensink et al., 2001; Bourguet et al., 2010; Waiblinger, Menke, Korff & Bucher, 2004). En el rastro, normalmente estas pruebas deben ser bastante breves (Hultgren et al., 2014) y realizarse en grupos de animales, para eliminar el estrés debido al aislamiento social, que puede afectar los resultados. Esta metodología ha sido útil para identificar problemas relacionados con el diseño de las plantas de sacrificio, deficiencias en la selección y capacitación del personal responsable, la actitud de los empleados y el estado emocional de los animales evaluados (Hemsworth, 2003; Hultgren et al., 2014; Romero et al., 2017).

El viaje al cajón de aturdimiento puede ser estresante, según la longitud y el diseño del mismo y la calidad de la HAR. Las vocalizaciones por el uso de arreadores eléctricos, evasivas, la negativa a moverse, retroceder y/o darse la vuelta, son indicadores que se pueden comparar entre diferentes animales (Grandin, 2017). Los arreadores eléctricos son muy estresantes para el ganado. Según Grandin (2010), el porcentaje de animales movidos con arreador eléctrico es una de las cinco medidas registradas por la industria privada y algunos gobiernos al auditar el bienestar animal en las plantas de sacrificio. Estudios previos han demostrado que una mayor interacción con el operario se correlaciona con una mayor respuesta de estrés fisiológico en el ganado, y que las interacciones táctiles y los ruidos agudos o fuertes están asociados con el miedo o el estrés del ganado (Breuer, Hemsworth, Barnett, Matthews & Coleman, 2000; Weeks, 2008; Hemsworth et al., 2011). También se ha demostrado que las interacciones auditivas artificiales o generadas por humanos generan un aumento de la frecuencia cardíaca y del movimiento en el ganado (Waynert, Stookey, Schwartzkopf-Genswein, Watts, & Waltz, 1999). Las observaciones objetivas del comportamiento del operario utilizadas por varios autores incluyen interacciones táctiles (p. ej., empujar, golpear y arrear eléctricamente), interacciones auditivas (p. ej., hablar, gritar, silbar y el uso de ruidos artificiales, como golpear accesorios de los corrales), interacciones visuales (p. ej., agitar los brazos o agitar objetos) y contacto con áreas sensibles (Hemsworth et al., 2011; Hultgren et al., 2014; Doyle et al., 2016). Doyle (2016) también desarrolló una evaluación subjetiva que evalúa la relación entre los operarios y los animales. Aunque esta escala puede ser una forma útil de registrar el comportamiento del operario y proporcionar una técnica rápida y eficaz para auditar, se necesita más investigación para confirmar su confiabilidad. La calidad del manejo durante la conducción de los animales influirá en la eficacia del aturdimiento. Probst et al. (2014), Bourguet et al. (2011) y Romero et al. (2017) mencionan que la facilidad con la que los animales son conducidos al cajón de aturdimiento puede estar asociada con la cantidad de disparos de aturdimiento requeridos. El número de arreos eléctricos puede dificultar el aturdimiento posterior o, alternativamente, los animales que eran reactivos cuando se introdujeron en el cajón de aturdimiento, también podrían ser reactivos durante el aturdimiento. El estado de estrés del operario también puede desempeñar un papel (Hemsworth, 2003). Las vocalizaciones durante el aturdimiento son un indicador útil ya que se relacionan con la calibración ineficiente de la pistola de aturdimiento, la falta de mantenimiento, la capacitación deficiente del personal, la presencia de ganado muy excitado y la presión excesiva del fijador de cabeza (Grandin, 2010). Como se mencionó anteriormente, las vocalizaciones en el cajón de aturdimiento son indicativas de reactividad, lo que ilustra que los animales deben ser aturdidos sin demora (Muñoz, Strappini & Gallo, 2012). Finalmente, indicadores como resbalones, reveses, caídas y saltos también podrían ser considerados al diseñar cajones de aturdimiento (Gallo, Teuber, Cartes, Uribe, & Grandin, 2003).

Los tipos de observaciones conductuales que se utilizan para evaluar el dolor se pueden dividir en medidas subjetivas u objetivas. Los sistemas de puntuación subjetiva han sido particularmente populares en la literatura veterinaria porque se consideran relativamente fáciles de aplicar en un entorno clínico. Un ejemplo bien conocido para el ganado lechero es la escala de la marcha para evaluar la cojera (Rushen, de Pasillé, von Keyserlingk, & Weary, 2008). La escala de la movilidad del ganado se está convirtiendo en uno de los métodos ampliamente aceptados para evaluar los efectos potenciales sobre el bienestar. Pero tal herramienta no existía hace dos años para el ganado finalizado (de engorda); sin embargo, es importante mencionar que se han realizado varios estudios de cojera a nivel granja, demostrando que se trata de un grave problema de bienestar (von Keyserlingk, Barrientos, Ito, Galo, & Weary, 2012; Cook, Hess, Foy, Bennett, & Brotzman, 2016). La escala de movilidad es una medida basada en los animales. Por lo general, implica el uso de un sistema de puntuación con una escala de gravedad de cuatro puntos que evalúa la movilidad del ganado (marcha o movimiento) siguiendo el patrón de movimiento de las extremidades durante la locomoción (Grandin, 2015; NAMI, 2016; Zinpro Corporation, 2016). Aunque el ganado finalizado ciertamente puede sufrir de cojeras (con impactos económicos significativos para los corrales de engorda), la movilidad reducida ha sido relativamente poco estudiada en el ganado finalizado en comparación con el ganado lechero (Edwards-Callaway, Calvo-Lorenzo, Scanga, & Grandin, 2017). Los animales cojos que tienen dificultad para caminar pueden evaluarse fácilmente cuando se descargan de los camiones en el rastro. Para facilitar las comparaciones entre rastros, tanto los productores como la industria cárnica deben elegir una herramienta de puntuación común (Grandin, 2017). Algunos de los desafíos asociados con la evaluación de la movilidad del ganado a gran escala son la consistencia y la subjetividad de la escala de movilidad, el entorno en el que se evalúa el ganado y la velocidad a la que se debe evaluar el ganado en entornos comerciales (Edwards-Callaway et al., 2017) . Debido a esto, algunos investigadores han propuesto utilizar la incidencia de problemas en las pezuñas y/o un sistema de monitoreo automatizado (p. ej., cámaras que detectan problemas de cojera o animales fatigados) (Thomson, Loneragan, Henningson, Ensley, & Bawa, 2015) como un enfoque más fiable que el análisis de la marcha. Sin embargo, existe poca estandarización con respecto a la puntuación de las lesiones en las pezuñas (Rushen et al., 2008; van Staaveren et al., 2017).

Se cree que algunos indicadores de comportamiento son más válidos que otros (Llonch et al., 2015). Si bien tienen la ventaja de ser no invasivos, algunos son más costosos en términos del tiempo requerido por el evaluador (María, 2017). Dado que el rastro es un entorno novedoso para el ganado, en comparación con la granja, los indicadores de bienestar conductual solo pueden considerarse válidos en el momento de la inspección en el rastro, sin proporcionar información válida sobre el bienestar previo (Visser et al., 2001). Por otro lado, el comportamiento del ganado en el rastro también podría verse influenciado por características individuales como la raza (Minka & Ayo, 2007; Hoffman & Lühl, 2012; Sant'Anna & Paranhos da Costa, 2013), el sexo (Probst et al., 2014; Hoffman & Lühl, 2012), la edad (Hoffman & Lühl, 2012; Hultgren et al., 2014) y experiencias tempranas (Lensink et al., 2000; Lensink et al., 2001; King et al., 2006; Bourguet et al., 2010; Pighin et al., 2013).

4.4 Calidad del producto e indicadores post mortem

Diversos estudios han demostrado que incluso defectos leves en la calidad de la carne indican sufrimiento *ante mortem*, corroborado por indicadores fisiológicos, plasmáticos o conductuales. Sin embargo, la falta de defectos en la calidad de la carne no asegura la ausencia de sufrimiento antes del sacrificio (María, 2008). En términos de calidad de la canal y la carne, el indicador de bienestar más común asociado con la mejora de las prácticas de manejo son las lesiones cutáneas, como raspaduras y hematomas, indicadores objetivos potenciales de bienestar. Un hematoma se define como una extravasación visible de eritrocitos en el subcutis y el tejido circundante, después de un traumatismo en el cuerpo por el impacto de un instrumento contundente (Pilling, Vanezis, Perrett & Johnston, 2010). La superficie de la piel está intacta, pero las paredes de las venas, las vénulas y las arterias pequeñas están desgarradas, por lo que la sangre se filtra hacia el tejido circundante (Barington & Jensen, 2016).

El registro de hematomas en canales a nivel rastro puede tener un potencial significativo como recurso para la vigilancia de problemas de bienestar en el ganado (Correia-Gomes et al., 2016). Los hematomas son indicadores altamente válidos y factibles del bienestar animal, indicando fallas básicas en la cadena logística previa al sacrificio. Pueden ayudar a identificar la fuente de problemas, como el uso de arreadores eléctricos, objetos que sobresalen o bordes ásperos, caídas, manejo abusivo del ganado, mezcla social o puertas abatibles (Miranda-de la Lama et al., 2012). Primero es importante establecer una base (distinguiendo entre lesiones accidentales y evitables), sobre la cual se pueden realizar mejoras y luego estandarizar la evaluación. Para mejorar la precisión, la misma persona debe realizar la evaluación en el rastro (Grandin, 2017). En términos prácticos, los hematomas se pueden separar en dos categorías: hematomas recientes y hematomas antiguos (que ocurrieron antes de la espera; Grandin, 2017). Es importante determinar la edad del hematoma para asociarlo con el manejo previo al sacrificio, pero si el transporte y la espera ocurren dentro de las 12 h, es muy difícil saber cuándo se infligió un hematoma (Strappini, Metz, Gallo & Kemp, 2009). Los hematomas de más de 18 h son más amarillos que los hematomas recientes (Langlois, 2007). Aproximadamente una hora después de infligir un hematoma, los cambios en su apariencia macroscópica dependen de la fuerza del impacto, lo que afectará su gravedad y la cantidad de tejido muscular necrótico (Barington & Jensen, 2016). A nivel mundial se han desarrollado diferentes evaluaciones de canales bovinas para su uso en rastros con fines comerciales (Strappini et al., 2009). El 'Australian Carcass Bruises Scoring System' (ACBSS) ideado por Anderson y Horder (1979) clasifica la gravedad de los hematomas de acuerdo con el área superficial de la lesión en tres grupos: 'leve', 'mediana' y 'grave'. El Instituto de Investigación de la Carne de Finlandia ha desarrollado un sistema de evaluación de hematomas en canales basado en el color y la gravedad del trauma (Honkavaara, Rintasalo, Ylonen, & Pudas, 2003). Mientras que en varios países de América del Sur (Argentina, Brasil, Chile y Uruguay), actualmente se utiliza una clasificación de grados de hematomas que se basa en la severidad del hematoma y los tejidos afectados en el área lesionada. Sin embargo, el uso de este sistema de calificación sólo es obligatorio en Chile (CHILE, 1994; [INN] Instituto Nacional de Normalización, Chile, 2002). Aunque los sistemas actuales de evaluación de hematomas en los rastros son útiles para conocer la prevalencia de hematomas en el ganado sacrificado, se requieren análisis epidemiológicos para obtener información precisa sobre los factores de riesgo para la aparición de hematomas y la probabilidad de causas presuntas (Strappini et al., 2009).

Las respuestas al estrés pueden influir en el metabolismo muscular *post mortem* y, en consecuencia, en la calidad de la carne (Bourguet et al., 2010; Hemsworth et al., 2011). A nivel comercial, la última medición de pH tomada es uno de los valores de referencia más importantes para medir la calidad de la carne y está relacionado con el agotamiento de las reservas de glucógeno y la liberación de lactato causada por el manejo estresante (Terlouw, 2015). También es el indicador instrumental más utilizado en los estudios que evalúan el manejo previo al sacrificio, ya que tiene en cuenta las rutas metabólicas y las reservas de energía muscular. El transporte de animales incluye las granjas, puntos intermedios (mercados de subastas, centros de acopio, centros de clasificación de logística, puntos de control sanitario, escalas logísticas y puntos de descanso) y la planta de sacrificio. En este contexto, Romero, Uribe-Velásquez, Sánchez, & Miranda-de la Lama (2013) encontraron que los animales provenientes de mercados o que hacían escalas durante el trayecto tenían niveles de pH más altos en comparación con los transportados directamente de la granja a la planta de sacrificio. María et al. (2003) y Ferreira et al. (2006) no encontraron muchos cambios significativos en el pH de la carne en términos de duración de los viajes, pero se notan pocos efectos cuando el estrés es leve o los animales gozan de buena salud. De acuerdo con Warriss, Kestin, Brown y Wilkins (1984), los recursos de glucógeno se pueden restaurar durante la espera y el ganado puede recuperarse del agotamiento físico incluso si no se alimenta. Por su parte, Gallo, Espinoza, & Gasic (2001), Mounier et al. (2006), del Campo et al. (2010) y Teke, Akdag, Ekiz y Ugurlu (2014) encontraron que el pH final era más bajo cuando el tiempo de espera era más prolongado. Varios autores sugieren que la capacidad del ganado para descansar o recuperarse durante la espera depende del entorno y de los efectos de la restricción de alimento y agua (Jarvis et al., 1996; Van de Water et al., 2003). Bourguet et al. (2011) informan que las diferencias en los procedimientos de sacrificio y el tipo de sacrificio ('halal' frente a convencional) también pueden influir en el pH final. En general, los factores estresantes parecen ser aditivos y múltiples factores estresantes en el período previo al sacrificio darán como resultado un pH muscular final más alto que un único factor estresante (del Campo et al., 2010). Otros estudios han encontrado que las diferencias en el pH final se deben al sistema de alimentación, el temperamento y la raza (Lensink et al., 2000; Lensink et al., 2001; Amtmann, Gallo, van Schaik & Tadich, 2006; Mounier et al., 2006; Ribeiro et al., 2012; Pighin et al., 2013; Mpakama et al., 2014), categoría comercial (Mach, Bach, Velarde, & Devant, 2008; Romero et al., 2013) y hematomas (McNally & Warriss, 1996; Strappini, Frankena, Metz, Gallo, & Kemp, 2010; Vimiso & Muchenje, 2013). Por tanto, el pH final es un indicador válido para medir la calidad de la carne, siendo fiable y comercialmente viable, hasta el punto de que muchos rastros miden sistemáticamente el pH de la carne (María, 2008).

El pH del músculo también puede afectar importantes características comerciales de color y capacidad de retención del agua. Cuando el pH final de la carne es de 5.8-6, las proteínas sufren varios cambios moleculares, entre ellos la presencia de espacios (gaping) que se llenan rápidamente de agua (mayor retención de agua), y son obstáculos para el transporte libre de oxígeno desde la superficie hacia el centro del músculo, con lo cual la mioglobina se transformaría en metamioglobina, dando un color más oscuro a la carne (Terlouw, 2005). Vimiso y Muchenje (2013) encontraron un efecto lineal negativo significativo de la distancia, la densidad de población y la duración del transporte sobre el color. Por el contrario, María et al. (2003) y Van de Water et al. (2003) no encontraron un efecto importante del transporte sobre el color de la carne. María et al. (2003) mencionan que ningún factor único es responsable de la decoloración de la carne, lo que probablemente se deba a una combinación de factores asociados con los cambios *post mortem*. Otros factores que se han relacionado con un aumento tanto del color como de la capacidad de retención del agua de la carne son la posición del animal dentro del vehículo de transporte (frente vs atrás) (Van de Water et al., 2003), el tiempo de espera (Gallo et al., 2001; del Campo et al., 2010; Teke et al., 2014), método de aturdimiento (Onenc & Kaya, 2004; Kim et al., 2013), temperamento de los animales (Voisinet, Grandin, O 'Connor, Tatum & Deesing, 1997; Lensink et al., 2000; Lensink et al., 2001; King et al., 2006; del Campo et al., 2010; Ribeiro et al., 2012; Miranda-de la Lama et al., 2013; Pighin et al., 2013; Mpakama et al., 2014; Peña et al., 2014; Francisco et al., 2015), y el método de suspensión de la canal (Kamatara et al., 2014; Hou et al., 2014). La medición de la capacidad de retención del agua en los rastros es limitada; sin embargo, el color de la carne podría evaluarse usando estándares de color.

Un pH superior a 5.8, junto con un color oscuro y una alta retención de agua, son características de la carne oscura, firme y seca (conocida como DFD por sus siglas en inglés o “dark cutting beef”). Este tipo de carne se ha relacionado con el temperamento de los animales (Voisinet et al., 1997), la categoría comercial (Voisinet et al., 1997; Kreikemeier, Unruh, & Eck, 1998; Scanga, Belk, Tatum, Grandin, & Smith, 1998), un pobre manejo durante el transporte (Pérez-Linares et al., 2013; Romero et al., 2017), el tiempo de espera (altas densidades de población y condiciones climáticas; Kreikemeier et al., 1998; Pérez-Linares et al., 2013; Teke et al., 2014; Romero et al., 2017), el tiempo necesario para entrar al cajón de aturdimiento (Pérez-Linares et al., 2013), el aturdimiento fallido (Miranda-de la Lama et al., 2012) y hematomas (Romero et al., 2013; Vimiso & Muchenje, 2013). Cuando el corte oscuro límite se determina por medios visuales, las canales clasificadas como "oscuras" no necesariamente exhiben verdaderas características DFD. Por ello, María (2008 y 2017) planteó la posibilidad de detectar animales propensos a este tipo de carnes defectuosas mediante cámaras termográficas infrarrojas (método de evaluación objetiva), el cual se considera no invasivo. Consiste en obtener una foto térmica del animal a través de una cámara infrarroja que dará una imagen característica de los candidatos a DFD. Este sistema se puede instalar en rastros e indicará a los operadores cuando un animal (que va a ser sacrificado) puede desarrollar carne anormal. Por tanto, indicará una conveniente espera para su total recuperación. Sin embargo, tanto el costo del equipo como la contratación de consultores para utilizar el equipo (o la capacitación del personal en el rastro) pueden ser un factor limitante en términos económicos (McGregor, 2017). Por lo tanto, podría utilizarse en su lugar una “muestra de color” (método de evaluación subjetiva).

Las alteraciones de la calidad instrumental (pH, color, retención de agua y textura), también influyen en las propiedades organolépticas de la carne. María et al. (2003) encontraron diferencias en la calidad sensorial con respecto al tiempo de transporte en términos de terneza y gusto general, mientras que Alende et al. (2014) encontraron los mismos cambios en la carne pero relacionados con tiempos de espera más prolongados. Onenc & Kaya (2004) y Hayes et al. (2015) encontraron que tanto el método de aturdimiento como el sacrificio religioso afectan la ternura de la carne. Finalmente, Miranda-de la Lama et al. (2013) encontraron que la puntuación de los paneles de sabor se vio afectada por el rango social de los animales, específicamente con respecto a la ternura y algunos olores y sabores. Aunque estos indicadores son ampliamente utilizados por los investigadores, su viabilidad de uso en los rastros es baja ya que sus métodos de evaluación son complejos de implementar comercialmente.

La acidosis aguda y crónica, condiciones que siguen a la ingestión de cantidades excesivas de carbohidratos de fácil fermentación, son problemas importantes de producción para los rumiantes alimentados con dietas ricas en concentrado. Con la acidosis aguda, la acidez ruminal y la osmolaridad, aumentan notablemente a medida que se acumulan los ácidos y la glucosa; éstos pueden dañar las paredes ruminales e intestinales, disminuir el pH de la sangre y causar deshidratación, laminitis, polioencefalomalacia y abscesos hepáticos (Owens, Secrist, Hill, & Gill, 1998). Todo esto deja huellas evidentes en los órganos del animal que pueden ser verificadas durante la inspección *post mortem*. Los abscesos hepáticos se detectan solo en el momento del sacrificio, porque el ganado, incluso aquellos que tienen cientos de pequeños abscesos o varios abscesos grandes, rara vez muestran signos clínicos (Nagaraja & Chengappa, 1998). Por otro lado, las lesiones de rumenitis pueden servir como secuelas patológicas "atemporales" e indicadores de agresiones químicas pasadas al epitelio ruminal (Rezac et al., 2014). Aunque existen desafíos logísticos para realizar el examen patológico del rumen a la velocidad de la cadena en las plantas empacadoras modernas (Llonch et al., 2015), existen varias ventajas al incluir datos de lesiones ruminales junto con datos de abscesos hepáticos cuando se monitorea la salud ruminal en un sistema de producción o durante la evaluación de intervenciones. Sin embargo, los métodos y los sistemas de puntuación deben estar bien documentados, ser consistentes, y la recopilación de datos debe cumplirse a lo largo del tiempo para establecer rangos de referencia o “normales” (Brown et al., 1975; Rezac et al., 2014; Amachawadi & Nagaraja, 2016).

4.5 Indicadores clave y consideraciones futuras

El bienestar animal es una parte esencial de cualquier agroecosistema. Los sistemas de producción animal siempre han tenido en cuenta el bienestar de los animales. La novedad es que el concepto de bienestar animal ahora se ha redefinido e incluye aspectos (antes poco considerados), como la posibilidad de expresar un comportamiento natural o la ausencia de estados emocionales negativos. Por tanto, los actuales sistemas de evaluación del bienestar animal deben tener en cuenta estas nuevas necesidades animales e incluir indicadores adecuados (válidos, fiables y viables) que permitan evaluar el bienestar físico y mental de los animales. El aumento del comercio mundial asociado a una demanda creciente de proteína animal ha incrementado el número de cabezas de ganado bovino criado, transportado y sacrificado, aumentando también los problemas de bienestar en varios puntos de la cadena de suministro (Miranda-de la Lama, 2013). Dado que el bienestar es un concepto multidimensional, tiene sentido utilizar un sistema de agregación multicriterio para evaluarlo (Czycholl, Kniese, Schrader & Krieter, 2017). Si bien existen limitaciones para el uso de indicadores de bienestar en las plantas de sacrificio, éstos podrían mejorar en gran medida el manejo al reducir el estrés y el dolor causado por un manejo deficiente (Grandin, 2017). La evaluación del bienestar es fundamental para el manejo de los animales, la vigilancia del bienestar, la aplicación de la legislación, el cumplimiento de los esquemas de garantía de granjas y el etiquetado de bienestar. En ese sentido, ‘los indicadores “iceberg” o “clave” brindan una evaluación general del bienestar, al igual que la punta saliente de un iceberg señala su masa sumergida bajo la superficie del agua' (FAWC, 2009). Si estos indicadores brindan información confiable sobre el estado de bienestar de los animales, las evaluaciones podrían limitarse a esas medidas específicas y el tiempo necesario para una evaluación podría reducirse en consecuencia (Heath, Browne, Mullan & Main, 2014).

En este contexto, la inspección de la carne es uno de los sistemas de vigilancia más implementado y antiguo. Su principal objetivo es identificar los animales que no son aptos para el consumo humano y retirar sus canales y decomisos de la cadena productiva. Los objetivos adicionales son apoyar el control de enfermedades animales y, más recientemente, identificar y procesar los problemas de bienestar animal (Stärk et al., 2014). Diversos autores han propuesto el uso de un conjunto completo de indicadores para comparar la prevalencia de los indicadores de bienestar en bovinos e informar la selección basada en el riesgo para las inspecciones que miden el cumplimiento de la legislación de bienestar animal (Støier, Larsen, Aaslyng & Lykke, 2016). No obstante, hay que tener en cuenta tanto el coste como la sencillez de la evaluación. Dado que la inspección de la carne también es una actividad que consume recursos, se ha propuesto el uso de indicadores clave como una herramienta útil para proporcionar una imagen del bienestar general del animal y funcionar como una señal de advertencia para los problemas subyacentes. Siempre que se demuestre que son válidos y factibles, los indicadores clave podrían sustituir el amplio conjunto actual de medidas utilizadas en la evaluación del bienestar (FAWC, 2009). Se podría implementar un sistema integrado basado en el uso de indicadores clave definidos para cada etapa de inspección con el establecimiento de umbrales de alarma. Este tipo de sistema permite la trazabilidad completa de un lote procesado con el registro de las señales de alarma emitidas durante el proceso de inspección de la carne y de las medidas de gestión aplicadas (Stärk et al., 2014).

Evaluar el bienestar de los animales en general, mientras se apunta a la objetividad y se utilizan medidas cuantitativas, no está completamente libre de valores. El bienestar animal es un concepto que admite valores morales y otras preferencias más emocionales (Heleski & Anthony, 2012). El científico del bienestar animal debe cumplir con los valores morales de la sociedad para generar enfoques sostenibles para la gestión del bienestar animal (Ohl & van der Staay, 2012; Ferguson, Schreurs, Kenyon, & Jacob, 2014). Recientemente, las cualidades instrumentales y sensoriales de la carne también se han correlacionado con la calidad ética, es decir, aspectos del bienestar animal que pueden verse comprometidos durante el proceso de producción (Webster, 2001). En este contexto, será necesario informar a los consumidores y a la industria cárnica que el valor ético de un producto es un elemento de creciente importancia económica y una creciente oportunidad de negocio (Miranda-De la Lama, Villarroel, & María, 2014). La atención a esos factores puede ayudar a evitar la aparición de barreras técnicas al comercio mundial de carne de res en el futuro (Pighin et al., 2013). Finalmente, vale la pena mencionar que aunque el bienestar animal en los rastros europeos y de habla inglesa ha sido evaluado e informado ampliamente, dichos datos son relativamente escasos en otros países. La forma en que se manejan y procesan los animales fuera de los mercados europeos y de habla inglesa puede ser marcadamente diferente en términos de escala de producción, infraestructura, requisitos del mercado, disponibilidad de mano de obra y tecnología. Como resultado, es necesaria la investigación en esas regiones (Doyle et al., 2016; Njisane & Muchenje, 2017).

5. Conclusiones

El conocimiento de las posibles sinergias y compensaciones (trade-offs) entre los indicadores de bienestar animal en bovinos y los sistemas de monitoreo voluntarios para la cadena de valor es esencial para la industria cárnica que tiene como objetivo mejorar el nivel de bienestar y la calidad de la carne en las operaciones comerciales previas al sacrificio. Esta revisión puede servir como una herramienta que proporcione indicadores muy útiles; sin embargo, también es importante tener en cuenta que puede haber variaciones en la efectividad de estos indicadores entre regiones (p. ej., países desarrollados frente a países en vías de desarrollo), e incluso en el mismo país (p. ej., plantas exportadoras frente a rastros municipales). Aunque la producción de carne se ha vuelto más eficiente y las velocidades de línea han aumentado, todavía hay margen de mejora en toda la cadena logística previa al sacrificio. Esta revisión sistemática identifica indicadores altamente válidos que son útiles para evaluar el bienestar del ganado en los rastros, incluida la escala de condición corporal, las interacciones entre humanos y animales, las vocalizaciones, los hematomas en las canales y el pH de la carne. Además, algunos indicadores válidos intermedios (es decir, frecuencia respiratoria, temperatura corporal y carne DFD) son útiles y deben investigarse más a fondo. La recopilación de datos en los rastros comerciales puede ayudar a mejorar los procedimientos. En general, la información a lo largo de la cadena productiva podría usarse de manera mucho más sistemática con el objeto de proporcionar una base para una inspección de la carne con más enfasis en el riesgo.

Conflicto de intereses

Todos los autores declaran que no existen conflictos de interés presentes o potenciales entre los autores y otras personas u organizaciones que puedan sesgar indebidamente su trabajo.

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Capítulo 2

Cattle welfare assessment at the slaughterhouse level: Integrated risk profiles based on the animal's origin, pre-slaughter logistics, and iceberg indicators

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Cattle welfare assessment at the slaughterhouse level: Integrated risk profiles based on the animal's origin, pre-slaughter logistics, and iceberg indicators

N. Losada-Espinosa [a], L.X. Estévez-Moreno [b], M. Bautista-Fernández [b], F. Galindo [a], A.Z. M. Salem [c], G.C. Miranda-de la Lama [b,]*

[a] Faculty of Veterinary Medicine, National Autonomous University of Mexico (UNAM), Mexico City, Mexico
[b] Department of Animal Production and Food Science, Faculty of Veterinary Medicine, Agri-Food Institute of Aragon (IA2), University of Zaragoza, Zaragoza, Spain
[c] Faculty of Veterinary Medicine and Animal Science, Autonomous University of the State of Mexico (UAEM), Toluca, Mexico

Abstract

Detection of on farm and transport animal welfare problems at slaughterhouse level is a key issue for the meat industry; however, usually, the assessments do not include basic aspects of animal health. For that reason, it is necessary to develop an assessment method that has an integrative scope and identifies the risk profiles in animals. Therefore, the aim of the present study was to detect cattle welfare indicators that can be implemented at the slaughterhouse level and to develop integrated risk profiles based on the animal's origin, pre-slaughter logistics, and animal-based indicators. We recorded the origin, commercial category, transportation details, and horn size of 1040 cattle upon arrival at the slaughterhouse. Cattle welfare was measured based on individual scores for vocalizations, stunning shots, carcass bruises, meat pH, severe hoof injuries, and organ condemnations. To characterize operational and logistic practices from the farm to the slaughterhouse, a two-step cluster analysis was applied to the aforementioned variables (production system, cattle type, horn size, journey distance, vehicle type), which identified four clusters: small feedlot and free-range profile (C1, n = 216, 20.8 %), feedlot profile (C2, n = 193, 18.6 %), culled dairy cows profile (C3, n = 262, 25.2 %), and free-range profile (C4, n = 369, 35.5 %). The animal's diet and environmental conditions might have influenced the development of hoof disorders in C1 animals (P = 0.023), the proportion of animals that were re-shot was highest in C2 animals (P = 0.033), and C3 and C4 animals were most likely to suffer injuries such as severe bruising (P = 0.001). In addition, the number of stunning shots, meat pH, carcass bruises, severe hoof injuries, and liver condemnations, explained a significant variation in the incidence of various health and welfare consequences based on an animal's origin, which confirmed their importance as 'welfare iceberg' indicators. The study provided detailed data that can be included into assessment methods for the welfare of slaughter cattle, which can be tailored to specific production systems.

Keywords: *Cattle welfare, Iceberg indicators, Slaughterhouse assessment, On-farm conditions, Pre-slaughter operations, Risk profiles*

1. Introduction

Many slaughterhouse companies have an interest in demonstrating to internal (e.g., farmers, hauliers, and operators) and external (e.g., consumers, authorities and NGOs) stakeholders that animal welfare is important to their operations (Estévez-Moreno et al., 2021). Consequently, codes of conduct, assessment protocols, and private standards have proliferated in many meat industries (Waddock and Leigh, 2006). Currently, farm-level animal welfare assessments are the main source of information on the conditions under which animals are reared. However, the results of these assessments can be affected by the operational, physical and environmental conditions of the farm during the assessment. Additionally, such assessments are a potential biosecurity risk due to the free flow of assessors between farms. Therefore, the potential advantages of animal welfare assessments at slaughterhouse level have been recognised (Harley et al., 2012). That said, the full potential of those types of assessments has not been fully examined. There is limited evidence on the accuracy of these methods to identify welfare problems at various stages in production (Carroll et al., 2018). In addition, during pre-slaughter operations animals are exposed to a range of novel stimuli (Ferguson and Warner, 2008), making it difficult to identify risk factors that are a source of stress (Bourguet et al., 2010). Those conditions can reduce meat quality by causing, e.g., carcass shrinkage, higher pH, dark cutting beef (DCB), and carcass bruising (Chandra and Das, 2001); therefore, an assessment method that has practical indicators would be useful in providing information on animal welfare (Sala et al., 2019).

The animal-based welfare indicators that are included in an assessment must be valid (measure what is intended), repeatable (produce the same results for repeated observations of the same animal by the same and different observers), reliable (produce consistent results of different animals), and feasible (in terms of speed, cost, and does not compromise operating procedures) (Llonch et al., 2015). The FAWC (Farm Animal Welfare Council) advocated the use of 'iceberg' animal-based indicators to assess overall animal welfare (Heath et al., 2014; Van Staaveren et al., 2017). Iceberg indicators can provide valuable information on two important aspects of the life of production animals: welfare problems that occur during the growth of fattening animals on the farm; and recent acute or traumatic conditions that were associated with pre-slaughter operations such as transport, lairage, and slaughter (FAWC, 2009; Grandin, 2017). If it is confirmed that these indicators have the potential to provide valuable information on the state of animal welfare during the various stages of rearing, their incorporation into assessment protocols could be limited to those specific measurements, which would reduce the time needed for an assessment (Heath et al., 2014).

Animal welfare involves measuring the quality of life of a living animal and is a dynamic, adaptive, and multidimensional phenomenon (Broom, 2014) that includes biological functioning (health and appearance), mental states (ability to experience emotions and feelings), and species-specific behaviours. For that reason, a welfare assessment requires a multi-criteria approach that is based on various measures of physiological, behavioural, production, health, and meat quality indicators (Miranda-de la Lama et al., 2020). Valid indicators have been identified that indicate stress signs and operational failures in slaughterhouse conditions (vocalizations, stunning effectivity), animal health status (hoof disorders, organ condemnations), and product quality (carcass bruising and meat pH) (see Losada-Espinosa et al., 2018). Though the effects of those indicators have been reported, individually, the interactions among the indicators are not well understood, especially among those involving production system management and logistic practices. Cockram (2017) suggested that future research should include an applied animal welfare vision to large-scale epidemiological studies that examine several risk factors. Our study tests the hypothesis that interactions and clustering patterns might exist between the animal's origin and the known and potential 'iceberg' welfare indicators. Specifically, the aims of this study were 1) to identify known and novel welfare indicators that are suitable for assessments at the commercial slaughterhouse level, 2) to quantify the occurrence of vocalizations, stunning, hoof disorders, carcass bruises, partial condemnations, and meat pH at slaughter among animals of different origins (feedlot, free-range, or dairy systems) through post-mortem inspection, and 3) identify integrated risk profiles based on the animal's origin, pre-slaughter logistics, and animal-based indicators.

2. Material and methods

The study was carried out between March and July 2018 at a Federal Inspected Type (FIT or TIF in Spanish) slaughter plant in Malaga, Durango, Mexico (24°09'37.8"N 104°30'19.3"W), which was in compliance with the stipulations of the Official Mexican Norms that establishes the sanitary, safety, and animal welfare requirements for the slaughtering, processing, storage, import and export of all meat and meat products (NOM-008-ZOO-1994; NOM-009-ZOO-1994; NOM-033-ZOO-1995; NOM-194-SSA1-2004). The study area has a semi-arid climate, a mean annual temperature of 19 °C, a mean annual rainfall of 500 mm, and was at approximately 1885 m above sea level. The slaughterhouse was chosen because of the homogeneity in the type of animals slaughtered (at least 85% of the animals slaughtered were *Bos taurus*), an infrastructure and operational quality that was at international standards, and its strategic geographical location from which it processed animals from grazing (free-range), feedlots, and dairy farms coming from three widespread ecosystems in Mexico (i.e., semi-arid, valleys, and mountain range). Permission to conduct the study was granted by the Institutional Subcommittee for the Care and Use of Experimental Animals in the Faculty of Veterinary Medicine, National Autonomous University of Mexico (Protocol Number DC-2018/2-11).

2.1 Study description

Ante-mortem and post-mortem assessments were implemented as a cross-sectional study to assess the stunning stage (vocalizations and number of stunning shots), hoof health, carcass pH, occurrence of bruises, and organ condemnation in cattle from the feedlot, free-range, and dairy systems that entered the slaughter chain through standard schedules. Data were collected from 1040 commercial cattle that had a median (90% confidence interval) live weight of 477 kg (467.0-484.0), of which 362 came from feedlots (Hereford, Charolais, Limousine, and Angus commercial crossbreds), 414 came from free-range systems (Wagyu or British and Continental crossbred animals, with up to one half *Bos indicus* influence), and 264 came from intensive dairy systems (Holstein breed). Of the cattle assessed, 52.2% (543/1040) were males. Among commercial categories, 8.5% (n= 88) of the livestock were bullocks (castrated or intact males, 1-2 years of age), 29.4% (n= 306) were young bulls (castrated or intact males, 2-5 years of age), 14.3% (n= 149) were old bulls (castrated or intact males, >5 years of age), 2.4% (n= 25) were heifers (females 1-2 years of age), 9.8% (n= 102) were young cows (females 2-5 years of age), and 35.6% (n= 370) were old cows (females >5 years of age). Information on journey distance (1-50 km, 51-100 km, 101-150 km, 151-200 km, or > 200 km), type of livestock vehicle [small trailer (3 tons), gooseneck trailer (10 tons), or potbelly trailer (30-50 tons)], animal origin (feedlot, free-range, or dairy system), and cattle type (steer, young bull, old bull, heifer, young cow, old cow) were obtained from the Veterinary Office of SENASICA (Mexican animal health authority) at the slaughterhouse. The study used a procedure that identified the location of each individual animal from the farm to the refrigeration chamber, which allowed us to identify any predisposing factors for injuries and carcass defects (Losada-Espinosa et al., 2021).

2.1.1 Slaughterhouse conditions

The slaughterhouse operated from Monday to Friday (0830-1500 h) and had a slaughter capacity of 9000 heads/month. The concrete unloading ramps (19°), which had nonslip floors that were as wide as the livestock trailers (6.0 m wide), were connected through a curved metal race (3.0 m wide) to a lairage area that contained 24 pens (6.5 m wide x 7 m long), which had nonslip concrete floors and were covered by Polyshade™ (high-density polyethylene screen) or galvanized sheet metal roofing (16 and 8 pens, respectively). In the slaughterhouse, animals from different livestock trucks were not mixed, and each group of animals was housed in a separate pen. During lairage, the animals had access to water *ad-libitum*, and food was not provided. A concrete passageway led from the lairage area to three parallel single-file races that had a single-file race in the last 10 m before the stun box. The floors were slatted concrete and had metal bars between the races. A stockperson drove the animals manually into the stun box using his body, hands, and various tools (mainly an electric goad). The slaughterhouse had a hydraulic, vertically sliding tailgate at the entrance of the box. The stunning box (2 m long x 1.5 wide x 1.8 m high) had an automatic head fixation system, and its surface was stainless steel and did not have a non-skid floor. One side of the stun box had a guillotine door that made the animal to fall out of the box after stunning, which was facilitated by a slight slope of the floor. The slaughterhouse used a standard, pneumatically powered, penetrating captive bolt gun (model STUN-BP1, FREUND®) and, occasionally, a handheld powder-loaded device. The stockpersons always worked the animals from outside the race or box. Normally, one person worked each animal in the stun box. After being stunned, the animals were suspended by a hind leg, bled, and transferred to the production line to begin the process of removing the head, feet, skin, viscera, and the splitting of the carcass (Losada-Espinosa et al., 2021).

2.2 Stunning stage

The scoring method for vocalizations was the same as that used by Grandin (2001). Each animal was classified as either a vocalizer (audible sound emitted from mouth and or nasal cavities) or a silent animal. All animals (n= 1040) were scored as they were moved into the stunning box. Vocalizations were scored when the animals were moved through the race into the stun box and during stunning. The acoustical features of vocalizations and the number of vocalizations per animal were not recorded. Animals that vocalized in the forcing pen and in the stunning box were counted once, only. Observations were made from the handler's catwalk near the entrance of the stunning box, where the stunning box and the forcing pen could be observed. Two observers assessed the number of stunning shots. Cattle origin (feedlot, free-range, or dairy breeds), cattle type (bullock, young bull, old bull, heifer, young cow, old cow), and the number of times each animal was shot at the stunning box were recorded.

2.3 Hoof disorders

Assessments were made on one front and one hind limb of each animal (n = 1040). Given the practical problems of sampling all limbs, and the order of amputation for each limb (front left, front right, hind left, hind right), the limbs from the left flank of each animal, which were the first and third limbs to be removed, were assessed. At the time that the animals arrived at the slaughterhouse, the official veterinarian assigned a number to each animal which was written on the animal's back and was used to identify it in the stunning box. Once stunned, the animal was hoisted and bled. Immediately after bleeding started, the operating personnel removed the front left limb and hind left limb at the tarsal-metatarsal joint. One assistant collected the portion of the limbs between the hock and claw. Each limb was evaluated for general and interdigital cleaning and, thereafter, the limb was submerged in water and surface organic matter was removed by a brush. Subsequently, the claw was placed on a flat surface and inspected as follows: 1) verification of conformation (heel height, wall length, interdigital opening, and presence of growth defects as asymmetrical or corkscrew hoof, scissor hoof, overgrown hoof, and chronic laminitis), 2) integrity of the skin on the metatarsals and metacarpals (skin wounds above the coronary band), 3) inspection of the wall, 4) inspection of the sole, and 5) inspection of the heel and for evidence of white line disease (Bautista-Fernández et al., 2021).

2.4 pH measurements

To measure carcass pH 24h post-mortem (pH24) of the *M. longissimus*, we used a digital pH meter that had a penetration probe (Hanna Instruments, H199163, Woonsocket, Rhode Island, USA), which was inserted into a small incision on the left side of the carcass (12/13th rib interface). After every five samples, two standard buffer solutions at pH 7.0 and 4.0 were used to re-calibrate the pH meter at the temperature of the operation room (4°C). The pH was the mean of the readings at the two sites. Carcasses that had a pH24 greater or equal to 6.0 were classified as dark cutting (DCB). Meat of normal quality has a pH24 <6.0.

2.5 Bruising assessment

The protocol for the carcasses post-mortem was based on one modified from Strappini et al (2012). The 1,040 entire carcasses (hanging by both hind legs) were evaluated by one researcher trained for a month prior to the start of the study. The recording of the bruises was carried out in the cooling chamber as the half carcasses arrived to rest for 24 hours. For the evaluation of each animal, the identification of the two half carcasses per animal was always considered, according to the slaughterhouse traceability numeral. A bruise was a lesion in which tissues had been crushed leading to a rupture of the vascular supply and an accumulation of blood and serum, without discontinuity of the skin (Capper, 2001). If bruises in the assessed carcass were present, the number of bruises per carcass and the number of bruises per anatomical site were recorded. The location, size, severity, and shape of each bruise was recorded. The carcass was partitioned into the following seven anatomical sections: 1 = neck, 2 = front leg, 3 = thoracic and abdominal wall, 4 = hind leg, 5 = *Tuber isquiadicum* and its muscular insertions (butt/pin), 6 = *Tuber coxae* and its muscular insertions (hip), and 7 = loin. The size of the bruise was assessed based on its diameter as follows: small = 5 cm, medium = 10 cm, large = 15 cm, extra-large = 20cm. The severity of the bruise was rated as follows: grade 1 = subcutaneous tissue affected, grade 2 = as grade 1, but with muscle tissue affected, grade 3 = as grades 1 and 2, but with the presence of broken bones.

2.6 Condemnations

All animals were subjected to macroscopic meat inspection involving separate inspections of the carcass, the plucks, and the intestines. The official veterinarian designated by the SENASICA performed the post-mortem inspection of the animals, which followed the protocols established in the NOM-009-ZOO-1994 regulation and the International Regional Organization for Agricultural Health meat inspection manual (OIRSA, for its acronym in Spanish) (2016). The inspectors have received extensive training in meat inspection, disease identification and pathology of farm animals, allowing them to accurately identify pathological lesions with a small margin of error (Ninios, Lundén, Korkeala, & Fredriksson-Ahomaa, 2014). Following applicable regulation (NOM-009-ZOO-1994), evisceration was performed within 30 min from the moment the animal was stunned and bled. Any carcass that had an injury was sent to the retention rail for examination by the official veterinarian, and the viscera and head that corresponded to that carcass were identified for a thorough inspection and could not be washed or cut before the final assessment. Post-mortem examinations involved visual inspection, palpation and systematic incision of each carcass and visceral organs. In Mexico, any carcasses, viscera, and other animal-derived products that are deemed unfit for human consumption and may only be utilized for industrial purposes are considered as a condemnation. Lungs, liver, heart, udder, and intestines were selected for this study because they were among the most commonly reported portion condemnations by inspectors throughout the study period and represent potential animal and public health concerns (Alton, Pearl, Bateman, McNab, & Berke, 2012). In the slaughterhouse assessed it was not necessary to determine the degree of injury intensity. The occurrence of abnormalities in the lungs (abscess, edema, pneumonia, haemorrhage, adherence, traumatic reticuloperitonitis -TRP-), liver (abscess, Fasciola hepatica, jaundice, telangiectasia, haemorrhage, TRP, calcification, adherence, cirrhosis), heart (edema, adherence, jaundice, TRP, calcification), udder (mastitis, brucellosis, abscess, fibrosis, haemorrhage), and intestines (TRP, gastrointestinal parasites, edema, abscess) were recorded daily on standardized forms. One of the authors of this study was present at each stage of the inspection.

2.7 Statistical analysis

Data were entered into Microsoft Excel (Microsoft Corporation, 2010) and analysed with the IMB© SPSS software 22 version. Prevalence was defined as the proportion of animals that had an occurrence of each animal-based indicator (vocalizations, stunning, pH, bruises, severe front and hind limb injuries, organ condemnation), and was calculated as the indicator frequency divided by the total sample (n=1040). To identify their distribution and to detect outliers, univariate analyses were performed for each of the variables included in the study. To identify logistic profiles (types or groups) based on production system type, cattle type, horn size, journey distance, and vehicle type, a cluster analysis was performed. Various combinations of the variables were assessed in several cluster analyses, which were accepted or rejected based on the overall silhouette measure of cohesion and separation. The two-step method was used as the conglomeration method. The log-likelihood distance measure was applied for clustering and Schwarz's Bayesian Criterion was used to select the optimal number of clusters (Miranda-de la Lama et al., 2020). A cluster number was assigned to each group and a dummy variable called "cluster membership" was created to identify the logistic profile group. Once the clusters were defined, they were characterized based on their orientation toward performance in the logistic chain. To identify the significant variables that allowed discrimination among clusters, Chi-square test was used. In subsequent analyses, Chi-square and Kruskal-Wallis Tests were used to identify significant differences between logistic profiles on a set of additional cattle welfare (vocalizations, number of stunning shots, carcass bruises, meat pH) and health variables (hoof disorders, organ condemnations) (both qualitative and quantitative) that were not used in the cluster analysis. If those tests indicated a significant relationship, a post-hoc test was performed using the adjusted standardized residuals method and the Mann-Whitney U-test for qualitative and quantitative variables, respectively (Estevez-Moreno et al., 2019). Differences were considered statistically significant at $P < 0.05$.

3. Results

Table 1 shows the distribution of the animals based on production system of origin, horn size, commercial category, journey distance, and vehicle type. Among the 1040 animals, 36.9% vocalized, 32.1% received >1 stunning shot, 23.8% had a pH ≥ 6, 41% had severe bruising (grade 2 or 3), and 43.9% had severe lesions on at least one limb (32.3% presented severe lesions in the front limb and 23.8% presented severe lesions in the hind limb). Most (79.8%) of the animals did not present any condemnation in the organs evaluated. Of the 244 condemned organs (n = 210 animals), 72.5% were liver, 12.3% were lungs, 8.2% were heart, 5.3% were udders, and 1.6% were intestines.

3.1 Integrated risk profiles: Animal origin and pre-slaughter logistics

The cluster analysis identified four main logistic profile groups (C1, C2, C3, C4; Table 2). All of the variables associated with production system, commercial category, and logistic practices differed significantly ($P < 0.001$) among groups. Significant differences in multiple variables associated with either operational or logistic practices, and cattle welfare and health indicators were used to characterize each group. C1 mostly consisted of animals from feedlot systems and or had been extensively raised (free-range). The presence of bullocks (18.4%) and young bulls (38.2%), as well as young heifers (8.0%) and young cows (14.2%) that had medium horns stood out. Most of the animals in that group had been transported in gooseneck trailers, that had made either short (1-100km) or long (151-200km) journeys. In C2, 98.4% of the animals were either bullocks or young bulls without horns, reared in feedlot systems, that travelled long (>200 km) distances in a trailer ($P < 0.001$). C3 consisted of young and old cows that had small horns and had come from dairy systems. Most of the cows in that group had been transported in gooseneck trailers (46.2%) or potbelly trailers (39.3%) in which they travelled intermediate (101-150 km) distances. In C4, 99.7% of the animals were mature cows and old bulls that had long horns (46.6%), had been extensively raised (free-range), and travelled short distances (1-100km) in small trailers.

3.2 Integrated risk profiles: Cattle welfare indicators

Table 3 shows the cattle profiles associated with the animal-based indicators. Vocalizations did not differ significantly ($P > 0.05$) among the clusters. The proportion of animals that received >1 shot in C2 (39.4%) differed significantly ($P = 0.033$) from that of the other groups. Animals in C1 (29.2%) and in C3 (27.9%) had a pH ≥ 6 ($P = 0.012$), and animals from dairy systems (C3) had the highest prevalence (47.0%) of severe bruising ($P = 0.017$). A total of 43.5% of C1 animals had severe hoof lesions in either front or hind limbs ($P = 0.023$).

3.3 Integrated risk profiles: Cattle health indicators

Table 4 shows the cattle profiles associated with the health indicators assessed in this study. The liver was the only organ for which condemnations differ significantly ($P = 0.005$) among clusters (17%). In C2, 88.6% of animals had no liver condemnations, 4.2% of C1 animals had liver abscesses, and 18.2% of C4 animals had *Fasciola hepatica* ($P = 0.005$). Old cows and bulls that had been raised in extensive systems (C4) tended to have 'other pathologies' in the liver, including telangiectasia, haemorrhage, reticuloperitonitis, calcifications, adhesions, and cirrhosis.

Table 1. Distribution of the animals included in the current study (n = 1040).

Variable	*Category*	*Frequency*	*Percentage*
Journey distance	1-50 km	374	36.0
	51-100 km	125	12.0
	101-150 km	335	32.2
	151-200 km	32	3.1
	>200 km	174	16.7
Vehicle type	Small trailer (3 Tons)	470	45.2
	Gooseneck (10 Tons)	255	24.5
	Potbelly (30-50 Tons)	315	30.3
Production system	Feedlot	362	34.8
	Free-range	414	39.8
	Dairy	264	25.4
Cattle type	Steer	88	8.5
	Young bull	306	29.4
	Old bull	149	14.3
	Heifer	25	2.4
	Young cow	74	7.1
	Old cow	398	38.3
Horn size	No horns	333	32.0
	1-8 cm	166	16.0
	9-16 cm	135	13.0
	>16 cm	406	39.0

Table 2. Integrated risk profiles of cattle slaughtered at Mexico and their association with pre-slaughter logistics (n = 1040).

Variable	C1 (N=216)	C2 (N=193)	C3 (N=262)	C4 (N=369)	*P*-value
Production system (%)					
Feedlot	76.9 (+)	98.5 (-)	0.0 (+)	0.0 (-)	
Free range	23.1 (+)	1.6 (-)	0.0 (-)	99.7 (+)	< 0.001
Dairy	0.0 (-)	0.0 (-)	100.0 (+)	0.3 (-)	
Cattle type (%)					
Bullock	18.4 (+)	17.1 (+)	6.1	0.8 (-)	
Young bull	38.2 (+)	83.0 (+)	6.1 (-)	13.0 (-)	
Old bull	3.8 (-)	0.0 (-)	2.3 (-)	35.8 (+)	< 0.001
Heifer	8.0 (+)	0.0 (-)	3.1	0.8 (-)	
Young cow	14.2 (+)	0.0 (-)	17.9 (+)	7.3 (-)	
Old cow	17.5 (-)	0.0 (-)	65.3 (+)	42.3 (+)	
Horn size (%)					
No horns	28.7	36.3 (+)	30.5	32.2	
1-8cm	15.7	14.0	23.3 (+)	11.9 (-)	< 0.001
9-16cm	18.1 (+)	16.6	11.5	9.2 (-)	
>16cm	37.5	33.2	34.7	46.6 (+)	
Journey distance (%)					
1-50km	45.8 (+)	3.6 (-)	5.0 (-)	68.8 (+)	
51-100km	28.8 (+)	0.0 (-)	1.5 (-)	15.7 (+)	
101-150km	15.1	11.4	92.8 (+)	10.6	< 0.001
151-200km	9.4 (+)	0.0 (-)	0.4 (-)	3.0	
>200km	0.9 (-)	85.0 (+)	0.4 (-)	1.9 (-)	
Vehicle type (%)					
Small trailer (3 t)	27.8 (-)	0.0 (-)	14.5 (-)	100.0 (+)	
Gooseneck (10 t)	63.2 (+)	0.0	46.2 (+)	0.0	< 0.001
Potbelly (30-50 t)	9.0 (-)	100.0 (+)	39.3 (+)	0.0 (-)	

NB: *P*-values correspond to Chi-square test, $P < 0.05$ denotes statistically significant differences. (+) or (−) indicate that the observed value is higher or lower than the expected theoretical value according to adjusted standardized residuals.

Table 3. Integrated risk profiles of cattle slaughtered in Mexico based on animal-based welfare indicators (n = 1040), with four clusters.

Variable	C1 (N=216)	C2 (N=193)	C3 (N=262)	C4 (N=369)	*P*-value
Vocalizations (yes) (%)[b]	38.9	38.9	35.8	38.5	NS
Stunning (No. of shots) (%)[b]					
One shot	64.6	60.6 (-)	71.4	71.1	0.033
>1 shot	35.4	39.4 (+)	28.6	29.0	
pH (%)[b]					
< 6.0	70.8 (-)	80.3(+)	72.1(-)	80.2	0.012
≥ 6.0	29.2 (+)	19.7 (-)	27.9 (+)	19.8	
Carcass bruises					
Prevalence of severe bruises (%)[b]	35.2 (-)	35.2 (-)	47.0 (+)	43.1	0.017
No. of bruises (median, 90% CI)[a]	0.0 (0.0-0.0) [a]	0.0 (0.0-0.0) [a]	0.0 (0.0-1.0) [b]	0.0 (0.0-0.0) [a]	0.001
Hooves					
Prevalence of severe front or hind limb injuries (%)[b]	52.8 (+)	42.5	43.5	39.8	0.023
Prevalence of severe front limb injuries (%)[b]	41.2 (+)	30.1	32.8	27.9	0.009
Prevalence of severe hind limb injuries (%)[b]	31.9 (+)	22.8	22.8	22.0	0.043

NB: *P*-values correspond to Kruskal-Wallis (a) and Chi-square (b) tests, $P < 0.05$ denotes statistically significant differences. NS: no significant. (+) or (−) indicate that the observed value is higher or lower than the expected theoretical value according to adjusted standardized residuals. [a,b,c] Different letters indicate significant differences (P < 0.05) between clusters according to the Mann-Whitney U test.

Table 4. Integrated risk profiles of cattle slaughtered in Mexico based on animal-based health indicators (n = 1040), with four clusters.

Variable	C1 (N=216)	C2 (N=193)	C3 (N=262)	C 4 (N=369)	*P*-value
Liver condemnations (%)					
No condemnation	84.3	88.6 (+)	85.1	77.8 (-)	
Abscess	4.2 (+)	3.1	2.7	1.1 (-)	
Liver fluke (Fasciola hepatica)	9.7 (-)	7.8 (-)	11.1 (-)	18.2 (+)	0.005
Jaundice	0.5	0.5	0.4	1.1 (+)	
Other pathologies	1.4	0.0	0.8	1.9	
Other organs condemnations (%)					
Lungs	2.8	4.2	3.1	2.1	NS
Hearth	0.9	1.6	1.5	3.0	NS
Udder	0.5	0.0	1.9	1.9	NS
Intestines	0.5	0.0	0.4	0.5	NS

NB: *P*-values correspond to Chi-square test, $P < 0.05$ denotes statistically significant differences. NS: no significant. (+) or (−) indicate that the observed value is higher or lower than the expected theoretical value according to adjusted standardized residuals.

4. Discussion

This study aimed to identify cattle welfare indicators that could be implemented at the slaughterhouse and to create integrated risk profiles based on the animal origin, pre-slaughter logistics transport, and animal-based indicators. Our study is among the first to integrate this knowledge. Throughout the chain, there was a clear effect of production system, cattle type, vehicle type, and journey distance on those indicators. Given those associations, we identified four main logistic profile types: C1, C2, C3, and C4. We will first present the logistic profiles identified, followed by their interactions with the welfare and health indicators evaluated.

4.1 Integrated risk profiles: Animal origin and pre-slaughter logistics

Feedlot and free-range beef systems are quite common in the arid and semiarid regions of Mexico, where there has been a long tradition of extensive systems, rather than feedlots. Yet, increased domestic demand for grain-fed beef has generated growth in the feedlot sector (Valadez-Noriega et al., 2020). In our study, the C2 profile was typical of a feedlot dedicated to the production of beef from young males or lots to be exported to the United States for finishing. Although C1 was associated with the presence of animals from confined systems, it had characteristics that distinguished it, e.g., the presence of young females (22%) and some old animals (21%), which suggests that these might have been feedlots dedicated to finish cull cows or some finished/cull cattle extensively raised. C4 could be considered to have a profile that is representative of the region of our study, and this cluster consisted of animals that came from extensive beef-only or dual-purpose productions, which are very common in the region. Although it might not be obvious why dairy systems are included in a discussion of beef production, in many areas of the world most meat production is a 'by-product' of milk production systems (Herring, 2014), which is true in Mexico. For example, the C3 profile comprised animals that came exclusively from dairy systems in the *Comarca Lagunera* region or communities that have had a tradition of cheese production (Mennonites). Cattle horn size was associated with conventional management practices in each type of production system. Slaughterhouses should have specific protocols for handling horned animals because they can cause lesions and contusions in other animals and can pose a risk to handlers and veterinarians during routine management practices (Losada-Espinosa et al., 2020).

In our study, vehicle type and production system of origin were strongly correlated. Potbelly trailer was the main means of transport for C2 animals (large feedlot cattle) and some of the C3 animals (dairy cattle). This type of trailer is divided into two parallel decks, the lower one being straight with a drop just past the rear tires of the truck and before the rear axle, thus dividing the trailer into the rear, belly, nose, deck and doghouse, with internal ramps for easy access (Schuetze et al., 2017). To a certain extent, it was expected that animals that travelled long distances and or that had a high live weight would be transported in that type of vehicle, primarily because of its high load capacity, which reduces the per-head cost of transport. These types of trucks have been criticised because they lack ventilation controls and, therefore, have great potential to affect animal welfare and health, particularly, in extreme weather conditions (Schwartzkopf-Genswein et al., 2012; Theurer et al., 2013). Although it is widely accepted that the physical condition and fitness to be transported is better in feeder cattle compared to cull cows, it is important to consider the animal welfare risk of this type of truck (Edwards-Callaway and Calvo-Lorenzo, 2020). In C3, a portion was characterized by a modern intensive production scheme affiliated with a milk-industrialization structure. Their logistics have been adapted to handle a large number of animals, including the transport of cull dairy cows in potbelly trailers, because these systems have large herds.

In our study, transportation by small (3 t capacity) and gooseneck trailers (10 t capacity) mainly were used for production systems that had small herds. The difference between C4 and C2 in the relationship between vehicle type and journey distance was very marked (C4 – small trailer/short journey distance; C2 – potbelly trailer/long journey distance). Short journeys are under less government control; therefore, the use of secondary vehicles that carry fewer animals is a widespread practice (Pulido et al., 2019). C1 and C4 comprised production systems that were near the slaughterhouse and which specialized in meat production for the domestic market. Common in both clusters was the mixing of animals from different commercial categories and different farms, which produced heterogeneous cattle lots. In some cases, the vehicles to transport those animals seemed somewhat improvised.

In northern Mexico, Mennonite cheese has become part of the region's identity and, typically, this product comes from relatively small production systems that are managed almost exclusively by owners and their families, which were significantly represented in C3. Often, cull cows were shipped from farms in small groups and, quite possibly, experienced delays and were mixed with other classes of animals before the truck was fully loaded. The animals in C3 were not a uniform group and tended to differ in age, parity, and type of clinical findings (see Dahl-Pedersen et al., 2018). In C3, the proportion of animals that travelled in potbelly or gooseneck trailers were similar; therefore, it is important to investigate whether the effects on the welfare and health indicators were because of the animal's origin (e.g., large/small herds, specialized/family labour), vehicle size and design, truck driver efficiency, or slaughterhouse management protocols. Systematic documentation of lorry driver ID, transportation lorry type, and slaughterhouse staff present per shift would facilitate identification of the source of welfare problems that become apparent (Knock and Carroll, 2019).

4.2 Integrated risk profiles: Cattle welfare indicators

Vocalisations can be indicative of the emotional state of the animal (Briefer, 2012). Unlike many physiological measurements, documenting vocalizations does not require physical interaction with the animal and, therefore, they can be a non-invasive measure of stress (Green et al., 2020). Measuring vocalisations at the time of stunning might be useful for detecting deficient personnel training, extremely excited cattle, inefficient gun calibration, lack of maintenance, or the excessive pressure of the head brace (Grandin, 2001). In our study, however, that indicator did not indicate clear differences between the profiles. Even though vocalisations are an effective indicator of poor welfare at the slaughterhouse, in the present study it did not show a relationship to either transport or farm of origin. Also, the information it provided was unclear and did not always provide a direct inference about the cause of a welfare problem. However, in general, the evaluated slaughterhouse had an extremely high percentage of cattle vocalising. According to a review of studies conducted in several abattoirs, the occurrence of more than 5% vocalisers can be indicative of handling and equipment problems (Grandin, 2001). On the other hand, observers should not conclude that a procedure is not painful to an individual animal, simply because it did not vocalize during the procedure (Rushen et al., 2008). In any case, our results show that classifying animals simply as either a vocaliser or a non-vocaliser might not help to develop robust vocal welfare indicators at the slaughterhouse. Because vocalisations are representative of short-lived emotional changes, classifying animals as vocal vs. non-vocal across a long period of time can be challenging.

In our study, the number of stunning shots distinguished the different production systems. It is widely recognised that stunning is a critical point during slaughter operations (Gibson et al., 2019). Audits and standards required by major buyers of meat have greatly improved conditions in the United States (Grandin, 2017); however, in Mexico, there is no consensus on a standard for assessing stunning and the procedure is unregulated (Miranda-de la Lama et al., 2012). For many years, the acceptable proportion of animals stunned effectively in USA slaughterhouses was 95% (Grandin, 2010), but it was raised in 2017 (96%) (Edwards-Callaway and Calvo-Lorenzo, 2020). If that efficiency rate is used as a reference point, none of the four clusters met those standards, and the proportion of animals' re-shot was higher in C2. Poor effective stunning rates might have been related to the lack of maintenance of the stunning equipment, deficiencies in the training of stunner operators (Hultgren et al., 2014), floor type within the chute, and head-restraint device features (Muñoz et al., 2012). The effectiveness of stunning is highly dependent on the previous handling of the animals (Romero et al., 2017). Specifically, for C2 cattle, phenotype characteristics (e.g., musculature, shape, size, weight, ticker skull), and animal age might have had an influence (Njisane and Muchenje, 2013). Trends in those data could be used to identify high/low risk categories of animals for double stunning shots, to quantify the influence of the operator, and aid in the development of guidelines for stunner operators, and the permanent maintenance of the stunning equipment.

In commercial terms, it is widely accepted that the ultimate pH is a reference indicator of meat quality (Terlouw, Stress reactivity, stress at slaughter and meat quality, 2015). This is because the pH allows to infer the stress experienced by the animals during pre-slaughter operations, because it includes muscle energy stores and metabolic routes (Losada-Espinosa et al., 2018). In our study, pH_{24} helped to identify differences between clusters; specifically, C1 and C3. Culled dairy cows, certain feedlot cattle, and old animals extensively raised had a greater likelihood of presenting dark cutting. The presence of females (Mahmood et al., 2019), animal breed (ease of handling) (Voisinet et al., 1997), susceptibility to heat stress (Gonzalez-Rivas et al., 2020), mixing with unfamiliar animals in transport to the slaughterhouse (Schwartzkopf-Genswein et al., 2012), slaughter season (extreme temperatures, food availability) (Scanga et al., 1998), and severe bruising (Vimiso and Muchenje, 2013) are some of the factors that might cause animals in C1 and C3 to have $pH_{24} \geq 6$. DCB is a multi-factor phenomenon that is influenced by on-farm, off-farm, and animal issues, and our study identified patterns associated with this condition (Ponnampalam et al., 2017).

Bruises can indicate welfare problems that occur in road transport, traffic accidents, loading/unloading, and stunning of livestock, which can be used to assess cattle welfare at the slaughterhouse level (Miranda-de la Lama, 2013). Traditionally, the study of bruises in cattle carcasses is focused on reporting prevalence by anatomical area, severity, colour and shape. This approach helps to understand the damage to the carcass but does not usually provide more information about profiles of occurrence of bruising (Miranda-de la Lama et al., 2021). In our study, the assessment of severe bruises identified a cluster that was associated with animals that were in severely deteriorated physical condition (C3) and indicated a relationship between bruising and cattle age (C4). The high prevalence of bruising reported in our study underlines the importance of including a bruising score in any assessment of cattle welfare. It is necessary, however, to have an efficient measurement system that is easy to use in commercial slaughterhouses. Bruises are a basic indicator for identifying areas where improvements can be made that effect the welfare of the most susceptible animals. There is evidence that there is a progressive loss of empathy by farmers towards sick or old animals because they involve economic and time losses (Losada-Espinosa et al., 2020). The type of care omission found in our study emphasizes the need to implement awareness and training programs for stockpersons.

The identification and prevalence of lame cattle are among the main factors evaluated in third-party welfare audit programs (Coetzee et al., 2017). Beef cattle can suffer lameness; however, hoof problems and impaired mobility have been relatively little studied compared to dairy cattle (Edwards-Callaway et al., 2017). Our study indicated a high prevalence of severe hoof injuries in the cattle population, particularly, among C1 animals, possibly because of diets high in carbohydrates, which are used to finish the fattening of the animals (feedlots) (LokeshBabu et al., 2018). In addition, a rapid increase in body weight places pressure on the base of the developing claws that, coupled with low physical activity, can affect claw health and might be an overlooked cause of claw pathologies (Pauler et al., 2020). Extensively raised cattle are reared and fattened in challenging climates and locations; therefore, it is difficult to perform routine claw inspections and trimming, which can be a predisposing factor for claw disorders (Álvarez et al., 2017). Severe hoof injuries are an indicator of the welfare state of the animals and the impact that these problems can have on cull rates and cattle longevity (Bruijnis et al., 2012; Alvergnas et al., 2019). The inclusion of severe injuries in a program for monitoring animal welfare at the slaughterhouse level might provide basis for identifying methods that either support or drive different risk management strategies that can be adopted by farmers and the beef industry (Bautista-Fernández et al., 2021).

4.3 Integrated risk profiles: Cattle health indicators

Slaughterhouse data can provide valuable evidence on the incidence and epidemiology of animal diseases, including zoonotic disease outbreaks; however, these data have been under-utilized in animal welfare science. The contribution of culling to disease-related losses is high, and half of the herd removals occur involuntarily and prematurely because of health disorders (Beaudeau et al., 2000). In our study, health problems and animal origin were strongly correlated. If this information were evaluated, improvements could be made to enhance the welfare of the animals to be slaughtered. Acute and chronic acidosis, conditions that follow ingestion of excessive amounts of readily fermented carbohydrates, are common production problems for ruminants fed diets that are high in concentrate (Losada-Espinosa et al., 2018). The term "rumenitis-liver abscess complex" is commonly used because of the strong correlation between the incidence of ruminal pathology and liver abscesses. Ruminal pathology can occur at all ages in all types of livestock, but abscesses that have an economically substantial impact occur in fattening cattle, especially (Tadepalli et al., 2009). In our study, C1 had the highest proportion of animals that had liver abscesses. Probably, animals from feedlot systems increased the prevalence of liver condemnations because of the high incidence of abscesses in this cluster. Studies in North America have shown that the prevalence of liver abscesses has increased in Holstein-type steers (and their crosses), probably, because of an increase in the number of feeding days (Reinhardt and Hubbert, 2015). Although C2, which had a profile that was more typical of feedlot, might have been expected to have more animals that had abscesses, this was not so. Apparently, cattle breed and nutritional management on the farm of origin have significant effects.

C4 animals had a high prevalence of *Fasciola hepatica* and a tendency to present other liver pathologies (telangiectasia, haemorrhage, TRP, calcification, adhesions, cirrhosis). Fascioliasis, a food-borne trematodiasis, has become a major public health concern because of the increasing number of human cases reported worldwide (Barbosa et al., 2019). The disease has caused large economic losses for livestock producers and food industries worldwide that are associated with decreases in meat and milk production, and with livers that are rejected for consumption that, in some slaughterhouses, has reached 50% (Almeida da Costa et al., 2019; Barbosa et al., 2019). In our study, 18.2% of C4 animals were infected with that parasite, which might have been influenced by the management practices implemented in the region (herds raised in extensive systems were constantly grazing) and with the longevity of some cattle breeds in these systems (Innocent et al., 2017). In that context, it is important to identify this situation as a simultaneous bias in which it is possible to underestimate the effects of fascioliasis in populations of older animals that have a high prevalence and an 'ideal weight for slaughter' (Mazeri et al., 2017; Almeida da Costa et al., 2019).

Contrary to what was expected, and even though it was the cluster that had the most udder condemnations, only 2% of the animals presented some type of damage or pathology in this organ. Bascom and Young (1998) reported that in high producing Holstein dairy herds, farmers were more reluctant to identify mastitis as a reason for culling. If the animals in C3 came from high-production herds they might have been under better management protocols, which resulted in better udder health and reduced culling because of mastitis. In the same study, farmers that had non-Holstein herds identified mastitis and low production as reasons for culling at a significantly higher frequency than did farmers that had the highest producing Holstein herds which suggests, perhaps, that certain dual-purpose cattle or breeds other than Holstein might have contributed to udder condemnations in C3. In our study, the condemnation data were evaluated for the specified organs, only; however, it is important to be aware of other pathologies/conditions that might be more common in dairy cattle. C3 and C4 had the highest number of vulnerable animals. The animals were old, usually with a deteriorated body condition and others health problems. For those animals, calm handling and management in separate groups should be used.

Meat inspection at slaughterhouse level is a highly regulated and demanding activity in terms of time and veterinary staff to perform, and has low detection sensitivity. However, several studies have assessed and recommended the use of risk-based surveillance to improve meat inspection sensitivity (Dupuy et al., 2014). The procedure involves implementing more surveillance resources in those animals that present a high risk of infection or other health conditions. Data identified in our study could be used to identify, upon arrival at the slaughterhouse, the types of animals that are at high or low risk. That evidence should provide a better understanding of the epidemiological and animal welfare conditions and help to identify the factors that influence the level of risk and, therefore, the implementation of risk-based approaches (Laranjo-González et al., 2016). For that reason, it is essential to have consistent surveillance systems, protracted data collection, and the measuring of multiple indicators, concurrently.

5. Conclusions

Our results suggest that the indicators assessed are suitable for assessment at commercial slaughterhouse level. Those animal-based indicators reflected a marked effect of the production system of origin and the pre-slaughter logistics to which animals were exposed. The prevalence of double stunning shots, severe bruising, claw disorders, and liver condemnations in the cattle population was high. Cluster analyses identified four profiles: small feedlot and free-range profile (C1), feedlot profile (C2), cull dairy cows' profile (C3), and free-range profile (C4). Those profiles were defined by the production system, cattle type, journey distance, and vehicle type. The number of stunning shots, meat pH, carcass bruises, severe hoof injuries, and liver condemnations were indicators that explained a significant proportion of the variation in the prevalence of various welfare and health outcomes based on animal origin, which confirmed their importance and/or potential as iceberg indicators. The associations between risk profiles and livestock health and welfare issues identified in this study provide useful information to improve pre-slaughter operations. Finally, our study shows that it is feasible to use a series of animal welfare indicators with differential sensitivity capable of identifying specific welfare problems in the animals sampled.

Conflict of interest

The authors declare that they have no conflict of interest.

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Capítulo 3

Integrative surveillance of cattle welfare at the abattoir level: Risk factors associated with liver condemnation, severe hoof disorders, carcase bruising and high muscle pH

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Integrative surveillance of cattle welfare at the abattoir level: Risk factors associated with liver condemnation, severe hoof disorders, carcase bruising and high muscle pH

N Losada-Espinosa†, LX Estévez-Moreno‡, M Bautista-Fernández†, H Losada§, GA María‡ and GC Miranda-de la Lama‡*

† Graduate Program in Sciences of Animal Health and Production, Faculty of Veterinary Medicine, National Autonomous University of Mexico, UNAM, Mexico
‡ Department of Animal Production and Food Science, IA2 Institute, University of Zaragoza, Zaragoza, Spain
§ Department of Reproductive Biology, Metropolitan Autonomous University, UAM-Iztapalapa, Mexico
* Contact for correspondence: genaro@unizar.es

Abstract

Given the multi-dimensionality of animal welfare, any monitoring system for slaughter animals should comprise an integrative vision that facilitates animal welfare and food safety assessment. Thus, the aim of this study was to investigate risk factors as possible causes for liver condemnations, hoof disorders, bruise prevalence, and the quality of beef carcases under commercial operating conditions in Mexico. Data were recorded for 143 journeys encompassing 1,040 commercial cattle, originating from feedlots, free-range, and dairy production systems. Details on journey distance, vehicle type, cattle type, and animals' origin were gathered from abattoir reports. We found that carcase bruising (41%) and hoof disorders (43.9%) had the highest prevalence, regardless of the production system. Variables such as cattle type and production system influenced liver condemnations; old bulls extensively raised were more prone to present parasitosis such as Fasciola hepatica. Transportation conditions (journey distance, vehicle type) and cattle type might have influenced the development of hoof disorders in the evaluated animals. Multivariable logistic regression showed that animals' origin was a potential risk factor for severe bruising and high muscle pH, with cull dairy cows getting the most serious damage. In general, cattle transport conditions were factors that showed interactions with three of the evaluated indicators (severe hoof injuries, carcase bruising, meat pH24h). Our study shows the need to implement integrative surveillance to identify risk factors according to the production system from which the animals originate. With this information it is possible to develop strategies to mitigate specific cattle welfare problems.

Keywords: *Animal welfare, Cattle, Indicators, Meat quality, Risk factors, Voluntary abattoir surveillance*

1. Introduction

Animal transport and pre-slaughter operations are an essential component of the farming industry (Ljungberg *et al* 2007). During the marketing process, livestock must confront different challenges that may represent a risk to their welfare. Even under favourable conditions, cattle may be exposed to multiple stressors, such as overcrowding in lorries, mixing with unfamiliar animals, rough handling, food and water deprivation, extreme temperatures, as well as goad use (Knock & Carroll 2019; Edwards-Callaway & Calvo-Lorenzo 2020). As a consequence of these preslaughter challenges, animals may experience fear, dehydration and hunger, increased physical activity and fatigue, and physical injury (Ferguson & Warner 2008). Animal welfare and food safety are major issues in food production (Iannetti *et al* 2020). Improper handling and transportation are also responsible for stress-induced meat quality problems, such as shrinkage of the carcase, higher pH, dark meat, and damage to the carcase through bruising (Miranda-de la Lama *et al* 2012). In this context, the presence of bruises in the carcases or a high muscular pH, and more recently condemnations due to health reasons and severe hoof injuries, have been used as post mortem indicators of welfare, since they are the result of a lack of welfare in the production system or during pre-slaughter handling (Sánchez-Hidalgo *et al* 2019).

Meat inspection is one of the most widely implemented and longest-running systems of surveillance. Its primary objective is to identify animals that are not fit for human consumption and remove their carcases and offal from the food chain (Stärk *et al* 2014). Nowadays, the prospective benefits of using abattoir-based animal welfare assessments are being increasingly recognised (Harley *et al* 2012; Velarde & Dalmau 2012). Nevertheless, due to the high chain speed (processing speed), collection of a large number of measurements poses a challenge, so it is important to detect those measures (indicators) that allow identifying a larger number of potential risks (Wigham *et al* 2018). In this context, the Farm Animal Welfare Council (FAWC 2009) suggested the use of 'iceberg' animal-based indicators as a means of assessing overall animal welfare (van Staaveren *et al* 2017). These indicators can provide valuable information on two relevant aspects of the life of production animals: (i) welfare problems during growth and development while fattening of animals at farm level; and (ii) acute or traumatic conditions of recent occurrence that are associated with pre-slaughter operations, such as transport, lairage and slaughter (Grandin 2017). Moreover, the scientific literature suggests that some animal-based measures that are currently being used to assess welfare have not been tested thoroughly for validity and reliability, and in that sense could be seen as insufficiently robust (FAWC 2009). Hence, increasing the knowledge both in those outcomes that have an indisputable link to welfare, such as bruises, and in those where the link is less obvious, eg health problems, is still crucial.

Transportation and the associated increase in handling are necessary components of the Mexican beef production chain. Cattle production is one of the most important sectors of Mexican agribusiness because it is the 7th largest producer of beef in the world (18 million heads; United States Department of Agriculture [USDA] 2018). Due to advances in embodied technologies, lower labour costs, a large domestic market, as well as international markets, the Mexican livestock sector has been in a process of modernisation in production conditions and its pre-slaughter logistics process (Valadez-Noriega *et al* 2020). Nevertheless, little information is available regarding the impact of transport and pre-slaughter operations on carcase bruises and meat quality (Cruz-Monterrosa *et al* 2017; Loredo-Osti *et al* 2019). Moreover, data on severe hoof injuries are often not collected with surveillance in mind while sanitary evaluations at abattoirs are not oriented to report the prevalence of animal health disorders from an animal welfare perspective. Therefore, this research aims to: (i) recognise the current practices of the commercial transport and pre-slaughter logistics of cattle slaughtered in Mexico and its relationship with risk factors associated to organ (liver) condemnations, hoof disorders, bruise prevalence, and the quality of beef carcases; and (ii) test the feasibility of 'classic' (carcase bruising and meat pH) and 'novel' (organ condemnations, severe hoof injuries) indicators under commercial operating conditions in Mexico.

2. Materials and methods

This study was carried out in Durango state (north of the Mexican Republic) from March to July 2018 at a Federal Inspected Type (FIT) abattoir in Malaga (24°09'37.8"N 104°30'19.3"W), which complies with the stipulations of the Official Mexican Norms (NOM-008-ZOO-1994; NOM009-ZOO-1994; NOM-033-ZOO-1995; NOM-194-SSA1-2004). The study area is characterised as having a semi-arid climate with mean annual rainfall and temperature of 500 mm and 19°C, respectively, at approximately 1,885 m above sea level. Cattle were transported and slaughtered in compliance with national regulations applied in research and commercial slaughtering. The study was approved by the Institutional Subcommittee for the Care and Use of Experimental Animals of the Faculty of Veterinary Medicine of the National Autonomous University of Mexico (Protocol Number DC-2018/2-11).

2.1 Study description

This post mortem assessment was implemented as a cross-sectional study to monitor the organ condemnation, hoof health condition, bruises prevalence, and carcase pH in cattle from the feedlot, free-range, and dairy systems that entered the slaughter chain through normal procedures. Data were recorded from 1,040 commercial cattle with a mean (± SD) live weight of 510.35 (±14.98) kg, of which 362 came from industrial feedlots (Hereford, Charolais, Limousine and Angus crossbreds), 414 from free-range systems (*Bos taurus* and *B indicus* crossbreds) and 264 from intensive dairy systems (Holstein breed). Of the cattle assessed, 52.2% (543/1040) were males and the remaining 47.8% (497/1040) females. Regarding commercial categories, livestock was classed as steers (castrated or intact males, between one and two years of age), young bulls (castrated or intact males, between two and five years of age), old bulls (castrated or intact males, older than five years of age), heifers (females between one and two years of age), young cows (females between two and five years of age), and old cows (females older than five years of age). The data related to the journey distance (1–50 km, 51–100 km, 101–150 km, 151–200 km or > 200 km), the type of vehicle used to transport the animals to the abattoir (small trailer of 3 tons, gooseneck trailer of 10 tons or potbelly trailer of 30–50 tons), the animals' origin (feedlot, free-range or dairy systems), as well as the cattle type (steer, young bull, old bull, heifer, young cow, old cow) were obtained from the 'reports of slaughtered livestock' generated by the State Operational Coordination for the Control of the Mobilisation of Livestock, Products, and By-products (SADER-Durango). The personnel responsible for this area within the abattoir generated the information and provided it to the research team. Data were discarded if any inconsistency or missing values for any independent variable (journey distance, vehicle type, production system, cattle type) were identified. These variables were recorded by the third co-author over four months.

2.2 Abattoir conditions

The abattoir operated from Monday to Friday (0830–1500h) with a slaughter capacity of 9,000 heads per month. The concrete unloading ramps (19°) had non-slip floors that were as wide as the livestock trailers (6 m). They were connected through a 3 m wide metallic curved race to a lairage area that consisted of 24 pens (7.0 × 6.5 m; length × width; 45.5 m^2), with non-slip concrete. Out of them, 16 had suspended canopies roofing (white-painted galvanised) and eight had galvanised sheeting. In the abattoir, animals from different livestock trucks were not mixed, and each group of animals was housed in separate pens.

At the lairage, the animals had access to water *ad libitum* while resting, no food was provided. A concrete passageway led from the lairage area to three parallel single file races with a single file race in the last 10 m before the stun box. The floors were slatted concrete, with metal bars between the driving races. A stockperson drove the animals manually into the stun box using his body, hands, and various tools (eg sticks, cattle talker and, in particular, an electric goad). The plant had a hydraulic, vertically sliding tailgate at the entrance of the box. The stunning box (2 × 1.50 × 1.80 m; length × width × height) had an automatic head fixation system, and its surface was made of stainless steel without a non-skid floor. One of the sides of the stun box had a guillotine door to let the animal fall-out from the side of the box after stunning. The abattoir used a standard, pneumatically powered, penetrating captive-bolt gun (model STUN-BP1, FREUND®) and, in emergencies, a hand-held powder-loaded device. During observations, the stockpersons always worked the animals from outside the race or box. Normally, only one person worked each animal in the stun box. After being stunned, the cattle were suspended by a hind leg, bled, and transferred to the production line to begin the process of removing the head, feet, skin, viscera, and the splitting of the carcase.

2.3 Liver condemnation

The post mortem inspection of the animals was performed by the official veterinarian assigned by the National Agro-Alimentary Health, Safety and Quality Service (SENASICA). One of the authors of this study was present at each stage of the inspection. The number and type of organs or condemned carcases, and the reason for each condemnation were recorded daily on standardised datasheets. A total of 1,040 carcases were subjected to post mortem inspection. After the animals were slaughtered, the carcase, organs, and tissues were subjected to a macroscopic examination. Any carcase in which an injury was observed was sent to the retention rail for examination by the official veterinarian. The viscera and head that corresponded to that carcase were also separated for a thorough inspection. Post mortem examination procedure employed visual inspection, palpation, and systematic incision of each carcase and visceral organs, particularly the liver. The main causes of liver condemnation were abscess, *Fasciola hepatica*, jaundice, telangiectasia, haemorrhage, traumatic reticuloperitonitis, calcification, adherence and cirrhosis.

2.4 Hoof disorders

Data were recorded from 2,080 thoracic and pelvic hooves, with an average of 26 hooves per day. The collection and evaluation of the hooves were performed by the same veterinarian, maintaining individual recognition and progressive order. In a room adjacent to the stunning box, the limbs of each animal were evaluated. Once the animal was stunned and bled, the operative personnel removed the left thoracic limb from the tarsal-metatarsal joint, and approximately 30 s later the same was done with the left pelvic limb. The inspection began with the cleaning of the hooves to remove the organic matter. Subsequently, the claw was supported on a straight surface for inspection through the following steps: (i) verification of conformation (claw symmetry, heel height, wall length, interdigital opening, and presence of growth defects); (ii) integrity of the skin in metatarsals and metacarpals (skin wounds above the coronary band); (iii) inspection of the wall; (iv) inspection of the sole; and (v) inspection of the heel and white line disease.

The protocol developed by Bautista-Fernández *et al* (2021) included all abnormal claw shapes (ie asymmetric claws, corkscrew claws, ACS, where 1 meant no abnormality, 2 mild abnormality, 3 serious abnormality), fissures of the claw wall (FCW, where 1 meant no injury, 2 non-severe injury, and 3 severe injury), skin wounds (SW, where 1 was no injury, 2 non-severe injury, 3 severe injury), sole disorders (SD, where 1 was no injury, 2 non-severe injury, and 3 severe injury), heel erosion (HE, where 1 was no injury, 2 non-severe injury, and 3 severe injury), white line disease (WLD, where 1 was no injury, 2 non-severe injury, 3 severe injury), and double sole (DS, without or with).

2.5 Bruising assessment

The protocol for the carcase post mortem assessment was based on one modified from Strappini *et al* (2012). The 1,040 entire carcases (hanging by both hind legs) were evaluated by one researcher trained for a month prior to the start of the study. A bruise was defined as a lesion where tissues are crushed with a rupture of the vascular supply and an accumulation of blood and serum, without discontinuity of the skin (Capper 2001). Each bruise present on the carcase was evaluated by registering its anatomical site, size, and severity. The carcase was divided into seven areas: anatomical location 1 = neck; 2 = front leg; 3 = thoracic and abdominal wall; 4 = hind leg; 5 = *Tuber isquiadicum* and its muscular insertions (butt/pin); 6 = *Tuber coxae* and its muscular insertions (hip); and 7 = loin. The size of the bruise was assessed based on its diameter as: small: 5 cm; medium: 10 cm; large: 15 cm; extra-large: 20 cm. The severity of the bruise was rated as grade 1: only subcutaneous tissue affected; grade 2: as grade 1, but with muscle tissue affected; grade 3: as grades 1 and 2, but with the presence of broken bones.

2.6 pH measurements

The assessment of carcases for the presence of high muscle pH was carried out by a researcher trained for one month prior to the start of the study. A digital pH meter with a penetration probe (Hanna Instruments, H199163, Woonsocket, Rhode Island, USA) was used to determine carcase pH 24 h post mortem (pHu) of the *M. longissimus*, which was inserted into a small incision in the left side of the carcase (12/13th rib interface). The pH meter was re-calibrated to the same temperature as the operation room (4°C) after every five samples, using two standard buffer solutions at pH 7.0 and 4.0. The pH was measured as the mean of readings taken at two sites. Carcases showing pHu values greater or equal than 6.0 were classified as dark cutting beef (DCB). The meat was considered as being of normal quality when pHu was < 6.0.

2.7 Statistical analysis

Data were entered into Microsoft Excel® (Microsoft Corporation 2010) and then analysed with the IMB© SPSS software 22 version. To establish the binary logistic regression models (univariate and multivariate), different selection procedures were used, starting by adding each variable and observing the model improvement. The journey distance variable (A 1–50 km, 51–100 km, 101– 150 km, 151–200 km, > 200 km) was re-categorised into broader ranges (B 1–100 km, 101–150 km, > 150 km) to have different alternatives to identify possible effects of the journey distance in the occurrence of severe bruises and DCB meat. Initial univariate logistic regression analysis allowed selection of the categorisation that showed a significant association between the journey distance and the variables response. Finally, the different categorisations were included in the multivariate logistic analysis. The likelihood of liver condemnation, total number of severe hoof injuries, carcase bruising, and pH ≥ 6, was analysed as a binomial response variable using the univariate logistic regression model. Subsequently, the effects of the predictive variables were expressed in terms of odds ratios (OR), and their 95% confidence intervals (CI), which is a suitable method of comparison of effects for binary data (Veneable & Ripley 2002). Multivariable logistic regression analyses were performed on the absence/presence of bruised carcases. Grade 2 and 3 bruises were merged with grade 1 bruises in one category. The general model was:

$$Y = \frac{e^{(\beta_o + \Sigma\beta i X i)}}{1 + e^{\beta_o + \Sigma\beta i X i)}}$$

Where Y = the probability of the presence of bruise, β_O is the intercept, βi are the regression coefficients, Xi are the explanatory variables included in the analysis. Additionally, another similar model was run on subsets of the data using the records that included information on pH, considering two categories: carcases with a pH < 6.0, and carcases with a pH ≥ 6.0. Each analysis began with a univariable analysis of each predictor variable to explore data. The step-wise forward conditional method was used to select model variables, which involved starting with no variables in the model, testing the addition of each variable using the selected model fit criterion, adding the variable whose inclusion gives the most statistically significant improvement of the fit, and repeating this process until none improves the model to a statistically significant extent. Finally, relevant interaction terms (Production system × Vehicle type) were added to the model. The goodness-of-fit of the models was checked by the Hosmer-Lemeshow statistic test. The effects of the predictor variables on the presence of bruises were expressed in terms of the odds ratios (OR) and their 95% confidence intervals (CI). An OR that is greater (smaller) than 1 indicates that the bruise is more (less) likely to be present in a specific category of the predictor variable compared to the reference category (Strappini *et al* 2010; Romero *et al* 2013). All statistical differences were considered significant at P < 0.05.

3. Results

The description of the categorical explanatory variables is presented in Table 1. Overall, 48% of the evaluated animals made short journeys (1–100 km) while only 16.7% made journeys > 200 km. The distance journeyed and the time required was approximately: 1–50 km ~ < 30 min; 51–100 km ~ 30–60 min; 101–150 km ~ 60–120 min; 151–200 km ~ 120–150 min; > 200 km ~ > 150 min. This is only an approximation, it would be necessary to add possible logistical stopovers and/or delays. Small trailer (45.2%) was the vehicle most used, followed by the potbelly trailer (30.3%) and the gooseneck trailer (24.5%). Regarding the animals' origin, 39.8% came from free-range systems, 34.8% from feedlots, and

25.4% from dairy systems. Most of the slaughtered cattle were old females (38.3%) and young bulls (29.4%), followed by old bulls (14.3%).

Upon examination, 23.8% (248/1,040) of the animals showed a pH ≥ 6, while 41% (426/1,040) of the carcases displayed severe bruising. Regarding hoof lesions, 43.9% (457/1,040) of the animals presented severe injuries (32.3% in the thoracic limb and 23.8% in the pelvic limb). Results for liver condemnations show that 83% (863/1,040) of the animals did not present condemnations. The main causes for condemnation were abscess (3.17%, 33/1040), *Fasciola hepatica* (12.69%, 132/1,040), and other pathologies (jaundice, telangiectasia, haemorrhage, traumatic reticuloperitonitis, calcification, adherence, and cirrhosis; 1.15%, 12/1,040).

Table 1. Frequencies of the independent categorical variables.

Variable	Category	Frequency	Percentage
Journey distance A	1-50 km	374	36.0
	51-100 km	125	12.0
	101-150 km	335	32.2
	151-200 km	32	3.1
	>200 km	174	16.7
Journey distance B	1-100 km	499	48.0
	101-150 km	335	32.2
	>150 km	206	19.8
Vehicle type	Small trailer (3 Tons)	470	45.2
	Gooseneck (10 Tons)	255	24.5
	Potbelly (30-50 Tons)	315	30.3
Production system	Feedlot	362	34.8
	Free-range	414	39.8
	Dairy	264	25.4
Cattle type	Steer	88	8.5
	Young bull	306	29.4
	Old bull	149	14.3
	Heifer	25	2.4
	Young cow	74	7.1
	Old cow	398	38.3

3.1 Liver condemnations and severe hoof injuries

The effects of the categorical explanatory variables on the health (liver condemnation) of the cattle evaluated can be seen in Table 2. The probability of risk for liver condemnation increased by 56% in cattle raised on free-range systems compared to dairy cows ($P < 0.05$). Cattle age and sex were a potential risk factor too, as old bulls were 97% more likely to have liver condemnation than older cows ($P < 0.01$). Table 2 also shows the factors influencing the presence of severe hoof injuries. The journey distance, vehicle type, and commercial livestock type had a significant effect on hoof disorders. Journey distances of 151–200 km increased the prevalence of severe hoof injuries 2.17× compared to journeys of 1–50 km. Cattle that journeyed in gooseneck trailers had 46% more risk of presenting severe hoof injuries compared to animals that journeyed in potbelly trailers. The commercial livestock type had a significant effect as well, as young bulls were 59% more likely to have severe hoof injuries than older bulls ($P < 0.05$).

Table 2. Likelihood of liver condemnation and severe hoof lesions in cattle for each causing variable based on the analyses of univariate logistic regression.

Consequence	Variable	Odds ratios	SEM	Confidence Intervals 95%	*P*-value
	Production system				
	Dairy	Ref.			
	Feedlot	.836	.232	0.53-1.32	NS
	Free-range	1.556	.209	1.03-2.34	<0.05
	Cattle type				
Liver condemnation	Old cow	Ref.			
	Old bull	1.974	.234	1.25-3.12	<0.01
	Young bull	.927	.216	0.61-1.42	NS
	Bullock	.849	.342	0.44-1.66	NS
	Heifer	1.025	.564	0.34-3.10	NS
	Young cow	1.153	.296	0.65-2.06	NS
	Journey distance†				
	1-50 km	Ref.			
	51-100 km	1.338	.219	0.87-2.06	NS
	101-150 km	1.188	.163	0.86-1.64	NS
	151-200 km	2.173	.372	1.05-4.51	<0.05
	>200 km	1.296	.196	0.88-1.90	NS
	Vehicle type				
	Small trailer (3 Tons)	Ref.			
	Gooseneck (10 Tons)	1.462	.164	1.06-2.02	<0.05
Severe hoof lesions	Potbelly (30-50 Tons)	1.108	.158	0.81-1.51	NS
	Production system				
	Feedlot	Ref.			
	Free-range	.746	.154	0.55-1.01	NS
	Dairy	.914	.171	0.65-1.23	NS
	Cattle type				
	Old bull	Ref.			
	Young bull	1.593	.223	1.03-2.47	<0.05
	Bullock	1.511	.293	0.85-2.68	NS
	Heifer	1.643	.457	0.67-4.03	NS
	Young cow	1.397	.283	0.80-2.43	NS
	Old cow	1.368	.219	0.89-2.10	NS

Ref: variable considered as reference. † The alternative journey distance categorisation (B 1–100 km, 101–150 km, > 150 km) did not show significant associations with the probability of occurrence of severe hoof lesions.

3.2 Severe bruising and dark cutting beef (DCB)

The effects of the categorical explanatory variables on carcase bruising and pH > 6 based on the analyses of univariate logistic regression can be seen in Table 3. Moreover, the journey distance, animals' origin (production system), and vehicle type were the variables that showed an explanatory significance within the final multivariable model for carcase bruising (Table 4). None of the interactions between these variables showed statistical significance. In the Hosmer-Lemeshow goodness-of-fit test of the final model, the null hypothesis was not rejected ($P = 0.793$). Our study shows that journey distances of over 200 km increased the prevalence of bruising 2.04× compared to short journeys (1–50 km) ($P < 0.05$). Animals' origin was a potential risk factor too. In comparison with feedlot cattle, animals raised on free-range systems and dairy cattle had, respectively, 1.56 and 2.23× higher risk of presenting severe carcase bruising ($P < 0.05$, $P < 0.001$). The likelihood of risk for severe carcase bruising decreased by 46.8% in cattle that journeyed in potbelly trailers compared to animals that journeyed in small trailers ($P < 0.05$). On the other hand, of the four explanatory variables, only the journey distance and the interaction between the animals' origin (production system) and the vehicle used by them showed an explanatory significance within the final multivariable model for DCB meat (Table 5). In the Hosmer-Lemeshow goodness-of-fit test of the final model, the null hypothesis was not rejected ($P = 0.984$). Our results indicate that the likelihood of obtaining DCB meat had a positive relationship with the journey distance; cattle that journeyed short and intermediate distances (1–100 km, 101–150 km, respectively) had 89 and 76% higher risk of presenting DCB compared to animals that journeyed more than 150 km ($P < 0.01$). The probability of risk for DCB meat decreased by 38% in cattle raised on free-range systems that journeyed by small trailers in contrast to dairy cows that journeyed by potbelly trailers ($P < 0.05$).

Table 3. Likelihood of severe bruising and pH>6 in cattle for each causing variable based on the analyses of univariate logistic regression.

Consequence	Variable	Odds ratios	SEM	Confidence Intervals 95%	*P*-value
Severe bruising	*Journey distance†*				
	>200 km	Ref.			
	1-50 km	1.233	.190	0.85-1.79	NS
	51-100 km	1.026	.243	0.64-1.65	NS
	101-150 km	1.345	.192	0.92-1.96	NS
	151-200 km	2.265	.390	1.06-4.84	<0.05
	Vehicle type				
	Potbelly (30-50 Tons)	Ref.			
	Small trailer (3 Tons)	1.525	.152	1.13-2.05	<0.01
	Gooseneck (10 Tons)	1.918	.174	1.37-2.70	<0.001
	Production system				
	Dairy	Ref.			
	Feedlot	.567	.166	0.41-0.79	<0.001
	Free-range	.877	.158	0.64-1.20	NS
	Cattle type				
	Old cow	Ref.			
	Old bull	.706	.198	0.48-1.04	NS
	Young bull	.676	.158	0.50-0.92	<0.05
	Bullock	.826	.240	0.52-1.32	NS
	Heifer	.759	.421	0.33-1.74	NS
	Young cow	.595	.233	0.38-0.94	<0.05
pH ≥ 6	*Journey distance‡*				
	>150 km	Ref.			
	1-100 km	1.500	.189	1.04-2.17	<0.05
	101-150 km	1.741	.198	1.18-2.57	<0.01
	Vehicle type				
	Potbelly (30-50 Tons)	Ref.			
	Small trailer (3 Tons)	.912	.158	0.67-1.24	NS
	Gooseneck (10 Tons)	1.213	.178	0.86-1.72	NS
	Production system				
	Dairy	Ref.			
	Feedlot	.747	.171	0.53-1.04	NS
	Free-range	.688	.167	0.50-0.96	<0.05
	Cattle type				
	Old cow	Ref.			
	Old bull	.669	.213	0.44-1.02	NS
	Young bull	.677	.167	0.49-0.94	<0.05
	Bullock	.911	.250	0.56-1.49	NS
	Heifer	1.626	.415	0.72-3.67	NS
	Young cow	.734	.243	0.46-1.18	NS

Ref: variable considered as reference;

† The alternative journey distance categorisation (B 1-100km, 101-150 km, >150 km) did not show significant associations with the probability of occurrence of severe bruising;
‡ The alternative journey distance categorisation (A 1-50 km, 51-100 km, 101-150 km, 151-200 km, >200km) did not show significant associations with the probability of occurrence of pH ≥ 6.

Table 4. Risk factors for carcass bruising in cattle assessed by multivariable logistic regression.

Variable		Odds ratios	SEM	Confidence Intervals 95%	*P*-value
Intercept		.483	.211		<0.001
Journey distance					
	1-50 km	Ref.			
	51-100 km	.938	.218	0.61-1.44	NS
	101-150 km	.963	.234	0.61-1.52	NS
	151-200 km	1.976	.386	0.93-4.21	NS
	>200 km	2.043	.287	1.16-3.59	<0.05
Production system					
	Feedlot	Ref.			
	Free-range	1.555	.211	1.03-2.35	<0.05
	Dairy	2.226	.248	1.37-3.62	<0.001
Vehicle type					
	Small trailer (3 Tons)	Ref.			
	Gooseneck (10 Tons)	1.184	.208	0.79-1.78	NS
	Potbelly (30-50 Tons)	.532	.262	0.32-0.89	<0.05

Ref: variable considered as reference.

Table 5. Risk factors for DCB meat in cattle assessed by multivariable logistic regression.

Variable		Odds ratios	SEM	Confidence Intervals 95%	*P*-value
Intercept		.334	.167		<0.001
Journey distance					
	>150 km	Ref.			
	1-100 km	1.886	.241	1.18-3.02	<0.01
	101-150 km	1.760	.199	1.19-2.60	<0.01
*Production system * vehicle*					
	Dairy * Potbelly (30-50 Tons)	Ref.			
	Feedlot * Small trailer (3 Tons)	1.034	.326	0.55-1.96	NS
	Feedlot * Gooseneck (10 Tons)	.893	.260	0.54-1.49	NS
	Free-range * Small trailer (3 Tons)	.619	.214	0.41-0.94	<0.05
	Free-range * Gooseneck (10 Tons)	1.520	.358	0.75-3.07	NS

Ref: variable considered as reference.

4. Discussion

Despite the large number of cattle transported daily in north-western Mexico and the significant role cattle play in the economy of the region, there is a paucity of information regarding the incidence of traumatic injuries and health problems sustained during the transportation of cattle. Likewise, research on risk factors that affect the clinical condition of animals during the pre-slaughter period as well as carcase and meat quality is scarce. In this sense, our results are an initial approach to the beef cattle production and slaughter systems in Mexico. In the current study, the journey distance, the vehicle type, the animals' origin (production system) as well as their commercial type, played a fundamental role in maintaining within acceptable ranges those outcomes that may be considered as a reflection of the animals' welfare. While these effects should not be seen as a reflection of the state of animal welfare nationwide, the results provide a first approximation of the operational risks within the Mexican beef production chain as well as the indicators' capability to provide information on these risks. This is the first study in Mexico to report on pre-slaughter characteristics and its interactions with liver condemnations, hoof disorders, bruise prevalence, and meat pH from an integrative welfare assessment perspective.

4.1 Liver condemnations and severe hoof injuries

Livers are important from a public health and economic standpoint, as they are a common edible portion in cattle and represent a possible food safety concern (Alton *et al* 2012). These are important factors to consider when selecting portion condemnation designations for syndromic surveillance as it has been noted that the quality of data recording could be poor for organs that are not considered to be economically important or a concern for food safety. Although our condemnations data only allowed a univariate level of analysis, our results suggest a marked effect of the production system of animals' origin on liver condemnations. Our findings showed that old bulls reared in extensive systems were more likely to present liver lesions. In Mexico's north-west region, herds raised in extensive systems are constantly grazing, which generates favourable conditions for the development of some parasitoses (Barbosa *et al* 2019). This situation highlights at least two important characteristics related to the animals' weight and age. Cattle parasitised with *F. hepatica* have been associated with reduced weight gain, poorer carcase conformation, and lower fat scores (Sanchez-Vazquez & Lewis 2013; Mazeri *et al* 2017). Furthermore, a higher prevalence of fascioliasis has been found in older cattle, so it would be expected that *F. hepatica*-infected animals arrive later to the abattoir (Almeida da Costa *et al* 2019). As they are older animals, with poor carcase conformation and lower fat scores, it is reasonable to postulate that cattle with liver problems may be prone to lesions such as bruising, further reducing the quality and price of their meat. Due to the great biotic potential of *F. hepatica* and their intermediate host, snails, only a continuous and coordinated strategic application of all available measures can provide economic control of the disease. Control should be on a preventive rather than a curative basis through: (i) the use of strategic anthelmintic treatments (to reduce the number of flukes in the host and the number of fluke eggs in pasture); (ii) the reduction on the number of intermediate host snails (improved drainage); and (iii) the management of fluke-prone areas, to reduce exposure to infection (fencing, grazing management) (Boray 2017).

Finally, yet importantly, is the link between *F. hepatica* and some bacterial pathogens. *F. hepatica* is known to modulate its host's immune response and affect susceptibility to bacterial pathogens such as *Salmonella Dublin* and *E. coli* O157, both of worldwide public health concern (Howell *et al* 2018). Thereby, we found that liver condemnations could be considered as a potential welfare indicator, which has been related to losses in carcase quality, cattle welfare, and public health. Animals' origin (production system) played a fundamental role as a predisposing or risk factor for the presence of liver pathologies. Given the detriment of these lesions to the animal, the cattle feeder, and the meatpacker, it would be advantageous to simultaneously monitor the lesion prevalence along with production measurements to provide an objective and more complete benchmarking of the entire beef production process (Rezac *et al* 2014). Changes in liver condemnation rates could be monitored over time and space, and when the condemnation rate reaches a certain threshold, it may signal a potential outbreak or quality control problem within an abattoir and/or region (Alton *et al* 2012).

Severe lameness events in finishing beef cattle are becoming a relevant issue for its implications for animal welfare and the negative consequences on beef farm economics (Magrin *et al* 2020). In the current study, commercial livestock type increased the appearance of severe lameness-related lesions. Young bulls (two to five years old) showed a greater risk of presenting severe hoof injuries compared to old bulls. These results were consistent with Hemsworth *et al* (1995). Factors influencing the presence of hoof disorders in young cattle include hoof hardness, housing, nutrition, social hierarchy rank, bodyweight, and hoof conformation (Bruijnis *et al* 2011). In our study, most of the young bulls came from feedlot systems. Thus, cattle genotype and management systems (such as feeding plans and housing solutions) could have influenced the occurrence of these disorders (Magrin *et al* 2018). Excitable temperament has been reported among *B. taurus* beef breeds, particularly in young animals on feedlots and cattle reared in extensive systems (Estévez-Moreno *et al* 2021). Therefore, it is possible that our results are due to a complex interaction between the origin of the animals, temperament, genotype, reactivity to novel environments and handling that may increase the probability that animals suffer limb injuries. Since claw disorders may have an impact on bodyweight and carcase characteristics (Sonoda *et al* 2017; Alvergnas *et al* 2019) interactions related to carcase bruising and meat pH should not be discarded.

To date, only a few studies have assessed the direct effects of journey distance on severe hoof injuries (Lee *et al* 2018). Results from the current investigation showed that journeys around 151–200 km increased the likelihood of severe hoof injuries compared to shorter distances (1–50 km). These findings seem to reinforce the results of other authors (Dahl-Pedersen *et al* 2018a) who found that short-duration transport increased lameness scores in cull dairy cows. Although journey distances were relatively short in this trial and no information was available on the clinical condition of cattle prior to transport, it is likely that compromised (lame) animals deteriorated during the journey and that pre-existing conditions worsened during transport. Even though the majority of hoof disorders are a reflection of chronic multifactorial processes, transport may exacerbate latent or underlying processes and even cause skin wounds (Bautista-Fernández *et al* 2021). The trucks that transport livestock are presumed to be a risk factor for lameness-related lesions as they may predispose animals to certain events, such as falls and entrapments in holes (Schwartzkopf-Genswein *et al* 2012). In our study, the gooseneck trailer increased the likelihood of severe hoof injuries compared to small trailers. In general, observed gooseneck trailers did not have bedding or non-slip floors, cattle were transported loose in one compartment, and moveable barriers were seen in a few trucks. Also, cattle in gooseneck trailers were mostly transported at low stocking densities (one or two animals per truck). Although low stocking density *per se* is not a cause of stress it leaves cattle more vulnerable to careless driving and emergency stops (Tarrant 1990). These conditions have probably caused the animals to lose their balance, thus increasing the chance of presenting/aggravating limb injuries during transport.

The fact that the animals' origin was not a risk factor for severe lameness-related lesions would indicate that this condition is not production system type-specific but rather is a widespread multifactorial issue. In this context, the monitoring and surveillance of severe hoof injuries can serve as a complementary tool to understand animals' degree of adaptation to the productive environment and accordingly recommend animal welfare practices even in extensive systems. Overall, the data show that severe hoof injuries could be considered a candidate for a welfare indicator that showed a relationship with pre-slaughter operations (Thomson *et al* 2015). Nevertheless, there is little standardisation regarding hoof lesion scoring, which could pose a challenge for its implementation at slaughter level both due to time and financial restrictions. One possible means of improvement could be a risk-based inspection programme, where animals identified at high-risk would receive an in-depth inspection whereas animals identified at low-risk would undergo a visual inspection only (Dupuy *et al* 2014). Factors associated with organ condemnations and hoof disorders identified through this study could be used for this purpose, to identify which kind of animals could be considered at high or low risk upon arrival at the abattoir. Finally, considering that the incidence of health problems as welfare indicators has been underestimated (Rushen 2003), further research is warranted and the (re)integration of health problems within cattle welfare monitoring should be encouraged.

4.2 Severe bruising and dark cutting beef (DCB)

It is generally recognised that the most prevalent physical injury that occurs during pre-slaughter handling is bruising (Ferguson & Warner 2008). Many authors have emphasised the relationship between distance journeyed and the occurrence of bruising in cattle, suggesting that the level of bruising might increase with the distance journeyed by the animals (Strappini *et al* 2009). Our findings support this statement as animals that journeyed > 200 km doubled the likelihood of severe bruising compared to those that journeyed short distances (1–50 km). These results do not coincide with those reported in other studies (Hoffman & Lühl 2012; Romero *et al* 2013). It has been proposed that the total duration an animal is transported is more important than the total distance it journeys (Schwartzkopf-Genswein *et al* 2016). However, long journeys can be more physically demanding (Simova *et al* 2016). The longer the transportation, the longer the action of all present factors which can adversely affect the welfare of transported animals and result in an increased bruising incidence. In our study, animals of different origins were mixed during transport (mainly from extensive systems) and later also penned together in lairage. Moreover, some of the evaluated farms were in remote locations, with mountainous and winding roads unpaved or gravelled. It has been observed that the distance journeyed on unpaved roads interferes with the occurrence of carcase bruising (Bethancourt-Garcia *et al* 2019). Unpaved roads hinder the motion of the trucks while their uneven surface leads to imbalance, bumping, and constant braking of vehicles, causing the animals to fall or bump against the loading compartment wall. The combination of these factors might be the reason that transport distance was linked to bruise levels in this trial.

The design of the vehicle influences bruising during transport. North America, including Mexico, primarily uses commercial potbellied cattle trailers at a standard size in large part because of its large load capacity, resulting in reduced transportation cost per animal (Schuetze *et al* 2017). From an animal welfare perspective, this vehicle type is somewhat controversial (Miranda-de la Lama *et al* 2018). However, in our study, its use was less likely to cause severe bruising in the carcases compared to small trailers. It is probable that factors such as vehicle maintenance (lack of), old and unfit small trailers, poor ramp design, and the presence of 'guillotine-type' doors at the rear end of some trucks, can explain a part of the obtained results (Huertas *et al* 2015). When vehicles are improperly designed handling animals becomes more complicated, so it is common to observe frequent use of devices to force animals to move (ie electric prod, sticks, loud shouts). The combination of inappropriate vehicles and rough handling may have increased bruising occurrence in this investigation. Additionally, stock carried by rigid vehicles tends to experience a rougher ride than cattle transported by articulated trailer (Tarrant 1990). This is mainly because rigid body trucks, since they are smaller and easier to handle, are generally driven faster than articulated vehicles. These events are further aggravated by the poor professionalism of hauliers during long-haul transport. Previous research has found an association between hauliers' perceptions towards animal welfare with years of driving experience and the risk of accidents on the road (Valadez-Noriega *et al* 2018). Although hauliers were consistent throughout the study, the skill and personality of drivers may have contributed to transport quality.

The type of cattle being transported defines how fit they will be for transport and ultimately how well they cope with the stress of transport (Schwartzkopf-Genswein *et al* 2016). In the current study, extensively raised animals and cull dairy cows had a higher risk of bruising compared to feedlot cattle. In cattle reared under extensive grazing systems, poor handling (Strappini *et al* 2009), a nervous temperament (Ferguson & Warner 2008), breed differences (*B. taurus* vs *B. indicus*) (Mpakama *et al* 2014), and either being horned or hornless (Hoffman & Lühl 2012) might increase bruising during transport. In this trial, the use of Zebu crossbreeds (*B. indicus*) was common to counteract the climatic challenges of the region, almost 70% of the animals had horns of different sizes, and some trucks were shared by different producers. It could be that these factors were further confounded with the journey distance influencing the degree of bruising observed. On the other hand, cull dairy cows have low commercial value and do not offer economic incentives to be treated well, hence they are more prone than other cattle categories to suffer from poor welfare (Sánchez-Hidalgo *et al* 2019). Our findings support this statement since cull dairy cows were associated with a two-fold or greater increase in carcase bruising in long-haul road transport. The presence of pre-existing diseases or other weaknesses potentially increases the severity of transport as a stressor, and indirectly, the prevalence and severity of contusions (Dahl-Pedersen *et al* 2018b; Cockram 2019). Although no information was available on the clinical condition of cattle before transport, it is likely that for weak, diseased, or injured animals, the journey entailed a greater welfare cost. However, some of the observed bruising may have occurred on the farm of origin or during the marketing process.

Regardless of animals' origin, it has been suggested that physical differences in fat cover, skin, and thickness of hide could affect susceptibility to bruising resulting from impacts of similar force (Hoffman & Lühl 2012). Dairy cows reared in intensive systems are probably pushed beyond their biological limits, causing a significant deterioration in their physical and clinical conditions. Likewise, the drought conditions in northern Mexico generate periodic liveweight and body condition changes in livestock raised in extensive systems. These circumstances may have influenced our results, increasing the presence of bruises in animals of both origins. However, Knock and Carroll (2019) did not find an association between body condition and carcase bruising. Some evidence exists in the literature that sex and age affect the level of bruising observed at slaughter. Although the commercial livestock type did not affect bruising in the final model, certain trends became apparent. In the present study, 53 and 85% of the free-range and dairy animals, respectively, were female. It has been suggested that females, as they have a higher reactivity when compared to males, may be more susceptible to severe bruising. Also, old animals tend to exhibit more bruises in the occurrence of traumatic events (Bethancourt-Garcia *et al* 2019). Almost 90% of the males in extensive systems were old bulls, while 49% of the females were old cows (> 5 years). In dairy systems, almost 50% of the slaughtered animals were old cows. Likely, these factors could also make animals in both groups more prone to bruising.

In many studies, and industrially, the pH of meat at 24 to 48 h post mortem has been used as a benchmark for detecting DFD meat (Ponnampalam *et al* 2017). The ultimate pH cut-off for classifying meat as DFD has been traditionally thought to be above pH 6.0, although some argue as low as 5.8 (Romero *et al* 2017). One of the factors that has been related to the depletion of muscle glycogen is the duration of transport to the abattoir. Contrary to findings by other authors (Tarrant 1990; Hoffman & Lühl 2012), short journeys (1–150 km) increased the risk of dark cutting carcases in this investigation. The possible reason for a higher pH over shorter transport distances may be the fact that breeders as well as hauliers underestimate the importance of ensuring adequate conditions on short-haul transportation (Simova *et al* 2016). However, it is necessary to recognise that the journey distance is often confounded with other factors, such as the hauliers' training and road type. Warren *et al* (2010) noticed that trained drivers delivered cattle with reduced DCB prevalence. In this context, it is possible that some drivers did not have specific training for transporting livestock since there are no laws or regulations that require compliance in the country (and therefore in the region studied). These events are further aggravated by poor road conditions (Miranda-de la Lama 2018). Animals transported on unpaved secondary roads could have been more affected because of the stress and fatigue through continual movements and a reduced ability to rest (Cockram & Spence 2012), hence transport conditions as journey distance, loading density, duration of transport, type of vehicle are relevant to consider.

One of the major challenges with cull dairy cattle transport is managing cull cow condition and ultimately fitness for transport. In Mexico and the United States, there is no consensus about a definition for 'fitness for transport', nor is this process regulated (Edwards-Callaway *et al* 2019). In our study, the impact of transport conditions on dairy cows is evident in the high pH levels of such animals compared to extensively reared cattle. Potbelly trailers were used primarily for shipments from large dairy pens and further distances. Although potbelly trailers are selected for hauling fat and cull cattle safely (Schuetze *et al* 2017), it has been suggested that larger trucks create more instability for the animals due to greater vibration (Bethancourt-Garcia *et al* 2019). Besides, animals in poor conditions may be more susceptible to exhaustion due to poor muscle strength and low levels of mobilisable energy (Nielsen *et al* 2010). The current results support these statements indicating that transport in potbelly trailers was demanding for cull dairy cows. In this context, knowledge about the clinical condition of cull dairy cows before transport is strongly needed to improve the understanding of potential welfare implications of transport of these animals (Dahl-Pedersen *et al* 2018c).

From our results, the lower risk of high pHu in extensively raised cattle could suggest that these animals had calmer temperaments or were properly handled during the preslaughter period (Ndou *et al* 2011). Conversely, the fact that cull dairy cattle were more likely to present high pHu may reflect the challenges in their management. The current findings may be evidence of the importance of nutrition (eg body condition, sub-clinical incidence of acidosis) (Ponnampalam *et al* 2017; Mahmood *et al* 2019), health status (mobility and locomotion, illness, injury, physiological stage) (Schwartzkopf-Genswein *et al* 2012; DahlPedersen *et al* 2018a,b,c), animal phenotype (carcase and muscle weight, subcutaneous fat depth) (Mahmood *et al* 2016), age and sex (Romero *et al* 2013) on meat quality assessed through pHu. In this context, it would be valuable to continue with studies on the effect of transport conditions and handling practices on more fragile cattle, such as cull cows to be able to provide a comprehensive characterisation and thus a benchmark.

The findings of the interaction between transport and animals' origin suggest a cumulative effect of individual stressors (risk factors) and how these invoke different temporal response profiles. In this investigation, it became apparent that DCB was affected by differing management philosophies and cattle-handling procedures. Our study found a significant effect on pH according to the origin of the cattle evaluated, highlighting the need to draw up protocols for actions that can be taken into each production system. The relevance of good animal handling practices during transport was also emphasised. Although vehicle type and journey distance may be somewhat inherent to the production system (and not so easy to change), other factors are subject to improvement (ie loading conditions, animals' fitness for transport, driver experience, construction and detour routes, among others). Using best management practices for transportation will increase economic value of cull animals, decrease labour requirements, decrease morbidity and mortality, and improve meat quality (Schwartzkopf-Genswein *et al* 2016).

In the current investigation, bruises and pHu proved to be indicators that provided relevant information on the evaluated pre-slaughter stages, showing a relationship both with transportation (vehicle type and journey distance) and animals' origin (free-range, dairy, feedlot). These indicators highlighted the importance of vehicle design (a poorly studied topic in Mexico) and the need for changes in handling practices during transport (eg journey distance, animal preparation for long transport, hauliers' skills, among others). Besides, both indicators showed a relationship with fitness to transport, noting the susceptibility of certain commercial categories and the ability to cope with the stress of transport depending on its origin (production system). In this sense, it is advisable to include an evaluation of bruises and pHu in animal welfare assessment protocols. However, it is also important to continue looking for methods that facilitate its measurement at slaughter level, since not all environments are ideal for its application.

5. Animal welfare implications

The integrative welfare risk surveillance in slaughtered cattle discussed here is easy to implement, is sensitive to all commercial categories of cattle slaughtered, and can contribute to the improvement of animal welfare assessment at abattoir level within the beef cattle industry in Mexico. The current study is the first to integrate the monitoring of animal welfare at the abattoir level under commercial conditions, analysing the risks associated with pre-slaughter operations (bruises and muscle pH) and the health status of the animals (hoof injuries and liver condemnations). From the perspective of risk prevention, both visions complement each other and give a comprehensive idea of how animals were raised, fattened, and slaughtered. This information can be strategic in making logistical, productive, and commercial decisions for farmers, companies, and retailers. In addition to its implications in certification and compliance schemes, and even for future consumer information programmes on the production systems of the animals they consume.

6. Conclusion

Our results indicate that alterations in the evaluated indicators were not randomly occurring but, instead, were a direct consequence of various factors present throughout the life of the animals and the pre-slaughter period. It became apparent that on-farm handling practices may predispose animals to higher welfare costs. We found that old bulls reared in extensive systems were more prone to present liver condemnations (*F. hepatica*). Also, young bulls show a greater risk of presenting severe hoof injuries compared to old bulls. The most serious damage was found in cull dairy cows (severe bruising, high pHult) and since they will continue to arrive at abattoirs, leadership within the industry is needed to tackle this welfare challenge. Likewise, transport conditions were evidently concomitant with an increased risk of limb injuries, bruising, and high muscle pH.

The current findings imply the need to reinforce transport structures and provide more training for personnel involved in handling livestock in the cattle supply chain. The assessed indicators proved to be useful and showed a relationship with the evaluated variables. At slaughter level, carcase bruises and meat pH are highly valid indicators of animal welfare as they are a clear reflection of diminished well-being during pre-slaughter period. Finally, the liver condemnations and hoof disorders at abattoir level could counteract the unfeasibility of checking health conditions at farm level (mainly in feedlot cattle and animals raised in extensive systems). These results warrant further research to continue to strive for efficient and sustainable cattle production practices.

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Capítulo 4

Discusión general

La presente tesis tuvo como finalidad identificar indicadores de bienestar bovino utilizados a nivel internacional, especialmente bajo condiciones comerciales, para evaluar su validez y factibilidad de uso en rastros, además de su potencial para actuar como indicadores tipo 'Iceberg'. Con base en la revisión sistemática realizada (Capítulo 1), se seleccionaron seis indicadores (vocalizaciones, disparos de aturdimiento, lesiones podales severas, hematomas en la canal, decomisos parciales y pH de la carne) para observar su comportamiento en un rastro Tipo Inspección Federal (TIF) ubicado en la región noroeste del país. Posteriormente, se crearon perfiles de riesgo integrados (perfiles logísticos) y se analizó su interacción con los indicadores de bienestar y salud evaluados. Por último, se examinó la relación entre la logística previa al sacrificio y los factores de riesgo asociados al decomiso de órganos (hígado), lesiones podales severas, hematomas y la calidad de las canales bovinas (pH). Desde nuestros resultados, la distancia de viaje, el tipo de vehículo, el origen de los animales (sistema de producción) así como su tipo comercial, tuvieron un papel fundamental para mantener dentro de rangos aceptables aquellos resultados (indicadores) que pueden considerarse como un reflejo de la calidad de vida de los animales, y por ende de su bienestar. Si bien estos efectos no son un reflejo del estado de bienestar animal a nivel nacional, los resultados muestran una metodología probada en condiciones nacionales y una primera aproximación a los riesgos operativos, así como el potencial de los indicadores para brindar información sobre dichos riesgos. Este es el primer estudio en México que informa sobre las características previas al sacrificio y sus interacciones con los indicadores analizados desde una perspectiva de evaluación integral del bienestar. Finalmente, el proyecto propone la posibilidad de considerar los indicadores evaluados como indicadores 'Iceberg' del bienestar animal en esquemas de monitoreo a nivel rastro.

México cuenta con dos tipos de establecimientos para el sacrificio de animales: los rastros municipales y las plantas Tipo Inspección Federal (TIF) (Villanueva y De Aluja, 1998). En la presente investigación, el rastro TIF se seleccionó por la homogeneidad en el tipo de animales sacrificados (al menos el 85% de los animales eran *Bos taurus*), una infraestructura y calidad operativa a nivel internacional, y por su ubicación geográfica estratégica desde donde procesaba animales de pastoreo (free range), corrales de engorda (feedlot) y granjas lecheras provenientes de tres grandes ecosistemas en

México (es decir, semiárido, valles y cordilleras). De esta manera se garantizó que la muestra experimental fuera válida para analizar la diversidad de orígenes (sistemas productivos) en la población bajo estudio, así como para identificar los factores de riesgo que pudieran estar asociados con los indicadores evaluados en la especie bovina.

Los protocolos de evaluación del bienestar científicamente robustos y factibles son vitales en la protección del bienestar de los animales de granja (Heath *et al*., 2014). Tradicionalmente, las evaluaciones a nivel granja han sido la principal fuente de información sobre las condiciones en las que los animales se crían. Sin embargo, este tipo de evaluaciones suelen ser muy demandantes en términos de tiempo y los recursos requeridos para implementarlas, además de estar orientadas a valorar las respuestas de los animales al ambiente productivo, sin tomar en cuenta el periodo *ante mortem* (pre-sacrificio) que suele tener un impacto significativo en los animales (Knock y Carroll, 2019). Por ejemplo, aunque solo toma ~ 1 minuto evaluar la distancia de huida en una vaca lechera usando el protocolo Welfare Quality, puede tomar hasta 70 minutos (dependiendo el tamaño del hato) evaluar lo mismo a nivel rebaño (Welfare Quality, 2009). En ese sentido, la posibilidad de utilizar la inspección rutinaria en rastros como una herramienta que permita realizar análisis retrospectivos sobre el estado general de bienestar de los animales, está siendo cada vez más reconocido (Harley *et al*., 2012). A pesar de ello, en México, la información al respecto es escasa (Cruz-Monterrosa *et al*., 2017; Loredo-Osti *et al*., 2019) y generalmente se orienta a reportar prevalencias. La medición de indicadores de bienestar animal a nivel rastro no es un requisito oficial y las empresas privadas no han generado ningún tipo de auditoría que permita tener un sistema de monitoreo permanente.

El bienestar animal es un término que, frecuentemente, se utiliza para expresar preocupaciones éticas sobre la calidad de vida que experimentan los animales, en particular aquellos que son utilizados por los seres humanos en la producción de alimentos (Hansen y Osteras, 2019). Sin embargo, desde un punto de vista científico, este término se refiere a la capacidad de un individuo para hacer frente a los desafíos generados por su entorno (Broom, 2014). En ese contexto, este proyecto de investigación identificó indicadores válidos que pueden señalar signos de estrés y fallas operativas en las condiciones del rastro (vocalizaciones, efectividad del aturdimiento), el estado de salud animal (trastornos podales, decomiso de órganos) y la calidad del producto (hematomas en la canal y pH de la carne). Dichos indicadores pueden considerarse como medidas no invasivas, son relativamente sencillos de medir, y pueden brindar información acerca del grado de adaptación que los animales tienen (o no) a su entorno productivo.

Las emociones tienen una función crucial para la vida de un animal, ya que facilitan las respuestas a eventos externos o internos de importancia para el organismo (Mendl *et al*., 2010). Las vocalizaciones pueden ser indicativas del estado emocional del animal. La exposición de los animales a un factor estresante provoca cambios en la respiración, la salivación y la tensión muscular mediante la activación del sistema nervioso autónomo (Briefer, 2012). Esto, a su vez, da como resultado cambios auditivos en las características vocales (por ejemplo, aumento de la frecuencia vocal, mayor tono/rugosidad). A diferencia de muchas mediciones fisiológicas, documentar las vocalizaciones no requiere interacción física con los animales y, por lo tanto, puede ayudar a evaluar el estrés de forma no invasiva (Green *et al*., 2020). En nuestro estudio, sin embargo, ese indicador no mostró diferencias claras entre los perfiles logísticos evaluados. Además, la información que proporcionaba no era clara y no siempre permitía inferir la causa del problema de bienestar. No obstante, en general, el rastro presentó un elevado porcentaje de bovinos vocalizando. Las vocalizaciones son un indicador conductual, por ende, solo pueden considerarse válidas en el momento de la inspección en el rastro (Visser *et al*., 2001). Esta situación sugiere que nuestros resultados podrían estar relacionados con problemas de manejo y equipo (Grandin, 2001). Sin embargo, el análisis de las vocalizaciones no es tan abstracto. Actualmente se sabe que las vocalizaciones transmiten muchos mensajes que no necesariamente reflejan un pobre bienestar (Taylor y Reby, 2009). En cualquier caso, nuestros resultados muestran que clasificar a los animales como se hizo en el presente proyecto podría no ayudar a desarrollar indicadores robustos de bienestar a nivel rastro. Dado que las vocalizaciones son representativas de cambios emocionales de corta duración, clasificar a los animales como vocalizadores frente a no vocalizadores durante un largo período de tiempo puede ser complicado. En ese sentido, Briefer (2012) y Padilla de la Torre *et al*. (2015) sugieren que las vocalizaciones se verifiquen utilizando otros componentes de las emociones (por ejemplo, indicadores fisiológicos y conductuales) y bajo condiciones relativamente tranquilas.

En nuestro estudio, el número de disparos de aturdimiento fue útil para hacer una distinción entre los diferentes sistemas de producción. El principal objetivo del aturdimiento es dejar inconsciente al animal para que pueda desangrarse sin causar dolor ni angustia, pero también ayuda al operario a desangrar al animal de manera más cómoda y segura (Terlouw, 2015). Es ampliamente reconocido que el aturdimiento es un punto crítico durante las operaciones de sacrificio (Gibson *et al*., 2019); sin embargo, en México, no existe consenso sobre un estándar para evaluar el aturdimiento y el procedimiento no está regulado (Miranda-de la Lama *et al*., 2012). Durante muchos años, la proporción aceptable de animales aturdidos de manera efectiva en los rastros de EE.UU. fue del 95% (Grandin, 2010), pero se elevó en 2017 (96%) (Edwards-Callaway y Calvo-Lorenzo, 2020). Si esa tasa de eficiencia se usa como punto de referencia, ninguno de los perfiles logísticos evaluados cumplió con esos estándares, y la proporción de animales que recibió más de un disparo (re-shooting) fue mayor en los que provenían de corrales de engorda (feedlot). En general, el rastro evaluado presentó un elevado porcentaje de animales que recibían más de un disparo de aturdimiento (39.0%), lo cual está por encima de lo reportado por Gregory *et al*. (2007) (9.0%), Von Wenzlawowicz *et al*. (2012) (9.0%), Atkison *et al*. (2013) (12.0%), y Hultgren *et al*. (2014) (7.0%). Las bajas tasas de aturdimiento efectivo reportadas en este proyecto podrían estar relacionadas con la falta de mantenimiento del equipo de aturdimiento, deficiencias en la capacitación de los operarios (Hultgren *et al*., 2014), el tipo de piso dentro del cajón de aturdimiento y las características del sistema de sujeción de la cabeza (Muñoz *et al*., 2012). Específicamente, para el ganado de engorda, el fenotipo (p.ej., musculatura, forma, tamaño, peso, cráneo más grueso) y la edad del animal (animales jóvenes) podrían haber influido (Njisane y Muchenje, 2013). Las tendencias observadas en este proyecto de investigación pueden utilizarse para identificar categorías de animales de alto/bajo riesgo para recibir más de un disparo de aturdimiento, y ayudar en el desarrollo de guías para operarios y el mantenimiento preventivo del equipo de aturdimiento. En nuestro estudio, fue posible observar que los toros jóvenes de engorda tenían más probabilidad de mostrar un nivel de riesgo más alto por una calidad de aturdimiento inferior en comparación con las demás categorías comerciales. El presente estudio destaca la importancia de las auditorías (internas y externas) para evaluar la calidad del aturdimiento a nivel rastro.

Las respuestas al estrés pueden influir en el metabolismo muscular *post mortem* y, en consecuencia, en la calidad de la carne (Bourguet *et al*., 2010; Hemsworth *et al*., 2011). A nivel comercial, el pH final (pH24 o pHu) es un indicador de referencia de la calidad de la carne (Terlouw, 2015). Esto se debe a que el pH permite inferir el estrés que experimentan los animales durante las operaciones previas al sacrificio al tener en cuenta tanto las rutas metabólicas como las reservas de energía muscular (Losada-Espinosa *et al*., 2018). Además, es un indicador que se ha utilizado como punto de referencia para detectar el corte oscuro (DCB, por sus siglas en inglés) (Ponnampalam *et al*., 2017). En un primer estudio (Capítulo 2), el pH24 ayudó a identificar diferencias entre grupos. En general, se observó que las vacas lecheras de descarte, cierto ganado de engorda y animales viejos criados extensivamente tenían una mayor probabilidad de presentar corte oscuro. Posteriormente, se realizó un segundo análisis (Capítulo 3) para estudiar los escenarios relacionados con los distintos sistemas de producción y conocer los factores de riesgo asociados a los mismos. Nuestros resultados mostraron que tanto los animales que hacían viajes cortos (1-150 km) como el ganado lechero de descarte tenían más riesgo de presentar un pH24 alto. Una posible explicación para un pH24 más elevado en distancias de transporte cortas pudo ser el hecho de que tanto los productores como los transportistas subestimaran la importancia de garantizar condiciones adecuadas en este tipo de viajes (Simova *et al*., 2016). Además, la distancia de viaje pudo haber interactuado con otros factores, como la capacitación de los transportistas y el tipo de carretera (Cockram y Spence, 2012; Miranda-de la Lama, 2018). En ese sentido, en México no existen leyes o reglamentos que exijan una capacitación específica para el transporte de ganado.

Por otro lado, el impacto de las condiciones de transporte en las vacas lecheras de descarte fue evidente. A partir de nuestros resultados, el mayor riesgo de pH24 elevado en el ganado lechero podría sugerir que los viajes en camiones con remolque (Potbelly) representan un desafío para este tipo de animales. Bethancourt-Garcia *et al*. (2019) mencionan que los vehículos más grandes generan más inestabilidad en los animales debido a una mayor vibración. Además, los animales en malas condiciones pueden ser más susceptibles al agotamiento debido a la poca fuerza muscular y los bajos niveles de energía movilizable (Nielsen *et al*., 2010). En ese contexto, el conocimiento sobre la condición clínica y aptitud (fitness) del ganado lechero previo al transporte es indispensable para mejorar la comprensión de las posibles implicaciones que el transporte pueda tener sobre el bienestar de dichos animales (Dahl-Pedersen *et al*., 2018b; Edwards-Callaway *et al*., 2019). Los hallazgos de la interacción entre el transporte y el origen de los animales sugieren un efecto acumulativo de estresores individuales (factores de riesgo) y como éstos invocan diferentes perfiles de respuesta temporal. El corte oscuro (DCB) es un fenómeno multifactorial que está influenciado por problemas dentro y fuera de la granja y con los animales, y en ese sentido, nuestro estudio identificó patrones asociados con esta condición (Ponnampalam *et al*., 2017).

El registro de los hematomas en la canal a nivel rastro puede tener un potencial significativo como recurso para la vigilancia de problemas de bienestar en el ganado (Correia-Gomes *et al*., 2016). Los hematomas son indicadores forenses valiosos para detectar fallas básicas en la cadena logística previa al sacrificio, porque pueden ayudar a identificar el origen de los problemas (Miranda-de la Lama *et al*., 2012). Además, son motivo de gran preocupación tanto para la industria cárnica como para los ciudadanos ya que se han asociado con el maltrato y sufrimiento de los animales, el recorte excesivo de la canal, una disminución en la frescura de la calidad de la carne y, potencialmente, pueden reducir las ganancias económicas (Cruz-Monterrosa *et al*., 2017). En el primer estudio (Capítulo 2), la evaluación de hematomas severos identificó un clúster asociado con animales que se encontraban en una condición física severamente deteriorada (C3) y mostró una relación entre los hematomas y la edad del ganado (C4). Para obtener información sobre los factores de riesgo en la ocurrencia de hematomas y la probabilidad de causas presuntas se realizó un segundo estudio (Capítulo 3) donde observamos que los animales que viajaron >200 km duplicaron la probabilidad de sufrir hematomas graves en comparación con aquellos que viajaron distancias cortas (1 a 50 km). En ese sentido, es posible que parte de nuestros resultados se relacionaran con carreteras en malas condiciones y/o caminos de grava o terracería; este tipo de rutas transmiten una mayor cantidad de vibraciones a los animales, producen fatiga, pérdida del centro de gravedad, así como caídas y lesiones (Valadez-Noriega y Miranda-de la Lama, 2020).

Por otra parte, contrario a lo que se observó en la evaluación de pH24, los animales que viajaron en camiones con remolque (Potbelly) tuvieron 50% menos probabilidad de presentar hematomas severos. Factores como la falta de mantenimiento de los vehículos, los remolques pequeños y viejos, un mal diseño de las rampas y la presencia de puertas "tipo guillotina" en la parte trasera de algunos camiones, pueden explicar parte de los resultados obtenidos (Huertas *et al*., 2015). Finalmente, nuestro análisis mostró que los animales criados en sistemas extensivos y las vacas lecheras de descarte tenían un mayor riesgo de desarrollar hematomas en comparación con el ganado de engorda. En el ganado criado bajo sistemas de pastoreo extensivo, la presencia de cuernos (Hoffman y Lühl, 2012), las cruzas con ganado Cebú (*B. indicus*), y la mezcla con animales desconocidos en el transporte al rastro (Schwartzkopf-Genswein *et al*., 2012) son algunos de los factores que pudieron influir en el grado de hematomas observados. Con relación a las vacas lecheras de descarte, éstas se asociaron con un incremento del doble o mayor de hematomas durante el transporte de larga distancia. Aunque no se disponía de información sobre el estado clínico del ganado antes del transporte, es probable que, para los animales débiles, enfermos o lesionados, el viaje implicara un mayor costo de bienestar (Dahl-Pedersen *et al*., 2018a; Cockram, 2019). La elevada prevalencia de hematomas reportada en este proyecto señala la importancia de incluir este indicador en las evaluaciones del bienestar del ganado. Sin embargo, es necesario contar con un sistema de medición eficiente que se adapte a los rastros comerciales. Los hematomas son un indicador básico para identificar áreas donde se pueden realizar mejoras que se reflejen en el bienestar de los animales más susceptibles. Se ha sugerido que existe una pérdida progresiva de empatía por parte de los productores hacia los animales enfermos o viejos debido a que implican pérdidas económicas y de tiempo (Losada-Espinosa *et al*., 2020). El tipo de omisión del cuidado encontrado en este proyecto de investigación enfatiza la necesidad de implementar programas de concientización y capacitación para los productores, transportistas y operarios.

Los eventos severos de cojera en el ganado de engorda se han convertido en un tema relevante por sus implicaciones en el bienestar animal y las consecuencias negativas en la rentabilidad de las granjas (Magrin *et al*., 2020). No obstante, las lesiones podales y los problemas de movilidad se han estudiado poco en comparación con el ganado lechero (Edwards-Callaway *et al*., 2017). En nuestro primer análisis (Capítulo 2), encontramos una prevalencia elevada de lesiones podales severas, particularmente entre los animales del clúster 1. Posteriormente (Capítulo 3), se observó que el tipo de ganado comercial incrementó la aparición de lesiones graves relacionadas con la cojera. Los toros jóvenes (de dos a cinco años) mostraron un mayor riesgo de presentar trastornos graves en las pezuñas, posiblemente debido a las dietas altas en carbohidratos que se utilizan para finalizar la engorda de los animales (LokeshBabu *et al*., 2018). Además, un aumento rápido en el peso corporal ejerce presión sobre la base de los cascos en desarrollo lo que, junto con una actividad física disminuida, puede afectar la salud de la pezuña (Pauler *et al*., 2020). Estévez-Moreno *et al*. (2021) informaron que ciertas razas *B. taurus*, particularmente animales jóvenes en corrales de engorda, pueden presentar un temperamento excitable. En ese contexto, es posible que nuestros resultados se deban a una interacción compleja entre el origen de los animales, el temperamento, el genotipo, la reactividad a entornos novedosos y el manejo.

En nuestro estudio, las distancias intermedias (151-200 km) y los viajes en remolque cuello de ganso incrementaron la probabilidad de trastornos podales graves. Aunque las distancias de viaje reportadas en esta investigación fueron relativamente cortas, y no había información disponible sobre la condición clínica del ganado antes del transporte, es posible que los animales comprometidos (cojos) se deterioraran durante el viaje y que condiciones preexistentes empeoraran durante el transporte. A pesar de que la mayoría de trastornos podales son un reflejo de procesos multifactoriales crónicos, el transporte puede exacerbar procesos latentes o subyacentes e incluso causar heridas en la piel (Bautista-Fernández *et al*., 2021). Por otra parte, la mayoría de los remolques cuello de ganso no tenían cama ni pisos antideslizantes, el ganado se transportaba suelto y generalmente a bajas densidades (uno o dos animales por remolque). Estas condiciones pudieron favorecer una conducción descuidada, paradas de emergencia (Tarrant, 1990) y pérdida de equilibrio en los animales, incrementando la posibilidad de presentar/agravar lesiones en las extremidades. El hecho de que el origen de los animales no fuera un factor de riesgo para las lesiones podales severas puede indicar que esta condición no es específica del tipo de sistema de producción, sino que se trata de un problema multifactorial generalizado. En ese contexto, el seguimiento y la vigilancia de las lesiones podales severas puede servir como una herramienta complementaria para conocer el grado de adaptación de los animales al entorno productivo y, en consecuencia, recomendar prácticas de bienestar animal. De igual forma, pueden ser un indicador del impacto que estos problemas tienen en las tasas de sacrificio y longevidad del ganado (Bruijnis *et al*., 2012; Alvergnas *et al*., 2019). La inclusión de trastornos podales en un programa para monitorear el bienestar animal a nivel rastro puede servir como base para comenzar a detectar patrones de lesiones asociadas a los sistemas de producción, tipo de camiones, duración del viaje, entre otros.

A pesar del reconocimiento temprano de la importancia de los problemas de salud para el bienestar animal (Broom, 1986), la incidencia de dichos problemas como indicadores de bienestar ha sido subutilizada. En el presente proyecto, los órganos seleccionados para su análisis (pulmones, hígado, corazón, ubres e intestinos) se encontraban entre los decomisos más comúnmente reportados por los inspectores durante el período de estudio, además, representaban posibles problemas de salud animal y pública (Alton *et al*., 2012). En un primer análisis (Capítulo 2), observamos que los problemas de salud y el origen animal estaban fuertemente correlacionados. No obstante, de los cinco órganos analizados, el hígado fue el único que mostró una relevancia significativa. Los abscesos y la fascioliasis fueron las principales patologías hepáticas encontradas en la población bajo estudio. Aunque nuestros datos solo permitieron un nivel de análisis univariante (Capítulo 3), los resultados sugieren un efecto marcado del sistema de producción de origen animal en los decomisos de hígado. Nuestros hallazgos mostraron que los toros viejos criados en sistemas extensivos tenían más probabilidades de presentar lesiones hepáticas. Aparentemente, las prácticas de manejo implementadas en la región (los animales criados en sistemas extensivos estaban en constante pastoreo) (Barbosa *et al*., 2019) y la longevidad de algunas razas utilizadas (Innocent *et al*., 2017) tienen efectos significativos. Esta circunstancia resalta al menos dos características importantes relacionadas con el peso y la edad de los animales. Los bovinos parasitados con *F. hepatica* se han asociado con un peso reducido, una conformación de la canal más pobre y un índice de grasa más bajo (Sanchez-Vazquez y Lewis, 2013; Mazeri *et al*., 2017). Además, se ha encontrado una mayor prevalencia de fascioliasis en animales viejos (Almeida da Costa *et al*., 2019). En ese sentido, es razonable postular que, al tratarse de animales viejos, con mala conformación de la canal y menores índices de grasa, los bovinos con problemas hepáticos pueden ser más propensos a sufrir lesiones como hematomas, reduciendo aún más la calidad y el precio de su carne.

Por último, aunque importante, destaca el vínculo entre *F. hepatica* y algunos patógenos bacterianos. Howell *et al*. (2018) mencionan que *F. hepatica* modula la respuesta inmunitaria de su huésped y afecta la susceptibilidad a patógenos bacterianos como *Salmonella Dublin* y *E. coli* O157, ambos de interés mundial para la salud pública. En ese contexto, encontramos que los decomisos de hígado podrían considerarse como un indicador potencial de bienestar, que se ha relacionado con pérdidas en la calidad de la canal, el bienestar del ganado y la salud pública. Estos son factores importantes de considerar cuando se seleccionan los decomisos para la vigilancia sindrómica, ya que se ha observado que la calidad del registro de datos podría ser deficiente para órganos que no se consideran económicamente importantes o una preocupación para la inocuidad alimentaria (Alton *et al*., 2012).

Los indicadores ‘Iceberg’ son medidas que, en teoría, proporcionan una evaluación general del bienestar animal y pueden ser potencialmente indicativos de otros problemas, aunque no necesariamente implican una relación causal (van Staaveren *et al*., 2017). Existe un reducido pero creciente cuerpo de investigación sobre la optimización del número de medidas incluidas en los protocolos de evaluación (Collins et al., 2021). Algunos estudios han investigado la existencia de indicadores ‘Iceberg’ que pueden usarse, por sí solos, para describir el estado de bienestar general de las granjas (p. ej., Knock y Carroll, 2019; Hernandez *et al*., 2020). En ese contexto, los hallazgos de nuestro estudio sugieren que los indicadores analizados tienen el potencial de actuar como indicadores 'Iceberg' del bienestar animal a nivel rastro. Dichos indicadores pueden ser utilizados para señalar que existe un problema a nivel animal y que se requiere una evaluación más detallada. En general, observamos que los indicadores evaluados tienen un origen multifactorial, cuyos factores de riesgo están relacionados con las distintas etapas dentro de la cadena logística de sacrificio, incluyendo el origen de los animales. Como sistema de información integrado, la evaluación de estos indicadores podría contribuir sustancialmente al control de una gama considerable de problemas de salud y bienestar animal (Stärk *et al*., 2014). Además, pueden brindar información sobre la capacidad que tienen los distintos sistemas de producción para proporcionar un nivel aceptable de bienestar animal (Rushen *et al*., 2008). No obstante, es necesario determinar una evaluación del costo en caso de incluir estas mediciones en los procedimientos operativos normales. Asimismo, la capacitación de los inspectores y la estandarización del registro de lesiones es fundamental.

La inspección de la carne es una actividad que consume recursos. Además, cada vez hay más conciencia de que los procedimientos de inspección tradicionales a menudo son ineficaces y pueden provocar brotes de enfermedades transmitidas por los alimentos (Edwards *et al*., 1997; Antunovic *et al*., 2021). En ese sentido, se ha recomendado el uso de programas de inspección basados en el riesgo, como una medida para mejorar la sensibilidad de los procedimientos y hacer que las evaluaciones sean más eficientes en términos de recursos disponibles (Dupuy *et al*., 2014). La idea general detrás del sistema consiste en implementar más recursos de vigilancia en aquellos animales que presenten un alto riesgo de infección u otras condiciones de salud y bienestar. Los datos descritos en el presente estudio pueden utilizarse para identificar categorías de animales de alto/bajo riesgo, previo a su arribo al rastro. Los lotes podrían clasificarse por adelantado conforme la probabilidad de riesgo, para determinar la intensidad del procedimiento de inspección (solo visual frente palpación/incisión), y las modificaciones necesarias en el manejo (Felin *et al*., 2016). Esa evidencia debería proporcionar una mejor comprensión de las condiciones epidemiológicas y de bienestar animal y ayudar a identificar los factores que influyen en el nivel de riesgo y, por lo tanto, en la implementación de enfoques basados en el riesgo (Laranjo-González et al., 2016). Por esa razón, es esencial contar con sistemas de vigilancia consistentes, una recopilación extensiva de datos y la medición de múltiples indicadores, simultáneamente.

Capítulo 5

Conclusiones y contribución global del proyecto

Los resultados del presente trabajo sugieren que los indicadores evaluados son válidos, viables y fiables para evaluar integralmente el bienestar animal a nivel rastro. Nuestros hallazgos indican que las alteraciones en los indicadores no ocurrieron al azar, sino que, por el contrario, fueron consecuencia directa de diversos factores presentes a lo largo de la vida de los animales y el período previo al sacrificio. En general, observamos una elevada prevalencia en el número de disparos de aturdimiento, hematomas severos, trastornos podales y decomisos hepáticos en la población estudiada. A partir de nuestros datos pudimos corroborar que las prácticas de manejo en la granja pueden predisponer a los animales a problemas de bienestar específicos. Encontramos que los toros viejos criados en sistemas extensivos eran más propensos a presentar decomisos hepáticos. Además, los toros jóvenes mostraron un mayor riesgo de presentar lesiones podales severas en comparación con los toros viejos. El daño más grave se encontró en las vacas lecheras de descarte (hematomas severos, pH24 elevado), lo que señala una necesidad urgente de liderazgo dentro de la industria lechera para abordar este desafío de bienestar. Finalmente, encontramos que las condiciones de transporte se asociaron con un mayor riesgo de lesiones en las extremidades, hematomas y pH muscular elevado. La evaluación retrospectiva de los indicadores analizados en este proyecto de investigación es una herramienta esencial para la industria cárnica que busca mejorar el nivel de bienestar y la calidad de la carne en las operaciones comerciales previas al sacrificio. En general, las medidas evaluadas podrían considerarse indicadores 'Iceberg' e integrarse en protocolos especializados para evaluar el bienestar del ganado.

La vigilancia integral del riesgo discutida en este trabajo es fácil de implementar, es sensible a todas las categorías comerciales de ganado sacrificado, y puede contribuir a la mejora de la evaluación del bienestar animal a nivel rastro dentro de la cadena productiva de carne de res mexicana. El presente estudio es el primero en integrar el seguimiento del bienestar animal a nivel rastro en condiciones comerciales, analizando los riesgos asociados a las operaciones previas al sacrificio (hematomas y pH muscular) y el estado de salud de los animales (lesiones podales y decomisos hepáticos). Desde la perspectiva de la prevención de riesgos, ambas visiones se complementan y dan una idea integral de cómo se criaba, engordaba y sacrificaba a los animales. Esta información puede ser estratégica en la toma de decisiones logísticas, productivas y comerciales para productores, empresas y minoristas. Además de sus implicaciones en esquemas de certificación y cumplimiento, e incluso para futuros programas de información al consumidor.

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Anexo 1

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Artículo No. 1

Stockpeople and Animal Welfare: Compatibilities, Contradictions, and Unresolved Ethical Dilemmas

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Stockpeople and Animal Welfare: Compatibilities, Contradictions, and Unresolved Ethical Dilemmas

N. Losada-Espinosa [a], G.C. Miranda-de la Lama [b], L.X. Estévez-Moreno [b]*

[a] Faculty of Veterinary Medicine and Animal Husbandry, National Autonomous University of Mexico, UNAM, 04510, Mexico City, Mexico
[b] Department of Animal Production and Food Science, Agrifood Institute of Aragon (IA2), Faculty of Veterinary, University of Zaragoza, 50013, Zaragoza, Spain
* Contact for correspondence: genaro@unizar.es

Abstract

The cornerstone of any system of livestock production is the stockpeople responsible for the welfare and productivity of the animals they work with. Nevertheless, it has been suggested that the industrialization of livestock production is breaking down the traditional relationship between stockpeople and their animals. Commercial livestock production creates a situation of structurally induced ambivalence for those working in these contexts. Besides, the scientific literature on stockpeople is limited, dispersed and specially focused on animals. Whereby, a review of current knowledge about the compatibilities, contradictions, and unresolved ethical dilemmas faced by stockpeople in their daily work and their implications on farm animals' welfare was carried out. The topics reviewed included: a) Attitudes and personality; b) Empathy towards animals; c) Workplace well-being; d) Occupational health issues; and e) Sustainability. Understanding the stockpeople emotional relationship with animals, gender, ethnicity, occupational roles, educational backgrounds, culture, and generational differences can be valuable for technicians, advisors, scientists, consultants, and owners when developing training for sustainability programs.

Keywords: *Stockpeople, Animal welfare, Ethics, Occupational well-being, Sustainability*

1. Introduction

The cornerstone of any system of livestock production is the stockpeople responsible for the welfare and productivity of the animals they work with. Within the commercial sector, stockpeople is mainly valued for its role in producing economically viable livestock (Wilkie, 2005). Benyon (1991) defines stockpeople 'as a human activity that applies the ability, knowledge, skills and common sense necessary in optimizing health, welfare, husbandry, management and thereby both physical and financial performance, in animal production'. However, livestock production is considered a stressful occupation, and stressed stockpeople are not coping well, besides being considered socially as 'the world's most undervalued profession' (Hansen and Osteras 2019). This reflects the ambiguous position of stockmen: they are absolutely central to the production of quality livestock, but until recently, their contribution has rarely, if at all, been formally recognized (Wilkie, 2005; Hemsworth, 2007; Daigle & Ridge, 2018). In recent years, animal and agricultural scientists have turned their attention to how stockpeople can further improve and refine their human-animal interaction skills to maximize the welfare and productivity of the animals under their care (Wilkie, 2005). Thus, such studies provide a partial account and focus almost exclusively on the economic and productive component of stockpeople's roles.

According to Wheeler and Sillanpaa (1997), employees are perceived as primary social stakeholders seeing that they have a direct stake in an organization's success. This leads to the idea that employees should receive more attention in social sustainability debates (Staniskiene & Stankeviciute, 2018). Social sustainability is of paramount importance in supply chain networks because of the need for increased stakeholder awareness regarding not only 'where' the products are made but also 'how' and 'in what conditions' they are produced (Mani et al., 2016). Moreover, the global economy is reliant upon supply chain networks to operate efficiently in order to prosper; a lack of attention to the well-being of stockpeople may contribute to inefficient or ineffective supply chains since this group is a key participant (Boyce, 2016). That said, Colonius and Earley (2013) mentioned that the separation between human, social, and animal welfare is an artificial compartmentalization, since these disciplines rely on the same set of scientific measures and heavily depend on each other in an ecological context. Therefore, stockpeople are of vital interest not only in the animal welfare perspective but also in the one-health perspective. The one-health concept has been extensively used to describe transdisciplinary actions that protect the health and welfare of animals, humans, and the environment, an approach that should be adopted by the veterinary science worldwide. In the livestock industry, One-Health could help to promote key global objectives such as standards that guarantee the health and welfare of farm animals, preventing or reducing occupational hazards that may affect stockpersons, promotes sustainability in animal production and generate an integrative vision of the human-animal interactions (Valadez-Noriega et al. 2018).

Research into stockpeople has been patchy. It tends to be either qualitative and contextual (in the case of the social sciences) or quantitative and psychometric -generally perceiving stockpeople as a discrete cognitive activity rather than a cultural process (in the case of animal welfare science) (Burton et al. 2012). In general, animal welfare researchers deal with the more practical issue of how to improve the relationship between stockpeople and animals through inducing attitudinal and behavioral change. Nevertheless, one particular concern about the standard attitude-behavior approach is that it treats the behavior of stockpeople towards their animals as being overwhelmingly 'cognitive' –based on rational and reasoned decisions via the experience of interactions with the animal rather than instinctive, subconscious, embodied or empathic responses. Additionally, it has been suggested that the industrialization of livestock production and the establishment of factory-style management techniques is breaking down the traditional relationship between stockpeople and their livestock. Within these new 'industrialized systems' stockpeople thus become increasingly difficult, but at the same time, increasingly important (Beach & Stammler, 2006; Burton et al. 2012; Kauppinen et al. 2013; Werkheiser, 2018). In this sense, the 'career path' of the animal itself (breeding or slaughter) seems to be an important element in the extent to which, if at all, the human-livestock relationship develops (Wilkie, 2005). Serpell (2004) proposes a model of human attitudes to non-humans described by two primary motivational considerations: affect –representing people's affective and/or emotional responses to animals, and utility –representing people's perceptions of animals' instrumental value. This inherent clash between the affect and utility dimensions helps to account for many of the tensions and paradoxes that arise in our relationships with animals (Serpell, 2004). Commercial livestock production similarly creates a situation of structurally induced ambivalence for those working in these contexts (Wilkie, 2005). Regularly, the scientific literature on stockpeople is limited, dispersed and specially focused on animals. Whereby, this paper aims to review current knowledge about the convergences, divergences, and unresolved dilemmas faced by stockpeople in their daily work and their implications on farm animals' welfare. Also, we propose an integrative model to understand the main factors related to stockpeople-animal relationships (Fig. 1). This integrative vision can provide the key elements for the design of training programs and the development of public policies inherent to animal welfare and the wellbeing of stockpeople.

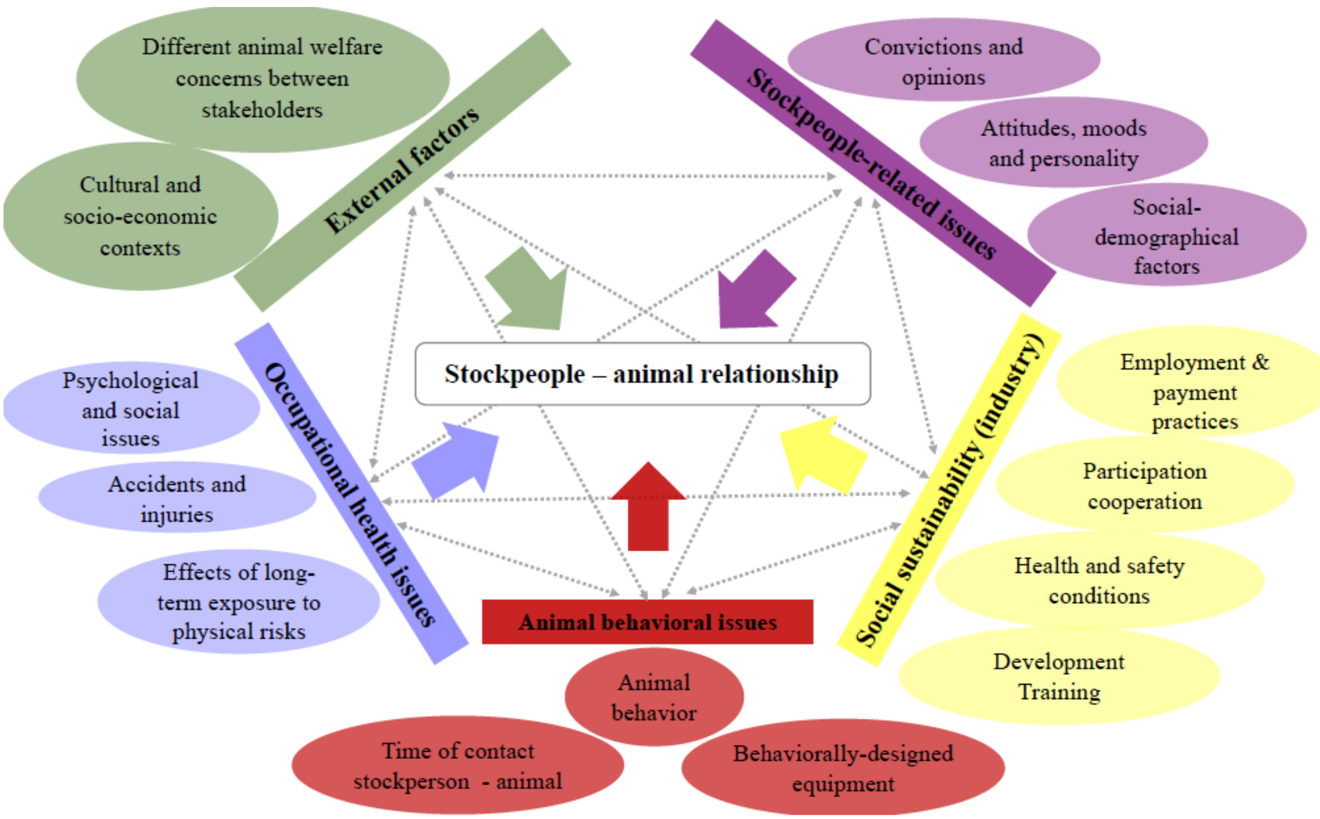

Fig. 1 Integrative model to understand the main factors related to stockpeople-animal relationships

2. Attitudes and personality

Given the importance of stockpeople for animal welfare several investigations have been carried out to try to define the 'good' and the 'bad' about the stockpeople's influence on animals. In this context, most research to date has shown that the behavior of stockpersons towards animals, and husbandry in general, is strongly influenced by attitudes and personality traits (Boivin et al. 2003; Fukasawa et al. 2017; Martínez et al. 2019). Waiblinger et al. (2006) define attitudes as the positive or negative evaluation of 'an entity' (species or particular animal); they are learned through experience with or information about the animals, and they can change with new experiences or information. Thus, daily interactions may affect attitude. An example of this is the research done by Lensink et al. (2001) and Coleman et al. (2003, 2012) who observed that the handlers that had negative beliefs about animals were more likely to behave negatively with them. Conversely, a stockperson with a more positive attitude toward animals tends to exhibit less negative or aversive behavior when handling animals (Fukasawa et al. 2017). Along with this is the acknowledgement about attitudes as important contributors to the welfare, productivity (Lensink et al. 2001; Hemsworth, 2007; Jääskeläinen et al. 2014; Fukasawa et al. 2017; Daigle & Ridge, 2018; Martínez et al. 2019), and fear reactions of animals (Hemsworth et al. 2019). Multiple studies have shown that the attitudes of the stockperson can influence the level of fear of animals through the way the stockperson handles the animals, so attitudes are considered as key factors determining the quality of daily human-animal interactions (Lensink et al. 2001; Rushen et al. 2008; Kauppinen et al. 2013; Ebinghaus et al. 2018).

Nevertheless, it is necessary to recognize that, in some cases, there could be several limitations to these studies –sometimes it is difficult to infer the causal relationship- (Rushen et al. 2008). In this regard, Ward & Melfi (2015) points out that the animal has also a big impact on how the interaction operates. Differences among animals in their responses to people may also be influenced by genetics – domestication must not be confused with the condition of tameness (Beach & Stammler, 2006; Rushen et al. 2008). A reciprocal relationship exists then between the attitude and behavior of the stockpersons towards the animal and the fear or behavioral response of the animal to the stockperson (Waiblinger et al. 2002; Hemsworth, 2003, 2007, 2008; Waiblinger et al. 2006; Ali et al. 2018; Ceballos et al. 2018). From the stockpersons' point of view, fearful animals are often more difficult to handle and manage; this, in turn, exacerbates the problems encountered during routine procedures decreasing job satisfaction, motivation, commitment and self-esteem (Waiblinger et al. 2002; Ceballos et al. 2018). In this context, it has been suggested that people should establish some level of dominance over their animals. This seems contrary to what is often argued; however, it may also be important for the safety of the handlers to ensure some degree of dominance, especially over the larger farm animals. Nevertheless, we are not talking about the use of unjustified force, but rather that animals can consider stockpeople as a member of their social group. This approach allows us to have animals that are not fearful towards humans but respect them (i.e. show no fear or social aggression and show obedience to human orders –man as ruler, man as partner, and man as steward) (Schoon & Grotenhuis, 2000; Boivin et al. 2003; Rushen et al. 2008).

As it was mentioned before, the behavior of stockpersons towards animals might also be influenced by personality, which is defined as the individual’s unique system of traits that affect how the person interacts with the environment, and unlike attitudes, it remains relatively stable over time (Waiblinger et al. 2006). It has been suggested that in certain situations personality may predict worker performance and that, in general terms, positive behaviors are probably more strongly related to the personality of the stockpeople (Rushen & de Passillé, 2015). For instance, Ward & Melfi (2015) refer to an investigation conducted in a zoo where the researchers found that when keepers were more ‘angry’ and ‘neurotic’ they were less likely to perform positive interactions towards captive tigers under their care. Another example is the research done by Coleman et al. (2003) who found that handlers at an abattoir who were rated as ‘tough-minded’ were more likely to use an electric prod when moving pigs. In this sense, it has been proposed that traits like ‘confident’, ‘inward-looking’, ‘self-assured’ and ‘open-minded’ are characteristics that should be sought in workers, because this type of personality is more likely to seek information about and to hold more profound and principled views on animal welfare (Seabrook, 2005; Kauppinen et al. 2013). Stockpeople’s personality characteristics have been correlated with their management and productivity as well (Serpell, 2004; Waiblinger et al. 2006). Another aspect is the influence of the ‘mood' of the stockperson on their behavior towards the animals. Even when the stockperson knows to treat the animals well, they may not necessarily act upon it as they are simultaneously acting upon other influences within their lives. In this case, the behavior may not reflect the worker’s beliefs towards the animals at all, but rather the influences of external and internal social environments on his/her mood (Maller et al. 2005; Burton et al. 2012; Ceballos et al. 2018). It is also possible that when people use negative behaviors (hitting, shouting, jumping, etc.) during handling, they feel more tired and bored. Grandin (2015) and Pulido et al. (2019) suggests that tired people will abuse animals and that, in poultry and pig companies, animal injuries and death may double after the truck loading team works more than 6 hours. On the other hand, boredom also may have effects in terms of the attentiveness of the stockperson to the animals, making their tasks less fulfilling or challenging (Burton et al. 2012).

Other socio-demographical factors that have emerged as important correlates of attitudes to animals are the variables such as gender, education, and pet ownership; however, little agreement has been so far achieved within the literature (Apostol et al. 2013; Hultgren et al. 2014; Ali et al. 2018; Pulido et al. 2018). Traditionally, the physical restraint and handling of livestock during breeding, husbandry practices, transport, and slaughter have been a labor activity related to masculinity. However, currently the tasks of livestock work have been divided less by gender, and the increase in female presence in the livestock industry is a reality (Kallioniemi et al. 2011). This phenomenon is increasingly noticeable in intensive farms and large slaughterhouses around the world (Hippert, 2011). The incorporation of women as stockpeople work is promising to improve the welfare of animals (Pulido et al. 2018), but it also entails challenges in these new occupational relationships between men and women which can affect the quality of the work environment. It has been reported that women in the livestock industry are more exposed than their male partners to sexual harassment (Saunders & Easteal, 2013), also to the disparagement of their strength and skills to handle livestock (Irvine & Vermilya, 2010). In the face of society, working with livestock is seen as a predominantly male activity, this creates a work environment that causes female workers to compensate for their ‘wrong' biological sex, typically through strategies of over-performance or neutralize their femininity (Mik-Meyer, 2015).

Personnel management in the care and handling of livestock must consider these particularities to improve the quality of the working environment for men and women. In this sense, aspects of femininity that are useful in the prevention of accidents in animals and personnel such as responsibility, prudence, and empathy (i.e. towards animal pain and suffering) should be strengthened. Although gender differences in attitudes to animals are now a commonly accepted fact (Serpell, 2004; Herzog, 2007) no attempt has yet been made to find out an underlying explanation for this tendency, and even some researchers mention that the deviation in attitudes within a gender is larger than between the genders (Kauppinen et al. 2012; Apostol et al. 2013). On the other hand, although it has been suggested that well educated young adults who live in urban settings seem to be keener to animals and their human treatment (Apostol et al. 2013), it appears that changed attitudes are linked more closely with the education level of people than to their affluence. In this context, Broom (2006) points out that in countries that are relatively poor, but well educated, interest in animal welfare may be such that people are willing to incur some degree of financial loss rather than benefit from poor welfare in animals. Finally, in reference to the pet ownership theme, Apostol et al. (2013) mention that having experiences with companion animals and forming attachment relationships with them also appear to contribute to developing a set of favorable attitudes to animals –in practice, however, it may be hard to isolate the direct developmental effects of animal exposure from the influence of parental attitudes and modeling (Kidd & Kidd, 1996; Serpell, 2004). The extent to which any of these human attitude modifiers is truly independent of the others is largely unknown, and present evidence suggests that none of them, either individually or combined, accounts for more than a relatively small proportion of the variance in individual attitudes to animals (Serpell, 2004).

3. Empathy towards animals

An important element in the development of good stockpeople skills is the direct contact between the stockperson and individual animals, which assists in the development of empathy and allows stockpeople to build up knowledge of behaviors or even ‘moods’ which can be used to identify welfare problems (Coleman et al. 2003; Burton et al. 2012). In large industrially managed systems, however, the lack of this contact can hinder the development of these relationships. The industrialization of livestock production has created a working context whereby store animals are not generally regarded as individuals (Wilkie, 2005; Burton et al. 2012; Werkheiser, 2018). Accordingly, it has been suggested that workers can develop more personal and enduring relationships with breeding animals as opposed to store livestock. Besides, people who are removed from the daily chores of looking after livestock (farm estate managers, dealers, auctioneers and slaughter workers) tend to distance themselves emotionally and perceive livestock as a pure commodity. This attitude deviates from the ‘ideal type' expected within the commercial production of livestock and may lead to workers inside the industry being labeled as ‘bad farmers' or ‘bad stockmen' (Wilkie, 2005). In this context, Hodges (1999), Grandin (2003) and Gjerris et al. (2011) propose that the fundamental moral wrong here is to see and treat the animals as lacking independent value, as resources. In this case, the ‘good stockman’ should be one disposed to respond to farmed animals in an empathic and responsible way and to resist the reductionism of sentient beings into mere commodities or mere relative goods. However, some researchers mention that the idea of ‘deanimalisation’ (i.e. perceive animals as a ‘unit’ or object) is to some extent implicit in certain situations. Humans have a strong tendency to define animal lives in terms of human-purpose. In this sense, there has been a tendency to assume that the reduction of animals to object or thing status is the condition of exploiting them – ‘animal consent’, the so-called ‘good-life’ justification of modern animal farming (Wilkie, 2005; Knight, 2018; Martínez et al. 2019). Nevertheless, it is important to realize that the majority of the cases of poor attitudes and behaviors of stockpeople in the livestock industries are not intentional cruelty: most of these attitudes are widely held, most of the negative behaviors intuitively appear harmless and are routinely used in the livestock industries (Hemsworth, 2007; Graça et al. 2016; Ceballos et al. 2018; Pulido et al. 2019). Along with this is the ‘bad becoming normal’ concept/idea: Grandin (2003) has noticed that even when employees have been trained to handle cattle in a careful-quiet manner, they tend to revert to rough practices –such as excessive electric prod use- without even noticing. In this sense Broom (2006) and Beach & Stammler (2006) mention that when there is no awareness one can hardly expect someone to take responsibility for their actions.

Empathy can also be influenced by environmental and social factors. How people regard and relate to livestock cannot be isolated from the cultural and socio-economic contexts in which they encounter them (Serpell, 2004; Wilkie, 2005; Phillips et al. 2009; Vanutelli & Balconi, 2015; Spence et al. 2017; Ceballos et al. 2018). An example of this is the reference about Japanese and Western cultures made by Fukasawa et al. (2017) where different emotional bases for positive attitudes toward animals are raised as a possibility (it has been proposed that in Japan positive beliefs with regard to animals originates with endearing which elicits kindness to animals, while in Western culture it appears to originate with compassion). On the other hand, the different ways in which animals are represented (or misrepresented) in art, language, literature, science, the media, and so on, are at least to some extent, cultural constructs. Even the language used to describe animals tends to reinforce culturally constructed roles. Classifying cows, pigs and poultry as ‘food animals’ or ‘production animals’, for instance, inevitably constrains people to think about them from an instrumental perspective (Serpell, 2004). However, it is also true that to understand a stockpeople's choices regarding his/her way of behaving, it is important to understand the role of all the different motives and convictions, not just the economic and social influences but the motives connected with his/her frame of reference as well (Schoon & Grotenhuis, 2000; Graça et al. 2016). Choices that people make between different possible types of behavior are rarely based on a single category of reasons. The freedom of choice is almost always limited by 'external' factors. Besides, most people are influenced by other factors too, such as social relations (family, neighbors, coworkers, certain role models) and signals from society (e.g., about accepted or not accepted ways of behaving). And finally, a person has his conscience, his unique personal value system, and worldview, based on his own experiences, moral values, and character. A stockpeople has, therefore, his conception of 'good behavior' that he wants to live up to. He has his own individual set of convictions and opinions that functions as an internal frame of reference, and that determines both his perception of external factors and his preferences. In other words, that provides him with his rationality (Schoon & Grotenhuis, 2000; Kauppinen et al. 2013; Graça et al. 2016).

4. Workplace well-being

The importance of the human-animal relationship in the context of stockpersons' work safety has been increasingly recognized over the last decades. A large number of publications refer to the interaction between workers and larger farm animals (dairy/beef cattle) (Hemsworth, 2003; Maller et al. 2005; Waiblinger et al. 2006; Burton et al. 2012; Martínez et al. 2019; Pulido et al. 2019). In this sense, Rushen et al. (2008) mention that even though dairy cows can be considered mostly as 'meek' we should not forget the changes that have taken place about the objectives of artificial selection –efficiency of production vs handling ease–. Thus, it is common to find fearful dairy animals that kick and step during the milking process and do not give all their milk. Besides, beef cattle often threaten or charge at stockpeople during handling and veterinary treatment. These types of situations help describe how both human and animal safety may be affected, simultaneously reducing worker comfort and time efficiency (Lensink et al. 2001; Boivin et al. 2003; Rushen et al. 2008; Ebinghaus et al. 2018). A heavy workload and the risk of accidents have been identified as stress-inducing job characteristics of stockpeople on cattle farms –farming is thought to be among the jobs with the highest levels of job stress. Stress influences stockpeople's decision-making, effectively lowering their willingness to adopt better handling practices (Ceballos et al. 2018). Thus, in a study Hansen and Osteras (2019) found that the higher the occupation well-being and the lower the farmer and stockpeople stress, the better the animal welfare in dairy cows. Furthermore, workplaces characterized by high injury risk, violence, high strain, and chronic stress have been linked to adverse health outcomes for the employees such as burnout, high injury rates, and depression (McCaughey et al. 2013; Roberts et al. 2017; Dalla Costa et al. 2019). In this context, workers who have experienced an illness or injury at work are more likely to change their perceptions of the organizational context and have poor perceptions of workplace safety climate. This may result in a cyclical effect between experience, perceptions, and outcomes (McCaughey et al. 2013).

In addition to attitudes and general opinions on animals, situational factors can have a marked influence on the quality of stockpeople. Difficulties in moving cattle can be a major cause of frustration for stockpeople and this can be responsible for much of the rough handling that occurs (Grandin, 1997; Rushen et al. 2008). In this context, the physical design of the work environment plays an important role (Rushen & de Passillé, 2015). Well-designed equipment facilitates tasks with animals, but it is useless unless it is operated correctly. In this sense, Grandin (2006) mentions that frequently people will buy the new facility but may not provide enough maintenance and management supervision to use it properly. Another condition is the poor adoption of behaviorally-based designs. Here designers play a crucial role because, in general terms, they tend to look for more practical solutions (Grandin, 2003). Good handling facilities are also particularly important for handling extensively-managed animals such as beef cattle, which are more likely to be fearful of people. Thus, finding better ways to move animals is likely to lead to significant reductions in the use of aversive handling (Rushen et al. 2008; Rushen & de Passillé, 2015). On the other hand, it has been recognized that poor facilities may even be one of the reasons for failing audits. In this sense, audits haven been suggested as a way to determine whether the performance of stockpeople and the unit as a whole is improving or becoming worse. Hence, to prevent bad from becoming normal it has been proposed that management must conduct regular internal audits using numerical scores (Grandin, 2003, 2006; Rushen & de Passillé, 2015). Nevertheless, managers with a poor attitude could also be the cause of multiple failed audits; managers that want a quick, easy fix and that do not want to find out that a commonly used agricultural practice is either stressful or painful to an animal, are not helpful (Grandin, 2003, 2006). Adding to the idea that stockpeople refers not only to a good relationship with the animals but also to other professional and personal components, Grommers (1987), Lensink et al. (2001) and Ward & Melfi (2015) highlight the influence of knowledge and experience in workplaces. These two characteristics can even help define stockpeople styles. In this sense, it must be taken into account that a large number of populations are becoming increasingly urban, so the knowledge that could have been gained during childhood working in agricultural environments may not be so present in all workers today (Daigle & Ridge, 2018). However, it is also true that knowledge can be acquired through training (Boivin et al. 2003; Coleman et al. 2003; Grandin, 2003; Hemsworth, 2003; Rushen & de Passillé, 2015) or even through other people. In this context, Werkheiser (2018) noticed that some of the sensitivity to animal communication could be a form of tacit knowledge that is sustained and passed down through working with more experienced stockpersons without being explicitly articulated or consciously believed.

It has been recognized that the diligence with which a job is done depends very much on the level of job satisfaction; low job satisfaction often results in careless work (Maller et al. 2005; Waiblinger et al. 2006; Rushen et al. 2008; Burton et al. 2012; Martínez et al. 2019). In this sense, it seems that despite the issues associated with maintaining long-term employees and their subsequent low financial compensation animal industry employees enjoy their work. Some examples of this are the results shown in investigations made with swine and dairy stockpeople in UK and Australian, and with beef cattle feedyard workers in Texas (Seabrook & Wilkinson, 2000; Hemsworth & Coleman, 2011; Daigle & Ridge, 2018). Studies demonstrate that people valued and enjoyed their interactions with their animals and that this enjoyment was increased with the implementation of new technologies. Some of the interviewees even mention that the nature of their interactions with animals was largely responsible for the difference between a 'good day' and a 'bad day' (Seabrook & Wilkinson, 2000; Daigle & Ridge, 2018). In contrast, time pressures and the complexity of the work, frustration with the animals being 'stubborn' or with equipment not working, family and home problems stand out as reasons of why stockpeople may act aversively towards the animals (Rushen et al. 2008; Rushen & de Passillé, 2015). Challenges that stockpeople face outside of the workplace may influence their performance in the workplace which can impact the animals in their care –some employees may be more interested in preserving their quality of life due to personal pressures like living in a low-income family (Daigle & Ridge, 2018). Workers' relationships with their managers are also an important issue. It has been suggested that the difficulties that owners/managers could have with workers may be in part because they cannot see the impediments others have performing the same behaviors –to them, they are obvious and ‘common sense’. In contrast, for workers, the owners' expectations may be seen as utterly unreasonable or even impossible to meet (Burton et al. 2012). Recognize this may be useful in showing what types of improvements are needed to improve job satisfaction and hence job quality (Rushen et al. 2008; Rushen & de Passillé, 2015). In this sense, Roberts et al. (2017) and Dalla Costa et al. (2019) argue that aside from providing health insurance and fair wages, managers/owners could seek to use ‘reflective supervision' to identify areas where employees may need more support (mental health support included). Additionally, strategies for coping with stress and self-care strategies such as healthy nutrition, physical activity, and social connectedness could be implemented. The implementation of strategies that focus on enhancing employee retention and stockperson welfare may indirectly enhance animal welfare and productivity (Kauppinen et al. 2012; Kauppinen et al. 2013; Daigle & Ridge, 2018; Pulido et al. 2019). In this context, a good stockperson working in a poor everyday environment may decline in terms of their response to animals and, likewise, a poor stockperson working in a good environment may, though imbibing the culture, improve their interaction (Burton et al. 2012). Animal agricultural operations can look to studies in occupational psychology that have thoroughly evaluated the needed factors to achieve job satisfaction and employee well-being. Positive emotional workplace culture, employee participation, and individual sense of belonging are all interdependent factors that promote employee well-being. Investing in employee morale on the farm not only increases the individual stockperson well-being and job satisfaction but can strengthen the whole workforce (Daigle & Ridge, 2018).

5. Occupational health issues

For the last century, farming practices have shifted with the growth of technology from a family-oriented model to an industrialized setup that maximizes profits and output. Today most of the world´s pork, poultry, beef, and dairy products are produced on large farms with a single animal species living in buildings or open-air pens (Hribar, 2010). This massification of animal production implies changes in labor relations, occupational health, animal breeding, mechanical innovations, specially formulated feeds, animal pharmaceuticals, and with them new risks for the health and welfare of workers and animals. In this context, occupational health problems in stockpeople are produced by three major categories of causality: 1) Accidents and injuries caused by direct interaction with animals; 2) Effects of long-term exposure to microorganisms, dust, noise, vibration, and other physical risks; 3) Psychological and social issues as smoking, drug and alcohol abuse, violence, bullying and sexual harassment (David, 2014; Nguyen et al. 2018).

Accidents during work are one of the main causes of morbidity and mortality in the livestock industry. Occupational injuries are caused by two types of risk exposures: acute and chronic. The injuries caused by sudden energy transfer to the body of the victim (short duration exposure) are termed as traumatic injuries, while the injuries caused by chronic exposure to repetitive motions or forceful exertions are termed as repetitive strain injuries (Khanzode et al. 2012). According to Svendsen et al. (2014), most of the stockpeople are aware of the injury risk related to animal handling, but they often think that they know their animals and that this kind of accident will not happen on their workplace. Serious injuries of the body are usually caused by attacks of large animals such as horses and cattle; kicks, stomps, and horn-wound are the most common risks to which the handlers are exposed (Caglayan et al. 2013). Most accidents occur inside outbuildings, gates, and fences. Incorporating safety aspects to a greater extent in the design and construction of such buildings could make a substantial contribution to injury prevention in the livestock industry (Svendsen et al. 2014). Additionally, several studies have shown the concentration of certain accidents to specific productive periods, such as in cattle (during calving season and lactation period), and sheep (around times of shearing, crutching and mating) (Tosswill et al. 2018). The most common fatal injury is a chest knock that usually causes a hemopneumothorax and lung damage (Karbeyaz et al. 2013), while the most common and least severe injuries occur on the extremities. Watts and Meisel (2011) found that hand and wrist injuries tend to occur due to being kicked by a cow, commonly at milking time. It appears that many of these occur when the milking cups are applied to the cows' teats – at this time the hand is exposed to a kick from the hind legs of the cow. Recently, it has been shown that cows are more reactive to hoof trimming than moving cows to milking or milking and that this reactivity increases the risk of the operator to be injured (Lindahl et al. 2016).

Particulate matter from livestock facilities has been regarded as an indoor pollutant causing detrimental effects on animal performance and efficiency and the health and welfare of stockpeople (Cambra-López et al. 2010). Particulate matter (microscopic solid or liquid matter suspended in the production environment) is a complex mixture of agents that are generated primarily from the animals (feathers or hair and dander), microorganisms, dried feces, and feed. Gases are generated inside the farm facilities from the decomposition of animal urine and feces (ammonia, hydrogen sulfide), whereas the animals' respiration may emit carbon dioxide and heat as well (Donham, 2013). Furthermore, fossil fuel-burning heaters present in some farrowing, nursery, and poultry or chick facilities may emit carbon monoxide and carbon dioxide. Inhaled particles can penetrate the deeper respiratory airways, compromising animal's and human's respiratory health, contributing to increased occurrence of chronic cough and/or phlegm, chronic bronchitis, allergic reactions, and asthma-like symptoms amongst stockpeople (Cambra-López et al. 2010). In this regard Dobashi et al. (2017) mention that some work-related allergies can be asthma and/or rhinitis (exposition to dust, wheat smut fungus spore, corn pollen, animals' hair and dander, dried feces, feed dust, chicken feathers, *Aspergillus niger* and *Micropolyspora faeni*) and skin allergies (grass pollen, straw, farm products and agrichemicals). Contact with livestock animals also can lead to transmission of microorganisms by inhalation, ingestion, via conjunctiva, or during incidents such as biting or other injuries inflicted by animals (Klous et al. 2016). Stockpeople have different type and intensity of human–livestock contacts which may result in transmission of microorganisms and associated zoonoses, such as *Coxiella burnetti*, *Mycobacterium tuberculosis*, *Toxoplasma gondii*, *Giardia duodenalis*, *Leptospira* and *Brucella* species (Singh et al. 2019) and exceptionally *Pasteurella multocida* (Pradeepan et al. 2016). Therefore, the hours a worker spends with animals also increases the risk of exposure to these microorganisms. In this sense, according to a study conducted by Whelan et al. (2011) in stockpeople working on Q-fever infected goat farms, an exposure-response-like relationship between the 'total number of hours worked inside the farm perimeter' and 'working mostly inside stables' and the risk of seroconversion for *Coxiella burnetii* markers was discovered. Additionally, stockpeople have a high risk of cancer mortality (especially in lip, lung, prostate, lymphatic system and skin), which is attributed to contact with chemicals and prolonged exposure to the sun. However, stockpeople are less likely to suffer from cardiovascular diseases, diabetes, and other chronic diseases. These can be attributed to better lifestyles such as a healthy diet and lower consumption of alcohol and tobacco, and selection bias (the healthy worker effect) because of the greater physical demands of agricultural work (Zhao et al. 2019).

Managing the mental health of workers in the livestock industry in rural communities is a serious labor and a public health challenge that has traditionally been ignored. Although rural areas experience similar rates of mental health morbidity relative to their non-rural counterparts, the suicide rate of farmers and stockpeople is substantially higher than the national average for employed adults (Morgan et al. 2016). Recently, a high prevalence of suicide among stockpeople has been noted in studies conducted in Australia, Canada, India, Japan and the UK (Hounsome et al. 2012). This elevated risk has been attributed to the unique combination of complex occupational and location-related stressors that confront farmers, including: low income, chronic physical illness, social isolation, work-home imbalance, depression due to chronic chemical exposure, barriers and unwillingness to seek mental health treatment, time pressure and dependency on weather and other environmental factors (Tiesman et al. 2015). In addition to these widely recognized stressors, new concerns related to new and changing animal welfare regulations in traditional livestock areas can further increase the burden of stress for farmers and stockpeople. Between stockpeople, men in general and older men are considered to be at higher suicide risk than younger women and men (Bryant & Garnham, 2013). Handling livestock is physically demanding and requires good health to carry it out; when a handler grows older, he has fewer possibilities to work, limiting his income and deteriorating his image as a health worker (Miranda-de la Lama 2018). This can be attributed to emotional conditions associated with their masculinity which requires stoicism and resilience thereby means that farming men are less likely to seek medical and psychological assistance (Bryant & Garnham, 2013).

6. Sustainability

Systems for the animal production or other products for human use, should be sustainable. This means that the system should be acceptable now and its expected future effects should be acceptable, in particular in relation to resource availability, consequences of functioning and morality of action (Broom, 2019). In this context, stockpeople are the stewards of our food animals and play a critical role in agricultural and social sustainability. Yet, they are usually regarded as itinerant and unskilled which can result in managers making minimal investments into their development as employees, on one hand, and in an impoverished public image, on the other (Daigle & Ridge, 2018; Staniskiene & Stankeviciute, 2018). In this, we can not exclude the presence of some mass media (TV, newspapers) who have been in a certain way co-participants by using a biased (sometimes almost hostile) presentation of agricultural production. Schoon & Grotenhuis (2000) conducted an investigation in the Netherlands where they found that stockpeople sometimes felt pretty much separated from the rest of society and that they experienced the lack of societal appreciation for their work as painful. In this context, it must be taken into account that –without justifying negative behaviors and attitudes of some stockpeople- it is also true that certain handling practices and ways of working haven been encouraged and promoted for a long time through agricultural policies (and therefore through some managers). At the same time, it is also important to note that even though in recent decades it has become popular to speak of 'sustainable development' in occasions this is nothing less than a disguised term, a type of human brand of ecology where 'rationalization' still occupies a preponderant role. In this regard, Beach & Stammler (2006) emphasize that nothing blows apart personal relations of reciprocity so effectively -be they between humans or between humans and animals- as rationalization. An important subject in all this 'sustainable development' speech is the perspective that employees have regarding their workplaces, which has been largely ignored even though employees are relevant stakeholders for business success. Matters like *a)* employees' input into decisions related to the organization and workplace (participation); *b)* teamwork and sharing the experience with colleagues (cooperation); *c)* fair employment practices (equal opportunities); *d)* employee training programs, mentoring, life-long learning practice (development); and *e)* health and safety conditions in the workplace, have been highlighted as critical for social sustainability from the employee perspective (Staniskiene & Stankeviciute, 2018). In this context, dealing with employees in a socially sustainable way is one of the pathways for an organization to cope with labor market challenges such as labor force shortages or aging society –it creates value for the organization and the society (Staniskiene & Stankeviciute, 2018).

Although equity is an important subject in terms of sustainability its significance is not reduced to ethical issues: research shows that inequality also is a factor in many of the problems of the world. A positive association between lower socioeconomic status and higher mortality; conflicts within and between classes and societies; raise prevalence of poor health, mental illness, crime, violence, and other societal ills; and international immigration has been well documented in contemporary populations (Gjerris et al. 2011; Rogers et al. 2012; Roberts et al. 2017). The livestock industry is a sector characterized by being deficit in skilled and unskilled labor. In many countries with consolidated or emerging agrarian economies, the lack of workers is a problem that immigration (legal or illegal) has contributed to mitigate (Durst et al. 2018). Immigrants can come from economically depressed populations within the same country, or neighboring countries and even from distant countries, and usually accept physically demanding jobs for lower wages compared to local workers. Lack of opportunities in their regions or countries of origin makes them vulnerable to accept jobs in poor security conditions and with work overload. Lack of language proficiency; labor exploitation; problems of socio-cultural adaptation; racial, ethnic and gender inequalities are the factors that can affect their work performance (Horst & Marion, 2019). However, the main risk to animal health and welfare is a higher number of immigrant stockpeople with a low degree of training in animal handling, and management issues may be associated with a higher number of at-risk activities (Theodoropoulos et al. 2010). An example of this is the tendency of immigrant stockpeople to have a high frequency of risk behaviors and low knowledge about the prevention of zoonotic diseases and occupational accidents (Singh et al. 2019). Additionally, the introduction of zoonotic diseases by immigrant workers to livestock has been demonstrated by Foddai et al. (2015). Conversely, many immigrants come from countries with agrarian subsistence economies, where livestock is part of livelihoods, where animals are an integral part of their ways of life. Therefore, their possible cultural closeness and empathy towards farm animals and a suitable training program could be an important factor to improve the welfare of the animals.

In recent years, the disconnection between stockperson pay, the level of knowledge and skill required to perform the job, and the impact these employees can have on the overall productivity and welfare of the animal, has become a recurring theme among some stakeholders groups (Daigle & Ridge, 2018). In this sense, those companies that reward speed through handling animals on a ‘piece work’ basis play an important role (Grandin, 2003). An example of this is the practice such as being paid by the head instead of by the hour and bonus compensations based upon the number of pigs weaned per sow per year. In this kind of work-environment, stockpeople can hardly think about animal welfare, even when these practices may increase health issues in the finishing sectors (Daigle & Ridge, 2018). Thus, the method of payment can affect the quality of handling. Conversely, a good motivator for ‘good stockpeople’ could be a financial incentive resulting from improvements in animal productivity or a reduction in bruises or broken bones (Grandin 2003, 2006). Another situation is the difference in salaries between the different participants in the supply chain network. It has been recognized that sometimes truck drivers that deliver the animals to the slaughterhouse are paid almost twice as much as the stockperson. This even though the duration of time stockpeople spend interacting with animals is substantially longer (and on occasions requires more knowledge and skills) than the interactions that truck drivers can have with animals (Boyce, 2016; Valadez-Noriega et al. 2018). Nevertheless, it is also true that the unwilling of society to financially support their ethical choices (their desire for animal products that are ‘animal welfare-friendly') presents as an additional challenge to investing in the stockpeople that are responsible for implementing these socially-valued-human-and-sustainable-husbandry-practices because while the need exists, the resources to support this need are minimal (Gjerris et al. 2011). Hence, perhaps a paradigm shift could be good: do we want to continue pointing fingers or do we want to start being more empathic among ourselves too? by assuming our responsibilities and obligations as different actors of society. In any case, it would be worthwhile to keep in mind that values determine the direction a society takes, and that values allocate resources in a society and thereby shape its nature (Hodges, 1999; Serpell, 2004; Broom, 2006; Hemsworth, 2007; Gjerris et al. 2011; Werkheiser, 2018).

7. Future considerations

The discourse of increasing efficiency in animal husbandry production has produced a whole range of analyses focusing on measuring the efficiency with which the different types of animal’s systems work. Measuring grades of efficiency produce a ranking order of societies and employees that lets some look more ‘advanced' than others, ignoring most other cultural variables and ways of adaptation of humans and animals to a particular natural and social environment (Beach & Stammler, 2006). The problem lies in the core of the approach. The discussion about stockpeople’s role raises issues that cannot be answered solely from a scientific or technological point of view (Gjerris et al. 2011). The tendency to focus on quantitative research and cognitive (attitudinal) solutions has done that much of the current understanding of how to improve welfare through behavioral change suffers from problems common to quantitative research. In this context, *a)* a neglect of the social and cultural construction of the variables studied, *b)* a focus on attitudes without considering how attitudes develop, and *c)* a tendency to provide ‘idealized’ accounts of attitudes and behavior which, because they are rationalizations have an uncertain relation to actual situations, presents as some challenges for this type of approaches (Burton et al. 2012). In this sense, it is clear that knowing how the animals are handled and how they become fearful towards people is important, however, we must not forget that stockpeople involves much more and that the relationships that can develop between people and animals can be quite subtle (Rushen et al. 2008; Rushen & de Passillé, 2015; Martínez et al. 2019). Thus, recommendations on handling behavior alone are unlike to be effective (Grandin, 2003; Hemsworth, 2003, 2008). Since there is no one simple model for human behavior, future research can benefit from integrating diverse social sciences and humanities’ theories and methods, which have much to contribute to our understanding of why people value animals (Saunders et al. 2006; Echeverri et al. 2018). On the other hand, considering the full range of how people physically and emotionally interact with breeding, store and prime livestock may be helpful too, because this more accurately reflects the ambiguity of the various productive contexts within which stockpeople negotiate their everyday practice (Wilkie, 2005). Finally, Schoon & Grotenhuis (2000) mention that studies should also involve other actors in the field of agriculture to analyze the convictions of each group of actors, their perception by others, and the way they influence each other, thereby studies could be more comprehensive.

Given that welfare can mean different things to different people, the types of stockpeople and animal welfare concerns may vary between stakeholder groups within and external to the animal industry as well. Sometimes the communication between the different stakeholder groups can be very difficult because of diverging basic convictions. This type of disagreement is likely to be frustrating for all sides and unhelpful in the development and implementation of welfare improvements and even agricultural policies (Schoon & Grotenhuis, 2000; Heleski et al. 2006; Jääskeläinen et al. 2014; Ventura et al. 2015). That is why policymakers should pay more attention to the personal motivations and values of different stakeholders' groups (stockpeople included) in different stages of the development of and communication about agricultural policy (Schoon & Grotenhuis, 2000; Hemsworth, 2007; Kauppinen et al. 2012; Kauppinen et al. 2013; Spence et al. 2017). On the other hand, it is also important to note that the kind of harm induced by our collective action is seemingly amorphous, i.e., unintentional, since there are layers of social, economic, and political barriers that obscure the discharge of duties. There is little agreement on what values should guide us in shaping strategies, and how we should prioritize between the different problems and challenges that surround the question of well-being (human and/or animal) (Saunders et al. 2006; Gjerris et al. 2011). In this sense, Broom (2006) proposes that it is better to base strategies for living on our obligations rather than to involve the concept of rights. By taking responsibility for or own acts the tendency under the more traditional 'human moralism' that tends to pit citizens against each other as separate stakeholders could be circumscribed –prefabricated speeches lead nowhere (Gjerris et al. 2011).

The question of stockpeople and animal welfare has strongly motivated biologists and psychologists, however, the issues are also sociological and philosophical (Boivin et al. 2003). It has been proposed that if an animal is used to provide valuable products and services this should arouse a sense of obligation on their human users –a kind of counterweight to the ‘work’ that animals do for humans. This is true for animals placed into relationships of dependence on and vulnerability to us, and it is especially true for those animals (such as many species of livestock) that have been created through breeding to require our care (Beach & Stammler, 2006; Broom, 2006; Gjerris et al. 2011; Knight, 2018; Werkheiser, 2018). However, modern husbandry systems and modern biotechnology have strongly distorted this ‘social contract’. The trend in modern husbandry is to increase working time productivity by reducing the number of stockpeople and increasing the number of animals per farm. Thus, one of the major questions for the future is: ‘What is the number of animals that a stockperson can care for concerning animal welfare and productivity’? (Boivin et al. 2003). Besides, since having a personal-attentive relationship with the animals is not merely laudatory but constitutive of being a ‘good stockpeople’, these trends could even erode (more) their identity as well (Werkheiser, 2018). In this sense, caring for and working with the animals that nourish us should be an honorable, respected, and desirable occupation. Employment as a stockperson is a privilege and opportunity to make meaningful contributions to agricultural animal welfare, and those engaged should be motivated to lead by example –it is worth keeping in mind that the welfare of stockpeople matters too (Hemsworth, 2007).

8. Conclusions

The welfare of farm animals is highly dependent on the relationship between animals and their handlers. Attitudes, gender, ethnicity, occupational roles, educational backgrounds, health condition, culture and generational differences of stockpeople condition the quality with which they handle animals on farms. Understand these realities can be valuable for technicians, advisors, scientists, consultants, and owners when developing training and corporative policies for animal welfare and health. In this context, it is imperative that the livestock industry develops a new occupational culture that promotes empathy towards animals, but also a fair wage, with decent working conditions, and preventive and occupational health programs. Also, to generate a new era of social recognition towards stockpeople and their livelihoods that allow maintaining rural life and the sustainable production of food. At the same time, it would be worthwhile that the veterinary educational programs (Animal Science) continue with the teaching of animal husbandry because the need to disseminate this knowledge has increased. In this regard, the fact that students maintain (or relearn) the sensitivity towards people who work with animals is an aspect that should not be left aside. Rural life and farm animals are an intangible heritage of any human society, and every participant of the supply chain network should keep that in mind. Possibly, in the past, the impact of stockpeople has been underestimated, but there is evidence that would suggest the importance of investing in occupational changes and training programs at present.

Conflict of interest

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

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Artículo No. 2

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

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

M. Bautista-Fernández [a], L.X. Estévez-Moreno [b], N. Losada-Espinosa [a], M. Villarroel [d], G. A. María [b], I. De Blas [e], G.C. Miranda-de la Lama [b,c,*]

[a] Faculty of Veterinary Medicine, National Autonomous University of Mexico, UNAM, Mexico
[b] Department of Animal Production and Food Science, Faculty of Veterinary Medicine, University of Zaragoza, Zaragoza, Spain
[c] Department of Food Science, Metropolitan Autonomous University, UAM, Lerma, State of Mexico, Mexico
[d] CEIGRAM, ETSIAAB, Technical University of Madrid (UPM), Madrid, Spain
[e] Department of Animal Pathology, Faculty of Veterinary Medicine, University of Zaragoza, Zaragoza, Spain

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ABSTRACT

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

1. I. Introduction

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

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

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* Corresponding author at: Genaro C. Miranda-de la Lama, Department of Animal Production and Food Science, Faculty of Veterinary Medicine, Universidad de Zaragoza, c/ Miguel Servet 177, 50013 Zaragoza, Spain.
E-mail address: genaro@unizar.es (G.C. Miranda-de la Lama).

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

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

2. Material and methods

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

2.1. Study description

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

2.2. Abattoir: operative conditions and facilities

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

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

2.3. Claw assessment

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

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

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

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

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

2.4. pH measurements

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

2.5. Statistical analysis

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

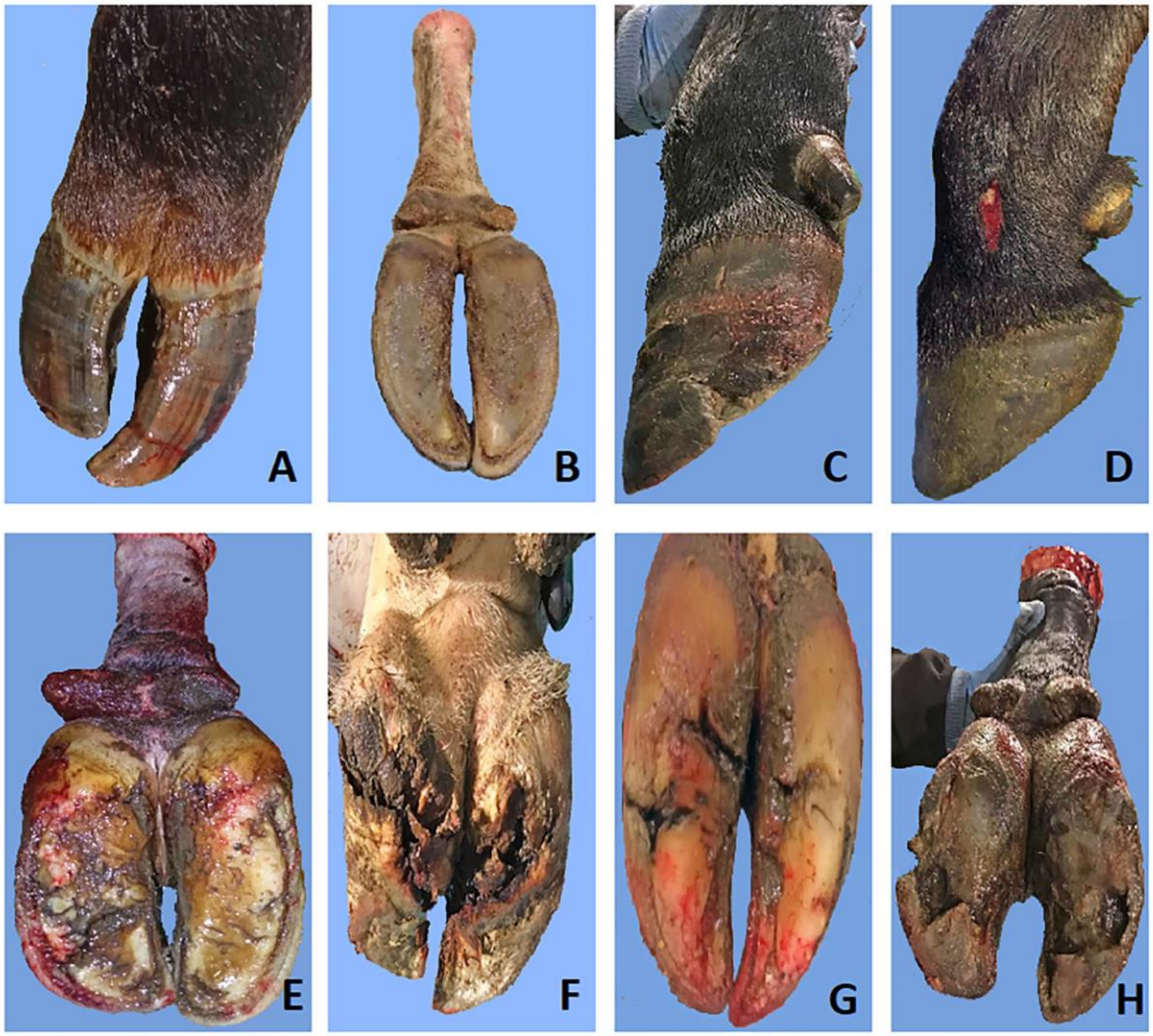

Fig. 1. Claw disorders evaluated in the study: Abnormal claw shapes -ACS- as asymmetric claws (A), and corkscrew claws (B); Fissures of the claw wall -FCW- (C); Skin wounds -SW- (D); Sole disorders -SD- (E); Heel erosion -HE- (F); White line disease -WLD- (G); Double sole -DS- (H).

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

3. Results

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

3.1. Prevalence of claw disorders

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

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

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

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

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

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

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

3.2. Associations between front and rear claw conditions or disorders

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

3.3. Associations between different types of claw conditions or disorders

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

3.4. Claw disorders and high muscle pH

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

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

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

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

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

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

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

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

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

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

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

4. Discussion

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

4.1. *Prevalence of claw disorders*

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

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

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

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

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

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

4.3. Associations between different types of claw conditions or disorders

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

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

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

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

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

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

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

5. Conclusions

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

CRediT authorship contribution statement

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

Declaration of Competing Interest

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

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Anexo 2

Artículo publicado en revista de divulgación

Artículo No.1

Indicadores de bienestar vacuno para su uso en plantas de sacrificio con sistemas de monitoreo voluntario: validez, fiabilidad y viabilidad

Publicado en **Eurocarne**

Indicadores de bienestar vacuno para su uso en plantas de sacrificio con sistemas de monitoreo voluntario: validez, fiabilidad y viabilidad

El objetivo del presente trabajo fue identificar indicadores de bienestar animal para su posible uso en plantas de sacrificio que desarrollen sistemas de monitoreo voluntario con una visión de validez, fiabilidad y viabilidad en condiciones comerciales. En este estudio se identificaron 72 indicadores de bienestar animal distribuidos en cuatro categorias: fisiológicos, morfométricos, conductuales y post mortem.

Natyieli Losada-Espinosa [a], Michelle Bautista Fernández [a], Morris Villarroel [b], Gustavo A. María [c] y Genaro C. Miranda de la Lama [d]

[a] Programa de Maestría y Doctorado en Ciencias de la Salud y de la Producción Animal,
Universidad Nacional Autónoma de México (México)
guera32@hotmail.com

[b] Departamento de Ciencia Animal, E.T.S.I.A.
Universidad Politécnica de Madrid·(España)

[c] Departamento de Producción Animal y Ciencia de los Alimentos
Instituto Agroalimentario de Aragón (IA2)
Universidad de Zaragoza·(España)

[d] Departamento de Ciencias de la Alimentación
Universidad Autónoma Metropolitana. UAM Unidad Lerma
Estado de México (México)
g.miranda@correo.ler.uam.mx

Introducción

El principal método para mejorar o asegurar el bienestar de los animales de granja ha sido, tradicionalmente, la legislación gubernamental (Bennett, 1997). No obstante, los sistemas de producción animal que promueven estándares más altos de bienestar pueden ser vistos como 'generadores' de mayores costos ambientales y financieros – los cuales finalmente se aplicarán al consumidor, a menos que

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se utilicen subsidios o exenciones de impuestos a los productores. En este sentido, diversas compañías han desarrollado sistemas de monitoreo voluntario que aseguran que los productores y consumidores no tengan un precio fuera del mercado (Clark *et al.*, 2017). Los sistemas de monitoreo voluntario pueden definirse como la medición, colección, análisis, interpretación y diseminación sistemática y oportuna de datos de salud y bienestar animal a partir de poblaciones definidas (Correia-Gomes *et al.*, 2017). Para dicho monitoreo, los indicadores que se basan en el animal se consideran como los más válidos, ya que los animales en sí son evaluados (Llonch *et al.*, 2015). Sin embargo, para poder interpretar las respuestas que presentan a variaciones en su ambiente, es necesario considerar un amplio rango de indicadores, incluyendo aquellos que se relacionan de manera indirecta con la calidad del producto.

La valoración de los bovinos a nivel granja ha sido el principal método utilizado para evaluar su bienestar, sin embargo, dichas evaluaciones son costosas (tanto por el uso de mano de obra como por el tiempo utilizado para realizarlas) y pueden inclusive incrementar la transmisión de enfermedades dentro y entre granjas (Dalmau *et al.*, 2009). La inspección *post mortem* de la carne tiene el potencial de detectar enfermedades y ciertas condiciones de bienestar que pueden no ser aparentes durante la inspección *ante mortem* de los animales al ingresar al matadero (Grandin, 2017). En el pasado, se desarrollaron las auditorías de bienestar como instrumentos de investigación -o por requerimientos comerciales- para documentar el bienestar animal a nivel matadero. Sin embargo, en la mayoría de los sistemas mundiales de vigilancia dichas auditorías no se realizan de manera rutinaria.

En este sentido, existe una tendencia internacional creciente para incorporar indicadores de bienestar durante la inspección de carne en los mataderos, que puedan servir como una herramienta de monitoreo para la salud de los bovinos. Por otro lado, se ha propuesto una idea relativamente nueva conocida como indicadores ‘iceberg’ o ‘clave’, los cuales pueden funcionar como un medio para evaluar y asegurar el bienestar general de los animales (Harley *et al.*, 2012; van Staaveren *et al.*, 2017). Desde que los animales salen de su lugar de origen hasta el momento en el que llegan al matadero -y en el matadero en sí- éstos pueden estar expuestos a una gran cantidad de estímulos desafiantes, lo que en ocasiones dificulta determinar qué procedimientos contribuyen de manera significativa a su nivel de estrés.

En este contexto, es fundamental contar con indicadores válidos (que midan lo que tienen que medir), factibles (que puedan realizarse de manera rutinaria) y fáciles de evaluar, que permitan que sea más auditable para los productores y más transparente para los consumidores.

FIGURA 1

Subcategorías utilizadas para la clasificación de los indicadores fisiológicos (%)

Indicadores fisiológicos

A nivel mundial, los parámetros sanguíneos han sido utilizados de manera considerable para evaluar la respuesta de estrés por parte del ganado a condiciones de manejo y transporte (Villarroel *et al.*, 2003; Tadich *et al.*, 2009). No obstante, debe recordarse que un principio básico de la ciencia (frecuentemente ignorado) es que cualquier medición debe ser validada de manera adecuada antes de utilizarse, situación que no siempre se ha hecho en muchas de las mediciones fisiológicas, de comportamiento e inmunológicas que se utilizan en la actualidad. En el presente trabajo se identificaron un total de 22 indicadores fisiológicos, los cuales fueron clasificados en 10 subcategorías (**figura 1**). La concentración plasmática de cortisol (medida endócrina), la glucosa (índice de miedo/excitación y también relacionada con la liberación de catecolaminas) y el lactato (índice de esfuerzo físico) fueron los indicadores más utilizados entre los autores correspondientes a esta categoría (83%). En algunos países, los gobiernos han comisionado pequeñas inspecciones periódicas utilizando indicadores tales como cortisol, lactato y glucosa. Sin embargo, no siempre es fácil interpretar los niveles de dichos indicadores; diversos factores tales como el muestreo, la restricción de movimiento, las hormonas e incluso ciertas infecciones pueden llegar afectar los niveles de cortisol por ejemplo. En este orden de ideas, es necesario tener en cuenta que cada individuo animal tiene diferentes métodos para afrontar adversidades, de tal manera que utilizar una sola medida de respuesta fisiológica puede dar la impresión de que la mayoría de los animales no están estresados. Los indicadores fisiológicos no se utilizan de manera consistente en los mataderos debido a que son costosos, invasivos, y requieren un manejo adicional de las muestras (Llonch *et al.*, 2015). Por otro lado, este tipo de medición puede no siempre ser un indicador preciso de bienestar animal; el metabolismo para la síntesis de ciertas hormonas (por ejemplo catecolaminas) y el estado fisiológico de los animales *per se* debe ser considerado también (O'Neill *et al.*, 2012; Chulayo *et al.*, 2015).

Los cambios fisiológicos en los animales también pueden medirse a través de la frecuencia cardiaca, la frecuencia respiratoria y la temperatura corporal, ya que dichas variables pueden proveer información acerca de cuánto está 'trabajando' el animal para poder afrontar una situación (Broom, 1991). Además, han sido utilizadas de manera frecuente para analizar los efectos del transporte y el tiempo de espera presacrificio. A nivel matadero, sin embargo, medir la frecuencia cardiaca o respiratoria no es factible, aunque la última puede ser calculada de manera indirecta tomando como base la temperatura corporal (utilizando una cámara termográfica por ejemplo). Estudios recientes han utilizado la Termografía Infrarroja para la vigilancia de la salud y el bienestar en el ganado. Esta evaluación consiste en utilizar una cámara para obtener una imagen de los animales en un corral, y después identificar la temperatura superficial de alguna parte del animal – la superficie del ojo es una selección común para la vigilancia de fiebre (Okada *et al.*, 2013; Yazdanbakhsh *et al.*, 2017). En este contexto, un estudio realizado en EE.UU. encontró que los toros 'temperamentales' pueden presentar una temperatura y frecuencia respiratoria más elevadas en respuesta a estresores, comparados con los toros 'calmados' e 'intermedios' (Burdick *et al.*, 2010).

Indicadores morfométricos

El peso vivo y la condición corporal (CC) son indicadores comunes para la evaluación del grado de desnutrición en el ganado de carne, aunque su uso a nivel matadero es limitado debido a que pueden variar en términos de la edad, sexo y raza del animal, entre otros. El 73% de las publicaciones (concernientes a esta categoría), evaluadas en esta investigación, utilizaron el peso vivo como el principal indicador morfométrico (**figura 2**). En el matadero, generalmente se calcula la pérdida de peso en grupos o lotes, no de manera individual. En este sentido, a pesar de que la CC no indica el estado actual de hambre que tiene el animal, ésta puede utilizarse como una medida de su estatus nutricional. De manera general, la CC estima la movilización de las reservas de energía del ganado o el grado de 'gordura' o 'delgadez' utilizando una escala de 5 puntos (0 = muy flaco, 5 = muy gordo). Otros *scores* utilizan una escala del 1-9 (EE.UU.) o la escala de 0-2 propuesta por el proyecto Welfare Quality (Corah, 1989; Welfare Quality, 2009).

La técnica para medir la CC puede aprenderse de manera fácil, no requiere equipo y, aunque puede ser un tanto subjetiva, provee resultados confiables cuando se relaciona con la cobertura de grasa subcutánea (Morris *et al.*, 2012). En este contexto, la CC puede considerarse como un indicador altamente factible; sin embargo, algunos *scores* pueden tener muchas categorías, lo que los vuelve susceptibles a presentar variabilidad inter-observador. Investigadores de Reino Unido mencionan que los resultados dependen de la persona que esté haciendo la evaluación, la familiaridad con las vacas, así como de la consistencia entre periodos de evaluación, y sugieren el uso de equipo automático (cámaras termográficas o ultrasonido) para que la valoración de la CC sea más objetiva (Halachmi *et al.*, 2013). Sin embargo, tanto el costo del equipo como el pago a los consultores pueden hacer restrictivo el uso de este tipo de tecnologías. En los países en desarrollo y en regiones remotas, los métodos de evaluación subjetivos de bajo costo tales como la CC en ocasiones son la única alternativa (McGregor, 2017).

FIGURA 2

Subcategorías utilizadas para la clasificación de los indicadores morfométricos (%)

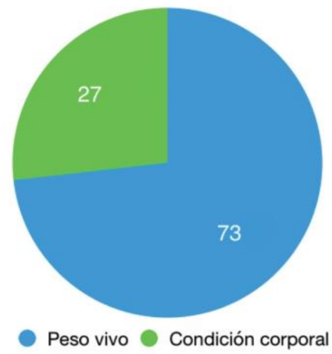
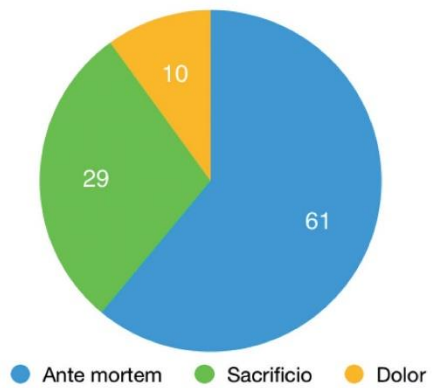


FIGURA 3

Subcategorías utilizadas para la clasificación de los indicadores de comportamiento (%)



Indicadores de comportamiento

El diseño de los mataderos está basado en criterios arquitectónicos convencionales, tales como la optimización del espacio o la facilitación de actividades humanas, muchas veces sin tomar en cuenta las necesidades de comportamiento de los animales (Miranda de la Lama *et al.*, 2012). Una evaluación completa de bienestar requiere observaciones desde la descarga hasta la inconsciencia de los mismos, incluyendo la bahía de descarga, el tiempo de espera, el arreo de los animales al chute y el desangrado. Mejorar una etapa/procedimiento dentro del matadero puede tener efectos positivos en etapas subsecuentes (Bourguet *et al.*, 2011). En el presente trabajo se identificaron un total de 32 indicadores de comportamiento, los cuales fueron clasificados en 3 subcategorías (**figura 3**). Las interacciones hombre-animal y las vocalizaciones fueron los indicadores *ante mortem* más comunes (48% y 44% de los autores correspondientes a esta categoría, respectivamente), en tanto que la actividad respiratoria y el reflejo corneal positivo destacaron en la subcategoría sacrificio (78% de los autores correspondientes a esta categoría). Para el ganado, la carga y descarga generalmente son más estresantes que el viaje en sí; sin embargo, no existen regulaciones que definan cuáles son las condiciones apropiadas para estos procedimientos. Diversos autores sugieren la medición de caídas, agresiones/peleas, resbalones, saltos, plantarse, regresar, montar y vocalizaciones (Van de Water *et al.*, 2003; Minka *et al.*, 2007; Bourguet *et al.*, 2011; Hultgren *et al.*, 2014), debido a que son indicadores (eventos) asociados con respuestas de comportamiento relacionadas con el miedo y pueden reflejar la eficiencia con la que los animales son manejados durante su llegada al matadero. Las condiciones durante la carga y descarga influyen en la calidad del tiempo de espera; sin embargo, un tiempo de espera en condiciones pobres puede afectar también el comportamiento de los animales.

El arreo del ganado puede ser una actividad fácil o difícil, dependiendo de las diferencias en la reactividad emocional de cada animal, es decir, la tendencia a mostrar reacciones marcadas a diferentes situaciones inductoras de miedo (Bourguet *et al.*, 2010). A nivel matadero, los test utilizados para evaluar el miedo en los animales durante la relación hombre-animal (RHA), deben durar poco tiempo y hacerse a nivel grupal para eliminar el estrés que provoca el aislamiento social, lo cual puede afectar los resultados. Esta metodología ha sido útil para identificar problemas relacionados con el diseño de las plantas de sacrificio, deficiencias en la selección y entrenamiento del personal responsable, actitudes del personal y el estado emocional de los animales evaluados (Hultgren *et al.*, 2014; Romero *et al.*, 2017). El arreo hacia el chute puede ser un momento muy estresante para los animales, dependiendo tanto del largo y diseño del chute como de la calidad de la RHA.

Algunos indicadores que pueden utilizarse para comparar animales de diferentes productores son las vocalizaciones (relacionadas con el uso de bastones eléctricos), plantarse, rehusar a moverse, retroceder y darse la vuelta (Grandin, 2017). Por otro lado, el comportamiento del manejador puede evaluarse a través de observaciones objetivas (empujar, pegar y uso de bastón eléctrico), interacciones acústicas (hablar, gritar, silbar y el uso de ruidos artificiales), interacciones visuales (mover los brazos u objetos en movimiento) y contacto con áreas sensibles (Hemsworth *et al.*, 2011; Hultgren *et al.*, 2014; Doyle *et al.*, 2016).

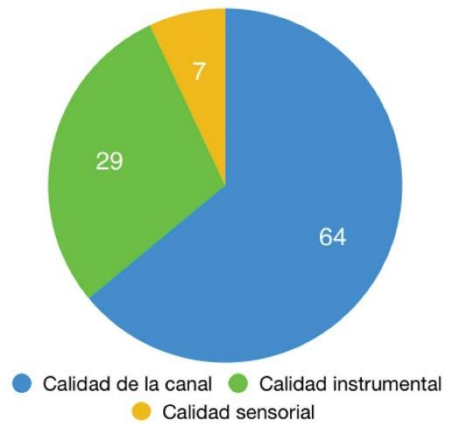
La calidad del manejo durante el arreo de los animales influye en la efectividad del aturdimiento; la facilidad con la que los animales son arreados hacia el chute puede relacionarse con el número de disparos requeridos. El nivel de estrés del operador puede jugar un papel importante también. Las vocalizaciones durante el aturdimiento son un indicador útil debido a que están relacionadas con una calibración ineficiente de la pistola, falta de mantenimiento del equipo, entrenamiento deficiente del personal, presencia de ganado muy excitado o presión excesiva del fijador de la cabeza (Grandin, 2010). Finalmente, indicadores tales como resbalones, darse la vuelta, caídas y saltos pueden considerarse también para el diseño del chute (Gallo *et al.*, 2003).

Los sistemas de evaluación subjetiva han sido particularmente populares en la literatura veterinaria debido a que se consideran relativamente fáciles de aplicar a nivel clínico. Un ejemplo bien conocido para el ganado de leche es el *score* que evalúa el paso (andar) para valorar las cojeras. La evaluación de la movilidad del ganado se está convirtiendo en un método ampliamente aceptado para evaluar efectos potenciales sobre el bienestar. Sin embargo, esta herramienta no existía hasta hace aproximadamente dos años para ganado finalizado. Los animales cojos que tienen dificultad para caminar pueden ser evaluados fácilmente cuando se descargan de los camiones en el matadero. Para facilitar las comparaciones entre diferentes mataderos, tanto los productores como la industria cárnica deben elegir una herramienta de evaluación común (Grandin, 2017). Algunos de los retos asociados con la evaluación de la movilidad del ganado a gran escala son: la consistencia y subjetividad del *score* de movilidad, el ambiente en el cual el ganado es evaluado, y la velocidad a la cual el ganado debe ser evaluado en ambientes comerciales (Edwards-Callaway *et al.*, 2017). Debido a esto, algunos investigadores han propuesto utilizar la incidencia de problemas en las patas y/o un sistema de monitoreo automatizado (cámaras que detecten problemas de cojeras o animales fatigados –no animales ambulatorios-) como un abordaje más confiable (Thomson *et al.*, 2015). Sin embargo, existe poca estandarización con relación a la evaluación de lesiones en patas. Los indicadores de bienestar basados en el comportamiento de los animales tienen la ventaja

El diseño de los mataderos está basado en criterios arquitectónicos convencionales sin tomar en cuenta las necesidades de comportamiento de los animales

FIGURA 4

Subcategorías utilizadas para la clasificación de los indicadores de calidad del producto (%)



de ser 'no-invasivos', no obstante, en ocasiones pueden llegar a ser más costosos en términos del tiempo requerido por el evaluador. Por otro lado, debido a que el matadero es un ambiente nuevo para el ganado -comparado con la granja- los indicadores de comportamiento sólo pueden considerarse válidos al momento de la inspección a nivel matadero (Visser *et al.*, 2001).

Indicadores *post mortem* y de calidad del producto

En el presente trabajo se identificaron un total de 2 indicadores *post mortem* y 15 indicadores de calidad del producto, los cuales fueron clasificados en 3 subcategorías (**figura 4**). Los indicadores más utilizados por los autores de esta categoría fueron pH, color y hematomas (68%, 47% y 34%, respectivamente). El registro de hematomas en las canales puede tener un potencial significativo como recurso para la vigilancia de problemas de bienestar en ganado, debido a que es un indicador altamente válido y factible, que puede señalar fallas básicas en la cadena logística pre-sacrificio. Además, pueden ayudar a identificar el origen de los problemas, tales como el uso de bastón eléctrico, objetos salientes o bordes ásperos, caídas, abusos por parte del personal, mezcla social, o caída de compuertas (Miranda de la Lama *et al.*, 2012; Correia-Gomes *et al.*, 2016).

> Podría implementarse un sistema integral basado en el uso de indicadores 'clave' definidos para cada etapa de inspección

A nivel mundial se han desarrollado diversos *scores* con fines comerciales para la evaluación de canales bovinas. El sistema de evaluación australiano (ACBSS, por sus siglas en inglés) clasifica la severidad de los hematomas de acuerdo al área de la lesión en tres grupos: ligero, medio y severo. En EE.UU. se desarrolló un sistema de evaluación basado en el color y la severidad del trauma, en tanto que en diversos países de Sudamérica (Argentina, Brasil, Chile y Uruguay) se utiliza un sistema de clasificación que se basa en la severidad del hematoma y los tejidos afectados en el área lastimada. A pesar de que los sistemas de evaluación son útiles para tener conocimiento acerca de la prevalencia de hematomas en el ganado sacrificado, es necesario un análisis epidemiológico que permita obtener información precisa sobre los factores de riesgo que influyen en la presencia de hematomas y la probabilidad de las causas aparentes (Strappini *et al.*, 2009).

A nivel comercial, el pH de la carne es uno de los valores de referencia más importantes para medir la calidad, y está relacionado con la reducción de las reservas de glucógeno y la liberación de lactato causado por un manejo estresante. El transporte animal incluye las granjas, puntos intermedios (mercados, centros de acopio, centros de clasificación logística, puntos de verificación sanitaria, paradas logísticas y puntos de descanso) y el matadero. En este contexto, investigadores de Colombia encontraron que los animales que provienen de mercados o que hacen paradas durante el viaje tienen niveles de pH más elevados comparados con aquellos que se transportan de manera directa desde la granja hasta la planta de sacrificio (Romero *et al.*, 2013).

Por otro lado, investigaciones realizadas en Francia (Bourguet *et al.*, 2011), reportan que diferencias en los procedimientos de sacrificio y el tipo de sacrificio en sí (halal *vs* convencional) pueden también influir en el pH muscular final. De manera general, se ha visto que no es solo un 'estresor' sino varios los que influyen en la elevación del pH; el sistema de alimentación, temperamento, raza y categoría comercial de los animales, así como los hematomas, han sido relacionados también con un pH final elevado. En este sentido, puede decirse que el pH final es un indicador válido para medir la calidad de la carne, es confiable y viable a nivel comercial, a tal punto que diversos mataderos realizan esta medición de manera sistemática. El pH muscular puede influir también sobre características comerciales importantes de color y capacidad de retención de agua. Cuando el pH final de la carne es de 5,8-6, las proteínas sufren diversos cambios moleculares dando el color más obscuro a la carne.

Estudios realizados en Sudáfrica (Vimiso *et al.*, 2013) encontraron un efecto lineal significativo de la distancia, la densidad animal y la duración del transporte sobre el color. Otros factores relacionados con un incremento tanto en el color como en la capacidad de retención del agua en la carne son: la posición de los animales dentro del camión (frente *vs* atrás), el tiempo de espera, el método de aturdimiento, el temperamento de los animales, y el método de suspensión de las canales. La medición de la capacidad de retención de agua a nivel matadero es limitada; sin embargo, el color de la carne puede ser evaluado utilizando estándares de color.

Un pH por encima de 5,8, junto con un color obscuro y una mayor retención de agua, son características de una carne DFD (por sus siglas en inglés: obscura, firme y seca). Este tipo de carne ha sido relacionada con el temperamento y la categoría comercial de los animales, un manejo pobre durante el transporte, el tiempo de espera (densidades animales elevadas y condiciones climáticas), el tiempo necesario para entrar al chute, disparos fallidos, así como hematomas (Voisinet *et al.*, 1997; Kreikemeier *et al.*, 1998; Pérez-Linares *et al.*, 2013; Miranda de la Lama *et al.*, 2012; Romero *et al.*, 2013). Cuando la carne se clasifica de manera visual, no siempre exhibe características exactas de tipo DFD. Por lo tanto, se ha sugerido el uso de cámaras termográficas infrarrojas (método de evaluación objetivo no-invasivo) para la detección de animales propensos a este tipo de carne (María, 2008). Este método consiste en obtener una foto térmica del animal que dará una imagen característica de los candidatos a carne DFD.

Este sistema puede instalarse en los mataderos e indicará a los operadores cuándo un animal (que va a ser sacrificado) puede desarrollar este tipo de

decimientos puede dañar las paredes ruminales e intestinales, disminuir el pH de la sangre, y causar deshidratación, laminitis, polioencéfalomalacia y abscesos en el hígado (Owens *et al.*, 1998). Todo esto deja marcas evidentes en los órganos de los animales que pueden ser verificados durante la inspección *post mortem*. Los abscesos en el hígado se detectan únicamente durante el sacrificio, debido a que el ganado, incluso aquellos que cargan cientos de abscesos pequeños o varios abscesos grandes, rara vez exhibe algún signo clínico. Por otro lado, las lesiones en el rumen pueden servir como una secuela patológica "intemporal". En este sentido, a pesar de que puede ser un reto a nivel logístico realizar la evaluación patológica del rumen en las plantas de sacrificio modernas, existen varias ventajas al incluir los datos de lesiones del rumen y abscesos en el hígado cuando se monitorea la salud general de un sistema de producción. Sin embargo, tanto los métodos como los sistemas de evaluación deben ser consistentes y correctamente documentados, realizando la valoración durante un tiempo prudente para poder establecer un punto de referencia o rangos "normales" (Rezac *et al.*, 2015; Llonch *et al.*, 2015).

carne, indicando el tiempo de espera conveniente para su recuperación. Sin embargo, tanto el costo del equipo como el pago a los consultores que utilicen el equipo (o el entrenamiento del personal en el matadero) puede ser un factor limitante en términos económicos (McGregor, 2017). En este sentido, en su lugar puede utilizarse un 'muestrario de color' (método de evaluación subjetivo).

Como se mencionó anteriormente, en el pasado ha habido una tendencia a confiar demasiado en las mediciones fisiológicas, inmunológicas y de comportamiento para evaluar el bienestar de los animales, sin considerar los problemas de salud – los cuales son una de las principales amenazas para los animales de granja (Rushen, 2003). En este contexto, un problema de producción importante para los rumiantes alimentados con dietas ricas en concentrado es la acidosis (crónica y aguda). Este tipo de pa-

El concepto de bienestar animal se ha ido redefiniendo e incluye aspectos como la posibilidad de expresar comportamientos naturales o la ausencia de estados emocionales negativos

Indicadores clave y futuras consideraciones

El concepto de bienestar animal se ha ido redefiniendo y ahora incluye aspectos (previamente poco considerados) tales como la posibilidad de expresar comportamientos naturales o la ausencia de estados emocionales negativos. Por lo tanto, actualmente es necesario tomar en cuenta dichas necesidades e incluir indicadores apropiados (válidos, confiables y viables) que permitan evaluar el bienestar físico y mental de los animales. Debido a que el bienestar es un concepto multi-dimensional, tiene sentido utilizar un sistema de agregación multi-criterio para evaluarlo (Czycholl *et al.*, 2017).

A pesar de que puede haber limitaciones para utilizar indicadores de bienestar en bovinos a nivel matadero, estos podrían ayudar de manera importante, al reducir el estrés y el dolor causados por un manejo pobre (Grandin, 2017). La inspección de la carne tiene como principal objetivo identificar a los animales que no son aptos para el consumo humano y eliminar cadáveres/despojos de la cadena alimentaria.

Otros objetivos de este tipo de inspección incluyen el control de enfermedades animales, y más recientemente, identificar y asegurar asuntos de bienestar animal (Stärk *et al.*, 2014). Se ha propuesto el uso de un set completo de indicadores para establecer puntos de referencia en la prevalencia de problemas de bienestar en bovinos, esto con la finalidad de asegurar que se cumpla con la legislación de bienestar animal (Støier *et al.*, 2016). Sin embargo, tanto el costo como la simplicidad de la evaluación deben tomarse en cuenta. Debido a que la inspección cárnica es una actividad que consume recursos, se ha propuesto el uso de indicadores 'iceberg' o 'clave' como una herramienta útil que pueda proveer una imagen general del bienestar de los animales y funcionar como una 'señal de alarma' para problemas subyacentes.

Este tipo de indicadores podría sustituir las listas de medición utilizadas en la actualidad para la evaluación del bienestar, una vez se haya probado que son válidos y factibles (FAWC, 2009).

En este sentido, podría implementarse un sistema integral basado en el uso de indicadores 'clave' definidos para cada etapa de inspección. Este tipo de sistema permitiría una trazabilidad completa del lote procesado, logrando detectar 'señales de alarma' durante el proceso de inspección o que se relacionen con las medidas de manejo aplicadas (Stärk *et al.*, 2014).

El bienestar animal es un concepto que admite valores morales y otras preferencias más emocionales (Heleski *et al.*, 2012). Los científicos que trabajan con este tema deben cumplir con los valores morales de la sociedad para poder generar un abordaje sustentable (Ohl *et al.*, 2012; Ferguson *et al.*, 2014).

Recientemente, la calidad instrumental y sensorial de la carne también ha sido correlacionada con la calidad ética, es decir, aspectos del bienestar animal que pueden verse comprometidos durante el proceso de producción (Webster, 2001). Teniendo en cuenta este contexto, será necesario informar a los consumidores y a la industria cárnica que el valor ético de un producto es un elemento creciente de importancia económica y una oportunidad de negocio en incremento (Miranda de la Lama *et al.*, 2014). Poner atención a esos factores puede ayudar a evitar la aparición de barreras técnicas en el comercio global de carne en el futuro (Pighin *et al.*,

2013). Finalmente, vale la pena mencionar que aunque el bienestar animal en mataderos europeos y en países de habla inglesa ha sido evaluado y reportado de manera amplia, en otros países este tipo de datos es relativamente escaso. La manera en la que los animales son manejados y procesados puede ser muy diferente en cada país en términos de escala de producción, infraestructura, requerimientos del mercado, disponibilidad de mano de obra y tecnología. Como resultado, investigación en estas regiones es necesaria (Doyle *et al.*, 2016; Njisane *et al.*, 2017).

> Existen algunos indicadores con validez intermedia (frecuencia respiratoria, temperatura corporal, carne DFD) que se han detectado como útiles y deben ser objeto de una mayor investigación

Conclusiones

El conocimiento de las sinergias potenciales y *trade-offs* entre indicadores de bienestar en bovinos y los sistemas de monitoreo voluntario es esencial para la industria cárnica que busca mejorar el nivel de bienestar y la calidad de la carne durante las operaciones comerciales presacrificio.

Sin embargo, es importante dejar claro, que puede haber variaciones en la efectividad de los indicadores entre distintas regiones (países desarrollados *vs* en desarrollo) e incluso en el mismo país (plantas exportadoras *vs* mataderos municipales). Algunos indicadores identificados como altamente válidos para evaluar el bienestar del ganado en los mataderos incluyen la condición corporal de los animales, las interacciones hombre-animal, vocalizaciones, hematomas en la canal y pH de la carne.

Además, algunos indicadores con validez intermedia (frecuencia respiratoria, temperatura corporal, carne DFD) se han detectado como útiles y deben ser más investigados.

La recolección de datos en los mataderos comerciales puede ayudar a mejorar ciertos procedimientos. En general, la información a lo largo de la cadena de alimentos puede utilizarse de manera mucho más sistemática para proveer puntos de referencia para una inspección cárnica más basada en riesgos.

Referencias

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