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Risk factors associated with the welfare of grazing dairy cows in spring-calving, hybrid pasture-based systems

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ABSTRACT

Large-scale investigation of risk factors for multiple welfare indicators in hybrid pasture-based dairy systems is scarce. Our objective was to identify grazing season welfare risk factors on spring-calving, hybrid pasture-based dairy farms where cows experience periods of both grazing and housing. Herd-level data were collected from visits to 93 farms in the primary dairy producing counties of Ireland. Zero-inflated beta regression analysis was used to assess potential associations between categorical management and resource factors, and commonly measured animal-based welfare indicators: locomotion, body condition, nasal and ocular discharge, tail injury, integument damage, and avoidance behaviour. To account for small sample size due to elimination of farms with missing data, analyses were conducted on both a dataset of complete cases, and a dataset where missing values had been substituted for the most common response through single imputation. Resulting risk factors from both methods of analysis were compared for each indicator. Analyses identified 14 risk factors associated with one or more welfare indicators. The proportion of lame cows was positively associated with a previous housing period of four months or more compared to three months, all cubicles being outside recommended lengths and repairing roadways every two to three years compared to either yearly or more than every four years to never. The proportion of cows below minimum target grazing body condition score of 2.75 was negatively associated with participation in elective herd disease-testing in the past year. The proportion of cows with tail lacerations was positively associated with using a single breeding method, not employing part-time staff and not using brisket boards in cubicles. Previous housing period length was significantly associated with the proportion of cows with integument damage, although the direction of association was unclear. Moderate to severe nasal discharge was positively associated with collecting yard holding times of ≤ 60 min compared to > 90 min. Ocular discharge was negatively associated with manual health record-keeping and a collecting yard below the recommended area of 1.4 m^2/cow. The proportion of cows with an avoidance response distance > 1 m was positively associated with herding cows without a dog present and having no additional full-time staff. Multiple risk factors were related to the housing period, suggesting that potential carry-over effects of housing management on welfare persist into the grazing period. This emphasizes the need for research to consider both housing and grazing periods in the management of welfare in hybrid pasture-based systems.

Abbreviations: CC, complete cases; SUB, substitution; ICBF, Irish Cattle Breeding Federation; OS, ocular score; NS, nasal score; LS, locomotion score; ZIBR, zero inflated beta regression; ZI, zero inflated component of ZIBR model; BR, beta distribution component of ZIBR model; AIC, Akaike's Information Criterion; AI, artificial insemination.

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1. Introduction

Dairy production systems vary worldwide, from full-time housing systems to full-time on pasture, each presenting unique risks and benefits for dairy cow welfare. Pasture-based dairy production systems where cows spend part of the year grazing pasture and the remaining winter months in housing, which can be considered hybrid systems (Mee and Boyle, 2020), are common in many countries where temperate climates allow cows to graze for a portion of their lactation. This includes Ireland, the UK and many countries throughout continental Europe. Welfare assessment protocols are commonly used to determine the impact of production systems on dairy cattle welfare. Because animal welfare is multifactorial and involves several interrelated aspects of a cow's health, behaviour and affective state (Fraser, 2008), many welfare assessments rely on measuring multiple animal-based indicators. Animal-based indicators are those that directly reflect how a cow is experiencing her surroundings, rather than measuring the resources provided to them (Whay et al., 2003). Some of the most commonly assessed animal-based welfare indicators include locomotion, body condition, injury, discharge and response to human interaction (AssureWel, 2018; National Milk Producers Federation, 2019; Welfare Quality®, 2009), which represent areas of concern for dairy cow welfare.

Lameness is a painful condition (Coetzee et al., 2017) impacting many aspects of a cow's welfare, such as reduced grazing time (Riaboff et al., 2021), changes in lying behaviour (Riaboff et al., 2021; Sepúlveda-Varas et al., 2014) and reproductive health (Huxley, 2013). In pasture-based systems, reports of lameness prevalence vary. Armbrecht et al. (2019) identified variation in lameness prevalence with the amount of pasture access on farms in Germany, reporting 27.1% when grazing less than six hours per day compared to 17.5% when grazing 10 hr/d or more. O'Connor et al. (2020) found differences in lameness prevalence by stage of the grazing season on Irish farms, reporting herd-level prevalence of 11% during the early grazing period compared to 5.9% in the late grazing season. While low body condition score itself is a risk factor for lameness (O'Connor et al., 2020), it may also reduce fertility and decrease milk production (Atkinson, 2016). Monitoring BCS is particularly important in grazing cows which may experience greater nutritional metabolic stress and display lower rumen fill, a measure of adequate DMI, than housed cows (Olmos et al., 2009b).

Tail injury may result from mechanical damage from the surroundings (e.g. doors, gates, scrapers) or from improper animal handling (AssureWel, 2018; Laven and Jermy, 2020). Other than tail docking, little information on the prevalence of tail injury is available. The few reports available indicate an average herd prevalence of tail breaks of approximately 10% in New Zealand (Bryan et al., 2019), and 3% in Canada (Zurbrigg et al., 2005). The Canadian study also reported that broken tails were observed on 38% of the 317 farms included. Other injury, such as damage to a cow's integument, typically observed on the legs (Brenninkmeyer et al., 2016; Zuliani et al., 2018), is less common in pasture-based than housed cows (Burow et al., 2013b; Kester et al., 2014; Zuliani et al., 2018). Indeed, greater pasture access has been shown to have a protective effect on the prevalence of hair loss and integument alterations. Armbrecht et al. (2019) observed a prevalence of hairless patches of 37.8% and 55.5% among cows grazing for more than ten compared to less than six hours per day respectively. Similarly, Wagner et al. (2018) reported the prevalence of hairless patches and lesions was 57% for cows provided pasture for six to twelve hours per day compared to 32% for cows with 12 hr or more pasture access per day.

Discharge from the eyes and nose can be indicators of poor health associated with altered respiratory function (Ferraro et al., 2021; Love et al., 2014). Predisposing factors that may compromise a cow's immune response to infection include stress, air quality and inadequate nutrition, particularly of micronutrients (Callan and Garry, 2002; Gorden and Plummer, 2010; Love et al., 2014). There have been contradictory reports on the prevalence of ocular and nasal discharge among cows on pasture. Armbrecht et al. (2019) found greater prevalence of ocular discharge, and nasal discharge with greater pasture access. For ocular discharge an average of 14.7% and 29.2% was observed at less than six or more than ten hours per day on pasture respectively. For nasal discharge, an average of 15.6% was observed with six to ten hours pasture access and 24% with more than ten hours per day on pasture. In contrast, Wagner et al. (2018) observed lower prevalence of both ocular and nasal discharge with more pasture access. Authors reported an average ocular discharge prevalence of 7% and 3% for none to six hours or less on pasture and more than six hours per day respectively. For nasal discharge, they report an average prevalence of 13%, 11% and 7% with increasing levels of pasture access from none to six hours or less, six to less than 12 hr/d and more than 12 hr/d respectively.

Previous interactions between stockpersons and cattle can influence a cow's behaviour and fear response both negatively and positively (Waiblinger et al., 2004, 2002). One method of testing this human-animal relationship is through measuring the avoidance distance from an approaching human (Waiblinger et al., 2003). In welfare assessment protocols, this test of avoidance response is typically conducted with cows at the feed-face. For example, Armbrecht et al. (2019) who found 4 – 7% of cows displayed an avoidance response of more than 1 m from a human approaching at the feed-face. However, for cows that primarily graze grass on pasture this method does not represent conditions experienced for most of the year. Battini et al. (2011) found cows displayed a greater avoidance response to humans at the end of the grazing season compared to the beginning. The authors concluded that a more accurate reflection of the human-animal response would be achieved by testing cows in the area where they spend the majority of their time. To date there is little research of avoidance response in pasture-based systems that investigates this while cows are grazing. Beggs et al. (2019) examined avoidance distance of grazing dairy cattle in Australia and found a wide variation between farms, with a mean and median avoidance distance of 1.7 m; however, they did not further investigate potential risk factors associated with the avoidance response.

While these welfare indicators are often examined individually or in small groups, investigation of multiple welfare indicators is necessary to gain a more complete picture of the risk factors affecting dairy cow welfare. Large-scale investigation of risk factors for multiple indicators of welfare in spring-calving hybrid dairy systems, such as those common in Ireland, are scarce. Previous welfare research within dairy production in Ireland has explored risk factors associated with lying behaviour (O'Driscoll et al., 2019, 2010a, 2009), grazing behaviour (O'Driscoll et al., 2010b), health around the time of parturition (Olmos et al., 2009b), udder discomfort (Gleeson et al., 2007) and hoof health and lameness (O'Connor et al., 2019; O'Driscoll et al., 2010a, 2008; Olmos et al., 2009a; Somers et al., 2019, 2015). Such previous research has largely been experimental in nature, involving only a small number of farms or replicates, and focusing on a limited number of welfare indicators. Any studies that have been larger in scale, such as Somers et al., (2015, 2019) with 10 farms and O'Connor et al., (2019, 2020) with 68 farms, were primarily focused on risk factors associated solely with lameness.

Information on the predominant risk factors for animal welfare is integral to the ability of farmers, veterinarians or advisors to make informed decisions to improve dairy cattle welfare on-farm. Therefore the objective of this study was to investigate the associations between management and resource factors and seven commonly measured animal-based welfare indicators: locomotion, body condition, nasal and ocular discharge, tail injury, integument damage, and avoidance behaviour; with the aim of identifying risk factors for these welfare indicators during the grazing season on spring-calving, hybrid pasture-based dairy farms.

2. Materials and methods

This study was conducted with approval of the Teagasc Animal

Ethics Committee (TAEC; TAEC197–2018), and in accordance with the Cruelty to Animals Act (Ireland 1876, as amended by European Communities regulations 2002 and 2005) and the European Community Directive 86/609/EC.

2.1. Farm recruitment and selection

We aimed to include as many farms as possible to conduct a risk factor analysis for multiple welfare indicators and concluded that approximately 100 farms was the maximum practically possible within the scope of this study. Target farms were spring-calving, pasture-based (> 200 d/year grazing grass) with a period of housing in winter, non-organic dairy farms located within the primary dairy producing counties (those with ≥ 70,000 dairy cows; Central Statistics Office, 2018) in the Republic of Ireland: Cork, Kerry, Limerick, Tipperary, Kilkenny, Waterford and Wexford. All farms had a herd size between 30 and 250 cows, which accounted for 95% of dairy farms in Ireland at the time of enrolment. Breeds represented were primarily cross-bred Holstein, Friesian or Jersey cows or pure-bred Holstein cows. For practicality, only farms located within a two hour driving distance from the Teagasc, Moorepark research centre located in Fermoy, Cork were included. Farms were randomly selected using SAS 9.4 (SAS Institute Inc., Cary, NC, USA) from a list of farms meeting the selection criteria, provided by the Irish Cattle Breeding Federation (ICBF), Ireland's national information database for the dairy and beef farming industry. Of the 518 farms contacted, 131 farms responded and 103 eligible farms were enrolled in the study. For a detailed explanation of the farm recruitment procedure see Crossley et al., 2021.

2.2. Data collection

All 103 farms were visited during the grazing period between April to September 2019. A second visit was made during the housing period from October 2019 to February 2020 to the maximum number of farms possible before the start of calving (n = 87). Welfare assessments were conducted at grazing and housing visits and the prevalence of each welfare indicator was measured at both periods (Crossley et al., 2021). This paper will focus on the welfare indicators measured during the grazing period only, however, the pool of potential risk factors were collected at both visits. Grazing period visits occurred between 31 and 213 d following pasture turn-out, with a median visit date of 132 d (IQR 92–163 d) after turn-out. A research team of three to four individuals visited one to two farms per day, and each visit involved animal scoring, infrastructure measurements and a management survey with the farmer. Details of all categorical scoring scales are provided in Appendix A. Tests of inter-observer agreement were performed for locomotion and body condition scoring with a mean agreement (weighted kappa) between scorers of > 0.7 (Crossley et al., 2021). While observer agreement was not carried out for the remaining scoring scales, all members of the research team participated in group training sessions, and reference photos with detailed definitions of the score levels were available to consult throughout each assessment. Nonetheless, the lack of observer agreement tests for these scores may be a limitation of this study. To ensure the overall assessment procedure was carried out consistently, it was pilot tested on six farms prior to beginning data collection.

2.2.1. Animal Welfare Indicators

Following the procedures described in Crossley et al., 2021, scoring was conducted for seven welfare indicators: body condition, ocular and nasal discharge, integument damage, tail injury, locomotion and avoidance behaviour. Body condition score (BCS) was measured using a 5-point scale at 0.25 increments between emaciated (1), and extremely over-conditioned (5; Agriculture and Horticulture Development Board, 2015a). Ocular and nasal discharge was scored on a 4-point scale (0 – 3), adapted from the University of Wisconsin-Madison calf-health scoring system (https://fyi.extension.wisc.edu/heifermgmt/files/2015/02/calf_health_scoring_chart.pdf). Integument damage was scored on a 4-point severity scale (0 – 3) with either none, single or multiple areas affected, within each of five zones on the body: head-neck-back (zone 1), hindquarters (zone 2), rear hocks (zone 3), side-body (zone 4), and front hocks (zone 5) adapted from Welfare Quality® (2009) and Gibbons et al. (2012). Tail injury was evaluated for the presence or absence of breaks and deep, circumferential lacerations to the tail. Locomotion was scored on a 4 - point scale (LS): good (0), imperfect (1), impaired (2) and severely impaired (3; Agriculture and Horticulture Development Board, 2015b). All team members that performed locomotion scoring received training through the UK Register of Mobility Scorers. A test of avoidance response, adapted from Rousing and Waiblinger (2004), was performed at the paddock. A proportion of cows, selected according to the Welfare Quality® (2009) sample size criteria, were approached by a single observer following a standardized procedure. Each cow's distance from the observer at first sign of retreat (backing away or turning head to either side) was recorded on a 5-point scale between retreat > 2 m from the observer (1) and accepting of touch (5). Avoidance response at > 1 m from the observer (level 1 or 2) was categorized as a "fearful" response.

2.2.2. Facility measurements

2.2.2.1. Roadways. The stretch of roadway leading into the collecting yard is travelled daily regardless of the destination paddock and represents the area most frequently used by cows. Beginning at the collecting yard, the first 50 m of each roadway was measured and the following roadway features were recorded: width of the track and the verge (area between the track edge and the fence-line), surface condition (very smooth, smooth, rough, very rough), surface material, presence of loose stones (measured as the proportion of squares that contain stones > 0.5 cm in diameter, within a 50 by 50 cm, 25 square quadrat) and the presence of sharp turns (approximately ≤ 90 degrees).

Because it was not feasible to measure all paddock roadways on every farm within the time-frame of this study, the roadway in use on the day of the visit was measured at two points; the estimated mid-way point between the farm-yard and the destination paddock, and at the endpoint where the roadway met the destination paddock. At each point, measurements were recorded for a cross-section of the roadway, perpendicular to the direction of travel, and included the previously described features, excepting the presence of sharp turns.

2.2.2.2. Paddock water sources. Water sources present in the destination paddock on the day of the visit were counted and measured, including the number, type (trough or bowl), dimensions (length, width, height, water-line depth), cleanliness (clean, partly dirty, dirty), and functionality (working/not working, drainable/not drainable).

2.2.2.3. Parlour & collecting yard. Measurements relating to the collecting yard included: the dimensions (length, width, entrance width and roof height if applicable) and the design (shape, flooring type, slope, presence and type of scraper, brushes, backing gate). Measurements relating to the parlour included: design (parallel, herringbone, rotary or robotic), presence and type of divisions between cows (none, head-partitions, head-locks, sequential bailing, rapid-exit), flooring type (grooved or smooth concrete, slats, rubber, slatted-rubber) and slipperiness (slippery, somewhat slippery, not slippery; de Vries et al., 2015), light level (bright, dim, dark; de Vries et al., 2015), distance from the milking row exit to the end of the parlour, and the presence of steps, turns (90 or 180 degrees) and footbath.

2.2.2.4. Sheds and pens. All loose and cubicle sheds that housed dry or milking cows outside of the grazing season were measured. Recorded measurements for all sheds included design (cubicles or loose-housing), shed dimensions (length, width, roof height, passage widths), feed-face dimensions (available length, feed-barrier height inside and outside pen, neck-rail height from the pen floor and from the top of the feed-barrier, number and width of partitions if applicable), flooring type (smooth or grooved concrete, slats, rubber, slatted-rubber), flooring slipperiness (slippery, somewhat slippery, not slippery; de Vries et al., 2015), presence or absence of an alley scraper or dead-ends, light-level (bright, dim or dark; de Vries et al., 2015), and the number of open sides for ventilation. For cubicle-sheds, additional measurements included the total number of rows, number and type of cubicles (head-head, wall-facing, passage facing), cubicle base type (concrete, wood, sand, soil, other), cubicle partition style (cantilever, mushroom, Newton-Rigg/front-rear fixed, double-front fixed), whether or not partitions were flexible and overall condition (very good, good, poor, bad). Detailed cubicle measurements (total length, bed length, diagonal length, lunge space, curb height, neck-rail height, cubicle width and presence or absence of a brisket board) were recorded for a randomly chosen 5% of each cubicle type (head-head, wall-facing, passage facing), for the two most common cubicle styles present in the shed (cantilever, mushroom, Newton-Rigg, double-front fixed). When sheds were occupied at the second visit, cubicle stocking rate, as well as the cubicle surface material (concrete, mat, mattress), mat thickness if applicable, cubicle hardness (hard, medium, soft), bedding type (none, sand, sawdust, shavings, woodchips, lime, other), bedding depth and amount of coverage if applicable (full, partial, minimal, none), and cleanliness (clean, partly dirty, dirty) of the top and bottom halves of the cubicle were also recorded for 5% of the total cubicles in each pen by selecting every 20th cubicle excepting the end-cubicles. For loose-sheds, the bedded area dimensions (length, width), bedding type (sand, straw, sawdust, shavings woodchips, other, none), bedding cleanliness (clean, partly dirty, dirty), and bedding depth (sparse, thin, thick, very thick) were recorded.

2.2.3. Management survey

In-person surveys were completed with the primary farmer at each visit to obtain information on general farm characteristics, management practices, animal health and farm infrastructure. A copy of the survey questions is included in Appendix B. General farm characteristics included size of grazing platform, number of milking cows, number of staff, history of expansion in the previous five years, plans for future expansion and participation in national herd health programs. Information regarding management practices included biosecurity protocols for purchased stock, breeding strategy, housing and pasture turn-out dates, milking protocols and grazing strategies. Animal health data collected consisted of health record protocols, disease testing, use of pain-relief medication, parasite control, locomotion and body-condition scoring practices. Lastly, collected information regarding the farm infrastructure included frequency of roadway repair and maintenance, roadway construction materials, roadway design, paddock distance, cows' travel time to the parlour, source of water supply, water availability and paddock water source maintenance.

A second survey completed during the follow-up housing visit recorded the date of housing, target dry period length, grouping strategy during housing, passageway and cubicle cleaning protocols, diet and feeding protocols, farmer demographics and the farmer's perception of animal welfare. Additionally, a health record form was sent to each farmer to complete in advance of our second visit. This form included details on each herd's vaccination protocols, disease status, and lameness level within the study period of the 2019 lactation. Access to herd health and production records within the ICBF database was also obtained.

2.3. Data management

Of the 103 total visited farms, 93 were included in data analyses. Seven farms were excluded due to a large proportion of their herd calving outside the conventional spring season (approximately 20% or more of 2019 calvings between July to November). Additionally, three farms were excluded whose milking practices were outliers among the final study herds (two herds that milked only once/day, and a single herd that used robotic milking). The remaining 93 farms included in the study had an average herd size of 125 cows (range: 38 – 253 cows) and an average grazing platform of 45 Ha (range: 14 – 101 Ha). Data for avoidance response was only available for 68 farms because the avoidance test was not conducted when conditions were deemed unsafe (e.g. a bull in the field, inclement weather) and, in four cases, due to recording errors.

Collected data for each indicator were summarised by farm using SAS 9.4 software (SAS Institute Inc., Cary, NC, USA) and expressed as a proportion. Response variables were the proportion of cows: below the recommended grazing BCS target of 2.75 (Butler, 2016); scored lame (LS2 and LS3); with tail lacerations and tail breaks; with moderate or severe nasal discharge (NS2 and NS3); with any signs of ocular discharge (OS1 to OS3); with areas of moderate or severe integument damage in all body zones; and with an avoidance response distance of > 1 m (level 1 and 2). In the case of ocular discharge, a low proportion of cows were scored with moderate or severe discharge (OS2 or OS3), yet a large proportion of cows were scored with mild discharge (OS1). This indicated that ocular discharge was common but not severe, potentially due to an unsuitable aspect of their environment; thus, we chose to look at risk factors for any signs of ocular discharge. A total of 90 categorical explanatory variables were derived from the collected data (Appendix C). Continuous variables were categorised into levels according to biological relevance, recommended guidelines (e.g. for cubicle dimension) or distribution of the data (e.g. quartiles, mean etc.). If variable levels contained 5 observations or fewer they were combined with the most closely related level. Individual datasets were created for each welfare indicator which included all potentially relevant factors according to the literature and the authors' experience (8 – 52 factors/ indicator). Any farms with missing data were omitted to obtain a dataset containing only complete cases (CC). The final datasets for each welfare indicator varied in size from 58 to 85 farms.

2.4. Data analysis

Data were analysed with a mixture model, zero-inflated beta regression (ZIBR), fit by the glmmTMB routine as part of the glmmTMB library (Brooks et al., 2017) in R (R R Core Team, 2020). A ZIBR simultaneously fits two model components to the dataset. With a probability p, a farm was considered a "pure zero farm" and expressed by the zero-inflated component of the model (ZI). The ZI component indicates the presence or absence of an effect by the categorical explanatory variable on the response variable. With a probability $(1 - p)$, a response between zero and one was generated by a beta distribution and expressed by the second model component (BR), which is conditional upon being a "non-pure zero farm". The BR component indicates the degree of effect of the categorical explanatory variable on the response variable. Effects of explanatory variables were introduced on the logit scale, both for probability p for a pure zero farm and for the mean of the beta distribution for a non-pure zero farm. Note that a large effect on the logit scale for the ZI component implies a higher probability for a pure zero farm, i.e. a zero response, while a large effect for the BR part implies a high response, i.e. a response close to one (or 100%). A limitation of a ZIBR model is that it cannot model proportions that are exactly equal to one. However, in the current dataset, this occurred for only a single farm value within the avoidance response indicator. To approximate this extreme value, it was replaced by the average of one and the next highest response. When no values equal to zero were present in the data (i.e. for lameness and avoidance response data), only the BR component of the ZIBR model was fit to the data.

Univariate analyses were conducted initially by introducing each explanatory variable individually into the ZIBR model, and those with a P-value < 0.2 were retained for further analysis. As a check for potential correlation between variables, all retained variables were tested pairwise with Fisher's exact test for association. In the case of significant association (P-value < 0.05) the explanatory variable considered most biologically relevant or with the lowest p-value was retained. All retained variables were then included in a stepwise selection procedure in the ZIBR model. Akaike's Information Criterion (AIC) was used as the initial criterion for selection and exclusion. The resulting preliminary model was restricted to variables with a P–value < 0.05 according to the Wald test, in either the ZI or BR component or both, unless the removal of a variable caused other significant factors in the model to become non-significant (P–value > 0.05). As a final check, all previously excluded explanatory variables that were not correlated with existing model factors were re-introduced individually into the model to check their significance and impact upon the significance of the selected explanatory variables once more. Re-introduced explanatory variables with a P-value < 0.05 for either the ZI or BR components were included in the model. Finally, all potential interactions between the explanatory variables in the model for either the ZI or BR component were examined and included in the final model if significant (P-value < 0.05) according to the Wald test. Any factors selected for the initial preliminary model that remained non-significant throughout were assumed to have a contributing effect on the significance of other factors, and therefore were retained in the final model. Odds ratios were calculated for all explanatory variables retained in the final model using the R package, 'emmeans' (Lenth, 2020). This included a Tukey type adjustment for P-values of pairwise comparisons for explanatory variables with three or more levels.

2.5. Accounting for small sample size

Considering only CC, the final datasets of between 58 and 85 farms per indicator were relatively small for risk factor analysis. To account for this, we repeated the modelling procedure incorporating single imputation through substitution (SUB) for missing values in the creation of the dataset (Curley et al., 2019). This method enabled us to preserve the data from a larger number of farms for analysis. Beginning with only those explanatory predictor variables displaying ≤ 5% missing values, the most frequently observed value was substituted for each missing value within each variable. This resulted in a dataset containing all 93 study farms for each indicator except avoidance response, which had 68 (the maximum number of farms with collected data). The ZIBR model procedure previously described was repeated using this larger, augmented dataset. The resulting variables from both analyses, with and without imputation, were compared for each indicator to serve as a check of the sensitivity of the analysis. Risk factors identified by both analyses suggest a robust association with the welfare indicator. Risk factors identified only after imputation indicate factors that may become more apparent with a larger number of farms and thus may benefit from continued research.

3. Results

Descriptive data for each indicator, including the number of farms, mean percentage, SD and range for both CC and SUB methods are presented in Table 1. The majority of identified risk factors resulted from the BR model component, thus all results described refer to the BR model component unless otherwise stated.

3.1. Body condition score

A total of 24 variables were included in initial univariate analyses for both CC and SUB; four variables for each of CC and SUB were retained for inclusion in further multivariable modelling (both CC and SUB: herd testing for disease in the past 12 months, herd size; CC only: routine parasite treatment; SUB only: performing grass measurement).

Risk factors identified for the proportion of cows scored with below target body condition scores during grazing were elective herd-testing for disease in the past 12 months (both CC and SUB) and herd size (SUB; Table 2). Not participating in herd-level disease testing in the past 12 months, other than regular bovine tuberculosis and Johne's testing, was positively associated with the proportion of cows below BCS 2.75. Additionally, the proportion of cows with BCS below target levels was positively associated with farms of below average herd size (≤ 80 cows) compared to average or larger herds (> 80 cows).

3.2. Tail injury: breaks and lacerations

A total of eight variables were included in initial univariate analyses of tail lacerations and breaks for both CC and SUB; three were retained through CC and four through SUB for inclusion in further multivariable modelling (both CC and SUB: backing gate, employment of part-time staff and breeding method; SUB only: total cubicle length). In the final step of the modelling procedure for tail lacerations, the variable brisket board use, which was previously excluded through univariate analyses for each of CC and SUB, was found to be significant (P < 0.05) and re-introduced to the models.

None of the analysed variables were identified as risk factors for tail breaks. However, breeding method and employment of part-time staff were identified as risk factors for the proportion of tail lacerations (Table 3) using both CC and SUB methods. Presence of a brisket board in cubicles was identified as an additional risk factor for the proportion of tail lacerations using SUB, where previously a tendency was found through CC. Utilising a single breeding method, either artificial insemination (AI) or stock bull, was positively associated with the proportion of tail lacerations compared to using a combination of both methods.

Table 1
Descriptive analysis of welfare indicators measured during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

	Complete Cases					Substitution				
Welfare Indicator[a] (%)	No. Farms	Mean	SD	Min	Max	No. Farms	Mean	SD	Min	Max
BCS < 2.75	72	2.2	2.73	0.0	14.9	93	2.2	2.74	0.0	14.9
Lame cows	77	9.7	5.48	0.9	31.5	93	9.8	5.92	0.8	31.5
Tail lacerations	85	1.7	3.43	0.0	17.7	93	1.8	3.55	0.0	17.7
Tail breaks	85	9.0	9.40	0.0	51.6	93	10.1	11.99	0.0	82.5
Moderate to severe integument damage	81	10.4	10.58	0.0	48.2	93	10.7	11.11	0.0	48.2
Moderate to severe nasal discharge	77	6.9	6.40	0.0	27.3	93	6.7	6.25	0.0	27.3
Ocular discharge	77	44.2	32.39	0.0	92.8	93	45.7	33.06	0.0	95.7
Avoidance response > 1 m	58	82.3	11.71	51.0	100.0	68	82.1	11.85	51.0	100.0

[a] Body Condition Score (BCS) < 2.75 is below the lowest recommended target body condition at grazing; lame cows are those scored 2 or 3 on a 4-point locomotion scale from 0 to 3; moderate to severe integument damage includes lesions scored 2 or 3; moderate to severe nasal discharge includes cows scored 2 or 3; ocular discharge includes cows scored 1, 2 or 3; avoidance response > 1 m refers to cows scored level 1 or 2 in the avoidance test.

Table 2
Risk factors associated with the proportion of cows with body condition score (BCS) below 2.75 during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

Analysis method[a]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[b]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	23	Disease Tested		BR	0.042	No vs Yes	1.43	1.01 – 2.03	0.046
		No	23.6	ZI	0.830	No vs Yes	0.88	0.28 – 2.74	0.831
		Yes	76.4						
Substitution	23	Disease Tested		BR	0.014	No vs Yes	1.48	1.08 – 2.01	0.016
		No	25.8	ZI	0.510	No vs Yes	1.37	0.53 – 3.54	0.512
		Yes	74.2						
		Herd Size		BR	0.011	≤ 80 vs ≤ 125	1.71	1.19 – 2.45	0.014
		≤ 80	22.6			≤ 80 vs > 125	1.55	1.09 – 2.20	0.043
		≤ 125	35.5			≤ 125 vs > 125	0.91	0.66 – 1.25	0.821
		> 125	41.9	ZI	0.680	≤ 80 vs ≤ 125	1.65	0.54 – 5.08	0.655
						≤ 80 vs > 125	1.34	0.46 – 3.9	0.857
						≤ 125 vs > 125	0.81	0.31 – 2.12	0.901

[a] Data from 72 farms were included in complete cases analysis and 93 farms in substitution analysis.
[b] The zero-inflated beta regression model fit to the data consisted of two model components: the beta distribution component (BR) and the zero-inflated component (ZI). ZI model estimates the probability of a zero proportion, thus there is an inverse effect of the odds ratio (> 1 is lower risk, < 1 is greater risk).

Table 3
Risk factors associated with the proportion of cows with tail injury during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

Analysis method[a]	Injury type[b]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[c]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases[d]	Lacerations	8	Breeding Method[e]		BR	< 0.001	Single vs Combined	4.15	2.72–6.29	< 0.001
			Single	17.6	ZI	0.568	Single vs Combined	1.45	0.41 – 5.18	0.570
			Combined	82.4						
			Part Time Staff		BR	< 0.001	No vs Yes	2.49	1.67–3.70	< 0.001
			No	29.4	ZI	0.703	No vs Yes	1.22	0.44 – 3.43	0.704
			Yes	70.6						
			Brisket Board		BR	0.065	No vs yes	1.70	0.97–2.97	0.069
			No	78.8	ZI	0.567	No vs Yes	0.71	0.22 – 2.31	0.569
			Yes	21.2						
Substitution		8	Breeding Method[e]		BR	< 0.001	Single vs Combined	3.80	2.32–6.17	< 0.001
			Single	16.1	ZI	0.557	Single vs Combined	1.46	0.41 – 5.15	0.559
			Combined	83.9						
			Part Time Staff		BR	0.001	No vs Yes	2.00	1.34–2.98	0.001
			No	26.9	ZI	0.723	No vs Yes	1.19	0.45 – 3.19	0.724
			Yes	73.1						
			Brisket Board		BR	0.018	No vs Yes	1.97	1.13–3.44	0.020
			No	79.6	ZI	0.434	No vs Yes	0.63	0.20 – 1.99	0.437
			Yes	20.4						

[a] Data from 85 farms were included in complete cases analysis and 93 farms in substitution analysis.
[b] Eight factors were tested for association with the proportion of tail breaks and none were found to be significant ($P < 0.05$) for either the complete cases or substitution methods.
[c] The zero-inflated beta regression model fit to the data consisted of two model components: the beta distribution component (BR) and the zero-inflated component (ZI). ZI model estimates the probability of a zero proportion, thus there is an inverse effect of the odds ratio (> 1 is lower odds, < 1 is greater odds).
[d] Complete cases model also included previous housing period length BR: $P = 0.441$, ZI: $P = 0.784$.
[e] Breeding: all breeding through either artificial insemination (AI) or stock bull (Single method), or through both AI and stock bull (Combined method).

Employing part-time staff and use of brisket boards in cubicles were negatively associated with the proportion of tail lacerations compared to farms without these factors.

3.3. Integument damage

A total of 20 variables were included in initial univariate analyses of integument damage for both CC and SUB; five were retained through CC (total cubicle length, cubicle width, length of previous housing period, routine parasite treatment, and 90 degree turns into the parlour entrance) and three through SUB (total cubicle length, previous housing period length, and floor slipperiness at parlour entrance) for inclusion in further multivariable modelling.

Length of the previous indoor housing period was identified by CC as a risk factor for the presence of moderate to severe integument damage in the ZI model component (Table 4). However, no significant pairwise comparison was detected that would indicate the direction of association. Total cubicle length was identified as an additional risk factor through SUB (ZI model component). The presence of moderate to severe integument damage tended to be negatively associated with having all cubicles within recommended lengths (2.3–2.6 m for wall facing or 2.2–2.5 m for head-to-head/passage facing; Clarke, 2016) compared to all cubicles outside (above or below) recommended lengths.

3.4. Nasal discharge

A total of 24 variables were included in initial univariate analyses for both CC and SUB; nine variables for CC and eight for SUB were retained for inclusion in further multivariable modelling (both CC and SUB: collecting yard area, maximum collecting yard holding time, frequency of cleaning water sources, herd testing for disease in the past 12 months, routine parasite treatment, length of previous housing period and employment of part-time staff; CC only: water quality testing, and health record-keeping method; SUB only: collecting yard roof coverage).

Risk factors for the proportion of moderate to severe nasal discharge (Table 5) were maximum collecting yard holding time at milking (CC) and collecting yard area (SUB). Collecting yard holding times of 60 min or less were positively associated with nasal discharge compared to holding times longer than 90 min. The presence of moderate to severe nasal discharge was positively associated (ZI component) with collecting yard areas below recommended levels (1.4 m^2/cow; Department of Agriculture Food and the Marine, 2020) compared to those that met or exceeded the recommended area. Furthermore, tendencies were found for associations between the proportion of moderate to severe nasal discharge and the frequency of water source cleaning (CC), as well as having a majority covered collecting yard (SUB). Nasal discharge tended to be negatively associated with cleaning water sources once/year compared with cleaning less frequently, and with having more than 50% of the collecting yard covered.

3.5. Ocular discharge

A total of 24 variables were included in initial univariate analyses for both CC and SUB; seven variables for each of CC and SUB were retained for inclusion in further multivariable modelling (both CC and SUB: collecting yard area, collecting yard roof coverage, frequency of cleaning water sources, health record-keeping method, footbath use, and separate sick and calving pens; CC only: herd testing for disease in the past 12 months; SUB only: herd biosecurity status).

Risk factors for the proportion of cows with ocular discharge (Table 6) were health record-keeping method (both CC and SUB) and collecting yard area (CC). Manual record-keeping for health records (i.e. notebook or whiteboard) was negatively associated with the proportion of cows displaying ocular discharge compared to using a digital method (i.e. computer or phone app). Collecting yards below the recommended area per cow (1.4 m^2/cow; Department of Agriculture Food and the Marine, 2020) were negatively associated with the proportion of cows with ocular discharge compared to those that met or exceeded the recommended area per cow. Ocular discharge also tended to be negatively associated with having separate sick and calving pens (CC). Additional risk factors identified through SUB were open or closed herd biosecurity status and whether a footbath was used. Open herds, those that brought outside stock such as heifers or bulls onto the farm, and not using a footbath were each positively associated with the proportion of cows displaying ocular discharge.

Table 4
Risk factors associated with the proportion of cows with moderate to severe integument damage (score 2 or 3) during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

Analysis method[a]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[b]	P-value	Pairwise comparison	Odds ratio	95% CI	P-value of pairwise comparison
Complete cases	20	Housing period length (2018–2019)		BR	0.305	3 vs < 3 months	0.81	0.55 – 1.21	0.559
		3 months	39.5			3 vs ≥ 4 months	1.17	0.71 – 1.89	0.799
		< 3 months	34.6			< 3 vs ≥ 4 months	1.44	0.89 – 2.34	0.312
		≥ 4 months	25.9	ZI	0.044	3 vs < 3 months	0.87	0.05–14.65	0.995
						3 vs ≥ 4 months	0.10	0.01–0.96	0.120
						< 3 vs ≥ 4 months	0.12	0.01–1.11	0.154
Substitution[c]	20	Cubicle length[d]		BR	0.398	R vs NR	0.67	0.31 – 1.43	0.556
		R	8.6			R vs M	0.83	0.36 – 1.92	0.900
		NR	72.0			NR vs M	1.24	0.81 – 1.92	0.592
		M	19.4	ZI	0.040	R vs NR	8.77	1.44–53.50	0.054
						R vs M	14.95	1.14–196.46	0.105
						NR vs M	1.70	0.18–15.87	0.886

[a] Data from 81 farms were included in complete cases analysis and 93 farms in substitution analysis.
[b] The zero-inflated beta regression model fit to the data consisted of two model components: the beta distribution component (BR) and the zero-inflated component (ZI). ZI model estimates the probability of a zero proportion, thus there is an inverse effect of the odds ratio (> 1 is lower odds, < 1 is greater odds).
[c] Substitution method model also included floor slipperiness at parlour entrance, BR: $P = 0.373$, ZI: $P = 0.133$
[d] Cubicle length: recommended length of 2.3–2.6 m for wall facing or 2.21–2.45 m for head-to-head/passage facing (R), above or below the recommended length (NR), > 50% herd housed with mix of R and NR cubicles (M).

Table 5
Risk factors associated with the proportion of cows with moderate to severe nasal discharge (score 2 or 3) during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

Analysis method[a]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[b]	P-value	Pairwise comparison	Odds ratio	95% CI	P-value of pairwise comparison
Complete cases[c]	24	Maximum collecting yard holding time		BR	0.038	≤ 60 vs > 60 ≤ 90 min	1.32	0.89–1.96	0.356
		≤ 60 min	28.6			≤ 60 vs > 90 min	1.83	1.15–2.89	0.034
		> 60 ≤ 90 min	48.1			> 60 ≤ 90 vs > 90 min	1.38	0.90–2.11	0.299
		> 90 min	23.4	ZI	0.275	≤ 60 vs > 60 ≤ 90 min	0.49	0.10 – 2.36	0.647
						≤ 60 vs > 90 min	2.82	0.25 – 31.93	0.681
						> 60 ≤ 90 vs > 90 min	5.78	0.60 – 55.96	0.291
		Water source cleaning frequency		BR	0.073	Once/yr vs < Once/yr	0.64	0.43–0.94	0.065
		Once/yr	54.5			Once/yr vs > Once/yr	0.88	0.58–1.33	0.806
		< Once/yr	26.0			< Once/yr vs > Once/yr	1.37	0.86–2.20	0.391
		> Once/yr	19.5	ZI	0.109	Once/yr vs < Once/yr	7.63	0.82 – 71.26	0.182
						Once/yr vs > Once/yr	4.64	0.50 – 43.31	0.374
						< Once/yr vs > Once/yr	0.61	0.03 – 11.26	0.940
Substitution	24	Collecting yard area[d]		BR	0.512	Below vs Equal/ Above	1.11	0.82 – 1.50	0.513
		Below	44.1	ZI	0.025	Below vs Equal/ Above	0.17	0.03–0.80	0.028
		Equal/Above	55.9						
		Collecting yard is majority covered		BR	0.070	No vs. yes	1.33	0.98–1.80	0.073
		No	55.9	ZI	0.195	No vs. yes	2.33	0.65 – 8.36	0.198
		Yes	44.1						

[a] Data from 77 farms were included in complete cases analysis and 93 farms in substitution analysis.
[b] The zero-inflated beta regression model fit to the data consisted of two model components: the beta distribution component (BR) and the zero-inflated component (ZI). ZI model estimates the probability of a zero proportion, thus there is an inverse effect of the odds ratio (> 1 is lower odds, < 1 is greater odds).
[c] Complete cases method model also contained health recording method, BR: $P = 0.118$, ZI: $P = 0.124$
[d] Collecting yard area: below recommended area of 1.4 m^2/cow (Below), equal or above recommended area of 1.4 m^2/cow (Equal/Above)

3.6. Lameness

A total of 52 variables were included in initial univariate analyses for both CC and SUB; seven variables for each of CC and SUB were retained for inclusion in further multivariable modelling (both CC and SUB: maximum collecting yard holding time, footbath use, length of previous housing period, and road repair frequency; CC only: total cubicle length, maintaining a separate lame cow group, and the time between treatment and diagnosis of lame cows; SUB only: 180 degree turns at the parlour exit, distance from milking row exit to end of parlour, and the proportion of stones on roadways). In the final step of the modelling procedure, two variables previously excluded through univariate analyses for each of CC and SUB were found to be significant ($P < 0.05$) and were re-introduced to the model; herd size and the proportion of loose stones on roadways to collecting yard for CC, and distance to furthest paddock and time between treatment and diagnosis of lame cows for SUB.

Identified risk factors for the proportion of lame cows (Table 7) were previous housing period length (both CC and SUB), cubicle length and road repair frequency (CC). A previous housing period of three months compared to four months or more was negatively associated with the proportion of lame cows. Having all cubicles outside recommended lengths was positively associated with the proportion of lame cows compared to when some or all cubicles were within recommended lengths. The proportion of lame cows was positively associated with repairing roadways Occasionally (every 2–3 years), compared to either Yearly or Rarely (every 4 years or more to never). Interactions between herd size and footbath use, as well as between maintaining a separate lame cow group and the proportion of loose stones on roadways to collecting yard were also identified through CC.

Analysis through SUB identified furthest paddock distance as an additional risk factor for a higher proportion of lame cows, as well as tendencies for the distance from milking row exit to end of parlour and proportion of loose stones on roadways. The furthest paddock being located less than 1 km from the parlour was negatively associated with the proportion of lame cows. Having 3 m or more distance from the milking row exit to the end of the parlour tended to be negatively associated with the proportion of lame cows. No significant pairwise comparison was detected for the proportion of loose stones on roadways. An interaction was also found between the frequency of roadway repairs and the time elapsed between the identification and treatment of lame cows.

3.7. Avoidance response

A total of 31 variables were included in initial univariate analyses for both CC and SUB; seven variables for each of CC and SUB were retained for inclusion in further multivariable modelling (practicing regular locomotion scoring, cubicle bedding or liming frequency, frequency of feed push-up to the feed-face, droving method [how cows are brought from the paddock to the parlour for milking], presence of a dog when herding cattle, how cows enter the parlour, and employment of additional full-time staff). Whether or not a dog was present when herding cattle to and from milking was identified as a risk factor for the proportion of cows with an avoidance response > 1 m (both CC and SUB; Table 8). Employing additional full-time staff was also identified by both CC and SUB, although with only a tendency for association through CC.

Table 6
Risk factors associated with the proportion of cows with ocular discharge (score 1, 2, or 3) during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

Analysis method[a]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[b]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	24	Collecting yard area[c]		BR	0.004	Below vs Equal/Above	0.51	0.32–0.81	0.006
		Below	42.9	ZI	0.520	Below vs Equal/Above	1.43	0.48 – 4.21	0.522
		Equal/Above	57.1						
		Health record-keeping[d]		BR	0.002	Manual vs Digital	0.48	0.30–0.76	0.003
		Manual	45.5	ZI	0.599	Manual vs Digital	0.75	0.25 – 2.23	0.601
		Digital	54.5						
		Separate sick pens		BR	0.093	No vs Yes	1.48	0.94–2.33	0.097
		No	42.9	ZI	0.655	No vs Yes	0.78	0.26 – 2.32	0.656
		Yes	57.1						
Substitution	24	Health record-keeping[d]		BR	0.003	Manual vs Digital	0.50	0.32–0.79	0.004
		Manual	43.0	ZI	0.639	Manual vs Digital	0.79	0.29 – 2.14	0.640
		Digital	57.0						
		Herd biosecurity status		BR	0.002	Closed vs Open	0.39	0.21–0.72	0.003
		Closed	18.3	ZI	0.913	Closed vs Open	1.07	0.30 – 3.77	0.913
		Open	81.7						
		Footbath		BR	0.012	No vs Yes	1.81	1.14–2.87	0.014
		No	41.9	ZI	0.713	No vs Yes	0.83	0.30 – 2.27	0.714
		Yes	58.1						

[a] Data from 77 farms were included in complete cases analysis and 93 farms in substitution analysis.
[b] The zero-inflated beta regression model fit to the data consisted of two model components: the beta distribution component (BR) and the zero-inflated component (ZI). ZI component estimates the probability of a zero proportion, thus there is an inverse effect of the odds ratio (> 1 is lower odds, < 1 is greater odds).
[c] Collecting yard area: below recommended area of 1.4 m^2/cow (Below), equal or above recommended area of 1.4 m^2/cow (Equal/Above)
[d] Health record-keeping: method classified as either manual (paper, notebook, whiteboard etc.) or digital (computer, app etc.)

Avoidance response > 1 m was positively associated with both herding cows without a dog present and with having no additional full-time staff other than the primary farmer. In addition, an interaction of cubicle bedding or liming frequency with the frequency of feed push-ups was identified (both CC and SUB). Through SUB, droving method was identified as an additional risk factor for the proportion of cows with an avoidance response > 1 m. Always using a vehicle compared to using a combination of methods (including vehicle, on-foot and on their own) was positively associated with an avoidance response > 1 m.

4. Discussion

Animal welfare encompasses a variety of different aspects relating to animals' health, behaviour and affective state (Fraser, 2008). Therefore, it follows that factors affecting indicators of welfare representative of these three pillars would be widely varied as well. In the current analyses, we identified 14 risk factors and three interaction effects that were significant, either in the complete cases or the combined complete cases and substitution analysis methods; each affecting one or more measured welfare indicators of body condition, locomotion, tail lacerations, ocular or nasal discharge, integument damage and avoidance response (Fig. 1). Identified risk factors were grouped according to those related to health management, general farm management and the provided facility resources.

In the following discussion of the identified risk factors, we present possible explanations for their associations with the examined welfare indicators. However, these explanations do not reflect causal relationships but rather potential suggestions for the observed associations based on the literature, with the aim of directing possible future avenues of research. It is also important to keep in mind that when a large number of potential risk factors are examined there is the possibility that some significant associations may occur due to chance. However, as it is not possible to identify if or when this has occurred, all associations are considered plausible and reasonable explanations are discussed when available.

4.1. Health management factors

The proportion of cows scored below the minimum target BCS of 2.75 when on pasture (Table 2; Butler, 2016) was negatively associated with participating in herd-level disease screening. Herd-level disease testing, primarily through bulk milk screening, is an effective and commercially-available method of detecting commonly occurring herd diseases such as bovine viral diarrhoea and infectious bovine rhinotracheitis (Sayers et al., 2015), salmonella, neospora, and leptospirosis (O'Doherty et al., 2013). A high proportion of cows unable to meet the minimum BCS target may be indicative of cows experiencing effects of underlying disease. Alternatively, more proactive farmers that take the initiative to enrol in such disease screening programs may be more conscientious regarding other aspects of herd management, such as maintaining adequate nutrition and body condition. Similar suggestions of farmer attitude influencing farm management can be found in the literature. A review by Adler et al. (2019) found that farmer attitudes identified as "conscientiousness" and "agreeableness" were associated with better farm performance. Furthermore, Barkema et al. (1999) reported that farmers with a management style described as "clean and accurate" kept better records, adhered to procedures such as dry cow therapy and teat disinfection longer and had better overall hygiene than farmers categorised as "quick and dirty".

Two risk factors related to sick-cow management were positively

Table 7
Risk factors associated with the proportion of lame cows (locomotion score 2 or 3) during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

Analysis method[a]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[b]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases[c]	52	Cubicle length[d]		BR	< 0.001	R vs NR	0.60	0.41 – 0.88	0.032
		R	9.1			R vs M	1.08	0.71 – 1.64	0.936
		NR	70.1			M vs NR	0.56	0.43 – 0.73	< 0.001
		M	20.8						
		Road repair frequency[e]		BR	< 0.001	Yearly vs Occasionally	0.50	0.37 – 0.66	< 0.001
		Yearly	23.4			Yearly vs Rarely	0.76	0.56 – 1.02	0.163
		Occasionally	26.0			Occasionally vs Rarely	1.53	1.19 – 1.97	0.006
		Rarely	50.6						
		Previous housing period length		BR	0.023	3 vs < 3 months	0.95	0.74 – 1.22	0.916
		3 months	40.3			3 vs ≥ 4 months	0.69	0.53 – 0.90	0.026
		< 3 months	32.5			< 3 vs ≥ 4 months	0.73	0.54 – 0.98	0.104
		≥ 4 months	27.3						
		Footbath[f] x Herd size[g]		BR	0.003	Footbath, ≤ 80 cows: No Footbath, > 80 ≤ 125 cows	2.29	1.38 – 3.81	0.028
						No footbath, > 80 ≤ 125 cows: Footbath, > 80 ≤ 125 cows	0.39	0.28 – 0.56	< 0.001
						Footbath, > 80 ≤ 125 cows: No Footbath > 125 cows	2.01	1.36 – 2.97	0.013
		Separate lame group[h] x Average percentage loose stones on road to collecting yard[i]		BR	0.006	No SLG, ≤ 25% stones: Yes SLG, ≤ 50% stones	3.70	2.07 – 6.59	0.003
						Yes SLG, ≤ 25% stones: Sometimes SLG, ≤ 50% stones	0.23	0.11 – 0.50	0.026
						Sometimes SLG, ≤ 25% stones: Yes SLG, ≤ 50% stones	3.30	1.77 – 6.17	0.021
						Yes SLG, ≤ 50% stones: Sometimes SLG, ≤ 50% stones	0.16	0.07 – 0.34	0.001
						Sometimes SLG, ≤ 50% stones: No SLG, > 75% stones	2.98	1.69 – 5.26	0.020
Substitution[j]	52	Previous housing period length		BR	0.008	3 vs < 3 months	1.23	0.96 – 1.58	0.255
		3 months	40.9			3 vs ≥ 4 months	0.78	0.60 – 1.01	0.156
		< 3 months	35.5			< 3 vs ≥ 4 months	0.64	0.48 – 0.85	0.007
		≥ 4 months	23.7						
		Furthest paddock distance		BR	0.031	< 1 vs ≥ 1 km	0.77	0.60 – 0.98	0.034
		< 1 km	39.8						
		≥ 1 km	60.2						
		Distance from row exit to end of parlour		BR	0.051	< 2 vs 2 to < 3 m	0.83	0.64 – 1.09	0.383
		< 2 m	29.0			< 2 vs ≥ 3 m	1.14	0.85 – 1.51	0.658
		2 to < 3 m	36.6			2 to < 3 vs ≥ 3 m	1.36	1.06 – 1.75	0.048
		≥ 3 m	34.4						
		Average percentage loose stones on roadway		BR	0.082	≤ 50 vs ≤ 75%	1.46	1.00 – 2.13	0.136
		≤ 50%	15.1			≤ 50 vs > 75%	1.12	0.82 – 1.54	0.764
		≤ 75%	28.0			≤ 75 vs > 75%	0.77	0.60 – 0.99	0.116
		> 75%	57.0						

(continued on next page)

Table 7 (*continued*)

Analysis method[a]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[b]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
		Road repair frequency[e] x Time to treat[k]		BR	0.013	Yearly, ≤ 24 h: Occasionally, ≤ 24 h	0.45	0.29 – 0.70	0.016
						Yearly, ≤ 24 h: Rarely, > 24 ≤ 48 h	0.44	0.29 – 0.67	0.010
						Yearly, ≤ 24 h: Yearly, > 48 h ≥ Week	0.41	0.24 – 0.70	0.046

[a] Data from 77 farms were included in complete cases analysis and 93 farms in substitution analysis.
[b] Only the beta distribution component (BR) of the zero-inflated beta regression model was fit to the data because there were no farms where the proportion of lame cows was equal to zero.
[c] Complete cases method model also included the interaction of separate lame group with herd size, BR: $P = 0.508$
[d] Cubicle length: recommended length of 2.3–2.6 m for wall facing or 2.21–2.45 m for head-to-head/passage facing (R), above or below the recommended length (NR), > 50% herd housed with mix of R and NR cubicles (M)
[e] Road repair frequency: 1 – 2 times/year (Yearly); once every 2 – 3 years (Occasionally); every 4 + years, as required, never (Rarely)
[f] Footbath used: No or Yes
[g] Herd size: ≤ 80 cows, > 80 ≤ 125 cows, > 125 cows
[h] Separate lame group (SLG): No, Yes, Sometimes
[i] Average percentage loose stones on road to collecting yard: ≤ 25%, ≤ 50%, ≤ 75%, > 75%
[j] Substitution method model also included footbath, BR: $P = 0.121$
[k] Time to treat: time from noticing a cow with a mobility or hoof problem to the time that cow is treated: ≤ 24 h, > 24 ≤ 48 h, ≥ 7 d

associated with the proportion of cows with ocular discharge: the use of digitally recorded health records (e.g. computer software or phone app), and farms without designated sick pens. In contrast to our findings, digital methods of record-keeping are designed and expected to improve the accuracy and ease of recording health events on-farm. This was demonstrated by Hille et al. (2017) who reported a negative association between the number of positive cases of *E. coli* and the use of management software. However, benefits of digital health recording software are dependent on correct and routine use, which may not be the case on all farms. Beggs et al. (2019) reported that less than 80% of farms regularly entered farm disease and treatment records into the computer within 7 d, which may introduce the potential for greater error in data input. Secondly, without separate sick and calving pens, shared space between sick and healthy cows is a potential source of disease transmission, particularly around parturition when cows are vulnerable to infection (Crookenden et al., 2016).

4.2. General management

Multiple measures related to the number of on-farm staff were identified as risk factors. Employing part-time staff in addition to the primary farmer was associated with a lower proportion of cows with tail lacerations, possibly because having fewer staff would provide fewer people to monitor animals and observe tail injuries or identify potential hazards. Farms that do not require part-time staff may also be smaller in size, and potentially have older facilities that may be in more disrepair, presenting greater opportunity for injury. Employing full-time staff in addition to the primary farmer was also negatively associated with the proportion of cows displaying a fearful response to an approaching observer. This is supported by the literature which shows that frequent positive contact between cows and humans, particularly through gentle non-aversive handling, is associated with reduced fearfulness (Rushen et al., 1999; Waiblinger et al., 2004) and with reduced avoidance distance (Waiblinger et al., 2003, 2002) in cattle. Animal handling practices were not recorded in this study, thus no conclusion can be made regarding the quality of the animal – stockperson interactions. This is an area that would benefit from further study to better understand this association.

One aspect of on-farm maintenance identified as a risk factor was repairing roadways every two to three years (Occasionally). Chesterton et al. (1989) similarly found roadway maintenance to be a risk factor for lameness on pasture-based farms in New Zealand. That repairing roadways Occasionally posed a greater risk than both those repaired Yearly and Rarely (> every four years or never) may be related to the underlying quality of the roads due to regional or environmental conditions. Farms with naturally poorer quality roadways (e.g. in areas with poor drainage, above average rainfall or frequent flooding) may require repairs annually, while farms in areas conducive to better quality roadways may inherently require infrequent repairs. Additionally, wetter conditions that could necessitate more roadway repairs could also soften hooves and increase the risk of hoof damage and lameness (Borderas et al., 2004). However, environmental conditions such as total rainfall and soil type were not recorded within this study and thus indicates a potential area of further research.

A maintenance-related factor, cleaning of water sources less than once per year, showed a tendency for positive association with moderate or severe nasal discharge. Poorly maintained hygiene of water sources could create reservoirs for infectious pathogens, leading to impaired health (Linn and Raeth-Knight, 2010; Phillips et al., 2003). Contaminated water may also be unpalatable to cows (Morgan, 2011), potentially decreasing water intakes, and leading to dehydration (which may occur at mild levels after reduced water and feed intakes over a 24 hr period; Enemark et al., 2009), predisposing cows to infection (Callan and Garry, 2002).

Where a dog was not routinely involved in herding practices, a greater proportion of cows displayed fearful avoidance responses. Initially this may appear to contrast the expected stress or flight response of cattle to dog vocalisations (Kaurivi et al., 2020). However, a possible explanation may be that cows on farms with noisy or unpredictable dogs would be more accustomed to disturbance and, therefore, be less fearful of a quiet human approach. Even cows exposed to quiet dogs have shown greater vigilance behaviour (a measure of fearfulness characterised by alertness to potential threats) than when exposed to either humans or no fearful stimuli (Welp et al., 2004). On farms where cows are accustomed to the presence of a dog, potentially viewed as a threatening predator, cows may be less threatened by an approaching human, thus accounting for the lower fearful response. As little previous research has focused on avoidance response of dairy cows while at pasture, further study could provide insight into this association.

The length of the previous housing period was identified as a risk factor for both integument damage and lameness, reflecting the connection between management during both the housing and grazing periods. For integument damage, no particular pairwise comparison was significant that would indicate the direction of the association. Although this suggests that some contrast between the three levels of housing period length was significant, the differences were not marked enough

Table 8
Risk factors associated with the proportion of cows displaying a "Fearful" avoidance response of > 1 m (level 1 and 2) during the grazing season on spring-calving, hybrid pasture-based dairy farms in Ireland.

Analysis method[a]	No. factors tested	Retained factors	Prevalence (% of farms)	Model component[b]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	32	Dog while herding		BR	0.001	No vs Yes	1.80	1.26 – 2.57	0.002
		No	63.8						
		Yes	36.2						
		Additional full-time staff		BR	0.056	No vs Yes	1.45	0.99 – 2.12	0.061
		No	74.1						
		Yes	25.9						
		Cubicle bedding or liming frequency[c] x Feed push-up frequency[d]		BR	0.031	OAD bedding, ≤ OAD feed push: < OAD bedding, > OAD feed push	0.23	0.10 – 0.51	0.009
						< OAD bedding, ≤ OAD feed push: < OAD bedding, > OAD feed push	0.19	0.08 – 0.46	0.008
						TAD bedding, ≤ OAD feed push: < OAD bedding, > OAD feed push	0.18	0.07 – 0.45	0.008
						< OAD bedding, > OAD feed push: TAD bedding > OAD feed push	4.40	1.87 – 10.34	0.016
Substitution	32	Dog while herding		BR	0.003	No vs Yes	1.62	1.18 – 2.23	0.005
		No	63.2						
		Yes	36.8						
		Additional full-time staff		BR	0.027	No vs Yes	1.48	1.05 – 2.11	0.031
		No	75.0						
		Yes	25.0						
		Droving Method[e]		BR	0.033	On-foot vs Vehicle	0.84	0.58 – 1.23	0.639
		On-foot	52.9			On-foot vs Combination	1.57	1.01 – 2.45	0.118
		Vehicle	32.4			Vehicle vs Combination	1.87	1.16 – 3.02	0.033
		Combination	14.7						
		Cubicle bedding/liming frequency[c] x Feed push-up frequency[d]		BR	0.044	OAD bedding, ≤ OAD feed push: < OAD bedding, > OAD feed push	0.30	0.14 – 0.63	0.028
						< OAD bedding, ≤ OAD feed push: < OAD bedding, > OAD feed push	0.26	0.11 – 0.63	0.043
						TAD bedding, ≤ OAD feed push: < OAD bedding, > OAD feed push	0.23	0.10 – 0.51	0.008
						< OAD bedding, > OAD feed push: TAD bedding > OAD feed push	4.07	1.86 – 8.94	0.011

[a] Data from 58 farms were included in complete cases analysis and 68 farms in substitution analysis.
[b] Only the beta distribution component (BR) of the zero-inflated beta regression model was fit to the data because there were no farms where the proportion of cows with an avoidance response > 1 m was equal to zero.
[c] Cubicle bedding/liming frequency: once/d (OAD), less than once/d (< OAD), twice/d (TAD).
[d] Feed push-up frequency: once/d or less (≤ OAD), more than once/d (> OAD).
[e] Droving method (method of collecting cows from the paddock to the parlour): on-foot always (On-foot), motorised vehicle always (Vehicle), combination of on-foot and vehicle (Combination)

to be detected by the pairwise comparisons. However, friction and impact with housing features throughout the housing period, particularly involving the hocks and hindquarters, has been shown to cause integument damage such as hair-loss or lesions (Brenninkmeyer et al., 2016; Weary and Taszkun, 2000). It would be expected that with a longer housing period there would be more opportunity for integument damage, although further research is required to confirm such an association within this system.

The positive association between a longer housing period and lameness is more straightforward. During housing, cows are exposed to many conditions associated with lameness, such as hard or slippery flooring surfaces (Endres, 2017; Solano et al., 2015), incorrect cubicle dimensions (Espejo and Endres, 2007; Faull et al., 1996; Haskell et al., 2006), insufficient bedding (Faull et al., 1996) and decreased cow comfort in cubicles (Dippel et al., 2009; Espejo and Endres, 2007). However, the time from onset of changes in a cow's gait to full recovery from lameness is dependent on many factors, including the promptness of identification and treatment (Leach et al., 2012) and the type and size of lesions (Miguel-Pacheco et al., 2017). Due to the potentially lengthy recovery time and the chronic nature of lameness, which has an increased likelihood of recurring in previously affected cows (Green et al., 2014), it is understandable that the effects of housing related risk factors may carry over into the grazing period. Such carry-over effects may explain why similar lameness prevalence was recorded at grazing (10%) compared to when cows were housed (9%; Crossley et al., 2021).

It is less clear why shorter collecting yard holding times were

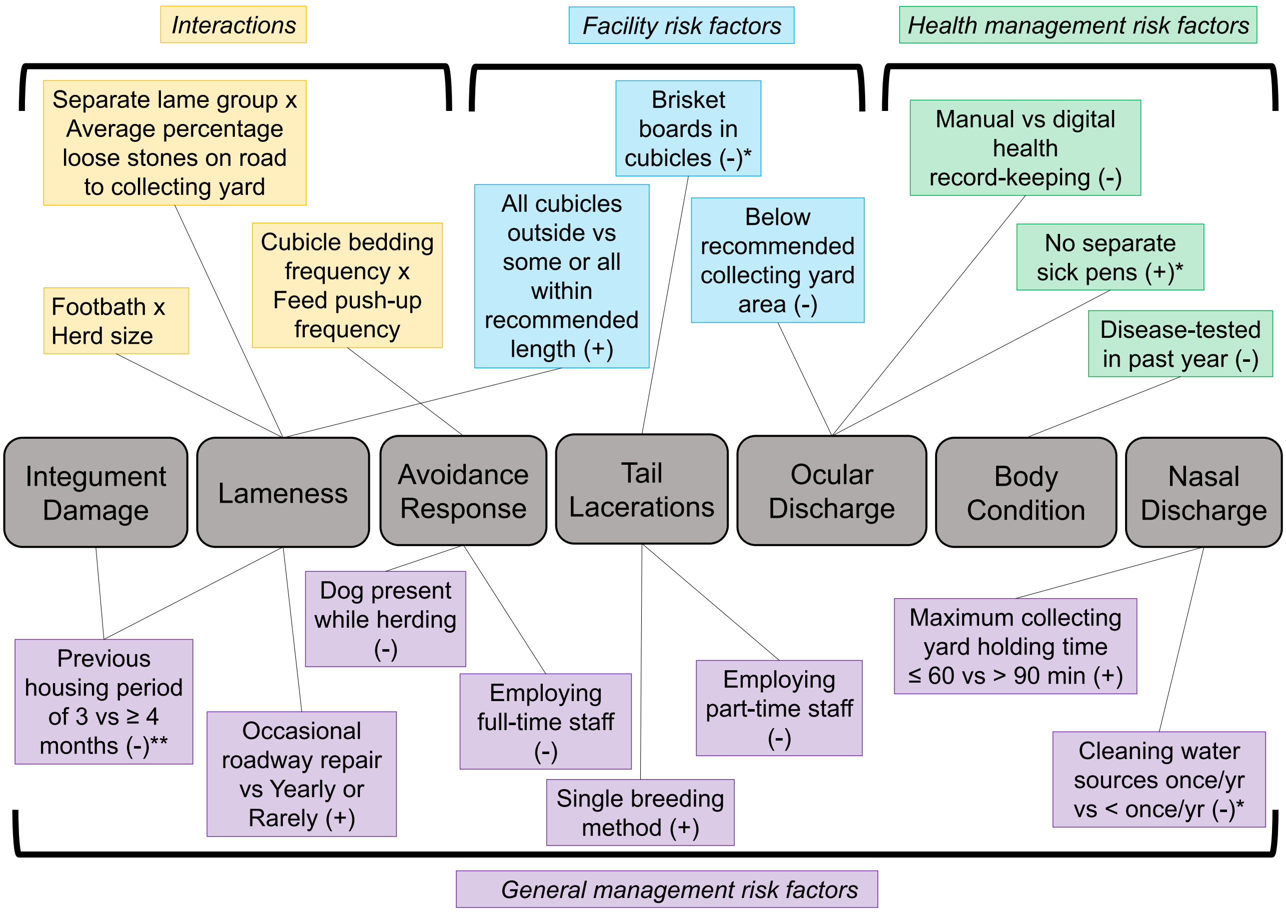

Fig. 1. Risk factors associated with indicators of welfare, grouped by category: general management, health management or facilities. The seven indicators of welfare were integument damage (hair-loss, lesions or swelling), lameness (cows locomotion scored 2 or 3), avoidance response (retreat > 1 m from approaching observer; level 1 and 2), tail lacerations, ocular discharge (cows scored 1, 2 or 3), body condition (below grazing target of 2.75), and nasal discharge (cows scored 2 or 3). Positive associations with the indicator (an increase in effect) are noted by a (+), and negative associations (a decrease in effect) by a (-). Road repair frequency was categorised as 1 – 2 times/year (Yearly); once every 2 – 3 years (Occasionally); every 4 + years, as required, never (Rarely). Cubicle length was categorised as recommended length of 2.3–2.6 m for wall facing or 2.21–2.45 m for head-to-head/passage facing (R), above or below the recommended length (NR), > 50% herd housed with mix of R and NR cubicles (M). Collecting yard area was categorised as below recommended area of 1.4 m^2/cow (Below), equal or above recommended area of 1.4 m^2/cow (Equal/Above) * Tendency ($P < 0.1$) * *Direction of association for integument damage unclear from pairwise comparison ($P > 0.1$).

positively associated with the proportion of cows displaying moderate and severe nasal discharge. Noxious gases and crowded environments, such as that of a collecting yard, are potential irritants and contributors to infection (Callan and Garry, 2002). High levels of ammonia have been shown to emit from urine excreted onto manure dirtied floors within the collecting yard (Misselbrook et al., 1998); thus in contrast to our findings, one would expect shorter holding times within the collecting yard to result in lower nasal discharge. Underlying factors not included in the present analysis, such as the parlour size, ventilation or number of cows in the collecting yard, may be influencing this association. Additionally, no plausible explanations were found as to why the use of a single breeding method over a combination of AI and stock bull, was positively associated with the proportion of the herd displaying tail lacerations. Similarly, there may be correlations with unmeasured factors and further research is required to understand this association.

4.3. Facility resources

Ireland's Department of Agriculture, Food and the Marine (Department of Agriculture Food and the Marine, 2020) recommends a minimum collecting yard area of 1.4 m^2/cow or more. Farms with a collecting yard area less than 1.4 m^2/cow were associated with a lower proportion of cows displaying ocular discharge. These findings are in contrast with the understanding that insufficient space may lead to animal crowding and impact ventilation, both contributing factors to increased airborne pathogens (Callan and Garry, 2002), and therefore increased ocular discharge. In this case, a larger collecting yard area per cow may correspond with larger facilities overall, such as greater roof height (if covered) and increased ventilation that could have a positive impact on occurrence of ocular discharge.

Without brisket boards, cows show more variation in the lying position within the cubicle (Veissier et al., 2004). Thus, the positive association between cubicles without a brisket board and the proportion of cows with tail lacerations is perhaps because they are more able to lie in a manner that leaves their tail in the alleyways, exposing it to injury from alley scrapers and other cows. However, the use of brisket boards has also been associated with reduced lying times (Tucker et al., 2006) and may not be a preferable option for controlling tail injury on farm unless it has become a widespread problem within the herd and no other options are available.

Recommended total cubicle length (from curb to first obstacle, i.e. wall or front rail) ranges from 2.3 to 2.6 m for wall-facing or 2.2 – 2.5 m for head – to – head or passage facing cubicles (Clarke, 2016). Having all sampled cubicle lengths outside these recommended levels (either above or below) was positively associated with the proportion of lame cows. Previous studies have shown associations between lameness and cubicle dimensions in relation to cow size (Dippel et al., 2009; Faull et al., 1996; Haskell et al., 2006). Additionally, Galindo and Broom (2000) found that when cows spent more than 10% of their time perched half-in and half-out of cubicles there was a higher incidence of lameness. Inappropriate cubicle dimensions have been associated with increased perching behaviour (Anderson, 2003; Lombard et al., 2010). Perhaps when cubicle dimensions were outside recommended lengths in the present study this resulted in more cows standing incorrectly in cubicles, leading to increased weight bearing and development of claw horn lesions (Cook et al., 2004). Improper cubicle dimensions could also be problematic when there is a wide variety of animal sizes within the herd due to breed differences. For example, larger purebred Holstein cows, may be less suited to housing designed with a smaller cross-bred animal in mind. In the current study a relatively small proportion of herds (8%) were composed of more than 50% Holstein cows, with the remainder being cross-bred or smaller breeds such as Jerseys. The effect of breed composition on locomotion score was examined further and no significant correlation was found.

4.4. Risk factor interactions

Multiple interacting variables were identified as risk factors for lameness. The interaction between footbath and herd size suggests there is little difference in the relative proportion of lame cows between farms that use a footbath or not, when those farms are below average or large in size. However, on average sized farms (81–125 cows), there was a significantly greater risk of having lame cows when a footbath was used. Most likely this is due to a higher incidence of lameness on those farms, which motivated farmers to use a footbath, rather than that footbathing resulted in lameness. Similar conclusions regarding the relationship between footbath use and lameness have been described in the literature (de Vries et al., 2015; O'Connor et al., 2020).

The interaction of separate lame cow group with the proportion of loose stones on roadways to the collecting yard indicated that when farms sometimes or never kept a separate lame group there was a greater proportion of lame cows than when there was always a separate lame group; however the greatest proportion of lame cows occurred at a different percentage of loose stones for each level of separate lame group frequency. This would suggest that track quality and stoniness played a role in the decision to maintain a separate lame group, perhaps because of the negative impact that rough roadways can have on lameness (Chesterton et al., 1989; Doherty et al., 2014).

For the indicator avoidance response, the interaction between the frequency of cubicle bedding and the frequency of feed push-up to the feed-face indicated, in general, that if cubicles were bedded more frequently, and feed pushed in less frequently during housing, there was reduced fearful avoidance response of cows in the paddock. The greatest response occurred with the combination of bedding cubicles once per day and feed push-up more than once per day compared to all others. Avoidance distance is highly correlated with continued positive contact with stockpersons (Hemsworth et al., 2000; Waiblinger et al., 2003), so it is understandable that increased frequency of cubicle bedding, requiring stockpersons to enter the pen, would result in a decreased fearful avoidance response. What is unclear from this interaction is why reduced fearful response was observed with less frequent feed push-up. More research is required to understand this association. In general, the fact that contact during housing continued to affect avoidance response during grazing emphasizes the lasting effect of human-animal interactions.

4.5. Risk factors identified through substitution

Incorporating the substitution method into our analysis enabled us to include information from more farms and provide confirmation of identified risk factors in a situation where a relatively small number of farms with complete data were available. While this method utilises estimated data, when applied to only a small amount of missing values ($\leq$ 5% in the present study) the potential for error is minimized (Curley et al., 2019). In conjunction with analysis of only complete cases, variables retained by models through both methods could be confidently identified as risk factors for welfare. Variables identified as risk factors only after substitution (for BCS: herd size; for integument damage: cubicle length; for nasal discharge: collecting yard area and whether majority covered; for ocular discharge: herd biosecurity status and footbath use; for lameness: furthest paddock distance, distance to end of parlour and percentage of loose stones on roadways; and for avoidance response: droving method) are potentially due to the inclusion of estimated data; however, would still benefit from further research to determine the nature of possible associations with welfare.

4.6. Carry-over effects

Despite the fact that welfare indicators were measured at a median of 132 days into the grazing period, there were still multiple identified risk factors pertaining to the facilities and management of cows during the housing period. Length of the previous housing period in particular was associated with both lameness and integument damage. While the housing period on Irish hybrid pasture-based dairy farms represents a relatively small proportion of the season compared to the grazing period, it still clearly has a considerable impact on dairy cow welfare. Previous studies have reported that integument damage, such as hair-loss and lesions, persists into the grazing season with gradual improvement over time (Armstrong, 2020; Burow et al., 2013a; Rutherford et al., 2008). Furthermore, the appearance of sole lesions typically occurs 8 – 12 weeks after the damage has taken place (Nocek, 1997), making it possible that cows diagnosed as lame months into the grazing period could, in fact, reflect injuries that occurred during housing. Over time, access to pasture has been shown to help improve lameness recovery (Hernandez-Mendo et al., 2007), but this can be a gradual process, resulting in cows diagnosed as lame during housing that persist into the grazing period. Similar to the carry-over effects of some negative aspects of housing, positive effects on dairy cow health and welfare have also been reported to carry-over from the grazing into the housing period (Arnott et al., 2017; de Graaf et al., 2017). Results of the present study emphasize the importance of studying hybrid pasture-based systems as a whole rather than focusing on the grazing or housing periods in isolation.

5. Conclusion

Fourteen risk factors were identified that impact a variety of welfare indicators for grazing dairy cattle: disease testing within past 12 months, breeding method, employing part-time and full-time staff in addition to the primary farmer, brisket boards in cubicles, health record-keeping method, previous housing period length, whether a dog is present while herding, maximum collecting yard holding time, water source cleaning frequency, collecting yard area, separate sick pens, cubicle length and frequency of roadway repairs. These risk factors reflect a variety of management and resource attributes measured on farm, some of which pertain to the time cows spend in housing during winter. Carry-over effects of housing into the grazing period emphasize that it is imperative to consider welfare in hybrid pasture-based dairy systems throughout the whole year rather than only at grazing. Identified risk factors provide avenues for future research, as well areas of focus for farms trying to improve or maintain good welfare.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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