Dairy cow welfare in spring-calving, pasture-based systems

Robin Crossley

Propositions

1. When considering dairy cow welfare, the housing period is an overlooked aspect of Irish pasture-based systems.
   (this thesis)

2. Damaged tails are the most puzzling challenge to solve in Irish dairy cow welfare.
   (this thesis)

3. Just because there is data to collect does not mean it is worth collecting.

4. The global pandemic has made scientific literacy an essential life skill.

5. Video calls are now the key to achieving a work-life balance.

6. Speaking the same language does not guarantee understanding.

Propositions belonging to the thesis, entitled
Dairy cow welfare in spring-calving, pasture-based systems.

Robin E. Crossley
Wageningen, 23 May 2022

Dairy cow welfare in spring-calving, pasture-based systems

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ABSTRACT

While pasture-based dairy production is often believed to provide cows with the best welfare due to its apparently more natural environment, challenges to dairy cow welfare are present within this system nonetheless. Even in spring-calving pasture-based systems, maintaining good animal welfare in dairy production is challenged by increased intensification. The three aims of this thesis were 1) to conduct a welfare assessment of spring-calving, pasture-based dairy farms in Ireland and identify the current state of dairy cow welfare, 2) to use the data collected through this welfare assessment to identify risk factors for welfare during both the grazing and housing periods, and 3) to investigate the effects of increased grazing intensity on indicators of welfare.

To achieve the first two goals a welfare assessment was conducted, incorporating both grazing and housing periods, to over 100 farms throughout southern Ireland. Data were collected on seven animal-based welfare indicators: locomotion, body condition, ocular and nasal discharge, integument damage, tail injury, and avoidance response to human approach. Opportunities to improve welfare included identifying causes and prevention of tail injury, nasal discharge, integument damage and fearful avoidance response, as well as the continued reduction of lameness despite being relatively low in comparison to other systems. Performance benchmarks were also established for each indicator which reflect the top and bottom performing 20% of study farms. These benchmarks illustrate the wide variation between farms and provide a reference for farmers to compare their performance and promote improvement.

Separate risk factor analyses were performed for each welfare indicator during both the grazing and housing periods. Analyses identified 14 unique risk factors associated with one or more welfare indicators for the grazing period. Multiple risk factors were related to the housing period, thus, it was concluded that carry-over effects of housing may persist into the grazing period. Housing period analyses identified 35 unique risk factors for welfare. A large number of risk factors associated with tail injury during housing suggests further study of the causes and prevention methods would contribute to improved welfare of dairy cows. Associations between recommended guidelines for housing features and greater negative welfare indicators suggests guidelines may benefit from regular re-evaluation to ensure facilities meet the welfare needs of cows during the housing period.

To achieve the final goal of this thesis, an experimental study was conducted to determine the effects of differing levels of increased grazing pressure, characterised by differing pasture allowances and stocking rates, on welfare indicators between the early and late grazing periods. Examined welfare indicators were locomotion score, hoof health, rumen fill, ocular and nasal discharge, and integument damage. Only minor treatment effects were found on welfare indicators, yet all indicators except rumen fill and locomotion score demonstrated significant improvements from early to late grazing.

Through this thesis knowledge was gained on the current state of welfare in spring-calving pasture-based dairy farms in Ireland. Identified risk factors will aid in guiding future research and on-farm recommendations to promote continued improvement of dairy cow welfare. It was also concluded that cows were able to cope well with increased grazing pressure, and that regardless of treatment, more time on pasture led to improvements in welfare.

According to Irish farmers,
good dairy cow welfare means…

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| CHAPTER 1 |

General Introduction

Animal welfare and sustainable dairy production

Dairy products are an excellent source of nutrition, which are in increasing demand by a rapidly growing worldwide population (FAO and GDP, 2018; Moscovici Joubran et al., 2021). Dairy production also plays an important role in global sustainable development because it enables the efficient conversion of human inedible forage into human digestible protein (Patel et al., 2017). This is especially true for pasture-based dairy production characteristic of countries such as Ireland, where the majority of the cows' diet is derived from grazed pasture rather than supplemented feed containing human-edible protein (Patel et al., 2017). However, dairy production also contributes to the many challenges of sustainable development, such as production of greenhouse gas emissions (FAO and GDP, 2018), progression of antimicrobial resistance (Oliver et al., 2011; Clark et al., 2016), and the impairment of animal welfare (Broom, 2019; Segerkvist et al., 2020).

In regards to dairy production, animal welfare can be linked to each of the three pillars of sustainability (environmental, economic, and social sustainability; Purvis et al., 2019). Well-cared for animals have less impact on the environment (Mostert et al., 2018c; 2018b) and are healthier, therefore requiring fewer or less costly treatments for illness (Bruijnis et al., 2010; Mostert et al., 2018a). However, animal welfare is typically considered to be part of the social domain, as acceptance by the public is a key factor in continued livestock production (Tucker et al., 2013). According to the 2015 Eurobarometer survey, 94% of Europeans polled, and 97% of Irish citizens specifically, consider the protection of farm animal welfare to be an important goal (European Commission, 2016). Furthermore, 80% of Irish citizens feel that animal welfare should be better protected, an increase of 22% between 2006 and 2016 (European Commission, 2016). With consumers increasingly concerned with farm animal welfare and the care of animals that produce their food, it is vital to the continuity of the dairy sector to ensure continued improvement of animal welfare. Underlying all of these concerns for the importance of animal welfare is the ethical motivation. As caretakers of dairy cows, stakeholders in the dairy sector have a responsibility to ensure the best possible welfare to the animals in their care, and that they are able to experience a life worth living (FAWC, 2009).

Describing animal welfare

There are numerous concepts of what constitutes animal welfare, and they range from complex definitions which attempt to outline all specific needs of an animal, to definitions which simply ask whether an animal is healthy, and whether it has what it wants (Dawkins, 2008; FAWAC, 2009). Early animal welfare research primarily focused on the prevention of negative states or experiences. This is apparent through the widespread adoption of the Five Freedoms welfare framework. The Five Freedoms are a set of guidelines describing conditions required to provide good welfare to animals: freedom from thirst, hunger and malnutrition; freedom from discomfort and exposure; freedom from pain injury and disease; freedom from fear and stress; and freedom to express normal behaviour. Originally envisioned as a method of translating areas of welfare study and concern for the lay-person, the Five Freedoms were introduced in 1993 and soon became the guiding principles for animal welfare legislation and research internationally (FAWC, 1993, 2009). However one shortcoming of the Five Freedoms is their emphasis on avoiding negative states, rather than promoting positive states. Thus current considerations of animal welfare involve a revised version that re-focuses the Five Freedoms to emphasize Five Provisions (good nutrition, good environment, good health, appropriate behaviour and positive mental experiences) required for good welfare, and outlining practical methods of achieving them (Mellor, 2016a; 2016b).

Another common animal welfare concept is that good welfare involves the interconnection of three different aspects: basic health and functioning - that animals have the basic necessities for a healthy life; natural behaviour - the animal's ability to express normal behaviour which they are motivated to perform; and affective state - the emotions or mood of an animal, influenced by both pleasant and unpleasant experiences (Fraser et al., 1997; Fraser, 2008). While some research may focus on individual aspects of health, behaviour or affective state, it is understood that the most complete picture of an animal's welfare is gained by considering the impacts of all three (Hewson, 2003). Furthermore, it could be interpreted that the behavioural indicators and physiological biomarkers are what provide us insight into the affective states of an animal, and enable a better understanding of their welfare (Webb et al., 2019).

Assessing animal welfare

As animal welfare is a concept rather than a physical characteristic of an animal, it is impossible to measure directly. Instead, a variety of different indicators are measured that together can provide information about the animal, how it copes with its environment, and insight into their overall experience. These indicators are commonly grouped into three categories: resource-based, management-based and animal-based measures. Resource-based measures are those that examine what is provided to animals to maintain welfare, such as feed and water availability, or appropriate facilities and lying space. Management-based measures are the result of farmer decisions, such as procedures for feed provision, treatment of sick animals, and the use of technology.

Finally, animal-based measures are those that reflect the influence of the environment and management practices on the animal themselves (e.g. behaviour, injury and response to stockpersons). Until we are able to assess affective state directly, these animal-based measures provide valuable information regarding an animal's welfare. For this reason, animal-based measures are often emphasised in welfare assessment protocols applied on farms.

Several different on-farm dairy cow welfare assessment protocols are used internationally, including AssureWel from the UK (AssureWel, 2018), the FARM program in the USA (National Milk Producers Federation, 2019), and the Welfare Quality® protocol in the EU (Welfare Quality®, 2009). These and similar assessment protocols employ a combination of resource-, management- and animal-based measures to monitor changes in welfare outcomes. The Welfare Quality® Assessment protocol for cattle was developed in collaboration with 40 institutions in 13 European and four Latin American countries, and categorises a series of collected animal-based measures into four areas: good feeding, good housing, good health and appropriate behaviour (Welfare Quality®, 2009). These categories were, in fact, also incorporated into the development of the Five Provisions concept of welfare (Mellor, 2016a). However, despite its widespread use, the Welfare Quality® protocol is not without its disadvantages. One limitation is that, like many existing welfare assessment protocols, it was designed to assess animals when housed rather than on pasture, which is the typical situation in pasture-based dairy systems. Because of this, the measures are not always applicable or appropriate to be carried-out as described. This is particularly evident in regards to one of the four main categories, "good housing", which would be problematic to evaluate in a herd which spends the majority of their lactation without housing facilities. Furthermore, for pasture-based cows specifically, it includes no measure of quality, length or management of roadways, which may be a risk factor for lameness in pasture-based systems (Chesterton et al., 1989; Lawrence et al., 2011). It also includes measures of avoidance distance carried out at the feed-face, which is less feasible when cows are only fed indoors for a relatively small portion of the year.

Pasture-based dairy production

Pasture-based dairy production is the most common management system worldwide (Boken et al., 2005), despite having reduced milk yields in comparison to continuous-housing systems (Fontaneli et al., 2005). It is the predominant system particularly in regions with temperate climates such as Ireland, New Zealand, UK, Australia, Argentina, Azores, and several countries in continental Europe e.g. Netherlands and France (Mee, 2012; Roche et al., 2017; Centraal Bureau voor de

Statistiek, 2019). As they are so widespread, the management of pasture-based systems can vary between locations; some provide full-time pasture access year-round, while others provide un-roofed cubicles, a feeding pad, or full-time housing for several months during winter (Mee, 2012; Mee and Boyle, 2020). Systems that involve periods both at pasture and in housing could also be characterised as hybrid systems, because cows are presented with the benefits and challenges of both indoor housing and outdoor pasture conditions (Mee and Boyle, 2020) and carry-over effects may also exist between the periods (de Graaf et al., 2017).

In Ireland, management of pasture-based dairy production is characterised by reliance on grazed forage or stored grass-silage as the primary component of the cows' diet (O'Brien et al., 2018; O'Donovan et al., 2021). This system has a strong reputation for being low-cost and environmentally sustainable (Dillon et al., 2008; Leip et al., 2010). Productivity, and profitability, are driven by improving pasture utilisation and increasing the proportion of grazed grass in the cows' diet (Dillon et al., 2008; Hanrahan et al., 2018). In typical seasonal-calving systems, the predominant method of dairy production in Ireland, the aim is to calve 90% of the herd within a single 50 - 60 day period (Roche et al., 2017), timed to coincide with the beginning of optimal grass growth which spans from April to October (Hennessy and Roosen, 2003). On average, the grazing season on Irish pasture-based farms is approximately 240 days (Creighton et al., 2011). When grass growth slows, cows are dried-off and housed throughout the winter months (approx. November-February) until calving the following spring. While grazing cattle may give the appearance of an extensive, agrarian system, the use of efficient, rotational-grazing practices that maximise milk solids production/ha, at increased stocking rates are defining attributes of intensive dairy production (Coffey et al., 2018; Mee and Boyle, 2020).

Intensification of pasture-based systems

Since the removal of European milk production quotas in 2015, the Irish dairy sector has undergone considerable expansion and intensification. In the last year prior to the elimination of quotas, dairy farms were an average of 55 ha in size, with 70 cows/herd (Hennessy and Moran, 2015). As of 2021, these figures have increased to an average dairy farm size of 60.5 ha, 82 cows/herd (Dillon et al., 2021a). The total number of farms also decreased from approximately 22,000 in 2005 to just over 18,000 in 2016 (Kelly et al., 2020), and currently to approximately 16,000 (Dillon et al., 2021a). Additionally, there has been a shift in the distribution of farm sizes, with only 14% of cows in herds greater than 100 cows in 2005, but 47% of cows in 2016 (Kelly et al., 2020). With such a high level of expansion and intensification, it is important to consider the potential impacts on dairy cow welfare.

With land being a limiting factor in herd expansion (Läpple et al., 2012a), farms may become more fragmented, and farmers may turn to zero-grazing practices to harvest and deliver fresh grass to cows from inaccessible parcels of land (Holohan et al., 2021). This could increase the time cows spend indoors, which may negatively impact aspects of their welfare, for example reduced hoof health and greater integument damage (Burow et al., 2013b; de Graaf et al., 2017; Wagner et al., 2018). Time spent by cows walking back and forth from the paddocks to the parlour will also increase with greater farm sizes, potentially reducing the time available for other important behaviours such as lying (Beggs et al., 2019). Improving pasture utilisation through higher stocking rates may lead to reduced body weights and BCS due to reduced individual daily herbage allowance and dry matter intakes (McCarthy et al., 2012, 2014). A study by Ma et al. (2020) on factors associated with herd health expenditures, found that they decreased with increasing herd size. Although the authors speculated that this may be an effect of increasing scale diluting the overall costs, they also considered that perhaps farmers were less able to monitor animal health in larger herds. This same study found an association between more hired labour and increased herd health expenditures. The authors suggested it could be due to better ability to identify health problems with more staff, yet that it may also be due to a lack of training among new staff leading to delayed diagnoses and greater overall costs.

Welfare of dairy cows in pasture-based systems

There is a strong belief that pasture-based dairy production provides the best welfare as it is perceived to be the most natural (Arnott et al., 2017; Charlton and Rutter, 2017). Public opinion reflects this, as studies of individuals in a variety of countries, from Canada and the US to Europe and the UK, have demonstrated a majority preference for cattle to be managed extensively with access to pasture (Ellis et al., 2009; Schuppli et al., 2014; Moscovici Joubran et al., 2021). Indeed, cows themselves have shown an overall preference for pasture when given the choice (Von Keyserlingk et al., 2017; Smid et al., 2018). For example, in preference tests by Legrand et al., (2009) and Falk et al., (2012), cows spent 54% and 57% respectively of total time on pasture as opposed to indoors. However, these and further studies indicate this preference varies with time of day and weather conditions such as rain and temperature-humidity index (Legrand et al., 2009; Falk et al., 2012; Arnott et al., 2017; Charlton and Rutter, 2017).

Providing an environment suited to cows' normal behaviour expression is a strength of pasture-based systems. Grazing, followed by ruminating and resting, are the primary behaviours performed by domesticated cattle on pasture, which together can account for up to 90 - 95% of their daily time budget (Kilgour, 2012). When unrestricted, cows will spend approximately 9 - 9.5 hr/d grazing (Kennedy et al., 2009; O'Driscoll et al., 2010b), and cows can modify their intakes by altering bite rate and size (dry matter intake per bite) to meet nutritional requirements (Kennedy et al., 2009). Resting and lying are highly motivated behaviours in dairy cows, regardless of production system (Krohn and Munksgaard, 1993; Munksgaard et al., 2005). Housed cows are reported to spend between 8 – 14 hr/d lying (Krohn and Munksgaard, 1993; Tucker and Weary, 2004; Charlton and Rutter, 2017). Grazing cows show somewhat lower lying times of 9 - 10.5 hr/d (O'Driscoll et al., 2010a, 2015); however, this is likely related to the greater demands on pasture-based cows for standing and walking to facilitate grazing. Yet even while standing, pasture provides a more comfortable, softer surface than indoor flooring (Charlton and Rutter, 2017). The lack of cubicle restrictions also allows cows the freedom to lie wherever they like and in any position they choose, e.g. in stretched out body postures (Krohn and Munksgaard, 1993), without risk of injury due to contact with housing features. Lying is a synchronous behaviour that cows are motivated to perform together at certain times of day (Flury and Gygax, 2016). Although synchronous lying behaviour takes place in both housing and at pasture, it is more pronounced at pasture where there is reduced competition for lying space compared to fully or overstocked cubicle housing (Crump et al., 2019).

With respect to health and biological function, among the many positive effects of pasture on cows, studies have demonstrated reductions or improvement in clinical lameness (Haskell et al., 2006; Hernandez-Mendo et al., 2007; Olmos et al., 2009a), reduced integument alterations (Burow et al., 2013b; Kester et al., 2014; Zuliani et al., 2018), and lower prevalence of mastitis (Washburn et al., 2002). However, negative effects have also been reported, such as metabolic signs of nutritional stress in early lactation compared to continuously housed cows (Olmos et al., 2009b), greater exposure to parasites (Arnott et al., 2017) or the transmission of infectious agents through contact with neighbouring livestock (Mee, 2012; Arnott et al., 2017). It is also common in a pasture setting for cows to be exposed to solar radiation, and inclement or changeable weather, often with little to no access to shelter (Van laer et al., 2014). This may result in periods of thermal stress, either heat or cold, even in temperate climates (Kendall et al., 2006; Van laer et al., 2014). It can be difficult for cows to adapt to sudden intermittent fluctuations of cold and wet weather (Bergen et al., 2001; Kennedy et al., 2005a; Arnott et al., 2017), particularly if they exceed the cow's thermoneutral zone; the range (approximately 5 – 25 °C for lactating dairy cows) when extra energy is not required to maintain normal body temperature (Becker et al., 2020). Cows have also shown a preference for shade that blocks more solar radiation, even in mild summer temperatures that do not exceed 25°C (Schütz et al., 2009).

All aspects of a cow's environment may affect their affective state either positively or negatively, yet this is considerably more difficult to measure directly than health or behaviour. Affective state is a subjective experience that varies in the quality or "valence" of an experience (either pleasant or unpleasant) and intensity or "arousal" (high or low), and may be of short duration (emotions) or long (mood) (Webb et al., 2019). For example the play behaviour (galloping, jumping, bucking) exhibited by cows when they are released to pasture following extended periods indoors (Loberg et al., 2004) may be interpreted as a highly pleasant experience and therefore suggestive of a positive affective state. Conversely, fearful response to humans may be interpreted as either a low or highly unpleasant experience, and thus suggestive of a negative affective state. Even in a pasture-based setting, human stockpersons must work closely with animals for milking, herding and routine health procedures, thus a good human-animal relationship is critical to the safety of both the cow and the stockperson. A history of negative interactions with humans may cause a fearful response from cows in these situations (Waiblinger et al., 2002). In contrast, continued positive interactions between cows and stockpersons, and gentle handling can reduce fearful responses and improve the human-animal relationship (Hemsworth et al., 2000; Waiblinger et al., 2003, 2004). Cows may also experience feelings of hunger if pasture allowance or quality is insufficient to meet energy demands (von Keyserlingk et al., 2009), especially in periods of high milk yields such as during peak lactation. Additionally, a painful condition such as lameness (Coetzee et al., 2017) may be exacerbated by long walks between paddocks and milking parlour. However, recent work has shown that pasture may provide dairy cows with a more rewarding environment than indoor housing, as they displayed less anticipatory behaviour to food rewards in a judgement bias test, suggesting that pasture promotes more positive emotional states (Crump et al., 2021).

Improving welfare on pasture-based farms

Although cows on Irish spring-calving, pasture-based dairy farms spend the majority of their lactation at pasture, they are also exposed to the effects of periods of indoor housing. Thus, it is important to monitor their welfare both outdoors and indoors, and strive for continued improvement at all stages. To address this gap in our knowledge, a welfare assessment is required that is adapted to address the unique challenges of evaluating cows during the grazing season, while also incorporating the experiences of cows when housed. However, until now, no such comprehensive welfare assessment, which incorporates multiple animal-based measures of welfare, has been conducted in a spring-calving, pasture-based system such as that found in Ireland. Without current, accurate baseline data on the status of dairy cow welfare in this system we have been unable to identify the areas in greatest need of improvement, as well as those areas where good welfare is being achieved, nor have we been able to establish benchmarks for continued enhancement. Lacking current data also prevents us from identifying risk-factors necessary to direct future welfare research and on-farm efforts into improving the areas where welfare is most impaired. Finally, in light of the on-going changes in the Irish dairy sector and the intensification of dairy production worldwide, there is also a need to examine how such intensification will impact welfare.

General aims and thesis outline

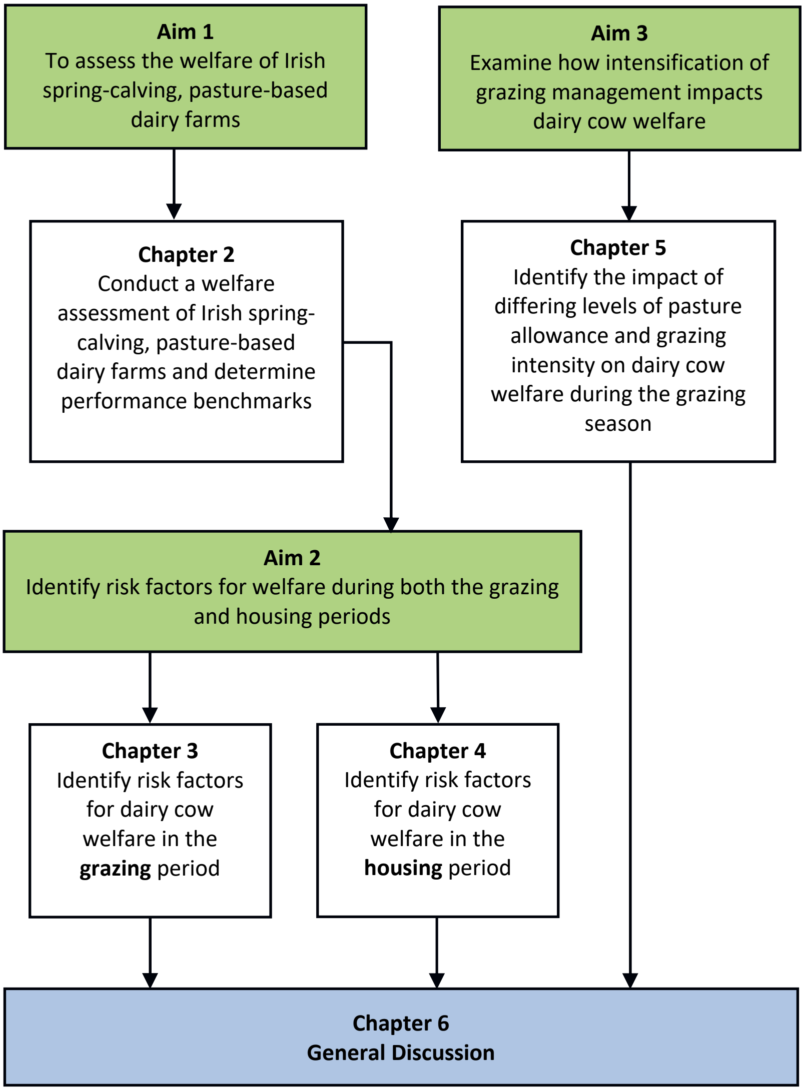

Figure 1. Summary of the research process followed for this thesis.

The general aims of this thesis were, firstly, to conduct a welfare assessment to identify the current state of welfare among spring-calving, pasture-based dairy farms in Ireland. The second aim was to use the data collected through this welfare assessment to identify risk factors for welfare during both the grazing and housing periods. The final aim was to examine how measures of welfare are influenced by increasing levels of grazing management intensity on spring-calving pasture based dairy farms.

The outline of this thesis is presented in Figure 1. In Chapter 2, the welfare assessment protocol applied is described and the resulting prevalence of select welfare indicators is identified and compared for both the grazing and housing periods. This information is used to establish performance benchmarks for the improvement of dairy cow welfare on-farms. In Chapter 3, based on the results of this welfare assessment, risk factors for welfare during the grazing period are identified. In Chapter 4, further welfare risk factors are identified for the housing period. In Chapter 5, the effects of intensification of grazing management are examined through experimental assessment of the effect of different levels of pasture allowance and grazing intensity on indicators of dairy cow welfare. Finally, in Chapter 6, the results of the previous chapters are amalgamated into a discussion of the overall current state and future directions of dairy cow welfare in spring-calving, pasture-based dairy production.

| CHAPTER 2 |

Assessing dairy cow welfare during the grazing and housing periods on spring-calving, pasture-based dairy farms

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ABSTRACT

The different periods characterising spring-calving, pasture-based dairy systems common in Ireland have seldom been the focus of large-scale dairy cow welfare research. Thus, the aim of this study was to devise and conduct an animal-based welfare assessment during both the grazing and housing periods on spring-calving, pasture-based dairy farms, to identify areas for improvement and establish benchmarks for indicators of good welfare. Assessment of seven animal-based welfare indicators was conducted during two visits (one each at grazing and housing) to 82 commercial dairy farms in southern Ireland. Herd-level descriptive statistics were performed for all welfare indicators at each visit, and differences between visits were analysed using paired t-tests and Wilcoxon signed rank tests. A mean of 9% and 10% clinically lame cows (locomotion score 2 and 3) were observed at housing and grazing respectively. Recommended body condition scores (BCS) were not met for a mean of 13% of cows at grazing and 23% at housing, with more over-conditioned cows present at housing than grazing ($P < 0.001$). Ocular discharge was uncommon in both periods. Prevalence of moderate and severe nasal discharge combined were lower during housing (5%) than grazing (7%). In both periods, similar mean levels of tail injury were observed; 2 to 3% of cows with tail lacerations, 9% with broken tails, and 8% (measured at housing only) with docked tails. Integument alterations involved primarily hair-loss and were most prevalent on the hindquarters (26%) during grazing, and on the head-neck-back region (66%), and the hindquarters (32%) during housing. Cows displayed an avoidance distance of > 1 m (indicative of a fearful response) from an approaching human in an average of 82% of grazing cows and 42% to 75% of housed cows, dependent on test location. Opportunities to improve welfare in this system were identified in the areas of tail injury prevention, nasal health and the management of indoor housing and feeding. The performance of the top 20% of farms for each welfare indicator was used to establish benchmarks of: 0 to 5% clinical lameness; 0 to 12% of cows outside recommended BCS; 0 to 27% ocular discharge; 2 to 16% nasal discharge; 0% tail lacerations and docked tails, and 0 to 3% tail breaks; 0 to 14% integument alterations; and 4 to 74% for avoidance distance of > 1 m. These represent attainable targets for spring-calving pasture-based farms to promote good dairy cow welfare.

Keywords: animal-based, avoidance behaviour, body condition, cattle, health, lameness

INTRODUCTION

Maintaining good animal welfare is a vital component of a sustainable dairy production system. Not only to sustain continued support from the public, but also because producers have an ethical responsibility to ensure that the animals under their care are free from unnecessary suffering and able to experience a life worth living. Optimal welfare requires that animals have all the necessities to maintain good biological health and function, are able to perform important and highly motivated natural behaviours and able to experience an overall positive affective state (Fraser, 2008). What most on-farm welfare assessment protocols have in common is their use of animal-based indicators of welfare, chosen because they directly reflect the experience of a cow within her environment as opposed to the resources provided (Whay et al., 2003; Webster et al., 2004). However, the majority of existing dairy cow welfare assessment protocols have been designed to evaluate animals when housed and thus do not take into account the grazing period in pasture-based dairy production systems.

Whereas there are many advantages of access to pasture on dairy cow welfare, including reduced prevalence of lameness (Olmos et al., 2009) and mastitis (Washburn et al., 2002) and the ability to perform natural grazing behaviours, there are also challenges. Cows at pasture have a greater risk of internal parasites (Mee, 2012) and are exposed to inclement weather, such as rain, wind or heat, rarely with access to shelter (Van laer et al., 2014). When cows are transferred indoors for the winter housing period they must contend with additional challenges, such as a change in diet from grazed pasture to silage (O'Driscoll et al., 2008), introduction to concrete or slatted flooring which may negatively affect claw health (Cook et al., 2004), reduced air quality (Casey et al., 2006), and reduced feeding and lying space allowance which may lead to increased agonistic behaviour (Kondo et al., 1989).

To date there has been little large-scale research into the welfare of dairy cows encompassing both phases of pasture-based systems which include a period of housing. Most previous studies of these systems have been small in scale, such as Olmos et al. (2009), which focused on groups of cows on a single Irish farm managed either at pasture or in continuous housing. Burow et al. (2013) evaluated 41 Danish herds, yet with a minimum access to pasture of only 5 h/d for ≥ 120 d/yr. Wagner et al. (2018), who studied a combination of 32 organic and conventional herds in Germany, categorised pasture access time between 0 to ≥ 12 h/d, and all farms were provided additional silage year-round. In contrast, cows on a typical Irish pasture-based dairy farm are at pasture 24 h/d for an average of 229 d/yr (Teagasc, 2019).

The paucity of dairy cow welfare data available for Irish pasture-based systems is particularly noteworthy considering that the Irish dairy sector has undergone substantial growth in recent years resulting from the elimination of European Union milk production quotas in 2015. Since this time in Ireland, farm sizes have increased by 7% to an average of 59 ha, herd sizes have increased by 13% to an average of 80 cows/farm and the total number of dairy cows in the country has increased by 21% to 1.4 million animals in 2019 (Hennessy and Moran, 2015; Donnellan et al., 2020). Such expansion throughout the sector poses a potential risk to dairy cow welfare if management practices and infrastructure are not adapted to the continually expanding herd and farm sizes.

In order to optimize cow welfare and ensure a sustainable dairy sector it is vital to understand the impact of current on-farm management practices. Therefore, the objective of this study was to devise and conduct an animal-based welfare assessment during both the grazing and housing periods on a large cross-section of Irish, spring-calving, pasture-based dairy farms. Through descriptive analysis of different welfare measures, this study further aims to identify areas for improvement and establish benchmarks for various animal-based indicators of welfare.

MATERIALS AND METHODS

All experimental procedures received ethical approval from the Teagasc Animal Ethics Committee (TAEC 197-2018), and were conducted 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. All statistical procedures were carried out using SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

Farm Selection Criteria

This study includes data from 82 commercial dairy farms in the Republic of Ireland, visited twice between April 2019 and February 2020. Farms were selected from the Irish Cattle Breeding Federation (ICBF), the national information database for the dairy and beef farming sector. All farms operated a conventional (non-organic), pasture-based (> 200 d/yr grazing grass), primarily spring-calving system (≤ 7% cows calving out-of-season from July to November 2019), consisting of primarily cross-bred dairy breeds (majority Holstein, Friesian and Jersey cross) and purebred Holstein cows. Target herd size was 30 to 250 cows, which represented 95% of all farms meeting the above criteria. All farms were selected from within the primary dairy producing counties of Ireland; Cork, Tipperary, Limerick, Kerry, Kilkenny, Waterford and Wexford, which account for 69% of all dairy cows in the country (Central Statistics Office, 2020). For feasibility, all farms were also within a 2-h driving distance from the Teagasc Moorepark research centre, located in Fermoy, Cork, Ireland.

Farm Recruitment

An initial target of 100 farms was determined as the maximum number of farms that could reasonably be visited within the time-frame, and with the resources available, while still providing as representative a sample as possible. Using the SURVEYSELECT procedure, 500 farms were randomly selected from an initial list of 3388 farms meeting the selection criteria. These farms were sent a letter outlining the study and inviting them to contact the research team if interested in participating. A total of 121 farms replied (24% response rate). Nine of these were deemed unable to facilitate the study procedures, and a further 10 declined to participate. The first 100 eligible farms were selected for enrolment in the study. In the final weeks of the study, seven initially enrolled farms were no longer available to participate. The two remaining farms from the first round of selection were contacted. A further 18 farms were randomly selected from the pool of remaining farms using the RANDBETWEEN procedure, and they were invited by phone to participate (56% response rate) in order to source the seven required farms.

In total, 103 farms were visited during the grazing season (VISIT1; April to September 2019). A second visit was planned for all farms during the housing period (VISIT2; October 2019 to February 2020) once their herd had transitioned to full-time housing (i.e. cows housed 24 hr/d). However, some farmers decided to withdraw from the study prior to VISIT2, therefore, only 87 farms were re-visited during this period. The mean interval between VISIT1 and VISIT2 was 168 ± 53.6 d (range 65 to 262 d).

Of the 103 total visited farms, two farms were excluded from the study as they were found, upon arrival, to milk cows only once per day. A third farm was excluded because it operated a robotic milking system which prevented us from collecting data in a manner consistent with the other study farms. A final four farms were excluded because too many cows calved out of season to meet the spring-calving criteria. For the purposes of this study only those farms from which we were able to collect data for both the summer grazing period and winter housing period were included, resulting in a total of 82 farms.

Farm Visit Procedure

At VISIT1 one farm was assessed each day, either during or immediately following morning milking. Visits began with animal scoring, followed by a behavioural test of the cows and a management survey completed with the farmer. At VISIT2 the team was able to assess two farms per day (one each in the morning and afternoon) because of a shorter visit duration and more flexibility in start time, as many farms had finished milking or had altered milking schedules during dry-off. The same animal scoring procedure was conducted as in VISIT1, followed by a modified behavioural test and a management survey specific to VISIT2.

Animal scoring consisted of locomotion (LS), body condition (BCS) and health scoring. To facilitate animal scoring, all cows passed sequentially through a handling area consisting of a race with a cow-restraining gate from which each animal was released individually. Locomotion scoring was performed by one observer as each cow exited the handling area. Simultaneously, a second observer performed the BCS and health scoring on a subset of cows within the handling area as they waited to be released. The number of cows scored was proportionate to herd size according to the sample size selection table utilized by Welfare Quality® (2009). Depending on the farm facilities, the cows either proceeded directly out to their destination paddock following scoring or were retained in a holding yard until later released by the farmer.

Farm Visit Team

Teams of three to four trained observers were present at each farm visit. All team members were similarly dressed, in dark-coloured clothing (brown/dark blue) and adhered to a biosecurity protocol at the start and end of each farm visit, ensuring fresh, disinfected equipment. Any members of the team tasked with conducting LS attended a training course from the UK Agriculture and Horticulture Development Board (AHDB) and were successfully accredited by the UK Register of Mobility Scorers. Furthermore, tests of observer reliability were carried out for all team members tasked with either LS or BCS on farms. Scores of agreement between observers (inter-observer reliability) were calculated as weighted kappa coefficients, with a target mean score of ≥ 0.7. Inter-observer reliability agreement was tested twice for each of LS and BCS; once at the start of VISIT1 (mean LS agreement score = 0.73, range: 0.62 – 0.84; mean BCS agreement score = 0.74, range: 0.66 – 0.82), and once at the start of VISIT2 (mean LS agreement score = 0.85, range: 0.80 – 0.91; mean BCS agreement score = 0.81, range: 0.73 – 0.86). An additional test of BCS inter-observer reliability was conducted part-way through VISIT1, when a new scorer was introduced (mean BCS agreement score = 0.77, range: 0.67 – 0.84). Intra-observer reliability (agreement within scorers) was tested at the start of VISIT2 for LS (mean agreement score = 0.77, range: 0.71 – 0.81) and BCS (mean agreement score = 0.87, range: 0.81 – 0.93).

Data Collection

Animal Scoring – VISIT1 and VISIT2

All lactating cows were assessed on each farm at VISIT1. At VISIT2, both lactating and dry cows that were part of the 2019 lactating group were assessed. At both visits, all eligible cows were scored for locomotion, while only a subset of cows proportionate to herd size (Welfare Quality®, 2009) were scored for body condition, health scores and behaviour.

Locomotion scoring utilized the AHDB 4-point scale (Agriculture and Horticulture Development Board, 2015a): 0, walking well with no visible gait imperfections; 1, an imperfect gait requiring further monitoring, but where no intervention was yet required; 2, an identifiable problem with the cow's gait in one or more limbs where intervention was required as soon as possible; and 3, severely impaired locomotion requiring immediate intervention. Those scored LS0 were considered not-lame, those scored LS1 were considered to have imperfect locomotion and those scoring LS2 (moderately lame) or LS3 (severely lame) were together considered clinically lame. All clinically lame cows received appropriate treatment by a trained hoof-care professional (Farm Relief Services Network, Derryvale Roscrea Co. Tipperary, Ireland) within 11 d of their assessment as part of a concurrent study (Browne et al., 2022).

Body condition scoring was conducted using a 5-point scale between 1 to 5 with increments of 0.25 (Agriculture and Horticulture Development Board, 2015b). Score 1 indicates an emaciated cow requiring immediate attention and score 5 indicates an extremely over-conditioned animal requiring managed weight-loss to maintain good health.

Health scoring consisted of assessing an individual cow's eyes, nose, tail and integument for signs of poor health or injury. The same subset of cows was scored for health as BCS at each visit. Both ocular and nasal discharge were scored on 4-point scales 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). Eyes received an ocular score (OS) from 0, "normal", to 3, "heavy" ocular discharge. A nasal score (NS) was assessed between 0, "normal serous discharge", to 3, "copious bilateral mucopurulent discharge". The tail was manually assessed for signs of injury, including circumferential lacerations, breakage and docking (both short, removal of tail approximately at the level of the rear udder attachment, and long, removal of tail just above the distal end to prevent long hair growth).

Integument was assessed for hair-loss and the presence of lesions and/or swelling according to a scoring key adapted from Welfare Quality® (2009) and Gibbons et al. (2012b). One full side of each cow was visually divided into five zones, each assessed for the presence of either single, multiple or no areas of integument alteration. The alterations were further assigned a score corresponding to the greatest level of severity: 0) no missing, thinning, or broken hair and no swelling; 1) bald area with none or very mild swelling; 2) medium swelling (1 to 2.5 cm) and/or a lesion (scab or open wound) present; 3) major swelling (> 2.5 cm), with or without the presence of a lesion. The side of the animal scored was dictated by the design and direction of the handling area through which the cows were scored, and therefore varied between farms.

Avoidance Behaviour Test – VISIT1

During VISIT1, an avoidance behaviour test was conducted with the cows while at pasture. The test, adapted from Rousing and Waiblinger (2004), measured the avoidance response to an approaching human. Subsequent to animal scoring, a trained observer followed the cows to the paddock. The observer selected a standing cow > 2 m ahead of their location and, while slowly approaching her head (approximately 1 step/sec), attempted to touch each cow according to a standardised procedure. The observer recorded the point at which each cow first showed signs of retreat (backed away or turned head away to either side) at five different levels: 1) > 2 m from the observer, 2) within 1 to 2 m from the observer, 3) within 1 m from the observer but before extending hand, 4) accepting of extended hand but not touch and 5) accepting of touch. The cows' responses to human approach were further categorized into Fearful (level 1 and 2), Intermediate (level 3) or Non-fearful (level 4 and 5).

Avoidance Behaviour Test – VISIT2

The avoidance test at VISIT2 followed the same procedure as in VISIT1 with some modifications accounting for the indoor environment. The proportion of cows scored was still determined by the Welfare Quality® (2009) sample size criteria; however, if the cows were housed in multiple groups the total number of cows to score was divided proportionately between each group. Because all cows were not always engaged in the same activities within the shed at each visit, it was necessary to score cows both at the feed-face and within the pen. The avoidance test was performed from outside the pen for cows at the feed-face, and from inside the pen for cows within the pen areas. The location of the tested animal (feed-face or pen) was recorded to account for any observed differences between the two test areas. Due to the more confined space of the shed compared to the paddock, the tag number was recorded for each scored cow to prevent duplicate scoring. No cows were encouraged to rise if lying. If there was an insufficient number of cows available to reach the target number, a minimum of 30 cows on each farm were scored. If this was not possible, the test was deemed incomplete and excluded from analysis.

Management Survey and ICBF Data

During VISIT1, a survey was completed with each farmer regarding general farm characteristics, management practices, animal health and farm infrastructure. A second follow-up survey was completed during VISIT2 to identify any changes that occurred between visits and to obtain details of cow management at dry-off and during the housing period. Additionally, herd health and production details were collected from the ICBF database for each participating farm. Acquired data consisted of general herd information, milk recording and fertility data from January 2019 to June 2020.

Data Management

All data were recorded on either paper worksheets or, when possible, using a handheld device (Psion Teklogix, Workabout Pro). The integument scores of one farm at VISIT1 were excluded from analysis due to recording errors. Fourteen farms at VISIT1 were excluded from analysis of avoidance behaviour; 11 which could not be completed due to safety concerns (e.g. the presence of a bull, inclement weather) and four due to recording errors. At VISIT2, seven farms were excluded from behaviour analysis that could not be completed because either less than the minimum of 30 cows were available for scoring or the research team was short-staffed.

Benchmarks were established for each welfare indicator by ranking the outcomes of all farms from best to worst performance for each visit. The rankings were divided into quintiles, with the top and bottom 20% of farms serving as benchmarks identifying the best and worst performing farms for each indicator. While the 20% upper and lower thresholds may be arbitrary, we believe they provide good distinction between the highest and lowest performing farms and facilitate meaningful comparisons. Locomotion rank was determined by the combined percentage of LS2 and LS3 scored cows. The BCS ranking was determined based on the percentage of cows meeting the target levels of 2.75 to 3.25 during grazing and 3 to 3.5 during housing (Butler, 2016). Ocular and nasal score ranks were determined by the combined percentage of cows scoring OS1 to OS3, or NS1 to NS3. For tail injuries, the prevalence of lacerations, breaks and docks were ranked individually. For integument, the mean total number of alterations observed in all zones were combined to create a single ranking. The avoidance levels representing the “Fearful” response (levels 1 and 2) were combined and ranked by the total percentage.

Statistical Analysis

Data were summarised on a herd level, the percentage of each score was calculated for individual farms, and the mean percentage of each score was calculated across all study farms using the FREQ and SUMMARY procedures. The mean, standard error, minimum and maximum values, median and 95% CI's are reported for all animal scores at each of VISIT1 and VISIT2.

To determine differences between scores at VISIT1 and VISIT2, all scores were first checked for normality using the UNIVARIATE procedure. A paired t-test (TTEST procedure) was used for all variables with normally distributed mean differences, while the Wilcoxon signed rank test (within the UNIVARIATE procedure) was used for all non-normally distributed variables. A Bonferroni correction for multiple comparisons was calculated for indicators with multiple score levels. This involved multiplying the P-value resulting from each individual comparison by the total number of tests conducted for each indicator; any P-values > 1 were rounded to 1. For all tests, significance was declared at $P < 0.05$.

Additionally, data were examined for trends in the timing of individual farm visits within each of the VISIT1 and VISIT2 collection periods. Each visit timeframe was divided into 2 equal periods based on the timing of the visit. For VISIT1, period A included farms visited from April to June (n = 36) and period B included farms visited from July to September (n = 46). For VISIT2, period A included farms visited from October to mid-December (n = 45) and period B included farms visited from mid-December to February (n = 37). The GLM procedure was used with score level as the response variable and time period as the explanatory variable. The Bonferroni correction was applied for multiple comparisons, and time effects are only reported where significant.

RESULTS AND DISCUSSION

Consensus in the literature is that animal-based indicators provide the best measure of welfare because they most accurately reflect the animals' experience, thus there are a wide range of different measures used in current welfare assessment protocols (Andreasen et al., 2014; Zuliani et al., 2018). However, one challenge with assessing welfare in a system where little previous data has been collected on the associated indicators is determining acceptable welfare targets. Much of the available data for pasture-based systems throughout the world are specific to the characteristics of that particular system (Zuliani et al., 2018). The aim of the current study was to examine a representative group of farms reflecting the Irish national average of 80 cows/herd (Donnellan et al., 2020), producing 5438 L of milk/cow at an overall stocking rate among top performing herds of 2.48 cows/ha and a grazing season length of 229 d/year (Teagasc, 2019). However, the resulting herd characteristics of the study farms are more representative of Irish dairy herds with above average size and performance (Table 1). The voluntary participation required in the current study, and the fact that smaller, lower performing herds may be less likely to be members of the ICBF database from which farms were selected, may account for why the study farms represent above average herds. However, given that expansion within the dairy sector is likely to continue, the greater average size and performance of study farms reflects this upward trend and suggests that the identified results will be applicable into the future as well. In fact, 68% of farms surveyed indicated that they had expanded in either herd size, farm size or infrastructure over the past 5 years, and 50% indicated that they have plans to, or are considering expansion in the next 5 years.

Welfare assessment protocols often rely on expert opinion to aggregate welfare outcomes and establish target levels for measured indicators. However, aggregation can sometimes allow the effect of one indicator to overshadow the effects of others in the combined score (de Vries et al., 2013). This potential problem can be avoided by considering the welfare impact of each indicator on its own. Another increasingly common method is to establish individual benchmarks collected from on-farm animal-based measures of welfare (Main et al., 2014; Zuliani et al., 2018; Kaurivi et al., 2020). This method alone does not address existing systemic welfare issues or set limits for acceptable levels; however, it does provide many advantages for improving welfare on farms. Benchmarking thresholds encourage continuous welfare improvement within a particular system (Main et al., 2014), they are critical in identifying points at which action is required (Zuliani et al., 2018), and they promote the sharing of best-practices among farmers to achieve enhanced welfare (von Keyserlingk et al., 2012). In the current study, the range displayed by the top performing 20% farms for each indicator (Table 2) were identified as current achievable levels that may serve as a benchmark for other farms within the system. Conversely, if farms exhibit comparable levels to the bottom ranked farms, this indicates that they are underperforming their peers operating within the same system and reveals an opportunity for achievable improvement.

Table 1. Herd characteristics for spring-calving, pasture-based farms in southern Ireland, visited for welfare assessment during the grazing (VISIT1) and housing (VISIT2) periods of the 2019-2020 season.

Herd Characteristic	No. Farms[1]	Mean	SD	Min	Max	Median
Herd Size	82	125	49.1	38	253	120
Farm Size, Ha	81	45	19.2	14	101	40
Milk 305d yield, kg/cow	72	6706	752.2	4013	8251	6769
Fat 305d yield, kg/cow	72	280	31.4	187	367	281
Protein 305d yield, kg/cow	72	242	26.5	157	291	241
Stocking rate						
Grazing platform, cows/ha	82	2.97	0.94	1.2	5.7	3
Cubicles, cubicles/cow	81	1	0.18	0.6	1.8	1
Loose-housing, m^2/cow	13	5.6	2.97	2.2	11.5	5.3
Grazing Season length (full-time, 24 h/d)	81	240	27.6	170	312	236
Days on grass at VISIT1	82	126	44.4	36	213	129
Days housed at VISIT2	82	39	25.1	0[2]	99	59

[1] Total of 82 study farms. Data for some characteristics was unavailable for some farms.

[2] One farm was visited on its first full day of housing.

Locomotion

Lameness is a painful condition (Rushen et al., 2007) and widely considered one of the biggest risks to dairy cow welfare. During the grazing season (VISIT1), lame cows were present on all study farms with an average of 10% clinically lame (LS2 and LS3; Table 3). This is lower or comparable to the 14.6% and 11.6% lameness prevalence observed before and after the breeding season in a smaller study of Irish farms (Somers et al., 2015), or the 15% (Haskell et al., 2006) and 16 to 19% (Rutherford et al., 2009) reported for UK farms during grazing. However, using the same locomotion scale, O'Connor et al. (2019) reported 38% of cows on dairy farms in Ireland demonstrated signs of sub-optimal mobility (LS1 to LS3) while grazing, which is considerably lower than the 64% of cows scored LS1 to LS3 in the current study. This is possibly due to variation in weather between study years, as wet conditions are shown to reduce claw hardness and potentially influence claw injuries (Borderas et al., 2004). Although "acceptable" levels of lameness vary within the literature, ideally, farms should aim for the lowest lameness prevalence possible within the herd, through early detection and treatment (Bell et al., 2009). Accordingly, the quality assurance scheme from the Irish Food Board, Bord Bia, recommends that farms "implement measures to minimize lameness" (Bord Bia Irish Food Board, 2013). The current study indicates that a low level of lameness is achievable during the grazing season within the Irish pasture-based system, with the top performing 20% of farms at VISIT1 displaying a mean of approximately 1 to 5% clinically lame cows (Table 2) including < 1% severely lame cows. The bottom 20% of farms had between 15 to 32% clinically lame cows, indicating there is considerable room for improvement among some farms.

Cows in continuous-housing systems have demonstrated higher lameness prevalence than cows at pasture (Haskell et al., 2006). However, there was no significant difference observed in the mean percentage of lame cows of score LS2 or LS3 between grazing at VISIT1 (10%) and housing at VISIT2 (9%; Table 3). These values are considerably lower than lameness levels found in previous studies, of 17% for cows scored 3 weeks into winter housing (Haskell et al., 2006) and 32.3% for cows scored a minimum of 2 weeks into housing (de Vries et al., 2015). Levels in these studies are more similar to those of the lowest performing 20% of farms in the current study, which ranged from 13 to 28% clinically lame cows during housing. In contrast, the top performing farms at VISIT2 achieved levels of clinical lameness between 0 to 5% during housing (Table 2) with ≤ 1% severely lame cows. Both Haskell et al. (2006) and de Vries et al. (2015) suggest that time on pasture has a protective effect on locomotion when transitioning from grazing to housing, thus perhaps the lower relative proportion of lameness observed within this study is influenced by the long grazing season length of 240 d/yr on average.

Correcting for multiple comparisons, there were no observed differences in any LS level between visits (Table 3). However, a higher mean percentage of LS0 cows scored at VISIT2 compared to VISIT1 was detected before correction (*P* = 0.04), suggesting that a larger future study may reveal some differences in LS. Timing of visit had no effect on LS during the grazing period. Those farms visited in the second half of the housing period had a higher percentage of LS0 scored cows (period A mean = 34.0%, 95% CI: 30.8 to 37.2%; period B mean = 46.3%, 95% CI: 42.8 to 49.8%; *P* < 0.001) and a lower percentage of LS1 (period A mean = 56.5%, 95% CI: 53.7 to 59.4%; period B mean = 44.6%, 95% CI: 41.4 to 47.7%; *P* < 0.001) than those visited in the first half; there was no impact on LS2 or LS3. This suggests a reduction in cows with imperfect locomotion over time housed. With fewer demands on cows during housing due to the cessation of lactation, such as shorter daily walking distances and lower pre-milking standing time, this may have resulted in reduced prevalence of mild claw disorders associated with imperfect locomotion (O'Connor et al., 2019). This may also be influenced by a carry-over effect from the cows' time on pasture at the start of VISIT2, suggesting future research is needed into the effects of the grazing period on imperfect locomotion and mild claw disorders.

Table 2. Range in outcome percentage of scored cows for each welfare indicator among the top and bottom performing 20% of study farms during grazing (VISIT1) and when housed (VISIT2).

	Grazing				Housed			
	Top 20%		Bottom 20%		Top 20%		Bottom 20%	
Ranked Indicator[1]	Min %	Max %	Min %	Max %	Min %	Max %	Min %	Max %
Locomotion	0.8	4.7	15.3	31.5	0	4.5	13.3	28
Body condition	95.5	100	28.3	80.5	87.7	95.7	28.9	66.7
Ocular discharge	0	0	78.7	95.7	6.5	27.4	68.4	94
Nasal discharge	1.8	14.9	43.8	85.5	1.9	15.7	53.3	88.6
Tail lacerations	0	0	2.3	17.7	0	0	5.9	21.8
Tail breaks	0	2.8	13.6	51.6	0	1.8	14	47.3
Tail docks[2]	-	-	-	-	0	0	10	74.5
Integument	0	2.4	12.4	29.3	4.1	14.2	29.3	49.2
Avoidance								
Total	51	73.8	91.4	100	-	- -	-	-
Pen	-	- -	-	-	33.3	60	91.2	100
FF	-	- -	-	-	4	25	60.5	89.3

[1] Locomotion - combined percentage of LS2 and LS3 scored cows; BCS - percentage of cows meeting the target levels of 2.75 to 3.25 at grazing, 3.0 to 3.5 for housing; Ocular discharge - combined percentage of cows scoring OS1 to OS3; Nasal discharge - combined percentage of cows scoring NS1 to NS3; Tail lacerations, Tail breaks and Tail docks - percentage of cows displaying each injury; Integument - mean total percentage of integument alterations observed in all zones combined; Avoidance - percentage of cows responding at levels 1 and 2 combined (Fearful response category).

[2] Docked tails were only recorded at VISIT2 when housed.

Table 3. Descriptive statistics and means comparison of locomotion scores for 82 spring-calving, pasture-based farms in southern Ireland during grazing (VISIT1) and when housed (VISIT2) in the 2019-2020 season[1].

		Locomotion Score[2]			
		0	1	2	3
Grazing					
	Mean %	36	54	8.8	1.2
	SEM	1.47	1.3	0.56	0.16
	Min	9.8	22.7	0.8	0
	Max	76.5	76.2	26.9	5.2
	Median	34.9	54.6	8	0.7
	Lower 95% CI	33.1	51.4	7.7	0.9
	Upper 95% CI	39	56.6	9.9	1.5
Housed					
	Mean %	39.6	51.1	8	1.3
	SEM	1.36	1.25	0.52	0.19
	Min	8	21.2	0	0
	Max	78	74.8	23	8.1
	Median	37.8	52	7.6	0.8
	Lower 95% CI	36.9	48.7	6.9	0.9
	Upper 95% CI	42.2	53.6	9	1.7
	P-value[3] (Grazing vs Housed)	0.18†	0.30†	0.59†	0.95‡

[1] Mean of 123 cows/farm (range: 38 to 253 cows/farm) scored at VISIT1 (grazing) and 114 cows/farm (range: 40 to 232 cows/farm) scored at VISIT2 (housed).

[2] Locomotion score (LS): 0) perfect mobility, 1) imperfect mobility, 2) impaired mobility/moderately lame, 3) severely impaired mobility/severely lame.

[3] Bonferroni corrected P-value for multiple comparisons of mean differences between VISIT1 and VISIT 2 (significant difference at $P < 0.05$). Tests were either paired t-tests for normally distributed variables (†), or Wilcoxon Signed Rank tests for non-normally distributed variables (‡).

Body Condition

Variable quality and quantity of grass allowance at pasture may put cows at greater risk of developing metabolic issues such as negative energy balance, ketosis and weight loss (Coleman et al., 2009; Mee and Boyle, 2020). Intakes of insufficient quantity or quality may also lead to a sensation of hunger, negatively impacting cows' affective state (von Keyserlingk et al., 2009). Thus, maintaining appropriate body condition, monitored through regular scoring, is fundamental to ensuring good welfare in dairy cows. In the current study, the mean BCS across farms at VISIT1 was 3.1 ± 0.01 SEM (range: BCS 2.8 to 3.5). An average of 87% of cows were within the recommended target grazing BCS of 2.75 to 3.25 (Butler, 2016), with 2% of cows below target and 11% above (Table 4). Given that most cows whose score fell outside target BCS were over-conditioned, concerns that cows are not obtaining sufficient nutrition when grazing and are experiencing feelings of hunger generally appear to be unfounded. Although, this may still be a concern for those cows with low BCS ($\leq$ 2.5) which constituted up to 14.9% of cows on farms during grazing and up to 10.6% of cows during housing (Table 4). The top 20% of farms were able to achieve 96 to 100% of cows within target levels at VISIT1 (Table 2).

Ensuring correct BCS at calving is key to ensuring cows remain healthy during the calving process and the following transition into lactation. Cows that are over-conditioned at calving are at greater risk of health problems such as calving difficulties, excessive negative energy balance, milk fever, ketosis, left displaced abomasum, fatty liver and retained foetal membranes (Atkinson, 2016). However, under-conditioning also leaves cows at greater risk of dystocia (Gearhart et al., 1990), lameness, retained foetal membranes, poorer fertility and lower milk production (Atkinson, 2016). Therefore, it is critical to the health and welfare of the cow that her BCS during the indoor dry period is managed appropriately. At VISIT2, an average of 77% of cows on farms were within the recommended housing season targets (BCS 3.0 to 3.5; Butler, 2016) with a mean BCS of 3.2 ± 0.02 SEM (range: BCS 3.0 to 3.7). However, greater proportions within target levels are attainable; the top performing 20% of farms at VISIT2 achieved up to 96% of cows within target levels (Table 2). The percentage of thinner cows (mean percentage of cows with BCS $\leq$ 3) was lower while the percentage of heavier cows (mean percentage of cows with BCS $\geq$ 3.25) was greater at VISIT2 compared to VISIT1 (Table 4). Furthermore, for farms visited in the latter half of VISIT2, fewer cows with BCS 3.0 (period A mean = 36.4%, 95% CI: 32.2 to 40.6%; period B mean = 25.7%, 95% CI: 21.1 to 30.4%; $P < 0.01$) and more cows with BCS 3.5 (period A mean = 14.2%, 95% CI: 11.7 to 16.8%; period B mean = 22.0%, 95% CI: 19.1 to 24.8%; $P < 0.001$) were scored. This shift towards heavier cows is likely the result of scored cows having been dried-off for a longer period of time, thus providing cows more time to gain body condition. The higher proportion of cows outside target BCS levels (11% below, 12% above) at VISIT2 compared to VISIT1 may suggest greater difficulty in managing the feed requirements of cows transitioning from the lactating to the dry period, coinciding with the transition from grazed grass to grass silage as cows move indoors. It may also be influenced by greater competition for feed access when housed. Study farms had an average linear feed space of 0.52 m/cow (range: 0.21 to 1.19 m/cow), whereas the minimum recommended feed space allowance is 0.6 to 0.75 m/cow (Farm Animal Welfare Advisory Council, 2018). In competitive feeding environments, silage composition and the greater time required to consume a silage-based diet can negatively affect DMI (Grant and Ferraretto, 2018), potentially affecting some cows' ability to maintain body condition. Competition for feed access can also promote feed sorting (Grant and Ferraretto, 2018), and as shown in studies of TMR diets, feed sorting can result in some cows, particularly subordinate individuals, consuming unbalanced diets when feeding at times further since fresh feed delivery (Leonardi and Armentano, 2003; Cook and Nordlund, 2009).

Table 4. Descriptive statistics and means comparison of body condition scores for 82 spring-calving, pasture-based farms in southern Ireland during grazing (VISIT1) and when housed (VISIT2) in the 2019-2020 season[1].

	Body Condition Score[2]						
	≤ 2.5	2.75	3	3.25	3.5	3.75	4+
Grazing							
Mean %	2.2	16.1	49.5	21.8	7.2	2.8	0.5
SEM	0.31	1.27	1.57	1.38	0.68	0.57	0.18
Min	0	0	15	0	0	0	0
Max	14.9	50	84.2	50	22.9	43.3	11.7
Median	1.7	15	47.8	22	5.5	1.6	0
Lower 95% CI	1.6	13.6	46.3	19.1	5.8	1.6	0.2
Upper 95% CI	2.8	18.6	52.6	24.5	8.5	3.9	0.9
Housed							
Mean %	0.8	10.4	31.6	27.8	17.7	9.7	1.9
SEM	0.19	1.01	1.67	1.02	1.03	1.03	0.47
Min	0	0	2.6	5.3	0	0	0
Max	10.6	48	68	50	40	45.9	31.6
Median	0	8.4	29.8	26.6	17.5	6.7	0
Lower 95% CI	0.4	8.4	28.3	25.8	15.7	7.6	1
Upper 95% CI	1.2	12.5	34.9	29.9	19.8	11.8	2.8
P-value[3] (Grazing vs. Housed)	< 0.001‡	< 0.01†	< 0.001†	< 0.01†	< 0.001†	< 0.001‡	< 0.001‡

[1] Mean of 54 cows/farm (range: 33 to 76 cows/farm) scored at VISIT1 (grazing) and 52 cows/farm (range: 31 to 72 cows/farm) scored at VISIT2 (housed).

[2] Body condition scored on a 5-point scale with 0.25 increments from 1 (emaciated), to 5 (severely over-conditioned).

[3] Bonferroni corrected P-value for multiple comparisons of mean differences between VISIT1 and VISIT 2 (significant difference at $P < 0.05$). Tests were either paired t-tests for normally distributed variables (†), or Wilcoxon Signed Rank tests for non-normally distributed variables (‡).

Ocular and Nasal Discharge

There was no significant difference in the mean percentage of ocular discharge between grazing and housing visits, and most cows displayed either none or mild signs of discharge (Table 5). Additionally, the top 20% of farms achieved 0% of cows in the herd displaying any signs of ocular discharge at VISIT1 and between 7 to 27% of cows at VISIT2 (Table 2). Signs of moderate (OS2) and severe (OS3) ocular discharge were uncommon at either visit. The combined percentage of moderate and severe ocular discharge of approximately 1% on average in our study (Table 5) is well below both the "warning" and "alarm" thresholds of 3% and 6% proposed for equivalent score levels in Welfare Quality® (2009). The "warning" threshold indicates prevalence levels are approaching the "alarm" threshold, at which point implementing a herd health plan to manage the issue is needed. This suggests health issues causing ocular discharge are not a major welfare concern on Irish farms.

Nasal discharge was absent in the majority of cows scored at either visit (Table 5). For cows that displayed nasal discharge, mild signs (NS1) were most prevalent and were present on 99% and 100% of farms at VISIT1 and VISIT2 respectively. The mean percentage of cows with mild nasal discharge was greater at VISIT2 than VISIT1, and the mean percentage with moderate discharge (NS2) was lower. The proportion of cows with moderate and severe (NS3) nasal discharge combined was approximately 7% on average at VISIT1 and 5% at VISIT2. This exceeds the Welfare Quality® (2009) "warning" threshold of 5% for nasal discharge at VISIT1, and is equivalent to this threshold for VISIT2. Most previous welfare assessments of dairy cattle have reported no signs of nasal discharge (Zuliani et al., 2018) or no difference in the levels of nasal discharge between housing and pasture (Wagner et al., 2018). This suggests there is some degree of compromised health of cows during both the grazing and housing periods. Potential causes of discharge include exposure to airborne contaminants such as dust, gases, odours and microorganisms (Casey et al., 2006), insects such as flies (Reiten et al., 2018), or contagious disease such as infectious bovine rhinotracheitis (Banks, 1999), for which only 60% of study farms vaccinated. However, levels of any signs of nasal discharge in 2 to 15% (during grazing) or 16% (during housing) of cows are achievable in this pasture system, as demonstrated by the top 20% of farms (Table 2).

Table 5. Descriptive statistics and means comparison of ocular and nasal discharge scores for 82 spring-calving, pasture-based farms in southern Ireland during grazing (VISIT1) and when housed (VISIT2) in the 2019-2020 season[1].

		Discharge Score[2]			
		0	1	2	3
Ocular discharge					
Grazing					
	Mean %	53.6	45	1.4	0
	SEM	3.61	3.51	0.25	0.03
	Min	4.4	0	0	0
	Max	100	93.5	14.1	2
	Median	46.8	51.7	0	0
	Lower 95% CI	46.4	38	0.9	0
	Upper 95% CI	60.8	52	1.9	0.1
Housed					
	Mean %	53.5	45.2	1.2	0.1
	SEM	2.31	2.21	0.27	0.08
	Min	6	6.5	0	0
	Max	93.6	92	11.4	4.9
	Median	54.9	43.8	0	0
	Lower 95% CI	48.9	40.8	0.6	0
	Upper 95% CI	58.1	49.6	1.7	0.3
P-value[3] (Grazing vs Housed)		1.0‡	1.0‡	1.0‡	1.0‡
Nasal discharge					
Grazing					
	Mean %	70	23.1	6.2	0.7
	SEM	1.86	1.53	0.62	0.18
	Min	14.5	0	0	0
	Max	98.3	74.2	26.7	10.3
	Median	72.3	21.2	4.4	0
	Lower 95% CI	66.3	20.1	5	0.3
	Upper 95% CI	73.7	26.2	7.5	1
Housed					
	Mean %	64.7	30.6	4.4	0.4
	SEM	2.23	1.85	0.65	0.12
	Min	11.4	1.9	0	0
	Max	98.2	67.1	31	6.1
	Median	64.4	31	2.8	0
	Lower 95% CI	60.2	26.9	3.1	0.1
	Upper 95% CI	69.1	34.3	5.7	0.6
P-value[3] (Grazing vs Housed)		0.33†	0.02†	0.03‡	0.70‡

[1] Mean of 54 cows/farm (range: 33 to 76 cows/farm) scored at VISIT1 and 52 cows/farm (range: 31 – 72 cows/farm) scored at VISIT2.

[2] Ocular discharge score: 0) normal, 1) small amount of discharge, 2) moderate discharge, 3) heavy discharge; Nasal discharge score: 0) normal serous discharge, 1) small amount of cloudy discharge, 2) bilateral, cloudy or excessive mucous discharge, 3) copious bilateral mucopurulent discharge.

[3] Bonferroni corrected P-value for multiple comparisons of mean differences between VISIT1 and VISIT 2 (significant difference at $P < 0.05$). Tests were either paired t-tests for normally distributed variables (†), or Wilcoxon Signed Rank tests for non-normally distributed variables (‡).

Tail Injuries

Tail lacerations are characterised by deep, circumferential lacerations along the tail. With 33% of herds affected at VISIT1 and 43% at VISIT2, lacerations to the tail were somewhat common; however, affected cows were not widespread within those farms (Table 6), and the mean percentage of cows scored with lacerations was only 1% greater during VISIT2 than VISIT1. This lack of observed difference between visits suggests there may be multiple causes of such injuries un-related to management period. Because 95% of study farms used automatic alley scrapers, to which cows were only exposed during housing, this potentially explains the observed numerical increase in tail lacerations. To prevent tail injury, some manufacturers recommend having a 1-inch buffer between the scraper's edge and the curb, using a smoother edge to reduce entanglement in tail hair and ensuring scrapers are properly maintained (GEA, 2019). The use of tail tape for marking cows (e.g. to indicate cows for breeding, dry-off or grouping), practiced on 62% of study farms, is another possible explanation for tail lacerations. Similar to what occurs during tail docking, where the application of a rubber ring prevents blood circulation to the distal portion of the tail (Sutherland and Tucker, 2011), the marking tape, if secured too tightly or left in place too long, could cause tissue damage that may result in the circumferential lacerations seen on some cows (DairyNZ, 2020). In this case, prevalence may be reduced by paying careful attention when applying tape to the tail so that circulation is not affected, or by using alternative methods of identification.

Tail breakage is a rarely documented injury in existing welfare assessment protocols (Laven and Jermy, 2020). Broken tails may result from mechanical damage (e.g. being stepped on or caught in manure scrapers) or from poor handling techniques, usually involving forceful tail twisting to motivate forward movement (Zurbrigg et al., 2005; Laven and Jermy, 2020). Understandably, there was no difference in the prevalence of tail breakage between visits as it constitutes a permanent injury (Table 6). However, at both visits, cows with tail breaks were present on 90% of farms, considerably higher than the 38% of farms reported by (Zurbrigg et al., 2005). Approximately 9% of cows with broken tails were observed at both visits, which is similar to the annual herd prevalence of approximately 10% reported for pasture-based farms in New Zealand between 2014 to 2018 (Bryan et al., 2019). Research by Laven and Jermy (2020) determined that considerable force (9.8 to 20 Nm) was required to cause full vertebral dislocation and concluded that it was unlikely such force could be applied accidentally while following recommended best practice for animal handling. It is possible that some injuries occurred as calves, when the force required to cause tail breakage is likely lower than that for an adult cow, however this has not yet been studied.

Further research is required to determine the cause and timing of such injuries in order to formulate preventative steps.

Tail docking is prohibited in Ireland according to Statutory Instrument No. 117 of 2014. Despite this, cows with either short or long docked tails, were present on almost 65% of farms visited in this study, and 47% of cows with docked tails had entered the herd after the restriction was put into place. At VISIT1, we did not distinguish between short and long tail docking, so only the results from VISIT2 are reported (Table 6). Considering only those farms where cows with docked tails were observed (n = 53), long docking was present on 75% of farms and short docking on 62%. Research does not support claims that tail docking improves cow hygiene or prevents the spread of disease such as mastitis (Tucker et al., 2001). Additionally, removal of a cow's tail impedes her ability to deter flies from her hind end (Sutherland and Tucker, 2011). The practice of tail docking is only acceptable for individual cows when medically necessary and performed by a veterinarian with the use of anaesthesia. Such procedures may account for a low prevalence of docked tails on farms. However, we found that 33% of study farms had over 5% of the herd with docked tails, and 11% of farms had docked tails observed in 20% or more of the herd, suggesting cows' tails are being docked illegally for non-medical reasons.

The performance of the top 20% of farms indicates that 0% of the herd with tail injuries due to lacerations, breaks and docking is an achievable target (Table 2). However, there is a need for further study of the causes of tail injury in Irish dairy herds, methods of prevention and better regulation of non-medical tail docking to improve cow welfare in this area.

Table 6. Descriptive statistics and means comparison of tail injuries for 82 spring-calving, pasture-based farms in southern Ireland during grazing (VISIT1) and when housed (VISIT2) in the 2019-2020 season[1].

		Tail Injury				
		Lacerations	Breaks	Docks - All	Docks - Short	Docks - Long
Grazing						
	Mean %	1.7	9.1	-	-	-
	SEM	0.38	1.07	-	-	-
	Min	0	0	-	-	-
	Max	17.7	51.6	-	-	-
	Median	0	7	-	-	-
	Lower 95% CI	0.9	7	-	-	-
	Upper 95% CI	2.4	11.2	-	-	-
Housed						
	Mean %	2.8	8.5	7.5	2.6	4.9
	SEM	0.56	1.03	1.53	0.66	1.25
	Min	0	0	0	0	0
	Max	21.8	47.3	74.5	40	72.6
	Median	0	4.9	1.8	0	0
	Lower 95% CI	1.7	6.5	4.5	1.3	2.4
	Upper 95% CI	3.9	10.6	10.6	3.9	7.4
P-value[2] (Grazing vs Housed)		0.11‡	0.31‡	-	-	-

[1] Mean of 54 cows/farm (range: 33 to 76 cows/farm) scored at VISIT1 and 52 cows/farm (range: 31 to 72 cows/farm) scored at VISIT2.

[2] P-value for comparison of mean differences between VISIT1 and VISIT 2 (significant difference at $P < 0.05$). Tests were either paired t-tests for normally distributed variables (†), or Wilcoxon Signed Rank tests for non-normally distributed variables (‡).

Integument Alterations

During the grazing period, only zone 2, corresponding with a cow's hindquarters, displayed considerable integument alterations, both single and multiple to similar degree (Table 7). Integument alterations to this zone were primarily mild, resulting in only hair loss (72 ± 3.3% SEM single mild alterations, range: 0 to 100%; 63 ± 4.2% SEM multiple mild alterations, range: 0 to 100%). This is likely due to frequent mounting behaviour among cows in heat, as VISIT1 coincided with the breeding season. The common use of tail paint as a heat detection aid could contribute to hair loss on the hindquarters. The paint is designed to rub off as an indicator of mounting behaviour (Diskin and Sreenan, 2000), and due to the thick consistency, has been observed to simultaneously remove hair. On farms visited in the latter half of the VISIT1 period compared to the first half, fewer single alterations were scored for the head-neck-back (zone 1; period A mean = 6.9%, 95% CI: 4.3 to 9.5%; period B mean = 1.4%, 95% CI: -0.9 to 3.6%; $P < 0.01$), the hindquarters (zone 2; period A mean = 17.5%, 95% CI: 13.9 to 21.0%; period B mean = 8.8%, 95% CI: 5.7 to 11.9%; $P < 0.01$), the rear hocks (zone 3; period A mean = 6.2%, 95% CI: 4.3 to 8.0%; period B mean = 2.7%, 95% CI: 1.1 to 4.3%; $P = 0.02$) and the front hocks (zone 5; period A mean = 2.8%, 95% CI: 1.7 to 3.8%; period B mean = 0.6%, 95% CI: -0.3 to 1.5%; $P < 0.01$). Fewer multiple alterations were also scored for the hindquarters (zone 2; period A mean = 24.3%, 95% CI: 20.2 to 28.4%; period B mean = 4.6%, 95% CI: 1.0 to 8.2%; $P < 0.001$) on farms in the latter half of the VISIT1 period.

During housing, the majority of scored cows had no integument alterations in zones 2 to 5 (Table 7). The greatest percentage of all types of alterations were scored along the head-neck-back region (zone 1), followed by the hindquarters (zone 2), with the fewest alterations scored on the sides of the body (zone 4). Single alterations to the head-neck-back were most common and primarily mild (98 ± 0.7% SEM, range: 61 to 100%), as were the multiple alterations (89 ± 3.1% SEM, range: 0 to 100%). When cows are housed indoors during the winter period, there is more opportunity for contact between the cows and housing elements such as cubicles, feed rails etc. and thus have greater risk of injury. Integument alterations to the neck are shown to be associated with feed barrier design (Kielland et al., 2010; Zaffino Heyerhoff et al., 2014). Ideal feed-rail height is related to cow size, with recommendations ranging from 1.1 m for smaller breeds such as the Norwegian Red (Kielland et al., 2010), to upwards of 1.3 or 1.4 m for the larger Holstein or Holstein-Friesian breeds (Huxley and Whay, 2006; Zaffino Heyerhoff et al., 2014). The average feed-rail height among current study farms ranged between 0.96 to 1.53 m, indicating that feed-rails on some farms may fall outside recommended heights. Competition for feed access and infrequent feed delivery may be other contributing factors as they have also been associated with increased risk of neck lesions (Kielland et al., 2010).

Generally, integument alterations were more prevalent during housing than while grazing (Table 7). The percentage of single alterations was higher at VISIT2 than VISIT1 in all zones except zone 2, the hindquarters, where no difference was observed. The percentage of multiple alterations was greater in only zone 1, the head-neck-back, at VISIT2 than VISIT1. However, prior to correction for multiple comparisons, a greater prevalence of multiple alterations was also detected for zone 2 ($P = 0.04$), potentially suggesting that a larger sample size in a future study may reveal more differences in integument condition. Similar levels of both single and multiple integument alteration to the hindquarters during grazing and housing indicate that multiple factors are responsible. In a spring-calving system, alterations to the hindquarters observed during housing cannot be attributed predominantly to estrus behaviour as discussed for VISIT1. Rather, a cow's hindquarters are likely more prone to contact with their surroundings while housed, since lesions in dairy cattle most commonly occur on protruding areas of the body such as the hips and pin bones (Weary and Taszkun, 2000). Considering all types of integument alterations combined across all zones of the body, the top 20% of farms were able to achieve between 0 to 2% alterations during grazing and 4 to 14% during housing (Table 2), reflecting the increased likelihood of integument damage experienced during housing.

The opportunity for injury due to housing features is greater with longer time spent in housing. Rutherford at al. (2008), for example, found an increase in hock damage of 34% between autumn and spring assessment. With the exception of the head-neck-back (zone 1), the observed differences were small, yet there was evidence of deteriorating integument condition during housing. At farms visited during the second half of VISIT2 compared to the first, more single alterations were observed on the rear hocks (zone 3, period A mean = 3.4%, 95% CI: 0.4 to 6.4%; period B mean = 14.3%, 95% CI: 11.0 to 17.6%; $P < 0.001$), the side body (zone 4, period A mean = 1.6%, 95% CI: 0.6 to 2.6%; period B mean = 3.7%, 95% CI: 2.5 to 4.8%; $P = 0.03$) and the front hocks (zone 5, period A mean = 2.5%, 95% CI: 1.3 to 3.7%; period B mean = 5.3%, 95% CI: 4.0 to 6.7%; $P < 0.01$). Higher percentages of multiple alterations were also scored for the head-neck-back (zone 1, period A mean = 12.9%, 95% CI: 5.9 to 19.8%; period B mean = 28.4%, 95% CI: 20.7 to 36.0%; $P = 0.01$), the hindquarters (zone 2, period A mean = 10.1%, 95% CI: 6.4 to 13.9%; period B mean = 28.8%, 95% CI: 24.7 to 32.9%; $P < 0.001$), and the rear hocks (zone 3, period A mean = 0.3%, 95% CI: -0.6 to 1.2%; period B mean = 2.5%, 95% CI: 1.5 to 3.5%; $P < 0.01$) at visits during the second half of VISIT2 than the first.

Table 7. Descriptive statistics and means comparison of integument alteration scores for all spring-calving, pasture-based study farms in southern Ireland during grazing (VISIT1) and when housed (VISIT2) in the 2019-2020 season[1].

	Zone 1[2]			Zone 2			Zone 3			Zone 4			Zone 5		
	N	S	M	N	S	M	N	S	M	N	S	M	N	S	M
Grazing															
Mean %	95.1	3.8	1.1	74.4	12.5	13.1	93.7	4.2	2.1	98.6	1	0.4	97.8	1.5	0.7
SEM	1.16	0.91	0.39	2.36	1.26	1.73	1.21	0.63	0.84	0.3	0.21	0.21	0.59	0.36	0.28
Min	43.6	0	0	14.3	0	0	35.4	0	0	84	0	0	66	0	0
Max	100	52.7	28	100	39.4	74.6	100	30.3	58.3	100	11.7	16	100	18.2	19.2
Median	98.3	1.5	0	79.2	7.8	6.3	98.1	1.8	0	100	0	0	100	0	0
Lower 95% CI	92.8	2.0	0.3	69.7	10	9.7	91.3	2.9	0.5	98	0.6	0	96.6	0.8	0.1
Upper 95% CI	97.4	5.6	1.9	79.1	15	16.6	96.1	5.5	3.8	99.2	1.4	0.9	99	2.2	1.3
Housed															
Mean %	34.2	45.9	19.9	67.8	13.7	18.5	90.4	8.3	1.3	96.8	2.5	0.6	94.7	3.8	1.5
SEM	2.78	2.65	2.71	2	0.74	1.73	1.51	1.26	0.35	0.5	0.4	0.15	0.82	0.47	0.57
Min	0	5.1	0	20.5	0	0	35.7	0	0	74.5	0	0	51.4	0	0
Max	92.5	92	92.9	98.1	32.2	64.1	100	58.9	20.5	100	19.6	5.9	100	17	41.4
Median	28.7	46.1	8.3	69.4	13.3	13.3	95.1	4	0	98.1	1.5	0	97.1	2.2	0
Lower 95% CI	28.7	40.6	14.5	63.8	12.2	15.1	87.4	5.8	0.6	95.8	1.8	0.3	93.1	2.9	0.4
Upper 95% CI	39.7	51.2	25.3	71.8	15.1	22	93.4	10.8	2	97.8	3.3	0.9	96.3	4.7	2.6
P-value[3] (Grazing vs Housed)	<0.001‡	<0.001†	<0.001‡	0.13†	1.0†	0.11†	0.22‡	0.05‡	1.0‡	<0.01‡	<0.001‡	0.26‡	<0.001‡	<0.001‡	0.40‡

[1] Mean of 54 cows/farm (range: 33 to 76 cows/farm) scored at VISIT1 (grazing) and 52 cows/farm (range: 31 to 72 cows/farm) scored at VISIT2 (housed). Integument was scored on a total of 81 farms at VISIT1 and 82 farms at VISIT2.

[2] One side of each scored cow was visually divided into 5 zones: 1) head-neck-back, 2) hindquarters, 3) lower rear legs, 4) flank, side and udder, 5) lower front legs. Each zone was scored for none (N), single (S), or multiple (M) areas of integument alteration.

[3] Bonferroni corrected P-value for multiple comparisons of mean differences between VISIT1 and VISIT 2 (significant difference at $P < 0.05$). Tests were either paired t-tests for normally distributed variables (†), or Wilcoxon Signed Rank tests for non-normally distributed variables (‡).

Avoidance Behaviour

Avoidance distance of cattle from an approaching human is a measure of the human-animal-relationship (Rousing and Waiblinger, 2004) and greater avoidance distance is indicative of more strain on this relationship. The cows' responses to human approach (Table 8) were interpreted as Fearful (level 1 and 2, retreat > 1 m from the observer), Intermediate (level 3, retreat < 1 m from the observer without extended hand) or Non-fearful (level 4 and 5, accepting of hand or touch). A mean of 82% of cows on farms at VISIT1 were categorised Fearful, 13% Non-fearful and 5% Intermediate. At VISIT2, those cows tested within the pen areas responded as 75% Fearful, 20% Non-fearful and 5% Intermediate. Of the cows scored at the feed-face from outside the pen, 42% were categorised as Fearful, 47% Non-fearful and 11% Intermediate. Fear response in dairy cattle is a natural aspect of their history as a prey species and serves to assist in avoiding potentially harmful situations (Rushen et al., 1999). However, disproportionate fear of humans can induce stress, negatively influencing a cow's affective state, and may be an indicator of aversive handling (Pajor et al., 2000). A good human-animal-relationship is crucial for maintaining the welfare of dairy cattle as contact with humans is an inevitable part of dairy management procedures and a fearful relationship can make handling more difficult and potentially dangerous for the cows and stockpersons (Rushen et al., 1999).

Cows most commonly retreated from the observer at level 1 (> 2 m) when approached in the paddock during grazing and at level 2 (within 1 to 2 m) when indoors during housing, both of which were categorised as Fearful responses. However, the proportion of animals exhibiting Fearful responses was generally lower during housing than when grazing, potentially because reduced space prevented them from retreating, or potentially because of more frequent close contact with farm staff. Greater familiarity with a person or object is known to result in a reduced flight zone in cattle (Grandin, 2017), and during housing cows are continually exposed to farm staff performing routine management such as cleaning cubicles or delivering feed, resulting in greater familiarity over time. A positive human-animal-relationship in cattle is built through continued experience of frequent, good quality interactions with stockpersons and reduction of aversive handling (Rushen et al., 1999; Rousing and Waiblinger, 2004). The top 20% of farms achieved Fearful category responses (level 1 and 2 combined) in a maximum of 51 to 74% of the herd while grazing, which may serve as reasonable targets in pasture settings (Table 2). When cows were indoors, where there would be greater exposure to humans and cows were more likely to anticipate human interaction, the Fearful category response among the top 20% of study farms, was lower at 33 to 60% when measured within the pen. This was further reduced to between 4 to 25% when measured at the feed-face. According to these benchmarks, we suggest that it should be considered unacceptable for any farms operating in this system to have more than approximately three-quarters of their herd retreat from humans at > 1 m when grazing. Furthermore, when housed, it should be unacceptable to have more than two-thirds of the herd retreating at > 1 m from humans within the pen, or more than one-quarter of the herd at the feed-face.

There was a marked difference in the individual response levels when housed cows were scored from within the pen compared to when they were scored from the feed-face outside the pen. Overall, there was a lower percentage of level 1 responses at both the pen and the feed-face at VISIT 2 than the paddock at VISIT1. Cows scored within the pen at VISIT2 displayed a higher percentage of level 2 and level 5 responses, and cows scored at the feed-face displayed a higher percentage of level 3, 4 and 5 responses compared to VISIT1. Windschnurer et al. (2008) similarly found that cows were more often accepting of touch at the feed-face (41%) compared to within the pen (33%). It is possible that when feeding at the feed-face, the cows' natural fear response as a prey species (Rushen et al., 1999) is reduced by the presence of the protective feed barrier between the cow and the observer, who may be seen as a threat. Additionally, research by Waiblinger et al. (2003), found that when tested at the feed rail, avoidance behaviour was most correlated to the level of agonistic social behaviour. Thus, the lower fearful response to approach from outside the feed-face compared to within the pen could also be related to increased competition for feed access promoting greater agonistic interactions. In that case, the cows' reluctance to forfeit their position at the feed-face may be overcoming their fearful response.

Table 8. Descriptive statistics and means comparison of avoidance behaviour responses for spring-calving, pasture-based study farms in southern Ireland at the paddock during grazing (VISIT1), and inside the pen and at the feed-face (FF) when housed (VISIT2)[1].

		Response Level[2]				
		1	2	3	4	5
Grazing						
	Mean %	46	36	4.9	5.3	7.8
	SEM	2.25	1.7	0.48	0.58	0.83
	Min	14.3	12.2	0	0	0
	Max	85.4	66.7	18.6	20	31.4
	Median	45.6	36.8	4.1	4.1	5.9
	Lower 95% CI	41.5	32.6	3.9	4.1	6.1
	Upper 95% CI	50.5	39.4	5.8	6.4	9.5
Housed						
Pen						
	Mean %	27.6	47	5.5	6.6	13.8
	SEM	2.12	1.92	0.75	0.87	1.4
	Min	0	15.4	0	0	0
	Max	80.8	100	25	40	52.6
	Median	23.6	45	3.9	5.6	12.1
	Lower 95% CI	23.4	43.2	4	4.8	11
	Upper 95% CI	31.8	50.8	7	8.3	16.6
FF						
	Mean %	8.1	33.5	11.1	19.8	27.5
	SEM	1.1	1.85	1.03	1.38	1.67
	Min	0	0	0	0	0
	Max	35.7	80	36	50	65.2
	Median	5	32.1	9.5	18.8	28.1
	Lower 95% CI	5.9	29.8	9.1	17.1	24.2
	Upper 95% CI	10.2	37.2	13.2	22.6	30.8
P-value[3] (Grazing vs Housed)						
	Pen	< 0.001†	< 0.001‡	1.0‡	1.0†	< 0.001‡
	FF	< 0.001†	1.0†	< 0.001†	< 0.001†	< 0.001†

[1] Mean of 43 cows/farm (range: 30 to 54 cows/farm) scored at VISIT1 (grazing) and 44 cows/farm (range: 30 to 79 cows/farm) at VISIT2 (housed). Avoidance behaviour data was available for a total of 68 farms at VISIT1 and 75 farms at VISIT2.

[2] The five levels of avoidance behaviour indicates distance of individual cows' retreat at: 1) > 2 m from the observer; 2) within 1 - 2 m from the observer; 3) within 1 m from the observer but before extending hand; 4) accepting of hand but not touch; 5) accepting of touch.

[3] Bonferroni corrected P-value for multiple comparisons of mean differences between VISIT1 and VISIT 2 (significant difference at $P < 0.05$). Tests were either paired t-tests for normally distributed variables (†), or Wilcoxon Signed Rank tests for non-normally distributed variables (‡).

CONCLUSION

The aim of this study was to provide a descriptive, exploratory analysis of welfare indicators for a dairy production system where little large-scale data is available. Throughout both the grazing and housing periods, Irish dairy farms in this study performed favourably in the area of lameness control compared with other studies, met recommendations for body condition management, and displayed signs of good ocular health. There is opportunity for improvement in dairy cow welfare through increased monitoring of housing facilities for potential sources of integument damage to the hindquarters. Areas were also identified that would benefit from further research. The cause of elevated levels of nasal discharge observed throughout the lactation is yet unclear. Signs of preventable or prohibited tail injury indicate a need to examine the causes, potential solutions, and enforcement of existing regulations. Furthermore, investigation into the impact of the level of competition for feed access on farms during housing is needed, as it may be linked to achieving target BCS levels, the prevalence of integument alterations on the head-neck-back region, as well as avoidance behaviour. Finally, the identified targets for welfare indicators within Irish spring-calving, pasture-based dairy systems may benefit future research, and may be used as benchmarks in the determination of future on-farm management and policy decisions for improving the overall welfare of dairy cows.

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| CHAPTER 3 |

Risk factors associated with the welfare of grazing dairy cows in spring-calving, 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.

Keywords: dairy cattle, grass-based, welfare assessment, grazing, health, avoidance behaviour

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 (Welfare Quality®, 2009; AssureWel, 2018; National Milk Producers Federation, 2019), 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 (Sepúlveda-Varas et al., 2014; Riaboff et al., 2021) 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. (2020a) 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., 2020a), 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., 2005b). This 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 upper respiratory tract infection (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; 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., 2002, 2004). 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. However, to date there is little research of avoidance response in pasture-based systems that investigates this while cows are grazing.

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., 2009a, 2010a, 2019), 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'Driscoll et al., 2008, 2010a; Olmos et al., 2009a; Somers et al., 2015, 2019; O'Connor et al., 2019). 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.

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.

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 - 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).

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 – 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). For all other scores, all members of the research team participated in group training sessions, and reference photos and definitions of the score levels were available to consult throughout each assessment. Additionally, to ensure the assessment procedure was carried out consistently, it was pilot tested on six farms prior to beginning data collection.

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, 2015b). Ocular and nasal discharge was scored on a 4-point scale (0 – 3), adapted from the University of Wisconsin-Madison calf-health scoring system (University of Wisconsin-Madison School of Veterinary Medicine). 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. (2012b). 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, 2015a). 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® sample size criteria (Welfare Quality®, 2009), were approached by a single observer following a standardised 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 categorised as a "fearful" response.

Facility Measurements - 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.

Facility Measurements - 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).

Facility Measurements - 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.

Facility Measurements - 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.

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. 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.

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 the 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; 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 B). 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 based on the literature and the authors' experience. 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.

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 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.

Accounting for small sample size

Considering only CC, the final datasets of between 58 - 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.

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.

Body Condition Score

Risk factors 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).

Tail Injury: Breaks and Lacerations

None of the analysed variables were identified as risk factors for tail breaks. However, breeding method and the presence 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. 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.

Integument Damage

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.

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

	Complete Cases					Substitution				
Welfare Indicator[1] (%)	**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
Integument damage (moderate to severe)	81	10.4	10.58	0.0	48.2	93	10.7	11.11	0.0	48.2
Nasal discharge (moderate to severe)	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

[1] 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 0-3; 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 hybrid pasture-based dairy farms in Ireland.

Analysis method[1]	No. factors tested	Retained factors	Prevalence (%)	Model component[2]	*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

[1] Data from 72 farms were included in complete cases analysis and 93 farms in substitution analysis.

[2] 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 hybrid pasture-based dairy farms in Ireland.

Analysis method[1]	Injury type[2]	No. factors tested	Retained factors	Prevalence (%)	Model component[3]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases[4]	Lacerations	8	Breeding Method[5]		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[5]		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						

[1] Data from 85 farms were included in complete cases analysis and 93 farms in substitution analysis.

[2] 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.

[3] 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).

[4] Complete cases model also included previous housing period length BR: $P = 0.441$, ZI: $P = 0.784$.

[5] Breeding: all breeding through either artificial insemination (AI) or stock bull (Single method), or through both AI and stock bull (Combined method).

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 hybrid pasture-based dairy farms in Ireland.

Analysis method[1]	No. factors tested	Retained factors	Prevalence (%)	Model component[2]	*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[3]	20	Cubicle length[4]		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	.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

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[1] Data from 81 farms were included in complete cases analysis and 93 farms in substitution analysis.

[2] 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).

[3] Substitution method model also included floor slipperiness at parlour entrance, BR: $P = 0.373$, ZI: $P = 0.133$

[4] 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).

Nasal Discharge

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 minutes or less were positively associated with nasal discharge compared to holding times longer than 90 minutes. 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.

Ocular Discharge

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.

Lameness

Risk factors for the proportion of lame cows (Table 7) were identified as 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

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 hybrid pasture-based dairy farms in Ireland.

Analysis method[1]	No. factors tested	Retained factors	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases[3]	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[4]		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						

[1] Data from 77 farms were included in complete cases analysis and 93 farms in substitution analysis.

[2] 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).

[3] Complete cases method model also contained health recording method, BR: $P = 0.118$, ZI: $P = 0.124$

[4] 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)

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

Analysis method[1]	No. factors tested	Retained factors	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	24	Collecting yard area[3]		BR	0.004	Below vs Equal/Above	0.51	0.32 - 0.81	0.006
		Below	42.9	ZI	0.520		1.43	0.48 – 4.21	0.522
		Equal/Above	57.1						
		Health record-keeping[4]		BR	0.002	Manual vs Digital	0.48	0.30 - 0.76	0.003
		Manual	45.5	ZI	0.599		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		0.78	0.26 – 2.32	0.656
		Yes	57.1						
Substitution	24	Health record-keeping[4]		BR	0.003	Manual vs Digital	0.503	0.32 - 0.79	0.004
		Manual	43.0	ZI	0.639		0.786	0.29 – 2.14	0.640
		Digital	57.0						
		Herd biosecurity status		BR	0.002	Closed vs Open	0.387	0.21 - 0.72	0.003
		Closed	18.3	ZI	0.913		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		0.83	0.30 – 2.27	0.714
		Yes	58.1						

[1] Data from 77 farms were included in complete cases analysis and 93 farms in substitution analysis.

[2] 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).

[3] 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)

[4] Health record-keeping: method classified as either manual (paper, notebook, whiteboard etc.) or digital (computer, app etc.)

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

Analysis method[1]	No. factors tested	Retained factors	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases[3]	52	Cubicle length[4]		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[5]		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[6] x Herd size[7]		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

Table 7. (Continued)

Analysis method[1]	No. factors tested	Retained factors	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete Cases	52	Separate lame group[8] x Average percentage loose stones on road to collecting yard[9]		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[10]	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						

Table 7. (Continued)

Analysis method[1]	**No. factors tested**	**Retained factors**	**Prevalence (%)**	**Model component[2]**	***P*-value**	**Pairwise comparison**	**Odds ratio**	**95% CI**	***P*-value of pairwise comparison**
Substitution	52	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						
		Road repair frequency[5] x Time to treat[11]		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, > 48h ≥ Week	0.41	0.24 – 0.70	0.046

[1] Data from 77 farms were included in complete cases analysis and 93 farms in substitution analysis.

[2] 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.

[3] Complete cases method model also included the interaction of separate lame group with herd size, BR: $P = 0.508$

[4] 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)

[5] Road repair frequency: 1 – 2 times/year (Yearly); once every 2 – 3 years (Occasionally); every 4+ years, as required, never (Rarely)

[6] Footbath used: No or Yes

[7] Herd size: ≤ 80 cows, >80 ≤ 125 cows, > 125 cows

[8] Separate lame group (SLG): No, Yes, Sometimes

[9] Average percentage loose stones on road to collecting yard: ≤ 25%, ≤ 50%, ≤ 75%, > 75%

[10] Substitution method model also included footbath, BR: $P = 0.121$

[11] 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

Avoidance Response

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. 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, how cows are brought from the paddock to the parlour for milking, 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.

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 hybrid pasture-based dairy farms in Ireland.

Analysis method[1]	**No. factors tested**	**Retained factors**	**Prevalence (%)**	**Model component[2]**	***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[3] x Feed push-up frequency[4]		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

Table 8. (Continued)

Analysis method[1]	No. factors tested	Retained factors	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
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[5]		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[3] x Feed push-up frequency[4]		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

[1] Data from 58 farms were included in complete cases analysis and 68 farms in substitution analysis.

[2] 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.

[3] Cubicle bedding/liming frequency: once/d (OAD), less than once/d (< OAD), twice/d (TAD).

[4] Feed push-up frequency: once/d or less (≤ OAD), more than once/d (> OAD).

[5] 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).

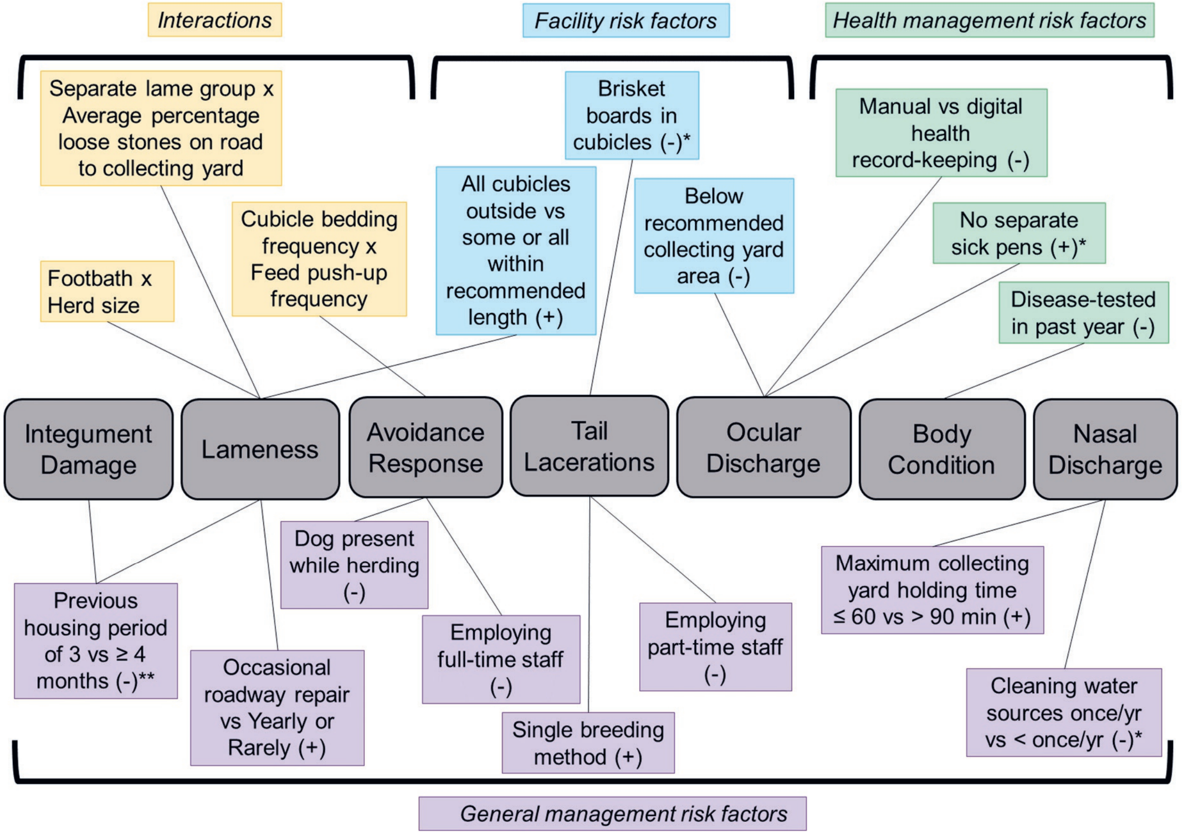
Interactions
Facility risk factors
Health management risk factors
Separate lame group x Average percentage loose stones on road to collecting yard
Footbath x Herd size
Cubicle bedding frequency x Feed push-up frequency
All cubicles outside vs some or all within recommended length (+)
Brisket boards in cubicles (-)*
Below recommended collecting yard area (-)
Manual vs digital health record-keeping (-)
No separate sick pens (+)*
Disease-tested in past year (-)
Integument Damage
Lameness
Avoidance Response
Tail Lacerations
Ocular Discharge
Body Condition
Nasal Discharge
Previous housing period of 3 vs ≥ 4 months (-)**
Occasional roadway repair vs Yearly or Rarely (+)
Dog present while herding (-)
Employing full-time staff (-)
Single breeding method (+)
Employing part-time staff (-)
Maximum collecting yard holding time ≤ 60 vs > 90 min (+)
Cleaning water sources once/yr vs < once/yr (-)*
General management risk factors

Figure 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 ($P > 0.1$)

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 (Figure 1). Identified risk factors were grouped according to those related to health management, general farm management and the provided facility resources.

Health management

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 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. 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).

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 negatively associated with the 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., 2002, 2003) in cattle.

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.

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 increased disease (Linn and Raeth-Knight, 2010). Contaminated water may also be unpalatable to cows (Morgan, 2011), potentially decreasing water intakes, and leading to dehydration which may predispose cows to infection (Callan and Garry, 2002).

Farms where a dog was not routinely involved in herding practices were positively associated with the proportion of cows displaying fearful avoidance responses. Initially this may appear to contrast the expected stress or flight response of cattle to dog vocalisations (Kaurivi et al., 2020b). 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 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 (Weary and Taszkun, 2000; Brenninkmeyer et al., 2016). 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 (Solano et al., 2015; Endres, 2017), incorrect cubicle dimensions (Faull et al., 1996; Haskell et al., 2006; Espejo and Endres, 2007), insufficient bedding (Faull et al., 1996) and decreased cow comfort in cubicles (Espejo and Endres, 2007; Dippel et al., 2009a). 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 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.

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 below this level were negatively associated with the 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, thus potentially reducing the impact on 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 – 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 (Faull et al., 1996; Haskell et al., 2006; Dippel et al., 2009a). 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. Perhaps when cubicle dimensions were outside recommended lengths in the present study this resulted in more cows standing perched in cubicles, potentially contributing to the increased risk of lameness. 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.

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 nature of the association between footbath use and lameness have been described in the literature (de Vries et al., 2015; O'Connor et al., 2020a).

The interaction of separate lame cow group and proportion of loose stones on roadways to the collecting yard generally indicates that farms that sometimes or never kept a separate lame group showed a greater proportion of lame cows than farms that always did. However, within each level of frequency of maintaining a separate lame group (always, sometimes, never) the greatest association with the proportion of lame cows was observed at a different percentage of stone prevalence. Loose stones may cause pressure and damage to the hoof sole when stepped on, particularly when located on concrete yards or tracks (Barker et al., 2009). Moreover, the fact that not regularly utilising a separate lame group was generally associated with greater lameness, could reflect what farmers consider to be a "lame" cow. Previous studies show that farmers regularly under-report lameness in their herds (Whay et al., 2003; Leach et al., 2010a; Sadiq et al., 2019). Farmers that do not perceive lameness to be a problem on their herd may be less likely to establish a separate lame group, whether or not lameness is in fact a problem.

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.

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.

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 (Rutherford et al., 2008; Burow et al., 2013a; Armstrong, 2020). 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.

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.

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| CHAPTER 4 |

Risk factors associated with dairy cow welfare during the housing period in spring-calving, pasture-based systems

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ABSTRACT

In a dairy production system where cows are grazing for a large portion of their lactation, little attention has been afforded to multiple indicators of dairy cow welfare and related risk factors during the housing period. The objective of this study was to identify risk factors for dairy cow welfare in a spring-calving, hybrid pasture-based system. Herd-level scores for seven indicators of welfare (locomotion, body condition, ocular and nasal discharge, integument damage, tail injury and human avoidance response) were collected from 82 Irish dairy farms during the housing period. Data were analysed using beta regression or zero-inflated beta regression to identify associations between these welfare indicators and measured housing, resource and management factors. Thirty-five unique risk factors were associated with one or more welfare indicators. Analyses identified a total of four risk factors for each of ocular discharge, nasal discharge, avoidance response of > 1 m from human approach, and body condition above the housing period target of 3.5. Six risk-factors each were associated with the proportion of lame cows and integument damage to the head-neck-back or hindquarter regions. The greatest number of risk factors, 12, were associated with broken, lacerated or incomplete tails. Risk factors associated with multiple indicators of welfare were cow comfort index (tail lacerations and hindquarter integument damage), cubicle width (broken and incomplete tails), shed floor slipperiness (lameness and head-neck-back integument damage), shed light-level (tail lacerations and avoidance response), shed passage width (broken tails and head-neck-back integument damage) and presence (incomplete tails) or absence (broken tails) of a collecting yard backing gate. With the large number of risk factors associated with tail injury, continued research is necessary to identify causes and determine prevention methods to contribute to improved overall welfare of dairy cows. Housing features meeting recommended guidelines from the literature were frequently associated with greater negative indicators of welfare. In light of this, housing guidelines may benefit from regular re-evaluation to ensure facilities meet the welfare needs of cows during the housing period.

Keywords – dairy cattle, health, behaviour, grass-based, welfare assessment, animal-based indicator

INTRODUCTION

Pasture-based dairy production in a hybrid system, where cows spend a portion of the year on pasture and a portion housed indoors (Mee and Boyle, 2020), is seen in countries worldwide wherever temperate climates allow for periods of grazing. These farms may differ in the amount of pasture access provided, from as little as two months as reported in parts of Sweden (Bergsten et al., 2015) to approximately eight months in Ireland (Crossley et al., 2021). Yet regardless of the length of the grazing or housing period, all cows experience the positive and negative welfare impacts of both indoor and outdoor systems.

To gain a better understanding of how different factors of both indoor and outdoor production systems impact dairy cow welfare, much research has been conducted using risk factor analyses. These analyses often examine factors that affect indicators of animal welfare. Animal-based indicators of welfare are those that directly measure attributes of the animal to reflect their welfare, rather than measures of the facilities or resources provided (Whay et al., 2003). Most studies have focused on individual indicators of welfare, such as lameness (Dippel et al., 2009a; Barker et al., 2010; Ranjbar et al., 2016; Bran et al., 2018; Somers et al., 2019; O'Connor et al., 2020a), integument damage (Rutherford et al., 2008; Kielland et al., 2009, 2010), and aspects of health such as subclinical ketosis (Garro and Mian, 2014), or on-farm mortality (Alvåsen et al., 2012). Fewer studies have incorporated multiple indicators of welfare. De Vries and colleagues (2015), for example, examined the impact of housing and management factors on Dutch dairy farms on four indicators of welfare: lameness prevalence, integument lesions, prevalence of dirty hindquarters, and frequency of displacements. Kathambi et al. (2019) also examined risk factors associated with lying time, cubicle and cow cleanliness as welfare indicators on dairy farms in Kenya.

Understanding the risks to good welfare is equally important during housing as during grazing, even when the period of housing is relatively short, because we have a responsibility to ensure optimal welfare in all environments to which a cow is exposed. However, in hybrid pasture-based systems with a relatively short period of housing compared to grazing, the welfare assessment is typically focused on the grazing period. Previous research of the Irish hybrid pasture-based system which focused on the housing period include examining the impact on lameness of out-wintering pads as an alternative winter housing (O'Driscoll et al., 2008). Additionally, the periparturient welfare has been compared between fully-housed TMR fed dairy cows and pastured dairy cows (Olmos et al., 2009b).

Optimizing cow welfare during housing is particularly important when considering seasonal calving systems. In a spring-calving system, the period of winter housing corresponds with the time of dry-off and the transition period when cows are particularly vulnerable to poor health and well-being (Ingvartsen and Moyes, 2015; Redfern et al., 2021). Additionally, what a cow experiences during this time can have lasting effects into the grazing season. Previous research has reported that integument damage during housing remains into the grazing season before it heals (Rutherford et al., 2008; Burow et al., 2013b) and visual evidence of hoof sole damage may take up to 12 weeks to appear (Nocek, 1997).

Despite the importance of this period in ensuring good dairy cow welfare, no large-scale study to date has investigated the risk factors for multiple indicators of welfare during the housing period on spring-calving, hybrid pasture-based dairy farms. Knowledge of risk factors for indicators of welfare will enhance the ability of farmers and farm advisors to make decisions on herd management and improve the welfare of dairy cattle. Thus, the objective of this study was to identify risk and protective factors for a variety of welfare indicators during the housed period on spring-calving, hybrid pasture-based dairy farms.

MATERIALS AND METHODS

This study was approved by the Teagasc Animal Ethics Committee (TAEC 197-2018), and conducted 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.

Farm recruitment and selection

As part of a larger welfare assessment, farms were selected that met the criteria of conventional (non-organic), spring calving (< 20% of cows calving outside spring period from Dec – June), pasture-based (> 200 d/yr on pasture) dairy herds located within the primary dairy producing counties (≥ 70,000 dairy cows; Central Statistics Office, 2018) in the Republic of Ireland (Cork, Kerry, Kilkenny, Limerick, Tipperary, Waterford and Wexford). Herd size of each farm was between 30 – 250 cows, which represented 95% of all eligible farms meeting the selection criteria. Breeds were primarily cross-bred Holstein, Friesian or Jersey cows or pure-bred Holstein cows. All farms were members of the Irish Cattle Breeding Federation (ICBF), the national information database for dairy and beef farms in Ireland. From a list of eligible farms provided by ICBF, 518 farms were randomly selected using SAS 9.4 (SAS Institute Inc., Cary, NC, USA) and invited to participate by mail or telephone with a 25% response rate. The maximum number of farms possible were visited during each of the grazing and housing periods. Visits were made to 103 Irish dairy farms during the grazing season

(April – September 2019; Crossley et al., 2021); 87 of which were re-visited during the housing period between October 2019 to February 2020. The focus of this study will be on those farms visited during the housing period.

Data collection

Data collection was performed by a team of three to four trained members at each visit and consisted of three components: scoring of animal-based welfare indicators, measurements of on-farm facilities and resources, and completion of a management survey with the farmers.

Animal-based measures

Animal-based indicators scored on each farm were body condition (BCS), locomotion, ocular and nasal discharge, integument damage, lacerated, broken or incomplete tails, and avoidance response to human approach. Chosen welfare indicators reflect the three interconnected spheres of welfare, health, behaviour and affective state; all of which are animal-based measures adapted from common welfare assessment protocols (Welfare Quality®, 2009; AssureWel, 2018; National Milk Producers Federation, 2019). Detailed descriptions of all categorical scales are included in Appendix A. Body condition was scored on a 5-point scale ranging from emaciated (1) to extremely over-conditioned (5) with 0.25 increments (Agriculture and Horticulture Development Board, 2015b). Locomotion was scored on a 4-point scale from good mobility (0) to severely impaired mobility (3) (Agriculture and Horticulture Development Board, 2015a). Discharge was scored on 4-point scales from normal (0) to heavy (3) for ocular, and from normal (0) to copious bilateral and mucopurulent (3) for nasal discharge adapted from the University of Wisconsin-Madison calf-health scoring system (University of Wisconsin-Madison School of Veterinary Medicine). Integument damage was scored for each of five body regions (head – neck – back, hindquarters, rear hocks, side body and front hocks) on the side of the body facing the observer (side scored varied depending on handling facility of each farm) according to the methods of Welfare Quality® (2009) and Gibbons et al. (2012b). Within each zone, damage was scored on a 4-point scale from "none" (0) to "lesion with or without major swelling" (3) and whether none, single and multiple areas of damage were observed. When there were multiple areas of damage within a single zone, that zone was assigned the score of the most severe alteration. Tail injury was scored as the presence or absence of any lacerations, breaks or incomplete tails (shortened or docked). Avoidance response test was adapted from Rousing and Waiblinger (2004) and measured the distance of a cow's first retreat from an approaching human observer within the indoor pen. This was scored on a 5-point scale ranging from "retreat at > 2 m from approaching observer" (1) to "accepting of touch" (5). A detailed description of the test procedure for avoidance response is available in Crossley et al. (2021). All cows were scored for locomotion, while all other scores were performed on a subset of animals selected according to herd size following the table provided in Welfare Quality® (2009). For BCS, ocular and nasal discharge, tail injury, and integument damage, every nth cow required to obtain the desired sample size was scored as they passed through the handling area. For avoidance response, the required number of cows were scored as they appeared while the observer moved through the pen; no animals were encouraged to rise if lying.

A series of instantaneous scan samples of the cows' behaviour were carried out throughout the visit at each farm. A target of three scans per pen were performed on each farm; a minimum of two on the day of scoring, and one additional scan performed within approximately 1 week of the initial visit during a follow up visit for a concurrent study (Browne et al., 2022). Utilising an ethogram of nine commonly observed behaviours (Standing - idle, Standing – active, Standing - social, Standing – eating, Standing – drinking, Standing – cubicle, perching, Lying – cubicle [includes those lying in loose-housing], Lying – passage) each scan was conducted by a trained observer who recorded the number of cows performing each behaviour, recording each cow's behaviour only once. Scans began with the observer in a position outside of each pen; if all areas of the pen could not be seen from one position, the area was visually sub-divided into zones and cows were scored within each. If it was still necessary for the observer to enter the pen, they proceeded slowly and carefully so as not to disturb the cows before they were counted. All scans were preceded by a minimum 15 min settling period when cows were undisturbed by either the observers or farmers, to allow a standardised period across farms for cows to return to their normal activities within the shed following any disturbance caused by the animal scoring. Results of these scans were used to calculate a cow comfort index (CCI). The CCI is a measure of cubicle use and is calculated as the number of cows lying in cubicles, divided by the total number of cows in contact with cubicles (standing either fully in, part-in part-out, or lying in cubicles; Nelson, 1996; Overton et al., 2002).

Facility measurements

Measured facilities included all sheds in use for housing the dry and milking herd outside of the grazing season, as well as the parlour and collecting yard because some farms continued to milk a portion of their herd after the start of housing. All measures are described in Table 1.

Table 1. Overview of facility measurements recorded on-farm

All sheds	Design (cubicles or loose-housing), shed (length, width, roof height, passage widths), feed-face dimensions (available length, feed-surface height inside and outside pen, head-rail height from pen floor and from top of the feed barrier, number and width of partitions if applicable), number and cleanliness of water sources (clean, partly dirty, dirty), water source dimensions (diameter or length and width, height, depth to waterline), water source functional and drainable, number of open sides, flooring type (smooth or grooved concrete, slats, rubber), flooring slipperiness (slippery, somewhat slippery, not slippery)*, automatic alley scraper, dead-end passages, light-level (bright, dim or dark)
Loose-housing sheds only (i.e. slatted sheds or straw-yards)	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)
Cubicle sheds only	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), partition flexibility and overall condition (very good, good, poor, bad), cubicle dimensions (total length, bed length, diagonal length, lunge space, curb height, neck-rail height, cubicle width, brisket board), cubicle stocking rate, cubicle surface material (concrete, mat, mattress), mat thickness if applicable, hardness (hard, medium, soft), bedding type (none, sand, sawdust, shavings, woodchips, lime, other), bedding depth and percent coverage (full, partial, minimal, none), cleanliness (clean, partly dirty, dirty)
Parlour	Design (parallel, herringbone), presence and type of divisions between cows, flooring type and slipperiness (slippery, somewhat slippery, not slippery)*, light level (bright, dim, dark)*, distance from last milking unit to end of parlour, presence of steps, turns (90 or 180 degrees), footbath
Collecting yard	Dimensions (length, width, entrance width and roof height if applicable) and design (shape, flooring type, slope, presence and type of scraper, brushes, backing gate)

* Measures adapted from de Vries et al., (2015)

Management Survey

Two in-person surveys were carried out as part of the overall welfare assessment which collected information regarding farm characteristics, management practices and animal health. The first survey was conducted during the initial visit to each farm during the grazing period and included questions regarding size of the grazing platform, number of milking cows, number of staff, history of expansion, plans for future expansion and participation in national herd health programs. Questions regarding management practices included biosecurity protocols for purchased stock, breeding strategy, housing and pasture turn-out dates, milking protocols and grazing strategies, source of water supply, water availability and water source maintenance. Questions related to animal health consisted of health record protocols, disease testing, use of pain-relief medication, parasite control, locomotion and body-condition scoring practices. The second survey was carried out during the housing period visit and included questions regarding autumn housing dates, target dry period length, grouping strategy during housing, passageway and cubicle cleaning protocols, diet and feeding protocols and farmer demographics. In addition to herd health and production records obtained from ICBF, a fillable health record form was also distributed to each farm by mail in advance of our second visit, requesting details on vaccination protocols, disease diagnoses, and lameness level within the herd for the study period of the 2019-2020 lactation.

Data Management

Of the initial 87 farms, five were excluded due to a large proportion of the herd (> 20%) calving outside of the typical spring calving period from December - June. As a result, 82 farms were included in the final analyses. Risk factor analyses were performed for seven welfare indicators derived from the animal score data. The locomotion score indicator consisted of the average percentage of cows that scored 2 or 3 (clinically lame) on the locomotion scale. The body condition indicator was the average percentage of cows that were scored above 3.5, the upper bound of the housing period target BCS (Butler, 2016). We chose to assess the percentage of cows above 3.5 because over-conditioned cows at calving are at elevated risk of dystocia, and metabolic disorders in early lactation (Roche et al., 2009; Atkinson, 2016). The ocular and nasal discharge indicators were the average percentages of cows scored with any signs of discharge (score 1, 2 and 3). For tail injury, separate analyses were performed for the average herd-level prevalence of each of lacerations, breaks and incomplete tails. Analysis of integument was performed only for the head-neck-back and hindquarter regions as these were the only regions that demonstrated substantial signs of damage during the housing period (Crossley et al., 2021). For both zones, the integument damage indicator consisted of any signs (single or multiple) of mild, moderate or severe integument damage (score 1, 2 and 3). The avoidance response indicator consisted of the percentage of cows with an avoidance response of > 1 m (levels 1 and 2) representative of a fearful avoidance response (FAR).

Data analysis

Risk factor analyses were performed for each welfare indicator. Data were analysed using a beta regression mixed model, fit by the glmmTMB routine as part of the glmmTMB library (Brooks et al., 2017) in R (R Core Team, 2020). The beta regression (BR) modeled a response for proportion data between zero and one generated by a beta distribution. Where the analysed indicator included values of zero, a zero-inflated component (ZI) was fit simultaneously with the BR component, which can only account for values between zero and one. The ZI component models the response for "pure-zero" values. The simultaneous fitting of BR and ZI components is known as a zero-inflated beta regression (ZIBR). Explanatory variables were modelled on the logit scale for probability for a pure zero farm and for the mean of the beta distribution for a non-pure zero farm (values > 0 < 1). On this logit scale, a large effect resulting from the ZI component implies a higher probability of a zero response, while a large effect from the BR component implies a response close to one. In other words, a significant effect in the ZI component indicates the presence or absence of an effect of the categorical variable on the response variable while the BR component indicates the degree of effect or the proportion of cows affected. The ZIBR analysis was only required for data from two welfare indicators, body condition score and tail injury. Due to a limitation of the Beta regression and ZIBR models, proportion values equal to one (100%) cannot be modelled, thus to approximate such values, they were replaced by the average of one and the next highest proportion. For the locomotion score analysis, a value of zero was observed on only a single farm, thus to eliminate the need to include a ZI model component, a similar procedure was followed and this value was replaced by the average of zero and the next lowest value.

Each analysis began with a univariate analysis of each potential factor determined to be relevant within the literature and by expert opinion of the authors. A list of all explanatory variables included in analyses for each welfare indicator is available as Appendix C. Factors were screened for potential significance at the level of P > 0.2 and those below this level were included in the analysis. Fisher's exact test was used to identify associations among all retained variables. Where significant association was found (P < 0.05) the explanatory variable deemed most biologically relevant was retained. Stepwise selection was performed among all retained variables, utilising the lowest Akaike's Information Criterion (AIC) for the initial selection and exclusion criterion, to identify a preliminary model. Any non-significant variables (P > 0.05), according to the Wald test, retained in the preliminary model were eliminated individually beginning with the factor with the greatest P-value until only significant ($P < 0.05$) factors remained. To check for any remaining effects, each excluded factor was reintroduced to the model individually; any significant ($P < 0.05$) factors for either the ZI or BR components were included in the final model. Tests of interaction were performed for all variables retained in the final model and any significant interactions were also included in the final model. For all explanatory variables retained in the final model, odds ratios were calculated using the R package, 'emmeans' (Lenth, 2020), including a Tukey type adjustment for P - values of pairwise comparisons for explanatory variables with three or more levels.

To account for a reduced sample size (63 – 69 farms), once any farms with missing data were eliminated, all analyses were repeated twice; once using only complete cases (CC), and once where missing values were substituted through single imputation (SUB; Curley et al., 2019). This method allowed us to maintain the data from the maximum number of farms within the analysis. Starting with a dataset containing only those potential explanatory variables with < 5% missing data, each missing value was substituted for the most frequently recorded value for each factor. The resulting SUB data set consisted of 82 study farms for all welfare indicators except avoidance response, for which the maximum number of study farms was 75. The previously described regression analysis was performed for both CC and SUB datasets, and the results of both are presented. Those risk factors identified by both methods of analysis show the most evidence for association with the particular welfare indicator. Risk factors identified through only SUB may indicate a weaker association that could become more apparent at larger sample sizes and thus may benefit from further research.

RESULTS

Descriptive statistics for each analysed welfare indicator for both CC and SUB are included in Table 2. Unless otherwise specified, reported results pertain to the BR model component, indicating an effect on the proportion of cows affected by each association.

Lameness

The proportion of lame cows (Table 3) was positively associated with treating cows seven days or more after being identified as lame compared to treating cows within both 48 or 24 hrs of identification, not testing silage quality, and having slatted compared to concrete flooring in the collecting yard (CC and SUB). Furthermore, the proportion of lame cows was positively associated (CC) with shed flooring being either all slippery or all non-slippery compared to a mixture of both surfaces, keeping manual compared to digital health records and farmers reporting that lameness is a problem in their herd. Lastly, the proportion of lame cows was positively associated with the diagonal length of all cubicles being outside recommended dimensions, and the widths of all cubicles being within recommended dimensions (SUB). Interacting effects included cubicle diagonal length and cubicle width (CC), as well as whether farmers consider lameness a problem in their herd and employing additional full-time staff (SUB).

Table 2. Descriptive statistics of the average herd-level prevalence of scored welfare indicators for both the complete cases and substitution data[1]

	Complete Cases						Substitution					
Welfare Indicator[2]	**No. Farms**	**Mean**	**SD**	**Median**	**Min**	**Max**	**No. Farms**	**Mean**	**SD**	**Median**	**Min**	**Max**
Ocular discharge	64	44.9	20.29	43.8	6.5	83.8	82	46.5	20.95	45.1	6.5	94.0
Nasal discharge	64	36.5	20.94	35.7	1.9	88.6	82	35.3	20.23	35.7	1.9	88.6
BCS above 3.5	67	5.9	6.44	3.3	0.0	36.5	82	5.6	6.09	3.2	0.0	36.5
Tail lacerations	69	2.9	5.27	0.0	0.0	21.8	82	2.8	5.05	0.0	0.0	21.8
Tail breaks	69	9.0	9.80	5.0	0.0	47.3	82	8.5	9.31	4.9	0.0	47.3
Incomplete tails	69	7.0	12.97	1.8	0.0	74.5	82	7.5	13.90	1.8	0.0	74.5
Lameness	68	8.7	4.72	8.9	0.0	23.0	82	9.3	5.71	9.0	0.0	28.0
Integument damage - HNB	65	66.4	25.00	70.7	11.9	100.0	82	65.8	25.17	71.3	7.6	100.0
Integument damage - H	65	32.8	18.24	30.6	1.9	79.5	82	32.2	18.13	30.6	1.9	79.5
Fearful avoidance response	63	75.0	17.47	76.9	33.3	100.0	75	74.2	17.03	75.8	33.3	100.0

[1] The complete case dataset included only those farms with no missing data. The substitution dataset employed single imputation of the most frequently observed value for each missing value within each variable, resulting in a dataset containing all 82 study farms.

[2] Body Condition Score (BCS) > 3.5 is above the highest recommended target body condition during housing; lame cows were those scored 2 or 3 on a 4-point locomotion scale from 0-3; integument damage to the head-neck-back (HNB) and hindquarter (H) regions includes hair-loss and/or lesions (score 1 - 3 on a 4-point scale from 0-3); ocular and nasal discharge include cows scored with any signs of discharge (1 – 3 on a 4-point scale from 0-3); fearful avoidance response refers to cows that displayed signs of retreat at > 1 m from an approaching observer (level 1 or 2 on a 5-point scale from 1 – 5) in an avoidance test conducted within the housing pen.

Table 3. Final beta regression model of risk factors associated with lameness during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels	Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	56	Shed flooring slipperiness		0.01	No vs Yes	1.27	0.99 - 1.63	0.160
		No	18		No vs Mixed	1.72	1.3 - 2.27	0.001
		Yes	51		Yes vs Mixed	1.35	1.1 - 1.67	0.019
		Mixed	31					
		Collecting yard flooring		0.001	C vs S	0.64	0.51 - 0.80	0.001
		Concrete (C)	56		C vs M	0.81	0.62 - 1.06	0.272
		Slats (S)	28		S vs M	1.26	0.95 - 1.67	0.252
		Mixed (M)	16					
		Silage quality tested		< 0.001	No vs Yes	1.86	1.52 - 2.29	< 0.001
		No	29					
		Yes	71					
		Health record-keeping		< 0.001	Manual vs digital	1.58	1.31 - 1.91	< 0.001
		Manual	43					
		Digital	57					
		Time from lame cow identification to treatment		< 0.001	≤ 24 h vs ≤ 48 h	1.01	0.79 - 1.28	0.999
		≤ 24 h	47		≤ 24 h vs ≥ 7 d	0.59	0.47 - 0.73	< 0.001
		≤ 48 h	25		≤ 48 h vs ≥ 7 d	0.58	0.45 - 0.75	< 0.001
		≥ 7 d	28					
		Farmers consider their farm to have a lameness problem		0.001	No vs Yes	0.72	0.60 - 0.87	0.001
		No	57					
		Yes	43					
		Cubicle diagonal length x cubicle width		0.001	R,R: NR,R	0.42	0.31 - 0.75	0.001
					NR,R: R,NR	2.67	1.73 - 3.44	< 0.001
					NR,R: NR,NR	2.53	1.46 - 2.99	< 0.001

Table 3. (Continued)

Analysis method	No. factors tested	Factor levels	Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Substitution	56	Diagonal cubicle length		< 0.001	R vs NR	0.65	0.53 - 0.80	< 0.001
		Recommended (R)	62					
		Non-recommended (NR)	38					
		Cubicle width		0.025	R vs NR	1.33	1.04 - 1.70	0.029
		Recommended (R)	17					
		Non-recommended (NR)	83					
		Silage quality tested		< 0.001	No vs Yes	1.61	1.32 - 1.96	< 0.001
		No	34					
		Yes	66					
		Time from lame cow identification to treatment		0.001	≤ 24h vs ≤ 48 h	0.96	0.74 - 1.22	0.927
		≤ 24 h	50		≤ 24h vs ≥ 7 d	0.66	0.52 - 0.82	0.002
		≤ 48 h	23		≤ 48h vs ≥ 7 d	0.69	0.52 - 0.90	0.025
		≥ 7 d	27					
		Collecting yard flooring		0.003	C vs S	0.70	0.57 - 0.86	0.004
		Concrete (C)	56		C vs M	0.95	0.70 - 1.28	0.936
		Slats (S)	31		S vs M	1.36	0.99 - 1.86	0.144
		Mixed (M)	13					
		Farmers consider their farm to have a lameness problem x Additional full-time staff other than primary farmers		0.013	N,N: Y,N	0.51	0.41 - 0.64	< 0.001
					Y,N: N,Y	1.84	1.25 - 2.72	0.016
					Y,N: Y,Y	1.81	1.31 - 2.50	0.003
		Farmers consider their farm to have a lameness problem x Method of health record-keeping		0.075	N,M: Y,M	0.59	0.42 - 0.82	0.013
					Y,M: N,D	2.18	1.62 - 2.93	< 0.001
					Y,M: Y,D	1.87	1.43 - 2.44	< 0.001

[1] Data from 68 farms were included in complete case data analysis and 82 farms in substitution data analysis. Lame cows were those scored 2 or 3 on a 4-point locomotion scale from 0-3.

Body Condition

The proportion of cows above 3.5, the BCS target for the housing period (Table 4), was positively associated with insufficient cubicle lunge space, and there being only one primary farmer compared to more than one (CC and SUB). Through CC analysis, either all or no feed partitions being uniformly present compared to a mixture of both, all feed passages meeting the required width compared to only some, and also some meeting recommended widths compared to none were positively associated with the proportion of cows above target BCS. Cleaning cubicles once/d compared to twice/d and not performing regular body condition scoring were positively associated with the proportion of cows above target housing BCS through SUB analysis. Additionally, through SUB analysis, both the presence (ZI component) and proportion (BR component) of cows above the target housing BCS of 3.5 were positively associated with farmers not reporting that BCS was an aspect of animal care to improve. Interacting effects were found between herd size and cubicle width, as well as the frequency of cleaning water sources and whether farmers perform regular BCS (CC). Analysis by SUB also revealed some significant interactions when included individually in the model, however the model did not converge when all were included simultaneously in the model. Therefore, no interactions were included for the SUB analysis.

Integument Damage

Damage to the integument of the head-neck-back (Table 5) was found to be positively associated with the presence of turns into the parlour entrance compared to no turns, diagonal lengths of all cubicles being within recommended dimensions compared to all not within recommended levels, shed passages all being of sufficient width (≥ 3 m; Agriculture and Horticulture Development Board, 2012) compared to not being sufficient width, and shed flooring being all or partially slippery compared to non-slippery (CC and SUB). Cubicles being in “good” condition compared to “very good” condition, all cubicles neck-rail heights being within recommended dimensions compared to outside recommendations, feed-rail heights being outside compared to within recommended dimensions, 180° turns not being present at the parlour exit compared to turns being present, and farmers reporting an aspect of animal care needed improvement, compared to farmers reporting no aspect of animal care needed improvement were also positively associated with integument damage to the head-neck-back-region (SUB).

Integument damage to the hindquarters (Table 5) was positively associated with housing cows in multiple groups compared to a single group (CC and SUB), the cow comfort index being below average compared to above average (CC), slippery flooring at the parlour entrance compared to non-slippery flooring and not using automatic alley scrapers compared to using them (SUB). Interacting effects (CC) included floor slipperiness at the parlour entrance and passage width, as well as the presence of turns into the parlour entrance with the presence of automatic alley scrapers.

Ocular and Nasal Discharge

The proportion of cows with ocular discharge was positively associated (Table 6) with drinking water being dirty compared to either clean or partly clean, collecting yard area/cow being below recommended allowance of 1.4m^2/cow (Clarke, 2016) compared to equal or above, and not being enrolled in a health management program (CC and SUB). Additionally, pushing feed up to the feed-face once/d or less compared to more than once/d was also positively associated with the proportion of cows with ocular discharge (CC).

The proportion of cows with nasal discharge (Table 7) were positively associated with farmers who did not report that facilities were an aspect of animal care in need of improvement on their farm compared to those that did (CC and SUB), delivering fresh feed less than once/d compared to once/d or more, employing compared to not employing full-time staff in addition to the primary farmer, and application of absorbent/antibacterial material onto the cubicles compared to no application (CC). Additional interacting effects were the average age of the farmer with both the presence of absorbent material on cubicles and the frequency of fresh feed delivery (SUB).

Table 4. Final zero-inflated beta regression model of risk factors associated with above target BCS (> 3.5) during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	43	Sufficient lunge space		BR	< 0.001	No vs Yes	1.82	1.35 - 2.44	< 0.001
		No	25	ZI	0.219				
		Yes	75						
		Feed partitions		BR	< 0.001	No vs Yes	0.78	0.56 - 1.06	0.271
		No	31	ZI	0.538	No vs Mixed	1.94	1.18 - 3.19	0.035
		Yes	54			Yes vs Mixed	2.51	1.57 - 4.01	0.002
		Mixed	15						
		Sufficient feed passage width		BR	< 0.001	No vs Yes	0.55	0.38 - 0.78	0.271
		No	54	ZI	0.356	No vs Mixed	0.61	0.45 - 0.84	0.035
		Yes	18			Yes vs Mixed	1.12	0.75 - 1.66	0.002
		Mixed	28						
		Number of farmers		BR	0.012	One vs > One	1.56	1.11 - 2.21	0.017
		One	75	ZI	0.199				
		> One	25						
		Herd size x cubicle width		BR	0.004	≤80, R: ≤125, R	7.22	3.0 - 17.37	0.001
				ZI	0.884	≤80, R: >125, R	2.74	1.47 - 5.12	0.037
						≤80, R: ≤80, NR	3.54	2.20 - 5.69	< 0.001
						≤80, R: ≤125, NR	6.44	4.07 - 10.19	< 0.001
						≤80, R: >125, NR	3.79	2.46 - 5.83	< 0.001
		Water cleaning frequency x Regular body condition scoring		BR	0.009	OAD, N: <OAD, Y	2.23	1.34 - 3.72	0.043
				ZI	0.873	>OAD, N: <OAD, Y	3.19	1.65 - 6.17	0.019
						OAD, Y: <OAD, Y	2.53	1.50 - 4.26	0.017

Table 4. (Continued)

Analysis method	No. factors tested	Factor levels	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Substitution[3]	43	Cubicle cleaning frequency		BR	0.001	OAD vs < OAD	2.01	1.08 - 3.73	0.080
		Once/day (OAD)	52	ZI	0.206	OAD vs TAD	1.79	1.29 - 2.50	0.003
		< Once/day (OAD)	10			< OAD vs TAD	0.89	0.48 - 1.66	0.934
		Twice/day (TAD)	38						
		Sufficient lunge space		BR	< 0.001	No vs Yes	1.96	1.41 - 2.73	< 0.001
		No	26	ZI	0.493				
		Yes	74						
		Regular body condition scoring		BR	0.03	No vs Yes	1.37	1.03 - 1.83	0.035
		No	52	ZI	0.36				
		Yes	48						
		Number of farmers		BR	0.017	One vs > One	1.56	1.08 - 2.24	0.020
		One	74	ZI	0.229				
		> One	26						
		BCS is aspect of animal care identified as needing improvement		BR	0.042	No vs Yes	2.38	1.03 - 5.51	0.047
		No	91	ZI	0.007	No vs Yes	0.02	0.001 - 0.35	0.009
		Yes	9						

[1] Data from 67 farms were included in complete case data analysis and 82 farms in substitution data analysis.

[2] 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).

[3] Substitution method model also contained herd size (BR: $P = 0.270$, ZI: $P = 0.945$), shed light level (BR: P = 0.094, ZI: P = 0.655), feed passage width (BR: P = 0.141, ZI: P = 0.447), and feeding advice (BR: P = 0.334, ZI: P = 0.065).

Table 5. Final beta regression model of risk factors associated with integument damage to the head-neck-back (HNB) and hindquarter (H) regions during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	Body Zone	No. factors tested	Factor levels	Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	HNB	47	Diagonal cubicle length		0.003	R vs NR	2.06	1.28 - 3.31	0.004
			Recommended (R)	58					
			Non-recommended (NR)	42					
			Turns into parlour entrance		< 0.001	No vs Yes	0.41	0.25 - 0.66	0.001
			No	57					
			Yes	43					
			Sufficient passage width		0.001	No vs Mixed	0.39	0.22 - 0.69	0.002
			No	74					
			Mixed	26					
			Shed flooring slipperiness		0.009	Not-slippery vs Slippery	0.36	0.18 - 0.71	0.012
			Not-slippery	17		Not-slippery vs Mixed	0.39	0.20 - 0.77	0.023
			Slippery	51		Slippery vs Mixed	1.08	0.65 - 1.79	0.952
			Mixed	32					
	H	42	Multiple housing groups		< 0.001	No vs Yes	0.42	0.28 - 0.63	0.000
			No	23					
			Yes	77					
			Cow Comfort Index		0.002	Below vs Above average	1.44	1.05 - 1.97	0.030
			Below average	48					
			Above average	52					
			Turns into parlour entrance x Automatic alley scraper		0.006	N, N: N, Y	4.26	2.23 - 8.11	< 0.001
						Y, N: N, Y	2.53	1.55 - 4.12	0.003
						N, Y: Y, Y	0.52	0.36 - 0.75	0.005
			Flooring slipperiness at parlour entrance x Sufficient passage width		0.008	N, N: Y, Y	0.21	0.10 - 0.43	< 0.001
						Y, N: Y, Y	0.28	0.14 - 0.58	0.006
						N, Y: Y, Y	0.25	0.12 - 0.52	0.003

Table 5. (Continued)

Analysis method	Body Zone	No. factors tested	Factor levels	Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	H	42	Flooring slipperiness at parlour entrance x Cow Comfort Index		0.139				
			Flooring slipperiness at parlour entrance x Turns into parlour entrance		0.247				
Substitution	HNB	47	Cubicle condition		0.001	VG vs G	0.43	0.27 - 0.67	0.001
			Very Good (VG)	60		VG vs P	0.71	0.36 - 1.40	0.589
			Good (G)	30		G vs P	1.67	0.81 - 3.46	0.352
			Poor (P)	10					
			180 degree turn at parlour exit		0.010	No vs Yes	1.76	1.15 - 2.70	0.012
			No	70					
			Yes	30					
			Feed-rail height		0.001	R vs NR	0.46	0.29 - 0.73	0.002
			Recommended (R)	72					
			Non-recommended (NR)	28					
			Reported any aspect of animal care farmers wish to improve		0.011	No vs Yes	0.57	0.37 - 0.88	0.013
			No	26					
			Yes	74					
			Neck-rail height		0.020	R vs NR	1.63	1.08 - 2.47	0.023
			Recommended (R)	38					
			Non-recommended (NR)	62					
	H	42	Multiple housing groups		0.015	No vs Yes	0.63	0.43 - 0.91	0.018
			No	26					
			Yes	74					

Table 5. (Continued)

Analysis method	Body Zone	No. factors tested	Factor levels		Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Substitution	H	42	Flooring slipperiness at parlour entrance			0.003	No vs Yes	0.61	0.44 - 0.85	0.004
				No	66					
				Yes	34					
			Automatic alley scraper			0.034	No vs Yes	1.51	1.03 - 2.22	0.038
				No	21					
				Yes	79					

[1] Data from 65 farms were included in complete case data analysis and 82 farms in substitution data analysis. Integument damage consists of hair-loss and or lesions (score 1 - 3 on a 4-point scale from 0-3).

Table 6. Final beta regression model of risk factors associated with ocular discharge during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels	Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete Cases	41	Collecting yard area		0.003	Below vs Above	1.73	1.20 - 2.48	0.005
		Below 1.4m^2/cow	42					
		Above 1.4m^2/cow	58					
		Frequency of feed push-up to feed-face		0.009	≤ OAD vs > OAD	1.63	1.13 - 2.34	0.011
		≤ OAD	48					
		> OAD	52					
		Shed water cleanliness		< 0.001	Clean vs Partly dirty	1.29	0.84 - 1.97	0.471
		Clean	26		Clean vs Dirty	0.49	0.29 - 0.84	0.033
		Partly dirty	55		Partly dirty vs Dirty	0.38	0.23 - 0.62	0.001
		Dirty	19					
		Enrolled in health management program		0.019	No vs Yes	1.66	1.09 - 2.54	0.023
		No	22					
		Yes	78					
Substitution	41	Collecting yard area		0.028	Below vs Above	1.48	1.04 - 2.09	0.0311
		Below 1.4m^2/cow	41					
		Above 1.4m^2/cow	59					
		Shed water cleanliness		0.028	Clean vs Partly dirty	1.12	0.73 - 1.71	0.859
		Clean	23		Clean vs Dirty	0.61	0.36 - 1.03	0.166
		Partly dirty	57		Partly dirty vs Dirty	0.55	0.35 - 0.85	0.025
		Dirty	20					
		Enrolled in health management program		0.029	No vs Yes	1.56	1.05 - 2.31	0.032
		No	24					
		Yes	76					

[1] Data from 64 farms were included in complete case data analysis and 82 farms in substitution data analysis. Ocular discharge includes any cows scored 1 – 3 on a 4-point scale from 0-3. Recommended collecting yard area is 1.4m^2/cow (Clarke et al., 2016).

Table 7. Final beta regression model of risk factors associated with nasal discharge during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels	Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete cases	40	Absorbent material on cubicles		0.006	Mixed vs Yes	0.52	0.33 - 0.83	0.008
		Mixed	25					
		Yes, all	75					
		Feed delivery frequency		0.016	≥ OAD vs < OAD	0.57	0.36 - 0.90	0.019
		≥ once/day (≥ OAD)	77					
		< once/day (< OAD)	23					
		Additional full-time staff other than primary farmers		0.047	No vs Yes	0.63	0.40 - 0.99	0.051
		No	75					
		Yes	25					
		Reported facilities need improvement		0.012	No vs Yes	1.74	1.13 - 2.68	0.015
		No	70					
		Yes	30					
Substitution	40	Reported facilities need improvement		0.002	No vs Yes	1.83	1.25 - 2.67	0.003
		No	71					
		Yes	29					
		Absorbent material on cubicles x Average farmer age		0.022	Y, ≤ 40: M, > 50	2.96	1.45 - 6.02	0.043
					M, > 50: Y, > 50	0.37	0.21 - 0.67	0.020
		Feed delivery frequency x Average farmer age		0.038	≥ OAD, ≤ 40: ≥ OAD, > 50	2.78	1.45 - 6.02	0.004
					< OAD, ≤ 50: ≥ OAD, > 50	4.28	1.98 - 9.24	0.006
					≥ OAD, > 50: < OAD, > 50	0.36	0.19 - 0.67	0.021

[1] Data from 64 farms were included in complete case data analysis and 82 farms in substitution data analysis. Nasal discharge includes any cows scored 1 – 3 on a 4-point scale from 0 - 3.

Avoidance response

The proportion of cows displaying a fearful avoidance response (FAR; Table 8) was positively associated with shed lighting being bright compared to low or mixed, performing regular locomotion scoring compared to not regularly scoring, and no dog being present when herding cattle compared to a dog being present (CC and SUB). Additionally, using tail marking tape compared to not using it (CC), not employing compared to employing full-time staff in addition to the primary farmers, and bedding cubicles once/d or less compared to twice/d (SUB) were also positively associated with the proportion of cows displaying a FAR. Lastly, an interacting effect was found between the frequencies of applying absorbent material to cubicles and push-up of feed to the feed-face (CC).

Tail Injury

The presence of cows with broken tails (ZI component) was positively associated (Table 9) with all cubicles being outside recommended widths compared to within, all or some cubicles being clean compared to all being dirty, and not having a backing gate in the collecting yard compared to having a backing gate (CC and SUB). The proportion of cows with breaks in their tail (BR component) was positively associated with having sufficiently wide shed passages (≥ 3 m; Agriculture and Horticulture Development Board, 2012) compared to having narrow passages (CC and SUB). Additionally, the use of tail tape compared to not using it, and using artificial insemination (AI) as the sole breeding method compared to using only stock bulls or a combination of AI and stock bulls were positively associated with the proportion of cows with tail breaks (CC).

The presence of cows with tail lacerations (Table 10; ZI component) was positively associated with above average compared to below average CCI (CC and SUB), as well as mixed compared to both low and bright (a tendency) shed lighting (CC). There was also a tendency for a positive association between the presence of cows with tail lacerations (ZI component) and alley scraper passage cleaning frequency of eight times or more in 24 hr compared with six to less than eight times/24 hr (CC). The proportion of cows with tail lacerations (BR component) was positively associated with some or all cubicles meeting the recommended lengths compared to all cubicles being outside recommended length dimensions (CC). Additionally, a herd size of 80 cows or less compared to herds of either 81 - 125 cows, or more than 125 cows, the use of tail tape for marking cows compared to not using tape, and farmers not reporting their facilities were an aspect of animal care they wanted to improve compared to those that did report facilities were also positively associated with the proportion of cows with tail lacerations (SUB). The risk factors, cubicles outside recommended levels, bright or low shed lighting compared to mixed lighting and a tendency for less-frequent passage cleaning by the alley scraper, were found to be interrelated. When considered in the model individually, significant interactions were identified between alley scraper passage frequency and either cubicle length or shed lighting level. However, the final model did not converge when both interactions were included, thus interactions were not included in this model.

The presence of incomplete tails (Table 11; ZI component) was positively associated with all cubicles being outside recommended widths (1.15 ± 0.025 m for partitions with no rear attachment and 1.25 ± 0.025 for partitions with rear attachments; Ryan, 2004; Clarke, 2016) compared with all or some cubicles being of recommended width (CC and SUB). Having a backing gate in the collecting yard compared to not having a backing gate (CC), as well as not having a brisket board in cubicles compared to having one (SUB) were also positively associated with the presence of incomplete tails. In addition, there were tendencies for a positive association between the presence of incomplete tails and bedding cubicles twice/d compared to once/d or less (CC), herds with 125 cows or more compared to herds with 80 cows or fewer, and for having an above average CCI compared to below average (SUB). The proportion of cows with incomplete tails (BR component) was positively associated with introduced heifers being familiar with cubicle housing compared to those that had no previous experience with cubicles (CC).

Table 8. Final beta regression model of risk factors associated with fearful avoidance response during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels		Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete Cases	32	Shed lighting			0.007	Bright vs Low	1.86	1.20 - 2.90	0.022
			Bright	25		Bright vs. Mixed	1.93	1.23 - 3.02	0.016
			Low	43		Low vs Mixed	1.04	0.70 - 1.53	0.983
			Mixed	32					
		Dog present when herding			< 0.001	No vs Yes	3.08	2.12 - 4.44	< 0.001
			No	63					
			Yes	37					
		Tail tape			0.002	No vs Yes	0.54	0.37 - 0.79	0.003
			No	35					
			Yes	65					
		Regular locomotion scoring			0.005	No vs Yes	0.49	0.30 - 0.81	0.007
			No	84					
			Yes	16					
		Cubicle bedding frequency x Frequency of feed push-up			0.027	OAD, ≤ OAD: TAD, ≤ OAD	3.36	1.88 - 6.01	0.002
						TAD, ≤ OAD: OAD, > OAD	0.30	0.16 - 0.57	0.007
						TAD, ≤ OAD: < OAD, > OAD	0.11	0.04 - 0.28	< 0.001
						< OAD, > OAD: TAD, > OAD	5.07	2.14 - 12.02	0.007
		Routine parasite treatment			0.055	No vs Yes	0.61	0.36 - 1.01	0.061
			No	13					
			Yes	87					

Table 8. (Continued)

Analysis method	No. factors tested	Factor levels	Prevalence (%)	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Substitution	32	Shed lighting		0.010	Bright vs Low	1.81	1.16 - 2.81	0.028
		Bright	27		Bright vs Mixed	1.97	1.24 - 3.14	0.015
		Low	41		Low vs Mixed	1.09	0.74 - 1.60	0.896
		Mixed	32					
		Dog present when herding		< 0.001	No vs Yes	2.23	1.55 - 3.20	< 0.001
		No	63					
		Yes	37					
		Regular locomotion scoring		0.009	No vs Yes	0.49	0.29 - 0.84	0.011
		No	87					
		Yes	13					
		Additional full-time staff other than primary farmers		0.025	No vs Yes	1.57	1.06 - 2.34	0.028
		No	75					
		Yes	25					
		Cubicle bedding frequency		0.011	OAD vs < OAD	0.81	0.49 - 1.36	0.713
		Once/day (OAD)	53		OAD vs TAD	1.64	1.12 - 2.41	0.035
		< Once/day (< OAD)	15		< OAD vs TAD	2.02	1.17 - 3.49	0.038
		Twice/day (TAD)	32					

[1] Data from 63 farms were included in complete case data analysis and 75 farms in substitution data analysis. Fearful avoidance response refers to signs of retreat at > 1 m from an approaching observer (level 1 or 2 on a 5-point scale from 1 – 5) in an avoidance test conducted within the housing pen.

Table 9. Final zero-inflated beta regression model of risk factors associated with broken tails during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels	Prevalence (%)	Model component[2]	P-value	Pairwise comparison	Odds ratio	95% CI	P-value of pairwise comparison
Complete Cases	33	Sufficient passage width		BR	0.018	No vs Yes	0.62	0.41 - 0.92	0.022
		No	74	ZI	0.886				
		Yes	26						
		Breeding		BR	0.012	Combined vs AI only	0.48	0.27 - 0.85	0.015
		Combined	87	ZI	0.855				
		AI only	13						
		Tail tape		BR	0.022	No vs Yes	0.59	0.38 - 0.93	0.026
		No	39	ZI	0.077				
		Yes	61						
		Cubicle cleanliness		BR	0.813				
		Clean	35	ZI	0.012	Clean vs Dirty	0.01	0.001 - 0.32	0.027
		Dirty	10			Clean vs Mixed	0.70	0.06 - 8.72	0.957
		Mixed	55			Dirty vs Mixed	53.61	3.13 - 919.66	0.022
		Cubicle width		BR	0.539				
		Recommended (R)	16	ZI	0.029	R vs NR	17.0	1.33 - 216.59	0.034
		Non-recommended (NR)	84						
		Backing gate		BR	0.672				
		No	78	ZI	0.036	No vs Yes	0.10	0.01 - 0.87	0.041
		Yes	22						

Table 9. (Continued)

Analysis method	No. factors tested	Factor levels	Prevalence (%)	Model component[2]	P-value	Pairwise comparison	Odds ratio	95% CI	P-value of pairwise comparison
Substitution	33	Sufficient passage width		BR	0.012	No vs Yes	0.59	0.39 - 0.89	0.014
		No	76	ZI	0.384				
		Yes	24						
		Cubicle width		BR	0.760				
		Recommended (R)	17	ZI	0.027	R vs NR	13.0	1.33 - 125.66	0.030
		Non-recommended (NR)	83						
		Backing gate		BR	0.260				
		No	79	ZI	0.025	No vs Yes	0.12	0.02 - 0.76	0.028
		Yes	21						
		Cubicle cleanliness		BR	0.417				
		Clean	35	ZI	0.038	Clean vs Dirty	0.03	0.002 - 0.57	0.059
		Dirty	12			Clean vs Mixed	0.56	0.07 - 4.70	0.851
		Mixed	53			Dirty vs Mixed	17.93	1.67 - 192.02	0.051

[1] Data from 69 farms were included in complete case data analysis and 82 farms in substitution data analysis.

[2] 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 10. Final zero-inflated beta regression model of risk factors associated with tail lacerations during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete Cases	33	Cow Comfort Index		BR	0.176				
		Below average	49	ZI	0.004	Below vs. Above average	6.47	1.81 - 23.20	0.006
		Above average	51						
		Passage cleaning frequency		BR	0.099				
		< 6 times/ 24 h	43	ZI	0.040	< 6 vs ≥ 6 < 8 times/ 24 h	0.22	0.05 - 0.94	0.111
		≥ 6 < 8 times/ 24 h	38			< 6 vs ≥ 8 times/ 24 h	2.06	0.41 - 10.33	0.657
		≥ 8 times/ 24 h	19			≥ 6 < 8 vs ≥ 8 times/ 24 h	9.29	1.47 - 58.87	0.056
		Shed Lighting		BR	0.018	Bright vs Low	0.40	0.17 - 0.95	0.106
		Bright	25			Bright vs. Mixed	0.32	0.14 - 0.71	0.018
		Low	42			Low vs Mixed	0.79	0.44 - 1.41	0.710
		Mixed	33	ZI	0.018	Bright vs Low	1.17	0.23 - 5.96	0.982
						Bright vs. Mixed	7.22	1.39 - 37.43	0.057
						Low vs Mixed	6.19	1.47 - 26.09	0.042
		Cubicle length		BR	< 0.001	Mixed vs NR	3.10	1.75 - 5.49	< 0.001
		Mixed	32	ZI	0.412				
		Non-recommended (NR)	68						

Table 10. (Continued)

Analysis method	No. factors tested	Factor levels	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Substitution	33	Herd Size		BR	< 0.001	≤ 80 vs ≤ 125	2.61	1.55 - 4.40	0.002
		≤ 80 cows	24			≤ 80 vs > 125	2.29	1.37 - 3.84	0.007
		≤ 125 cows	33			≤ 125 vs > 125	0.88	0.53 - 1.46	0.872
		> 125 cows	43	ZI	0.318				
		Reported facilities need improvement		BR	0.019	No vs Yes	1.83	1.10 - 3.03	0.023
		No	71	ZI	0.805				
		Yes	29						
		Tail tape		BR	0.025	No vs Yes	0.61	0.40 - 0.94	0.028
		No	38	ZI	0.419				
		Yes	62						
		Cow Comfort Index		BR	0.448				
		Below average	49	ZI	0.001	Below vs. Above average	7.49	2.35 - 23.68	0.001
		Above average	51						
		Cubicle cleaning frequency		BR	0.383				
		Once/day (OAD)	52	ZI	0.070				
		< Once/day (< OAD)	10						
		Twice/day (TAD)	38						

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[1] Data from 69 farms were included in complete case data analysis and 82 farms in substitution data analysis.

[2] 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 11. Final zero-inflated beta regression model of risk factors associated with incomplete tails during the housing period on spring-calving, hybrid pasture-based Irish dairy farms.[1]

Analysis method	No. factors tested	Factor levels	Prevalence (%)	Model component[2]	*P*-value	Pairwise comparison	Odds ratio	95% CI	*P*-value of pairwise comparison
Complete Cases	33	Introduced heifers are familiar with cubicles		BR	0.030	No vs Yes	0.48	0.24 - 0.93	0.035
		No	29	ZI	0.676				
		Yes	71						
		Cubicle width		BR	0.647				
		Recommended (R)	16	ZI	0.002	R vs NR	25.0	3.32 - 188.44	0.003
		Non-recommended (NR)	84						
		Backing Gate		BR	0.252				
		No	78	ZI	0.013	No vs Yes	16.40	1.80 - 150.63	0.016
		Yes	22						
		Cubicle bedding frequency		BR	0.654				
		Once/day (OAD)	51	ZI	0.049	OAD vs < OAD	0.47	0.10 - 2.18	0.605
		< Once/day (<OAD)	17			OAD vs TAD	6.57	1.14 - 37.80	0.098
		Twice/day (TAD)	32			< OAD vs TAD	13.88	1.61 - 119.94	0.052
Substitution	33	Brisket board		BR	0.241				
		No	77	ZI	0.039	No vs Yes	0.22	0.05 - 0.92	0.042
		Yes	23						
		Cubicle width		BR	0.302				
		Recommended (R)	17	ZI	0.044	R vs NR	5.8	1.05 - 32.17	0.048
		Non-recommended (NR)	83						
		Herd size		BR	0.722				
		≤ 80 cows	24	ZI	0.046	≤ 80 vs ≤ 125	4.38	1.00 - 18.99	0.128
		≤ 125 cows	33			≤ 80 vs > 125	5.53	1.33 - 22.96	0.055
		> 125 cows	43			≤ 125 vs > 125	1.26	0.33 - 4.92	0.939

Table 11. (Continued)

Analysis method	**No. factors tested**	**Factor levels**		**Prevalence (%)**	**Model component**[2]	***P*-value**	**Pairwise comparison**	**Odds ratio**	**95% CI**	***P*-value of pairwise comparison**
		Cow Comfort Index			BR	0.558				
			Below average	49	ZI	0.048	Below vs. Above	3.45	1.02 - 11.76	0.052
			Above average	51						
		Backing gate			BR	0.330				
			No	79	ZI	0.106				
			Yes	21						

[1] Data from 69 farms were included in complete case data analysis and 82 farms in substitution data analysis.

[2] 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).

DISCUSSION

This is the first large-scale study investigating risk factors for the welfare of dairy cows during the housing period of a spring-calving, hybrid pasture-based system. In total, 35 risk factors and six interaction effects were identified through CC or both CC and SUB analysis methods. A further 12 risk factors and four interaction effects were identified through SUB analyses alone, each of which involved at least one variable that was also identified in their respective CC analyses. Those risk factors identified through both analysis methods indicate factors with the most robust association because they remained present regardless of changes in sample size. Factors identified only through analysis of CC data avoid any possible effects of including estimated data in the analysis. For risk factors identified only after imputation of missing values, while unlikely to lead to error when applied to only a small amount of data (≤ 5% in the present study; Curley et al., 2019), they still represent variables whose effects were only detectable at larger sample sizes. These present promising avenues for future research; however, for the purposes of this study, only variables identified through both CC and SUB analysis together, or CC analysis alone will be discussed. Similarly, while interaction effects also indicate interesting areas of further study, for the purpose of brevity only the significant main effect variables will be discussed. The identified risk factors generally fall into three categories, those related to the facilities, feed resources and management.

Facilities – Cubicles

After the transition from pasture to indoor housing, appropriate facilities are necessary to ensure good welfare. In the current study, both total and diagonal cubicle length, cubicle width and insufficient lunge space were associated with multiple indicators of welfare: incomplete, lacerated or broken tails, integument damage to the head-neck-back and above target body condition. Improper cubicle design has been shown to lead to abnormal lying and rising movements in cows (Lidfors, 1989; Dirksen et al., 2020), increased skin lesions (Regula et al., 2004), and reduced lying time and lying bouts (Tucker et al., 2006). For both diagonal and total cubicle length, adhering to recommended cubicle dimensions (Clarke, 2016) was determined to be a risk factor for good welfare. This suggests that some guidelines for appropriate cubicle housing design may need to be better tailored to suit existing animals within the herd when constructing indoor facilities, as appropriate cubicle dimensions are proportional to body size (Dirksen et al., 2020). The fact that in a spring-calving pasture-based system cows are dried-off as they enter housing and therefore heavily pregnant, with a consequently larger body size at the end of housing should be considered when recommending facility dimension requirements.

Greater time spent lying in cubicles of inappropriate dimensions may expose the tail to potential injury. This could contribute to the association found between above average CCI and the presence of tail lacerations. Cubicle comfort level was also found to be linked to integument damage. Below average CCI was associated with a greater proportion of cows with hindquarter integument damage, possibly due to collisions with cubicle features when rising or lying, which may contribute to cubicle discomfort. Similar damage to hock lesions has been linked to collisions with cubicles as shown by Weary and Taszkun (2000). A CCI of 85% or more is recommended as an indicator that cubicles are comfortable and meeting the needs of cows to encourage lying time (Overton et al., 2003). However in the current study the average CCI across farms was only 55%, with only two farms achieving the 85% target. One contributor to cubicle discomfort may be the lack of bedding observed. While 82% of farms applied some form of moisture absorbent material to cubicles, primarily hydrated lime (calcium hydroxide), only 4% applied any bedding to a depth greater than 0.5 cm. Increased use of bedding can increase total lying time and reduce the occurrence of cows perching half in and half out of cubicles, indicating an increase in cubicle comfort (Tucker and Weary, 2004).

The observed presence of broken and incomplete tails with more frequent application of fresh bedding and cleaner cubicles, less contaminated with manure or urine, further suggests that tail injury is occurring while cows are resting. Cows show a clear preference for cubicles with dry bedding over wet, and substitute lying time for greater time standing or perching half-in half-out of cubicles when they are wet (Fregonesi et al., 2007; Reich et al., 2010). The addition of hydrated lime as a moisture-absorbing and bacteria-inhibiting material to the cubicles was associated with greater nasal discharge when used on all cubicles compared to only a portion. Commonly used on Irish farms, hydrated lime is an alkaline powder with an approximate pH of 12 (Gleeson, 2013). It is effective at reducing bacterial counts on cubicle surfaces, yet can cause some skin irritation of teats (Kristula et al., 2008; Gleeson, 2013). At such a high pH it is likely that it could also be an irritant if inhaled as dust in the air or through contact with a cow's nose and nasal passages. In fact, stockpersons utilising hydrated lime on farm are advised to wear personal protective equipment and to seek medical help if contact with the eyes is made (Francesca et al., 2011).

It is also important to consider appropriate facilities for the needs of young stock. The greater proportion of incomplete tails among cows with experience in cubicle housing as newly housed heifers also suggests that cubicle housing of young stock compared to other forms of housing may result in greater tail injury. Young animals lying incorrectly on, or outside of, cubicles may create more opportunities for their tails to be injured by the alley scraper or trampling by other cows. Slatted flooring in particular has been associated with tail-tip injury in housed feedlot calves and adult beef cows (Drolia et al., 1991; Schrader et al., 2001; Grooms et al., 2010). Farms in the USA have also been reported to prophylactically dock feedlot cattle's tails when housed in slatted flooring, supposedly to prevent further injury (Miller, 2010). Intentional tail docking is prohibited in Ireland except where deemed medically necessary and performed by a veterinarian, and thus should represent a relatively small proportion of incomplete tails observed on farms. However, in the current study, 15% of the 82 study farms had more than 15% of cows with incomplete tails, the threshold proposed by Welfare Quality® (2009) for considering farms to be practicing tail docking.

Facilities – Shed

One of the major environmental differences in the transition to indoor housing from pasture is the exposure to hard and potentially slippery flooring surfaces. Shed flooring that was scored as either all "slippery" or all "non-slippery" were both associated with a greater proportion of lame cows compared to sheds with a combination of surfaces. Slipperiness is commonly associated with accumulation of slurry which can soften the heel horn (Gregory et al., 2006) and increase exposure to infections causes of lameness such as interdigital dermatitis and heel erosion (Somers et al., 2005). More abrasive flooring is less slippery, yet may cause greater wear resulting in thinner soles and increased hoof lesions (Shearer and Van Amstel, 2007). It is unclear why a combination of these flooring surfaces would provide a protective effect on the proportion of lame cows. Potentially providing a variety of surfaces offers a degree of relief from continuous exposure to the negative effects of either slippery or non-slippery flooring. Sufficient passage cleaning frequency can help to control floor slipperiness. However, more frequent passage cleaning also tended to be associated with a greater likelihood of tail lacerations, suggesting that such injury is related to contact with the scraper.

Shed floor slipperiness was also linked to integument damage to the head-neck-back. In competitive feeding environments such as those observed on the majority (84%) of study farms, displacements from the feed-rail are common, particularly among subordinate cows (DeVries et al., 2004; Huzzey et al., 2006). Cows are capable of exerting up to 2000 N of pressure on the neck-rail when feeding (Dumelow, 1987), thus perhaps if cows are displaced from the feed-rail while on slippery flooring, the friction between the cow's neck and the feed-rail could account for the observed integument damage. Inappropriate feed-rail heights may also contribute to integument damage to the neck (Kielland et al., 2010b). Lower odds of head-neck-back integument damage for feed-rails within recommended heights (1.18 m; Clarke, 2016) were identified in our analysis, although only through substitution analysis, thus the effect may be more apparent in a larger data set.

Sufficient passage widths allow for free movement of cows within the shed, space for cows to perform social interactions and ease of cleaning (Agriculture and Horticulture Development Board, 2012). The fact that recommended passage widths were associated with greater tail breaks and integument damage to the head-neck-back once again suggests that guidelines may not be suitable for the modern cow in this system or for a cow at a late stage in their pregnancy. Feed passages in particular should be wider to prevent feeding cows blocking the movement of others (Agriculture and Horticulture Development Board, 2012). Having feed passages above or equal to recommended widths will allow greater feed accessibility, at which point the focus should be on providing correct quantities and quality of feed to moderate intakes. Above target BCS, especially towards the end of the housing period, is of particular welfare concern as over-conditioned cows at calving at a BCS of ≥ 3.5 may also reduce DMI into early lactation and lead to a greater risk of metabolic disorders and negative energy balance (Roche et al., 2009; Atkinson, 2016).

The primary reasons farmers gave for housing cows in multiple groups were based on BCS, calving or dry-off date, parity, or space availability. A potential explanation for the association between greater integument damage to the hindquarters and multiple housing groups may be an increase in agonistic behaviour. Housing cows in multiple groups may necessitate re-grouping which has been shown to increase agonistic behaviour due to social stressors (Proudfoot and Habing, 2015).

Indoor sheds provide very different lighting conditions compared to outdoor environments, and it is known that cows have difficulty distinguishing objects in shadow or at differing light intensities (Moran and Doyle, 2015). Such difficulty with vision in low light may have contributed to the reduced fearful avoidance response observed if the cows were unable to observe the approaching scorer. In mixed-light conditions, where more shadows may result from the combination of bright and low light, the occurrence of tail lacerations was more common. This suggests injury may be due to impaired vision and inability to distinguish and avoid hazards in shadowed environments. It is also possible that the association with tail injury is in fact due to other aspects of housing that are found in conjunction with particular lighting conditions. De Vries et al. (2015) found greater prevalence of hock lesions and swellings to be associated with low shed lighting and concluded that it may be due to superior housing conditions, such as wider alleys, longer and cleaner cubicles, being more common in sheds with brighter lighting. This supports our results that when tail lacerations were present, the proportion of affected cows was reduced in bright lighting environments.

Facilities – Collecting yard

The collecting yard continues to be an area commonly used by dairy cattle during the housing period, whether because some cows are still milked daily up until dry-off, or because many farms use this area as additional housing space. However, it is important that these areas continue to be operated at the proper capacity, as demonstrated by the greater ocular discharge found among collecting yards below the recommended area per cow. Crowding cows within an insufficient space may increase airborne pathogens (Callan and Garry, 2002), increase ammonia emissions due to greater volumes of deposited manure and urine (Misselbrook et al., 1998), and reduce air quality which can contribute to an impaired immune system (Love et al., 2014).

Additionally, the association between slatted concrete flooring in the collecting yard and greater lameness supports previous studies which also found greater odds of lame cows when housed on slatted compared to solid concrete flooring (Dippel et al., 2009b; Fjeldaas et al., 2011). Compared to solid flooring, slatted floors have been shown to have lower friction, making them more slippery (Telezhenko and Bergsten, 2005; van der Tol et al., 2005), and modelling scenarios show slatted flooring in isolation to have a more uneven distribution of stress with greater maximum peaks across the hoof sole (Hinterhofer et al., 2006).

The purpose of a backing gate or crowd-gate in the collecting yard is to reduce available space and encourage cows to move into the milking parlour. Conflicting effects on tail injury were found when backing gates were used, with broken tails occurring less often, yet incomplete tails occurring more often. Without a backing gate to encourage cows into the parlour, direct handling of the animals may be required. Tail breaks have previously been attributed to excessively forceful animal handling practices, such as tail twisting to force a cow's forward motion (Alam et al., 2010; Lindahl et al., 2016). However, milking is not typically an aversive activity requiring such forceful handling (Lindahl et al., 2016). The cause of a greater likelihood of incomplete tails when a backing gate is used is difficult to determine without knowing whether the injury is due to accidental damage or intentional removal. Further research is required to identify the nature of this injury and how it may be linked to the milking facilities.

Sharp turns can be challenging for walking cows (Rushen et al., 2004) and are considered risk factors for lameness, particularly when they occur near the entrance or exit from the parlour (Barker et al., 2010). However, rather than lameness, we found that the proportion of cows with integument damage to the head-neck-back region to be greater when turns into the parlour entrance were required. Navigating fewer turns improves cow flow (Grandin, 1980) and reduces the opportunity for contact with objects that my cause harm or damage to the cow.

Feed Resources

Ensuring cows are receiving adequate nutrition throughout the housing period is critical to maintain good welfare. This is demonstrated by the reduction in lameness associated with silage quality testing. Since nutrition is known to play an important role in hoof health, testing of silage quality to monitor feed supply during housing can prevent or reduce lameness. Insufficient quantities of vitamins, minerals, fibre, protein or lipids in a cow's diet may contribute to a variety of metabolic and nutritional disorders such as acidosis and laminitis, which in turn impact hoof health (Westwood and Lean, 2001; Langova et al., 2020).

A positive association was found between practicing less frequent feed push-up and greater ocular discharge, as well as less frequent fresh feed delivery and greater nasal discharge. It is possible that less frequent feed disturbance could allow moulds the opportunity to flourish in the stagnant feed. Breakdown by rumen microorganisms normally protects dairy cattle from mycotoxin ingestion. However, cows in the transition period from dry-off to post-calving, which coincides with housing in a seasonal system, may be especially vulnerable to exposure to mycotoxin contaminated feed due to negative energy balance (Fink-Gremmels, 2008). Similarly, greater signs of ocular discharge were associated with poor water cleanliness, and dirty water is also a potential source of pathogens that may pre-dispose cattle to disease (Linn and Raeth-Knight, 2010).

Results suggest that the use of a combination of both partitions and open-rail feed-faces had a protective effect on the proportion of cows that were above the target housing BCS of 3.5 (Butler, 2016). The majority of study farms (84%) were overstocked at the feed-face when considering a feeding stocking rate 0.6 cm/cow (Farm Animal Welfare Advisory Council, 2018). Vertical feed-face partitions have been shown to reduce the occurrence of displacements in competitive feeding situations (O'Connell et al., 2010). This may be of particular benefit to more socially subordinate animals (Endres et al., 2005) as it could provide an area for them to feed, protected from displacements by other cows. This may balance intakes of provided feed more evenly between cows within the herd and reduce the proportion of cows with above target BCS.

Management - Health

Lameness is widely considered one of the greatest welfare challenges in the dairy sector. It is a painful and debilitating condition (Coetzee et al., 2017) and can impair a cow's welfare as long as it is left untreated. The positive association we found between greater time from diagnosis to treatment of lame cows and a higher proportion of lameness supports findings by Leach et al. (2012) and Bell et al. (Bell et al., 2009) who demonstrated that reducing the time between diagnosis and treatment resulted in fewer severe cases of hoof lesions and lameness.

Performing regular locomotion scoring on farms as a means of identifying lame cows was found to increase the proportion of cows displaying a fearful avoidance response. This could either be related to the process of locomotion scoring itself or whether or not cows were in fact lame. If the scoring process is an aversive experience for the cow due to improper animal handling, poor facilities, loud noises etc., it could negatively affect the human-animal relationship resulting in a greater fearful avoidance response (Pajor et al., 2000). Lame cows experiencing pain may also have a heightened stress response resulting in a greater fearful avoidance response. More frequent scoring would likely also result in more frequent trimming, a potentially negative and painful interaction which could increase a cow's fear of humans.

In a review discussing farmer perceptions of lameness, Dutton-Regester et al., (2020) illustrated agreement within the literature that lameness often is underdiagnosed by farmers and thus goes without treatment. In the current study, on average, farmers reported approximately 5% lame cows in their herd on the day of the housing period visit, whereas 9% of cows on average were scored as lame by the research team. However, farmers were also asked whether they considered lameness a problem in their herd, and those that replied yes were associated with a greater proportion of lame cows. Therefore, even though lameness is, on average, underreported by farmers in the current study, they appear to at least be aware when a problem exists.

Monitoring the development of illness within the herd enables accurate monitoring of disease prevalence and is a critical component of disease control. This involves keeping updated health records, although the method of record-keeping may vary between farms. We found that maintaining digital health records was associated with reduced proportions of lame cows. Use of digital health recording, such as phone apps e.g. HerdWatch, provide additional tools for visualising health data and interpreting trends that would be unavailable through manual notation. This additional information has the potential to increase a farmer's ability to diagnose and treat disease such as lameness in their herd, and can be shared with those involved in herd health management such as vets and advisors (Tremblay et al., 2016).

Participation in herd health management programs may also improve health monitoring, and thus disease management. Ocular discharge in cows was reduced when farmers were enrolled in herd health management programs. Ocular discharge is a common sign of respiratory diseases in adult dairy cows (Banks, 1999; Decaro et al., 2008; Ferraro et al., 2021). Respiratory diseases may severely impact a cow's welfare, thus any practices associated with a reduction in ocular discharge should be promoted. Further research into whether farmers enrolled in herd health management programs were more proactive in other aspects of animal health, such as practicing vaccination or meeting space requirements, would provide greater insight into this association.

Management – General

Multiple aspects of general herd management were found to be associated with broken tails; practicing AI as the only breeding method, and using tail tape for marking cows. Tail marking tape is often used to identify ill or medically treated cows in the parlour. It seems unlikely that either of these practices alone would result in the force capable of breaking a tail when carried out appropriately. However, while these two variables were not directly correlated ($P = 0.139$), it is possible that herds that use solely AI exhibit some similarity to those that use tail tape. Perhaps if excessively forceful animal handling is used to separate cows either previously identified with tail tape for medical treatment, or for breeding by AI this could explain these associations. A connection between forceful tail twisting and broken tails has been speculated (Alam et al., 2010; Lindahl et al., 2016; Laven and Jermy, 2020); however, research on the causes of broken tails is sparse and further study is required.

The use of tail tape was also associated with greater fearful avoidance response. This is likely in response to its use in identification of ill or treated cows. Because conditions such as mastitis can be painful (Huxley and Whay, 2006b; Leslie and Petersson-Wolfe, 2012) a cow may associate the use of tail tape with aversive experiences and in turn increase their avoidance response of the humans who apply the tape (Pajor et al., 2000). Another factor associated with greater fearful avoidance response was the absence of a dog when herding. As a prey species, the presence of a dog is typically considered a fearful stimulus (Welp et al., 2004; Lee et al., 2018). However, for herds accustomed to disturbance or threatening stimulus from proximity to a dog, the approach of a lone human may be experienced as less threatening in contrast. This is supported by Welp et al. (2004), who found that exposure to a dog elicited a greater vigilant fear response from cows than exposure to humans.

The number of principle farmers and presence of additional farm staff were also associated with indicators of welfare. Seventy-four percent of farms reported that there was only a single principle farmer, and it was this group that was associated with a greater proportion of cows above target housing BCS. No correlation was found between the number of principle farmers and farmer age; both sole farmer and multiple farmer operations had a median age of 47 years, therefore it is not likely to be a difference in experience driving this association. Potentially a shortage of labour necessitates differences in feeding management between farms with either sole or multiple farmers that impacts cow BCS; however, no trend could be identified from the current data. Also unexpectedly, employing additional full-time staff other than the primary farmer was associated with increased proportion of cows with nasal discharge. With increased staff to identify health issues, one might expect reduced signs of poor health. The relationship between stockpersons and animals was not examined in detail in this study and would benefit from further research to understand these relationships.

When asked during the survey if there were aspects of animal care they would like to improve, those farmers that specified facilities needed improvement were negatively associated with nasal discharge. These farmers may be more aware of shortcomings within their facilities and may be more likely to have made improvements leading to reductions in signs of poor health or injury. Previous research has shown that farmers consider animal welfare to be one of their primary goals of health management (Kristensen and Enevoldsen, 2008) and that personality and attitudes of farmers contribute to dairy cow welfare, health, production and management on farms (Adler et al., 2019). The responses to this question could reflect farmers' desire to improve welfare of cows on their farms.

CONCLUSION

With 35 identified risk factors, this study has demonstrated that a wide number of variables influence the welfare of dairy cows during the housing period in hybrid pasture-based systems with seasonal calving. These risk factors were primarily related to facility design, feed resources and management practices on farm, with multiple risk factors associated with more than one indicator of welfare. Of the measured welfare indicators, the greatest number of risk factors were associated with tail injury. Further research is required to determine the causes of tail injury and to take steps toward prevention and improved welfare. Aspects of facility design that met with recommended design specifications were frequently associated with greater negative indicators of welfare. This suggests that recommended guidelines may not be suitable, particularly for cows in a later stage of pregnancy. This system may benefit from more frequent updates to facility guidelines that better reflect evolving cow characteristics and ensure optimum welfare during indoor housing.

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| CHAPTER 5 |

Effect of differing levels of grazing pressure during the early and late grazing periods on the welfare of spring-calving, pasture-based dairy cows

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ABSTRACT

The objective of this study was to identify potential effects of increased grazing pressure, characterised by differing pasture allowances and stocking rates, on indicators of welfare during both the early and late grazing periods. A total of 70 grazing Holstein-Friesian and cross-bred dairy cows, averaging 35 ± 16 d in milk on the first day of data collection, were assigned to three treatment groups (20-26 cows/group) representative of a range in grazing pressure; treatments were, LOW (high pasture allowance, opening cover of 980 kg DM/ha, 2.75 cows/ha, 90:10% pasture:concentrate diet), MOD (medium pasture allowance, opening cover of 720 kg DM/ha, 2.75 cows/ha, 90:10% pasture:concentrate diet), and HIGH (low pasture allowance with opening cover of 570 kg DM/ha, 3.25 cows/ha, 80:20% pasture:concentrate diet). The examined welfare indicators were locomotion score, hoof health (digital dermatitis and white line disease), rumen fill, ocular and nasal discharge, and integument damage to the neck-back and hock regions. All indicators except hoof health were scored weekly for five weeks during early grazing in spring (EG) and over seven weeks during late grazing in autumn (LG). Hoof health indicators were scored four times, once at the beginning and once at the end of both EG and LG. Results demonstrated only minor treatment effects. Cows on MOD ($P < 0.001$) and HIGH ($P = 0.047$) were more likely to display nasal discharge compared to LOW. Cows on MOD tended to have more neck-back alterations than LOW ($P = 0.069$). Total locomotion score was greater for cows on LOW compared to HIGH ($P = 0.033$). The average prevalence of lame cows for EG and LG respectively was 15.3 ± 3.12% and 39.2 ± 3.00% for LOW, 20.0 ± 2.58% and 24.2 ± 5.69% for MOD and 14.9 ± 4.79% and 17.0 ± 3.44% for HIGH. Cows on HIGH were less likely to have an impaired walking speed than either LOW ($P = 0.010$) or MOD ($P = 0.035$). Cows on both HIGH ($P = 0.001$) and MOD ($P = 0.003$) were less likely to display impaired ab/adduction compared to those on LOW. The greatest effects were seen between grazing periods, with all indicators except rumen fill and locomotion score demonstrating significant improvements during LG compared to EG ($P < 0.01$). This suggests that cows were able to cope well with increasing levels of grazing pressure, and that regardless of treatment, more time on pasture led to improvements in welfare indicators.

Keywords - pasture allowance, stocking rate, intensification, welfare indicator

INTRODUCTION

Agricultural intensification, the increase in production by unit of input such as animals, land or labour (Ma et al., 2020) is a common characteristic of dairy production worldwide (Mee and Boyle, 2020). Pasture-based systems of production are reputed to be highly profitable (Dillon et al., 2008), but are reliant on achieving efficient pasture utilisation. It has been reported that for every additional tonne of pasture DM/ha utilised, there is an increase in net profit of €173/ha (Hanrahan et al., 2018). Much research has focused on intensification through improved pasture utilisation by examining increases in stocking rate (McCarthy et al., 2016; Macdonald et al., 2017; Coffey et al., 2018), differing levels of pasture allowance (Evers et al., 2021) or extending the length of the grazing season (Läpple et al., 2012b; Claffey et al., 2020) in order to maximize grass intakes, and ultimately milk yield/ha. However, for a dairy production system to be sustainable, such intensification must not come at the expense of animal welfare. Studies of intensification methods in grazing systems rarely have the animal welfare impact as a primary focus. Therefore, there is a need for a greater understanding of the effects of grazing intensification on animal welfare.

Pasture-based systems are generally perceived to provide a more natural environment than indoor systems and as such to contribute to good welfare. Several studies have demonstrated the benefits of pasture, including reduced lameness prevalence and severity of hoof problems (Olmos et al., 2009a), improvement of lameness over time (Hernandez-Mendo et al., 2007), lower ocular discharge (Wagner et al., 2018), reduced clinical mastitis (Washburn et al., 2002), fewer instances of hock hair loss and lesions (Burow et al., 2013b; Armbrecht et al., 2019), and increased lying time and lying bout length (Olmos et al., 2009a). However, the progression towards more intensive systems has the potential to negatively impact these positive effects of pasture access. In Ireland, where spring-calving, pasture-based dairy systems predominate, the dairy sector has experienced considerable changes since the removal of dairy production quotas in 2015. From 2008 – 2018, herd sizes, farm area and stocking rates have increased from 54 cows, 50 ha and 1.71 livestock units/ha, to 79 cows, 59 ha and 2.06 livestock units/ha; increases of 46.3%, 15.3% and 20.5% respectively (Connolly et al., 2009; Dillon et al., 2019). Such expansion and intensification may impose further stress on pasture-based cows. A 2017 survey of stakeholders within the Irish dairy sector, including farmers, veterinarians and farm advisors, found that 77% of farms had expanded their herd size in the previous three years without a corresponding increase in infrastructure such as housing or roadways (Boyle et al., 2017). Inappropriate and overcrowded housing facilities may increase the risk of integument damage which can carry-over into the grazing season (Rutherford et al., 2008; Kielland et al., 2009, 2010; Burow et al., 2013a; Armstrong, 2020). Increased stocking rates are crucial for increasing pasture utilisation, yet may result in lower body weights and BCS in individual cows due to reduced daily herbage allowance and dry matter intakes (McCarthy et al., 2012, 2014). Cows with reduced pasture allowance have been shown to have fewer and shorter lying bouts, as well as a longer latency to lie down after milking compared to a higher feed allowance (O'Driscoll et al., 2019).

The potential impact of farm-system intensification on dairy cow welfare could also be influenced by seasonal changes between the early and late periods of the grazing season. During early grazing in Ireland (spring), weather may be more variable, with heavy rainfall necessitating periods of on-off grazing where cows are housed for short periods (Kennedy et al., 2009). Furthermore, in a spring-calving system, the calving season is timed to coincide with increasing grass growth; however, following initial turn-out, cows' feed demands may out-pace grass supply, requiring supplementation with silage or concentrates (Kennedy et al., 2005b). Although grass growth rates are lower, pasture quality is high at this time of year compared to other periods, due to the higher organic matter digestibility, and crude protein level than in the late grazing season (autumn; Kennedy et al., 2006). Grass growth reaches its peak after three to four months of increasing growth (approx. May), thereafter grass growth will begin to decline and remain low throughout the winter months (Hurtado-Uria et al., 2013; PastureBase Ireland, 2020). Cows also experience considerable physiological changes during the early grazing period, with both a rapid reduction in body condition, and a peak in milk production taking place within approximately the first two months post-calving (Roche et al., 2007, 2009). With such differences between the early and late grazing periods, it is possible that the influence of increased grazing pressure on welfare could manifest differently during each period.

To gain a better understanding of how intensification may impact dairy cow welfare at different points during their lactation, the objective of this study was to identify the effects of increased grazing pressure on animal-based indicators of welfare during both early and late grazing periods by imposing different levels of pasture allowance and stocking rates. We hypothesised that cows under higher levels of grazing pressure would experience more negative effects on welfare indicators. Additionally, we hypothesised that the observed effects on welfare indicators would differ between the early and late periods of the grazing season.

MATERIALS AND METHODS

This study was approved by the Teagasc Animal Ethics Committee (TAEC169-2017) and was conducted 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. Data collection was conducted in conjunction with a system-level study investigating the effect of pasture availability and farm system stocking intensity on spring-calving, pasture-based dairy production. For further details of the farm system study design and management see Evers et al. (2021).

Animals and Feeding

Seventy lactating Holstein-Friesian (HF; n = 34) and cross-bred dairy cows (n = 36; primarily HF x Jersey) were enrolled in the study (9 primiparous and 61 multiparous). All cows calved between January and April, 2018 (mean calving date February 20th 2018 ± 22 d), and had an average DIM of 35 ± 16 d on the first day of data collection. Data were collected during two periods; an early grazing period (EG) of five weeks from March 18th to April 21st 2018, and a late grazing period (LG) of eight weeks from September 16th to November 10th 2018. Data collection was not possible during the 4th week of the LG due to unavoidable circumstances, reducing the maximum number of LG inspections to seven weeks. Average body weight and BCS in the first week of EG data collection was 493 ± 88.7 kg, and 3.0 ± 0.24 respectively, and 542 ± 71.9 kg and 2.9 ± 0.20 respectively in the first week of LG data collection.

At pasture, cows grazed a sward of predominantly perennial ryegrass (*Lolium perenne* L.). Concentrate supplementation was based on pasture availability; cows were supplemented when pasture supply was insufficient to achieve target pasture allowance. Pasture was provided through a rotational grazing system, with access to fresh pasture provided every 24 – 36 hr. Cows remained on pasture 24 hr/d other than when traveling to and from the parlour for milking. However, during periods of inclement weather, grazing was managed by providing shortened periods at pasture (12 hr), practicing on-off grazing (Kennedy et al., 2009), or housing cows during extreme rainfall. Cows were housed (indoor cubicle shed) for a cumulative total of either 15.5 or 17.5 days, depending on treatment, during EG, and zero days for all treatment groups during LG. When housed during these periods, cows were supplied with ad-libitum pasture silage.

Treatments and Experimental Design

Treatments are described in detail in the larger farm system study described by Evers et al. (2021). In short, the experiment consisted of a 3 × 2 factorial arrangement of treatments; three pasture allowances (low, medium or high) and two farm system intensities (medium or high). The medium intensity farm system maintained a stocking rate of approximately 2.75 cows/ha (20 - 22 cows/group) and provided a 90:10% pasture:concentrate diet. The high intensity farm system maintained a stocking rate of approximately 3.25 cows/ha (23 - 26 cows/group; consistently 0.5 cows/ha greater than medium), an 80:20% pasture:concentrate diet (additional 1.8 kg DM/cow/d of concentrates compared to medium) and a post-grazing sward height 0.5 cm lower than that of medium. During EG, cows on medium intensity received a total of 116 kg DM (0 – 4 kg DM/cow/d) of concentrates, and cows on high intensity received 186 kg DM (2 – 6 kg DM/cow/d). During LG cows received a total 280 kg DM (5 kg DM/cow/d) and 392 kg DM (7 kg DM/cow/d) of concentrates on medium and high intensity systems respectively. A description of how differences in pasture allowances were established can be found in Evers et al. (2021). The low pasture allowance treatment (spring opening cover = 570 kg DM/ha) reflects the current production level on farms based on nationally collected data (PastureBase Ireland; Hanrahan et al., 2017). The medium pasture allowance (spring opening cover = 720 kg DM/ha) reflects recommended best practice established through previous research (Tuñon et al., 2014). The high pasture allowance (spring opening cover = 980 kg DM/ha) reflects proposed levels of increased autumn grass availability suitable for a higher stocking rate system (Evers et al., 2021). Three treatment combinations from the larger study were chosen for investigation in the current study because they represented the greatest range in grazing pressure (the combination of pasture allowance and farm system intensity) among all the treatments. The lowest pressure grazing group (LOW) was characterised by high pasture allowance and medium intensity farm system, a moderate pressure grazing group (MOD) was characterised by medium pasture allowance and medium intensity farm system, and the highest pressure grazing group (HIGH) was characterised by low pasture allowance and high intensity farm system.

All cows were assigned to their respective treatments prior to calving, balanced by treatment according to expected calving date, breed, parity, body weight, BCS and economic breeding index. Upon the start of the treatments, cows that had already calved were assigned to their treatment. Any cows that calved after this date were placed directly into their respective treatment after calving. Cows that calved more than 7 d after the first day of data collection (n = 5) were not included in the EG analyses.

Due to low rainfall and poor pasture growth during the 2018 grazing season, it was necessary to reduce the total number of grazing cows to maintain pasture allowance levels. In mid-September 2018, prior to the start of the LG, the total number of cows was reduced by seven, distributed across treatments (three from HIGH, two each from LOW and MOD), to maintain consistent differences in stocking rates between treatments; thus only 63 cows remained on the trial during LG.

Experimental Measurements

Clinical health

Several aspects of clinical health were scored on a weekly basis. Two trained observers scored cows during EG (n = 5 inspections), and just one of these observers (the primary) scored during LG (n = 7 inspections). Following the morning milking one day per week, each cow was restrained in a handling gate after exiting the parlour. The eyes and nose of each cow were scored for signs of ocular or nasal discharge on a 3-point scale, from zero (no discharge) to two (heavy discharge; Welfare Quality®, 2009). The integument of the neck and along the back to the tail head was examined for any abrasions or alterations and scored on a 4-point scale (from zero - no alterations, to three - major swelling with or without hair loss or lesions; Welfare Quality®, 2009). The left side of the cow, just behind the last rib and below the short ribs, was palpated and assigned a score for rumen fill according to a 5-point scale (from one – deep indentation, least fill, to five – no definition, most fill) adapted from the scale by the Agriculture and Horticulture Development Board (2019). During a subsequent afternoon milking, both rear hocks of each cow were scored while standing in the parlour for integument alterations on a 4-point scale (from zero - no alterations, to three - major swelling with or without hair loss or lesions; Gibbons et al., 2012b).

Locomotion scoring

Locomotion scoring of all cows was conducted by a single trained scorer throughout; the same primary scorer that performed clinical health scores. One day per week, after morning milking during both EG (n = 5 weeks) and LG (n = 7 weeks), each cow was released from the handling gate individually and their locomotion was scored as the cow walked past and away from the scorer. Five different components of the cow's locomotion (speed, spine-curvature, head-carriage, step-tracking and ab/adduction) were each scored on a 5-point scale (from one – normal, to five - most severe deviation possible), according to the methods of O'Driscoll et al. (2010a). Running cows were not scored. The five individual scores were then summed into a single overall locomotion score (minimum score 5, maximum score 25). According to O'Callaghan et al., (2003), a minimum of two components with a score of three or more would be considered a lame cow, thus we concluded that the minimum possible score for lameness was nine. The proportion of cows with a score of nine or greater was summarised by treatment and week for each of EG and LG to determine the average prevalence of cows categorised as lame.

Hoof health

Manual hoof inspections were performed on the rear hooves of each cow by the primary trained observer with the assistance of a professional hoof trimmer (Farm Relief Services, Derryvale, Roscrea, Tipperary, Ireland). Four inspections were performed for each cow. Depending on calving date, the first inspection occurred between approximately three weeks prior to and one week following the start of treatments (mean trial day -5 ± 11 d SD, mean DIM 24 ± 19 d SD). The next inspection took place after a minimum of six weeks had elapsed since the start of treatments (mean trial day 64 ± 14 d SD, mean DIM 92 ± 27 d SD). The final two inspections took place at the start and end of the LG; all cows were scored over three consecutive days at the beginning (mean trial day 185 ± 1 d SD, mean DIM 212 ± 21 d SD) and on four separate days approximately six to eight weeks later (mean trial day 256 ± 7 d SD, mean DIM 282 ± 20 d SD).

During the inspections, cows were individually restrained within a hoof trimming crate and each rear leg was lifted in succession to provide access to the sole of the hoof. Water was used to remove any dirt and then a thin layer of the sole surface was pared away by the trained hoof trimmer to expose fresh, clean sole surface for inspection. Each hoof was scored for digital dermatitis on a 6-point scale (from zero – none visible, to five – hyperkeratotic lesions; O'Driscoll et al., 2008), white line disease on a 5-point scale (from zero – none apparent, to four – complete separation of the white line; O'Driscoll et al., 2008), sole haemorrhage or bruising on a 6-point scale (from zero - none, to five - red and raw with possibly fresh blood; Leach et al., 1998; O'Driscoll et al., 2009b), and the presence or absence of sole ulcers. Any hoof issues deemed to pose an immediate risk to the animal's hoof health and overall welfare were treated accordingly by the trained hoof professional at the time of the inspection.

Data Management

Several of the variables had few observations in the upper score levels indicative of the most severe levels of impairment (sum of incidences of third level severity score or greater over both EG and LG for ocular discharge = 1, nasal discharge = 1, neck-back integument alterations = 29, hock integument alterations = 60, digital dermatitis = 22) and thus these health scores were summarised into binary data and analysed for the presence (score > 0) or absence (score 0) of impairment. White line disease, which had a wider range of scores, was categorised into three levels, absent (score 0), mild (score 1) and visible separation (score ≥ 2). There were only three instances of sole bruising with a score ≥ 2 observed throughout the study, and because a mild bruise (score 1) has previously been categorised as similar in severity to no bruising by O'Driscoll et al. (2017), sole bruising was not analysed further. Similarly, only a single instance of a sole ulcer was observed throughout the study, and therefore could not be analysed. Rumen fill scores were categorised into a binary score of ≤ 2, indicative of insufficient feed intake, and > 2, indicating sufficient intakes. In addition to analysing the sum score for locomotion, the probability that each locomotion score component was impaired (score > 1) was investigated for each of speed, spine curvature, step-tracking and ab/adduction. The probability of impaired head-carriage was not analysed as only 11 observations were > 1.

Statistical Analyses

All data were analysed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA) with cow as the experimental unit. Significance was declared at $P < 0.05$, and tendencies at $P \geq 0.05 < 0.1$. Clinical health and locomotion score component variables (ocular and nasal discharge, neck-back and hock integument alterations, rumen fill, speed, spine curvature, step-tracking, ab/adduction) were analysed using a generalized linear mixed model, using the GLIMMIX procedure with a binomial distribution and logit link function. Total locomotion scores approached a normal distribution so were analysed using a general linear mixed model using the MIXED procedure; all reported values are least squares means. Residuals were examined for continuous variables to ensure assumptions of normality were met.

All these models included the fixed effects of treatment, grazing period and the interaction between treatment and grazing period. Parity and calving date were also included to control for any differences across treatments; effects of these variables are reported only when they meet the level of significance ($P < 0.05$). These models also included the Kenward-Rogers adjustment for estimating degrees of freedom and an LSmeans statement with the Tukey's adjustment for multiple comparisons. The SLICE option was included to investigate treatment differences within EG and LG individually. Inspection number was included as a repeated effect, with an autoregressive covariance structure for neck-back integument alterations and rumen fill, and heterogeneous autoregressive for all others.

The hoof health variables digital dermatitis and white line disease were also analysed in a generalized linear mixed model, using the GLIMMIX procedure. The digital dermatitis model had a binomial distribution and logit link function, while the white line disease model had a multinomial distribution and cumulative logit link function. Fixed effects were treatment, inspection number within grazing period and their interaction. Cow was modelled as a random effect because PROC GLIMMIX does not model repeated measures for multinomial distributions. An LSmeans statement was included through the addition of the PLM procedure to the white line disease multinomial model to allow for inclusion of the Tukey's adjustment for multiple comparisons. As in previous models, parity and calving date were included to control for any variation across treatments, and the Kenward-Rogers adjustment for estimating degrees of freedom was included.

RESULTS

Clinical health scores

An overview of all clinical health scores is given in Table 1. No difference in ocular discharge was observed between treatments, nor was there an interaction between treatment and grazing period. However, regardless of treatment, cows were more likely to display ocular discharge in EG compared to LG (OR = 1.97, CI = 1.12 – 3.46, P = 0.019).

Cows in MOD were more likely to display nasal discharge compared to LOW (OR = 3.11, CI = 1.81 – 5.32, $P < 0.001$). Cows on HIGH were also more likely to display nasal discharge than those on LOW (OR = 1.95, CI = 1.12 – 3.38, P = 0.047), but no difference was detected between HIGH and MOD (P = 0.120). Nasal discharge for all treatments was more likely during EG than LG (OR = 2.41, CI = 1.58 – 3.67, P < 0.001). The effect of treatment was detected within both EG (P = 0.006) and LG (P = 0.0122).

There was an overall effect of treatment on the occurrence of neck-back alterations, yet due to the multiple comparison adjustment, the only detectable difference was a tendency for more neck-back alterations among cows on MOD than LOW (OR = 4.26, CI = 1.18 – 15.34, P = 0.069). Regardless of treatment, cows were considerably more likely to have neck-back alterations in EG compared to LG (OR = 32.32, CI = 13.14 – 79.48, P < 0.001).

There was no difference in hock alterations detected between treatments. During EG, cows were more likely to display hock alterations than during LG (OR = 7.57, CI = 4.86 – 11.80, P < 0.001). Additionally, multiparous cows were more likely to have hock alterations than primiparous cows (OR = 3.38, CI = 1.56 – 7.32, P = 0.002).

Cows were less likely to have a rumen fill score ≤ 2 in EG than in LG (OR = 0.27, CI = 0.15 – 0.48, P < 0.001). However, there was a tendency for an interaction between treatment and grazing period on rumen fill, as the difference between grazing periods was only apparent for LOW (P = 0.001), and not for MOD (P = 0.850) nor HIGH (P = 0.245). The effect of treatment was detected during EG (P = 0.019), but not during LG (P = 0.452). Multiparous cows were less likely to display a rumen fill score ≤ 2 compared to primiparous cows (OR = 0.32, CI = 0.11 – 0.90, P = 0.032).

Table 1. Effects of low, moderate and high grazing pressure treatments (LOW, MOD, HIGH), early or late grazing period (EG, LG), and their interaction on measures of clinical health.[1]

Variable	Treatment			P-value of Odds Ratio Comparison		
	LOW (SE)	**MOD (SE)**	**HIGH (SE)**	**Treatment**	**Period**	**Treatment x Period**
Ocular discharge				0.336	0.019	0.519
EG	23.9 (8.89)	22.1 (6.53)	16.1 (7.44)			
LG	12.5 (4.23)	6.7 (2.11)	11.9 (5.01)			
Nasal discharge				< 0.001	< 0.001	0.506
EG	20.1 (5.48)	40.0 (3.57)	37.7 (7.22)			
LG	12.5 (3.59)	25.0 (4.47)	16.4 (3.56)			
Neck-back alterations				0.046	< 0.001	0.191
EG	53.1 (10.13)	63.2 (8.81)	53.5 (3.43)			
LG	0.8 (0.83)	10.0 (2.58)	4.3 (2.75)			
Hock alterations				0.199	< 0.001	0.352
EG	68.4 (7.98)	67.4 (6.94)	60.0 (5.07)			
LG	23.3 (4.01)	26.7 (6.79)	19.3 (3.78)			
Rumen fill				0.889	< 0.001	0.060
EG	74.9 (3.04)	88.4 (4.53)	86.7 (3.96)			
LG	96.7 (2.47)	93.3 (3.07)	94.9 (3.44)			

[1] Values presented for each treatment and grazing period are the average weekly proportion of cows scored 1 (variable present), except for rumen fill, which is presented as the average weekly proportion of cows scored ≤ 2.

Locomotion score

Total locomotion score was greater on LOW compared to HIGH, yet no difference was detected between LOW and MOD, or MOD and HIGH (Table 2). Although there was no effect of treatment on total locomotion score in the EG (P = 0.491), during LG, cows on LOW displayed the highest locomotion scores and those on HIGH the lowest locomotion scores (P = 0.004). Additionally, total locomotion score was greater in multiparous cows compared to primiparous (MP = 7.5 ± 0.011, PP = 6.1 ± 0.25, P < 0.001). The average prevalence of cows categorised as lame (locomotion score > 9) for EG and LG respectively was 15.3 ± 3.12% and 39.2 ± 3.00% for LOW, 20.0 ± 2.58% and 24.2 ± 5.69% for MOD and 14.9 ± 4.79% and 17.0 ± 3.44% for HIGH.

Cows on HIGH were less likely to have an impaired walking speed than either LOW (OR = 0.24, CI = 0.09 – 0.63, P = 0.010) or MOD (OR = 0.29, CI = 0.11 – 0.77, P = 0.035). Again, there was no effect of treatment in the EG (P = 0.131), and was only a tendency in the LG (P = 0.057). Overall, walking speed was more likely to be impaired in the early than late grazing periods (OR = 4.23, CI = 2.16 – 8.58, P <0.001).

Spine curvature was neither influenced by treatment nor grazing period. Although there was an interaction between treatment and grazing period, after adjustment for multiple comparisons, cows on HIGH only tended to be less likely to display an arched spine during EG than LG (OR = 0.29, CI = 0.13 – 0.68, P = 0.053), with no difference in LOW (P = 0.653) or MOD (P = 0.619). Multiparous cows tended to be more likely to display an arched spine than primiparous cows (OR = 3.14, CI = 0.96 – 10.2, P = 0.058).

There was an interaction between treatment and grazing period on step tracking. No effect of treatment was detected during EG, yet during LG, cows on HIGH were less likely to display impaired tracking than both those on LOW (OR = 0.20, CI = 0.09 – 0.47, P = 0.003) and MOD (OR = 0.13, CI = 0.05 – 0.33, P < 0.001). However, no difference was detected between LOW and MOD during LG (P = 0.955). Indeed within grazing periods, there was an overall effect of treatment during LG (P < 0.001), yet not during EG (P = 0.141). Multiparous cows were more likely to display impaired step tracking than primiparous cows (OR = 11.60, CI = 5.73 – 23.48, P < 0.001).

Table 2. Effects of low, moderate and high grazing pressure treatments (LOW, MOD, HIGH), early or late grazing period (EG, LG), and their interaction on total locomotion score (LSmeans), and each locomotion score component.[1]

Variable	Treatment			Grazing Period		P-value		
	LOW (SE)	MOD (SE)	HIGH (SE)	EG (SE)	LG (SE)	Treatment	Period	Treatment x Period
Total locomotion score[2]	7.1^{a} (0.20)	$6.8^{a,b}$ (0.20)	6.5^{b} (0.19)	6.7 (0.18)	6.9 (0.14)	0.033	0.123	0.553

Locomotion score component	LOW (SE)	MOD (SE)	HIGH (SE)	P-value of Odds Ratio Comparison		
				Treatment	Period	Treatment x Period
Speed				0.014	< 0.001	0.39
EG	26.9 (1.83)	31.6 (7.81)	19.3 (5.04)			
LG	20.8 (3.00)	15.0 (3.87)	9.7 (4.23)			
Spine curvature				0.951	0.124	0.007
EG	25.8 (5.71)	26.3 (2.88)	24.1 (6.49)			
LG	33.3 (4.94)	16.7 (2.47)	34.2 (2.59)			
Step-tracking				0.013	< 0.001	< 0.001
EG	64.2 (7.30)	47.4 (4.40)	62.7 (7.04)			
LG	86.7 (1.67)	90.0 (1.83)	67.5 (5.16)			
Ab/adduction				0.001	0.15	0.135
EG	74.1 (2.30)	57.9 (6.86)	64.1 (6.86)			
LG	83.3 (4.41)	68.3 (3.33)	60.7 (2.66)			

[1] lsmeans values are presented for total locomotion score. All values for locomotion score components are the average weekly proportion of cows scored as impaired (score ≥ 1) within each treatment and period.

[2] Differing superscripts denote significantly different comparisons.

Cows on both HIGH (OR = 0.36, CI = 0.21 – 0.61, P = 0.001) and MOD (OR = 0.40, CI = 0.23 – 0.69, P = 0.003) were less likely to display impaired ab/adduction compared to those on LOW. Within each grazing period there was an effect of treatment in LG (P < 0.001) yet not during EG (P = 0.20). Multiparous cows were more likely to have impaired ab/adduction than primiparous cows (OR = 3.31, CI = 1.90 – 5.78, P < 0.001).

Hoof health

There was no effect of treatment nor any interaction between treatment and inspection number within grazing period on digital dermatitis (Table 3). However there was an effect of inspection number within grazing period. At the end of EG cows were less likely to display signs of digital dermatitis than at the first inspection (OR = 0.22, CI = 0.07 – 0.66, P = 0.035). Likewise at the start of LG cows were also less likely to display signs of digital dermatitis than at the first inspection (OR = 0.17, CI = 0.06 – 0.52, P = 0.012). No difference was detected between inspections at the start and end of LG (P = 0.35).

There was no effect of treatment on white line disease, nor any interaction between treatment and inspection number within grazing period (Table 3). However there was an effect of inspection number, with incidence decreasing over time. White line disease was less likely at the end of LG compared to both the start (OR = 0.25, CI = 0.11 – 0.56, P = 0.005), or end of EG (OR = 0.21, CI = 0.10 – 0.48, P = 0.001). There was also a tendency for less white line disease at the start of the LG compared to the end of the EG (OR = 0.40, CI = 0.19 – 0.82, P = 0.064). No difference in white line disease was detected between the start and end of either the EG or LG. Additionally, multiparous cows tended to have more white line disease than primiparous cows (OR = 3.54, CI = 0.93 – 13.44, P = 0.063).

Table 3. Effects of low, moderate and high grazing pressure treatments (LOW, MOD, HIGH), early or late grazing period (EG, LG), and their interaction on measures of hoof health.[1]

Variable		Treatment		Odds Ratio Comparison P-value		
	LOW (SE)	MOD (SE)	HIGH (SE)	Treatment	INSP(Period)	Treatment x INSP(Period)
Digital Dermatitis				0.974	0.006	0.483
Score ≥ 1						
EG	23.8 (14.29)	28.9 (13.16)	24.0 (0.0)			
LG	23.5 (7.73)	19.3 (4.26)	18.4 (5.38)			
White Line Disease				0.795	0.001	0.527
Score 1						
EG	45.2 (7.14)	31.6 (0.0)	36.0 (12.0)			
LG	23.5 (7.73)	17.9 (12.06)	18.0 (3.73)			
Score ≥ 2						
EG	21.4 (2.38)	29.0 (2.63)	30.0 (6.0)			
LG	19.4 (6.91)	21.3 (3.68)	9.1 (0.41)			

[1] Values presented for digital dermatitis are the average weekly proportion of cows scored 1 (signs of dermatitis present), and for white line damage, the average weekly proportion of cows scored 1 (mild) and score ≥ 2 (visible separation). INSP = inspection number.

DISCUSSION

In Ireland, there has been a focus on increasing milk production/ha since the removal of EU milk quotas. Stocking rates in Ireland rose by 20.5% in the 10 years from the announcement in 2008 that quotas would be removed, until the year of this study (Connolly et al., 2009; Dillon et al., 2019). It is predicted they will continue to rise (Dillon et al., 2021b), because increasing stocking rate is considered one of the main drivers of productivity in pasture-based dairy systems (Hoden et al., 1991; Macdonald et al., 2008; Baudracco et al., 2010). In New Zealand, where pasture-based dairy production also predominates, stocking rates are already higher than those in Ireland. Based on national data, the average stocking rate in New Zealand between 2005 and 2014 was 2.96 cows/ha (Ma et al., 2019), whereas experimental studies utilised stocking rates up to 4.3 cows/ha (Macdonald et al., 2008; Beukes et al., 2019). With pasture-based dairy production continuing this trajectory towards more intensive production, investigating how varying levels of intensification impact dairy cow welfare is vital to ensure the sustainability of pasture-based production. Thus, all three treatments investigated in this study represent some degree of intensification, with the lowest examined stocking rate still above the 2018 Irish national average of 2.06 LU/ha (Dillon et al., 2019).

Of all the welfare indicators investigated, only three (nasal discharge, neck-back integument alterations and locomotion score) differed between treatment groups; however, no treatment consistently demonstrated greater impairment than others. Indeed, the greatest effects observed in this study were differences between grazing periods. Both nasal and ocular discharge, integument alterations to the hocks and neck-back region, and the speed component of locomotion score all demonstrated improvement as the grazing season progressed. Additionally, incidence of both digital dermatitis and white line disease was reduced at the end of the grazing season compared to the beginning. This supports our hypothesis that differences between the EG and LG would be apparent, as they are characterised by differences in grass growth, weather patterns, and cow physiology, and therefore management practices as well. The EG and LG were also preceded by drastically different environments. In the EG, cows had recently regained access to pasture after a prolonged period of indoor housing of two to three months (November – January), which is lower than the average of approximately four months (Creighton et al., 2011; Crossley et al., 2021). Additionally, the unseasonably poor weather experienced during the EG in 2018 resulted in practicing on-off grazing, where cows spend short periods of time indoors (e.g. overnight) (Kennedy et al., 2009). Cows are exposed to a different variety of risk-factors during housing than on pasture, and carry-over effects of the housing period have been observed to persist into the grazing period and improve after time on pasture, such as lameness (Wagner et al., 2018; Armbrecht et al., 2019) and integument alteration (Rutherford et al., 2008; Potterton et al., 2011; Burow et al., 2013b). In contrast, the LG followed a prolonged time on pasture, which provides time to recover from any lingering effects of housing, yet exposes cows to a new set of challenges such as long daily walking distances on potentially rough surfaces (Doherty et al., 2014).

While only a minor effect of treatment was detected on the occurrence of integument alterations, there was a large impact of grazing period, particularly for integument of the neck and back. At over 30 times greater risk of integument alterations to the neck and back and eight times greater for the hocks in the EG than the LG, this indicates a strong carry-over effect from the housing environment. Due to the previously described uncharacteristic spring weather during the study, cows were also practicing on-off grazing and spending partial days or nights indoors during this period. Protruding areas of the body are vulnerable to injury due to contact with housing elements (Weary and Taszkun, 2000; Brenninkmeyer et al., 2016), particularly when the design of the housing facilities such as cubicle dimensions and feed neck-rail heights are inappropriate for the size of the cow (Kielland et al., 2010; Zaffino Heyerhoff et al., 2014; Gieseke et al., 2020). Appropriate cubicle dimensions are particularly important towards the end of the housing period to ensure heavily pregnant cows fit sufficiently into cubicles without injury. The average of 53 - 63% of cows displaying neck and back integument alterations in the EG is comparable to levels observed previously during housing periods on Irish farms (66% to the head-neck-back region and 32% to the hindquarters; Crossley et al., 2021), in the UK (median of 20-50% to the neck, back or tailbone; Huxley et al., 2004), and in Norway (22% to the neck; Kielland et al., 2010). Integument alterations to the hocks, which is typically the most commonly affected region of the body (Brenninkmeyer et al., 2016), were present during the EG at comparable or higher levels to previous studies of hybrid pasture-based farms recorded during the housing period in Norway (35 – 61%; Kielland et al., 2009) and Denmark (47%; Burow et al., 2013b). Studies of hock injuries have shown that integument alterations are more likely with longer housing periods and can improve with greater time on pasture (Rutherford et al., 2008; Potterton et al., 2011; Burow et al., 2013b) where lying surfaces are softer and there is less risk from contact with infrastructure. This supports the observed improvement between the EG and LG for both neck-back and hock integument alterations in our study. Similarly, de Graaf et al. (2017) found that integument alterations were less common at the start of housing, following prolonged periods on pasture, than at the end of a housing period.

Poor ventilation or air quality experienced during housing can predispose cows to illness or irritants resulting in ocular or nasal discharge (Callan and Garry, 2002). Thus the reduction in ocular and nasal discharge from the EG to LG may be due to exposure to fresh air at pasture. Nasal discharge may be an indicator of impaired health such as respiratory infection (Love et al., 2014), and increased stress and reduced plane of nutrition may increase the risk of illness (Gorden and Plummer, 2010), which could play a role in the observed effect of treatment on nasal discharge as well. Indeed nasal discharge was the only welfare indicator to support our hypothesis that cows experiencing greater grazing pressure would display more indicators of poor welfare; nasal discharge was more commonly observed among cows under the moderate and high levels of grazing pressure than those on the low level. The principle difference between cows on LOW vs MOD is pasture supply, as they both represent the same farm system intensity. Cows on LOW vs HIGH, however, differ in both pasture supply and farm system intensity. At the higher stocking rate of the more intensive system and lower pasture allowance, there could be greater competition for access to pasture, perhaps leading to more nutritional and social stress, and thus a greater risk of illness. However, as the relationship between nasal discharge and physiological stress and immune function were not examined in this study, such an interpretation cannot be confirmed. Further study is needed to investigate the potential connection between nutritional stress and increased nasal discharge due to illness.

Unlike the majority of indicators, which improved across the grazing season, rumen fill declined between the EG and LG, which was counter to expectations. Due to the increasing energy demands of cows in early lactation (Jorritsma et al., 2003) which exceed grass growth rates until late spring (Hurtado-Uria et al., 2013), one would expect cows to display more signs of insufficient intakes during EG rather than LG. However, the unseasonably cold and wet weather during the early grazing season required that cows on-off grazed and thus were housed for a portion of the EG (e.g. individual full days or only overnight), with a cumulative total of 15.5 d for both LOW and MOD, and 17.5 d for HIGH. Consequently, in addition to treatment diets, cows were provided with *ad-libitum* grass silage during these periods. This allowed them to consume greater DMI than would be provided under typical grazing conditions for the same period, and likely resulted in greater rumen fill.

Overall locomotion score was one factor that did not show an effect of grazing period, although there was a small yet significant improvement in locomotion score as grazing pressure increased. This was counter to our hypothesis that more intensive grazing management would result in more negative impacts on welfare indicators. While the average score was low for all treatments, the average prevalence of lameness within the herd, using a minimum threshold score of nine derived from O'Callaghan et al. (O'Callaghan et al., 2003), ranged from 15 – 39% depending on treatment and grazing period. This is higher than some previously reported levels of clinical lameness on Irish farms during the grazing season of 6 - 11%, (O'Connor et al., 2020a) and 10% (Crossley et al., 2021). However, the scale used in our study makes no distinction between cows presenting with mild rather than severe lameness, and may be more similar to cows scored as having suboptimal mobility rather than clinical lameness. Suboptimal mobility describes any cows whose quality of locomotion deviates from the normal optimal gait (O'Connor et al., 2019). Previous research of suboptimal mobility on Irish dairy farms reported a prevalence of 38% of cows scored with suboptimal mobility, and found it associated with low BCS and the presence of claw disorders (O'Connor et al., 2019). For comparison, studies reported the prevalence of clinical or severe lameness on pasture-based systems to be 31 - 35% in in Brazil (Bran et al., 2018), and 32% in the UK (Griffiths et al., 2018), as well as 28%, 31% and 55% for continuous housing systems in British Columbia, California and the North Eastern US respectively in North America (von Keyserlingk et al., 2012).

Examining individual locomotion score components revealed that no single treatment consistently demonstrated greater impairment. Cows on HIGH displayed the least impaired walking speed and lower impairment of step tracking than other treatments. These cows may have experienced more motivation to return to pasture to feed as they received the lowest pasture allowance and were under a greater level of competition for feed access due to increased stocking rate. Motivation to access fresh feed has been associated with changes in gait (Flower et al., 2006), and the use of a feed reward has been shown to result in increased walking speed and stride length, even in lame cows (Mokhtarnazif et al., 2020). Later in the grazing season, cows on all treatments displayed less impaired walking speed. This may be due to increased exercise experienced throughout the grazing season. Walking from paddocks to parlour daily on less hard and slippery surfaces than concrete flooring has been suggested to alleviate stiffness and promote limb flexibility (Hernandez-Mendo et al., 2007; O'Driscoll et al., 2009b). In contrast, cows generally demonstrated greater impairment for the components of step-tracking, and spine curvature, and a similar level of impaired ab/adduction during the later grazing period. These opposing changes in gait components could explain why the overall locomotion score did not vary by grazing period, despite the increase in the prevalence of cows categorised as lame across all treatments.

The observed treatment differences in locomotion components, even though there was little effect on overall locomotion score, also supports the presence of largely mild hoof disorders. Although these can influence the cows' gait they are less likely to result in impaired locomotion or lameness than more severe disorders (O'Connor et al., 2019). Of the initial four types of hoof lesions assessed, both sole bruising and sole ulcers were present at such low levels that comparison between treatments or grazing periods was not possible. For those lesions that were present at greater levels (white line disease and digital dermatitis) the proportion of affected cows was not influenced by the levels of grazing pressure investigated in this study; however, they too demonstrated improvement from the EG to LG. This was evident over a shorter term for digital dermatitis, between the two EG inspections, and over a longer period for white line disease, between the start of the EG and end of the LG.

Digital dermatitis is the result of infectious agents, and multiple reported risk factors are associated with housing, including solid grooved flooring (Barker et al., 2009) and exposure of hooves to slurry (Cook et al., 2004a). Thus, this would explain the greater occurrence of digital dermatitis in the EG as a period of time is required for lesions to resolve following a decrease in infectious agents, and cows were still occasionally housed for partial days due to variable weather. Laven and Lawrence (2006) similarly identified effects of grazing season, with fewer cases of digital dermatitis reported in the months of June to October compared to February. In contrast, white line disease is the result of mechanical damage to the hoof. During the EG, cows have been more recently exposed to the hard indoor flooring surfaces, which is commonly associated with white line disease (Barker et al., 2009; Shearer and van Amstel, 2017). Cows are also more recently calved at this time in a spring-calving system, and may therefore be at greater risk of white line disease due to weakening of the connective tissues in the hoof which occurs around parturition, leaving hooves susceptible to physical stress (Tarlton et al., 2002; Knott et al., 2007). Exposure to these factors would explain the greater incidence of white line disease observed in our study during early than late grazing periods. Although white line disease sometimes occurs more often in the later grazing season (Laven and Lawrence, 2006), likely after experiencing greater walking distances on pasture as poorly maintained roadways are a commonly reported risk factor (Chesterton et al., 1989; Doherty et al., 2014). The farm used in the current study has extremely well-constructed and maintained roadways, which could explain the lack of development of the disorder as the grazing season progressed.

CONCLUSION

Increasing levels of grazing pressure in this study, due to modifications of pasture allowance and farm system intensity, resulted in only small impacts on indicators of welfare. Greater grazing pressure was associated with more signs of nasal discharge, minor increases in integument damage to the neck and back, and reduced impairment of locomotion score and some associated components. The greatest effects were instead observed between the early and late grazing periods, which saw the improvement of all welfare indicators, except for rumen fill and locomotion score. However, uncharacteristic weather throughout the experimental grazing season influenced grazing management, and thus may have also had an impact on the results to some degree. Further study of the impact of increased grazing pressure in commercial settings and under more typical weather conditions may provide additional support for these findings.

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| CHAPTER 6 |

General Discussion

Introduction

Ireland prides itself on the sustainability and high welfare standards of its dairy sector, yet in order to support or refute this belief, data must be collected on the current and evolving state of dairy cow welfare on Irish spring-calving, pasture-based farms. This was the motivation behind my thesis research. Pasture has known benefits to dairy cow welfare, yet also presents its own set of challenges. Many studies of Irish dairy production have incorporated components of welfare into their research questions, such as reproductive health (Coleman et al., 2009; McCarthy et al., 2012), body condition (Roche et al., 2009), hoof health and locomotion (O'Driscoll et al., 2008; Olmos et al., 2009a), feeding time (O'Driscoll et al., 2009a) and lying time (O'Driscoll et al., 2009a; Olmos et al., 2009a). Particular aspects associated with lameness have been the primary focus of studies examining the impact of grazing systems, such as those by Somers (2015, 2019) and O'Connor (2019, 2020b; 2020a). However, animal welfare is multifactorial in nature and is impacted by a wide variety of components. Thus, what has been missing from the body of research surrounding dairy cow welfare in Irish spring-calving pasture-based production was a large-scale welfare assessment, which incorporated multiple aspects of welfare. This is necessary in order to identify risk factors associated with welfare which may potentially be used to make welfare improvements. This led us to the first aim of this thesis, to conduct a welfare assessment to collect information on the current state of welfare on farms (Chapter 2). The data collected through this welfare assessment provided valuable information enabling the identification of risk factors for dairy cow welfare on Irish farms during both the grazing and housing periods (Chapters 3 and 4), which is the second aim of this thesis.

A recent study began to address this lack of information surrounding cow welfare on Irish dairy farms through a survey of Irish dairy sector stakeholders to determine their opinions on dairy cow management and infrastructure (Boyle et al., 2017). One potential welfare concern highlighted by this project was that herd expansion following the removal of milk quotas was out-pacing the improvements of infrastructure on farms, and that such rapid expansion and associated intensification may negatively impact dairy cow welfare. Thus, the third aim of this thesis examined how management changes due to intensification within the dairy sector impact dairy cow welfare (Chapter 5).

Assessing welfare in pasture-based systems

Animal welfare is a very challenging characteristic to assess. As cows cannot tell us what each individual's suitable environment would look like and what management they would prefer, we must deduce this from information we can collect.

The use of preference tests and motivation tests provide some insight into which environments are favourable to cows, such as their preference to lie on dry bedding over wet (Fregonesi et al., 2007), pasture over cubicle housing (Von Keyserlingk et al., 2017; Smid et al., 2018), and their preference for shade that provides more protection from solar radiation on pasture (Schütz et al., 2009). However, they are limited to those options presented to them by researchers. Recent research shows promising developments in novel methods of understanding the welfare needs of dairy cows, such as the use of judgement and attention bias tests to assess affective state (Crump et al., 2021; Kremer et al., 2021) and routine collection of physiological biomarkers of stress and immune function in saliva and hair samples (Burnett et al., 2014; Barrell, 2019; Ghassemi Nejad et al., 2021). Although these methods would be valuable, and sometimes more objective measures of welfare, they are currently not practical or possible to perform as part of routine on-farm assessment. Thus, our best strategy at the moment was to measure indicators of welfare as a proxy for measuring welfare itself.

Throughout the literature and in practice there are a multitude of indicators utilised in welfare assessment, and the challenge is to identify those which best reflect the system being investigated. Thus, a thorough literature search was conducted to identify the top prospective indicators in order to determine those most suited to an on-farm welfare assessment of a pasture-based system. While all these indicators provided valuable and interesting information on the welfare of cows within this system, some were determined to be either unsuitable or impractical to perform in a pasture-based setting on commercial farms. The full list of measures initially examined to address the aims of this thesis are described in Table 1. Some measures, such as hygiene scoring, may be less relevant in a pasture-based herd, because cows may be dirtier during periods of high rainfall when conditions are muddy, and not necessarily the result of soiling with manure. Additionally, the high water content of the grass diet can result in looser faeces, which may otherwise be interpreted as a symptom of digestive illness. Due to seasonal calving within this system, variation in vulvar discharge, a sign of endometritis (Drillich, 2006), was only observed for a brief period following calving in spring, and thus would not provide useful information unless welfare assessment of all farms were to take place during this period; which was not realistically possible during the studies in this thesis, nor would it be in a future practical commercial setting. The visual hoof inspection method in the parlour, while having the advantage of being able to monitor changes in heel erosion and dermatitis (O'Driscoll et al., 2015) does not provide information about hoof lesions such as sole bruising and ulcers as manual inspections can. Several other measures were simply determined to be too labour intensive or impractical to perform in a reasonable time frame as part of a regular on-farm welfare assessment. These included direct observation of social behaviours performed at pasture (Wagner et al., 2018), tail hair sampling to measure cortisol as an indicator of chronic stress (Burnett et al., 2014; Creutzinger et al., 2017), and the use of data collection technology, such as attaching rumination and activity collars (e.g. MooMonitor+; Dairymaster, Tralee, Co. Kerry, Ireland), accelerometers for step and lying behaviour (e.g. IceTag; IceRobotics Ltd., Edinburgh, Scotland, U.K.), and telemetric reticulorumen pH boluses (e.g. eBolus; eCow Devon Ltd., Exeter U.K.).

The indicators that were considered to assess welfare were those that were either part of routine management on farms (e.g. body condition scoring) or could be easily and efficiently performed in a pasture-based system when cows return to the parlour for milking. An emphasis was put on including applicable measures used in the Welfare Quality® protocol, a commonly used assessment in Europe (Welfare Quality®, 2009). The selected measures also related to at least one of the three principal domains of welfare. Scoring of locomotion, body condition, ocular and nasal discharge, integument alteration and tail injury provide information on the cows' health; appropriate normal behaviours are reflected by locomotion score and avoidance response to human approach; and affective state is addressed indirectly through locomotion, integument alteration and tail injury scoring as indicators of potentially painful conditions, avoidance response as an indicator of fear, and low body condition or rumen fill as indicators of hunger.

Once the appropriate indicators had been selected, the next challenge was choosing the appropriate timing of the assessment, as past research has demonstrated that timing of welfare assessments can impact their results (de Graaf et al., 2017). In year-round calving systems, herd management remains relatively consistent throughout the year, and at any point there are cows in various stages of their lactation. In general, the same risk factors would be involved and a welfare assessment conducted at any point during the year should return similar outcomes. However, in a seasonal, spring-calving system, herd management changes considerably throughout the year, as all cows are at a similar stage of their lactation. Different risk factors would be impacting the cows' welfare at different times of the year, and consequently the level of welfare experienced may differ as well. In other words, different risk factors may be involved during indoor housing of dry cows compared to the outdoor grazing of lactating cows. Therefore, it was decided that for a welfare assessment of the Irish spring-calving system to be complete it must account for the different management practices and assess welfare during both the grazing and housing periods. Performing an assessment of each farm at multiple points would improve its ability to provide an accurate overview of the welfare situation over the entire year.

Table 1. Welfare indicators considered for inclusion in the studies in this thesis and their relation to welfare

Indicator	Relation to welfare	Included in this thesis
Hygiene scoring for cleanliness of rump, flank, and udder	May indicate cows lying improperly in cubicles or illness causing digestive issues. Manure on the udder may put cows at greater risk of mastitis infection. (Reneau et al., 2005; Cook, 2011)	No
Vulvar discharge	Sign of endometritis (Drillich, 2006)	No
Visual hoof inspection	Monitor changes or development of heel erosion and dermatitis visually while cows stood in the milking parlour (O'Driscoll et al., 2015)	No
Manual hoof inspection	Physical lifting of cows' hooves to inspect for a variety of sole lesions (Sadiq et al., 2021)	Ch. 5
Hair cortisol	Indicative of chronic stress over time (Burnett et al., 2014; Creutzinger et al., 2017)	No
Social behaviour at pasture	Observe behavioural indicators of positive (e.g. grooming, synchronous lying) or negative (e.g. agonistic interactions, stereotypies) welfare (Wagner et al., 2018)	No
Telemetric reticulorumen pH bolus	Automatic recording of rumen pH. Prolonged periods of reduced reticulorumen pH may be indicative of subacute ruminal acidosis (Falk et al., 2016)	No
Activity collar	Automatic recording of rumination, lying and grazing time, as well as heat detection (Grinter et al., 2019)	No
Pedometer/ accelerometer	Automated recording of walking and lying behaviour (Gibbons et al., 2012a)	No
Locomotion score	Painful condition and often considered one of the greatest welfare challenges in dairy cows. Multiple scoring scales are available to differentiate levels of impairment (O'Driscoll et al., 2010a; AHDB, 2015a)	Ch. 2, 3, 4 & 5
Body Condition Score	Indicator of sufficient nutrition, particularly important in pasture systems. May also be a risk factor for other welfare issues such as lameness (O'Connor et al., 2020a)	Ch. 2, 3 & 4
Ocular and nasal discharge	Indicators of poor health associated with upper respiratory tract infection (Love et al., 2014)	Ch. 2, 3, 4 & 5
Integument alterations	Indicator of unsuitable environment, such as hard lying surfaces or impact with infrastructure (Weary and Taszkun, 2000; Kielland et al., 2009, 2010)	Ch. 2, 3, 4 & 5
Tail injury	Painful injury with lasting implications for proper mobility of the tail. Likely result of either mechanical damage (e.g. doors, gates, scrapers) or improper animal handling (AssureWel, 2018; Laven and Jermy, 2020)	Ch. 2, 3 & 4
Rumen fill	Indicator of low or insufficient intakes (AHDB, 2019)	Ch. 5
Avoidance behaviour	Indicator of quality of human-animal relationship (Waiblinger et al., 2003)	Ch. 2, 3 & 4

Dairy cow welfare on Irish farms

Through conducting the assessment during both grazing and housing periods on Irish farms as described in Chapter 2, I was able to identify key areas where improvements for dairy cow welfare could be made. These areas included physical signs of health such as elevated levels of nasal discharge, integument damage to the neck-back and hindquarter regions, and tail injuries consisting of both broken and docked tails. A behavioural indicator of compromised welfare was also observed in the high proportion of cows displaying a fearful response to human approach. Based on the data collected throughout this thesis, I was unable to identify the exact conditions leading to these compromises in welfare. However, the risk factor analyses conducted in Chapters 3 and 4 provide further detail regarding what may be influencing these welfare indicators. They also provide farmers struggling to deal with impaired welfare in any of these areas a starting point for making changes on their farm.

Associated factors were largely related to facilities and the management of indoor conditions, even during the grazing period. This emphasizes the interconnection between the grazing and housing periods, and justifies considering Irish dairy production to be a hybrid pasture-based system because, however short, the housing period still plays a key role in the cows' overall welfare. The impact of the housing period is also apparent in the considerable number of risk factors that were identified from the analysis of the housing period (Chapter 4); more than double that of the indoor period (Chapter 3). For example, considering nasal discharge, recognized in Chapter 2 as an area where improvements could be made, a collecting yard holding time of 60 – 90 minutes was identified as a welfare risk factor from the grazing analysis. Yet from the housing period analysis, less frequent feed delivery, employing full-time staff in addition to the primary farmer, farmers not identifying facilities as needing repair, and applying moisture absorbent material to cubicles were identified as risk factors. Similarly, the length of the previous housing period was the only risk factor identified during the grazing period for integument alterations, while risk factors for the housing period included turns into the parlour, slippery shed flooring, aspects of facility dimensions, use of multiple housing groups, and below average cow comfort index. Such a strong apparent influence of the housing period on dairy welfare highlights the need for assessments of welfare in pasture-based system to consider any periods of housing as well as grazing to obtain an accurate picture of the welfare status.

An interesting result was that no risk factors were identified during the grazing period that influence the proportion of cows with broken tails (Chapter 3), while several were identified during the housing period (Chapter 4). This may be evidence of the time period when this injury has been occurring. Or perhaps there is another unmeasured factor contributing to the prevalence of this injury. One area which was not measured as part of this thesis work was the quality of animal handling and stockperson interactions with cows. Previous research has suggested that tail breaks may be the result of poor handling practices involving forceful tail twisting (Zurbrigg et al., 2005b; AssureWel, 2018; Laven and Jermy, 2020), and given the frequency at which broken tails were observed, this would be a valuable topic for future research. Appropriate stockperson behaviour is vital for fostering a good human-animal relationship (Rushen et al., 1999; Waiblinger et al., 2004). Thus, further study of the typical animal handling practices within this system may also shed light on the considerable fearful avoidance response to human approach observed at both grazing and housing periods. Indeed, several identified risk factors for fearful avoidance response were related to interaction with humans, such as performing locomotion scoring, using tail marking tape, applying bedding material to cubicles and feed push-up frequency.

Maybe the most concerning finding was the continued occurrence of incomplete tails on several farms (Chapter 2). Intentional tail docking, whether at the traditional level close to the tail head or of only the tail-tip, is a prohibited practice in Ireland (Statutory Instrument No. 225/2014) as it is an unnecessary cause of pain and stress. Further research is required to understand to what degree this may still be occurring intentionally on farms, and if so, then greater enforcement is required. Or if it is due to accidental injury, the causes of this injury must also be determined to ensure good welfare of dairy cows.

There were also areas identified where more positive indicators of welfare were evident for cows in the Irish dairy system. The assessment in Chapter 2 revealed that target body condition is achieved for the majority of cows during both the grazing and housing periods. Where targets are not met cows more often tend toward being over-conditioned, which relieves a potential concern that cows in pasture-based systems may not consume a sufficient quantity or quality of grass and may lead to feelings of hunger (von Keyserlingk et al., 2009). Rumen fill, another measure of sufficient feed supply, was also found to be unaffected by increasing levels of grazing pressure as discussed in Chapter 5. However, this indicator may have been influenced by the poor spring weather necessitating extended indoor periods where cows had access to additional feed. I would recommend further study of the impact of increased grazing intensity on rumen fill over multiple years to determine if this finding is supported.

While signs of ocular discharge were observed on farms, it was rarely severe in either the grazing (Chapter 3) or housing period (Chapter 4), and was unaffected by increasing grazing pressure (Chapter 5). On average, lameness prevalence was similar to other pasture-based systems (Fabian et al., 2014), and lower than that reported in non-pasture systems (von Keyserlingk et al., 2012; Solano et al., 2015; Griffiths et al., 2018). However, this should be considered with caution as there was a wide range in average prevalence between farms, ranging from 0 - 31% across both grazing and housing periods (Chapter 2). Additionally, when considering cows with sub-optimal mobility (any level of impaired mobility; score > 0; O'Connor et al., 2019) rather than clinical lameness (locomotion score of 2 or 3 on a 4-point scale of 0-3) the prevalence across farms drastically increases. However, we also learned through the welfare assessment that routine locomotion scoring is not a common practice on farms in Ireland, despite this practice being an effective tool for earlier diagnosis and prompt treatment of lame cows that may improve their rate of recovery (Leach et al., 2012). A good first step to reduce the prevalence of lameness on farms (or the first occurrence of impaired mobility) could be to establish programs to encourage regular, formal locomotion scoring with the aim of reducing the level of both suboptimal mobility and lameness, thereby increasing the cows' welfare.

Although these are areas where the Irish dairy system shows positive indicators of welfare, it is important to acknowledge that there is always scope for improvement and not to become complacent with any "acceptable" level of compromised welfare. As demonstrated by the benchmarking of welfare indicators in Chapter 2, there was a wide range found among both the best and worst performing farms for each indicator. A key factor in promoting improved welfare within this or any system will be motivating farmers to invest time and effort into making changes to their farms or management practices. Dairy farmers have shown to be motivated by the pride of maintaining a healthy herd (Leach et al., 2010b). However, with continued exposure, farmers may begin to view conditions that reflect poor welfare in their cows as normal, thus the ability to visualise performance of peers may enlighten farmers that improvements are possible and help to motivate changes (von Keyserlingk et al., 2012). The performance benchmarking discussed in Chapter 2 may be one method of promoting continued improvement of welfare. Rather than setting targets for "acceptable" welfare based on consensus of expert opinion, performance benchmarking compares the achievements of individual farmers against others in the same system (Zuliani et al., 2018; Bergschmidt et al., 2021). This method has the advantages of being system specific, and facilitating continuous improvement, as there is no level that indicates sufficient welfare has been achieved (Main et al., 2014). It may also motivate farmers by comparison with their peers, and encourage the sharing of best practices between farmers to drive improvement (von Keyserlingk et al., 2012). This method does not replace the vital role of research-based targets set by experts, as this is necessary information to ensure that all farms still achieve the minimum baseline requirements for good welfare (Bergschmidt et al., 2021). However, defining welfare as either acceptable or not fails to provide information to farmers and stakeholders on how to proceed in elevating the level of welfare (Colditz et al., 2014).

Another challenge of relying on performance benchmarking, is that in order to reflect the current welfare status on farms, benchmarks must be regularly re-evaluated at a national level to monitor progress; a time-consuming process particularly when, as shown in this thesis, welfare should be assessed at multiple points throughout the year to provide a more complete overview. The inclusion of routinely collected herd data from national databases, such as change in BCS, milk yields, parity, culls and reproductive data (de Vries et al., 2011; Somers et al., 2019) could be one strategy of reducing the time required to conduct such an assessment. Another solution would be to partner with existing animal welfare monitoring programmes in Ireland such as the Bord Bia Sustainable Dairy Assurance Scheme (SDAS: Bord Bia Irish Food Board, 2013). The SDAS is a government-industry partnership that conducts regular evaluations of Irish dairy farms to ensure they meet baseline standards of animal welfare and sustainability. However, recent research evaluating this and similar welfare assurance programmes highlights some drawbacks of SDAS. These include its reliance on only resource-based measures, a lack of benchmarking of welfare indicators, and a focus on meeting but not exceeding EU welfare standards, which impedes its ability to be a driver of welfare improvement (More et al., 2021). Incorporation of an animal-based welfare assessment and benchmarking protocol could improve such a programme which provides consumer confidence in dairy production, while also improving dairy cow welfare on farms.

Animal welfare and the development of sustainable livestock systems

Consumers have become increasingly concerned with how their food is produced and how the animals involved are cared for. In fact, 65% of Irish citizens polled in 2015 indicated they would like more information on how farm animals are treated (European Commission, 2016). Public pressure can be a powerful driver of change within animal production, and can play a large role in what practices are considered acceptable and which are not (Tucker et al., 2013). To date, the Irish pasture-based dairy sector is at an advantage when it comes to public support, as the perceived naturalness of the pasture environment means it is considered to provide animals with better welfare compared to other production systems. However, there is no guarantee that this outlook will remain. Changing consumer views on farm practices such as cow-calf separation (Ventura et al., 2013; Hötzel et al., 2017), increasing use of zero-grazing (Hötzel et al., 2017) and antibiotic use in farm animals (Castro-sánchez et al., 2016; Clark et al., 2016) is resulting in a constantly evolving dairy sector. Thus, monitoring welfare on Irish farms, and striving for the constant improvement of dairy cow welfare and continued public support is vital to the sustainability of dairy production in Ireland.

It is not only sustainability of the dairy sector where the study of animal welfare can be beneficial. We now understand from the concepts of One Health and One Welfare, that animal welfare is inextricably connected with both human health and welfare, and the environment (Lerner and Berg, 2015; García Pinillos et al., 2016). For example, ensuring animals have better welfare can result in healthier animals in less need of treatment for illness. Less illness can reduce the use of antibiotics and help to reduce the growing risk of antimicrobial resistance, which poses a great threat to both animal and human health (Oliver et al., 2011; Clark et al., 2016). In a pasture-based dairy system, healthier and better welfare cows will also have greater productivity per hectare, requiring less land to produce the same or greater amounts of milk. In fact, productivity losses due to illness have been shown to increase greenhouse gas emissions by an average of 14 kg CO2e/t FPCM per case of hoof lesion, and 20.9 kg CO2e/t FPCM per case of subclinical ketosis, as a result of reduced milk yields, discarded waste milk, culling and prolonged calving interval (Mostert et al., 2018b; 2018c). Additionally, fewer costly treatments and improved productivity of healthier animals may improve the livelihood of the farmers that care for them (Bruijnis et al., 2010; Mostert et al., 2018a; Gussmann et al., 2019), and may have positive impacts on the farmer's own mental health and well-being (García Pinillos et al., 2016).

Although animal welfare has been a topic of study for decades, the role it can play in helping to develop sustainable livestock systems overall has only recently been acknowledged. References to animal welfare were not included when the UN created their Sustainable Development Goals (SDG) in 2015, with the aim of improving food security and reducing the effects of climate change (Keeling et al., 2019). However, recent research has found that animal welfare can, in some manner, be linked to every SDG (Keeling et al., 2019; Olmos Antillón et al., 2021). Updates to the SDG by the UN Committee on World Food Security have also shown progress in acknowledging the important role of animal welfare by publishing recommendations that include the aim "Improve animal welfare, delivering on the five freedoms and related OIE standards and principles" (United Nations, 2016; Buller et al., 2018). This acknowledgement is a big step forward for considering animal welfare an important component of developing sustainable livestock production, and contributing to the overall sustainable development goals around the world.

Future directions of dairy cow welfare on pasture-based farms

Dairy production in Ireland, and worldwide, has undergone considerable change over the last decade and that is likely to continue into the future. As agricultural intensification increases to meet the food demands of a growing global population (FAO and GDP, 2018), the welfare of the animals in these systems is more important than ever. The impacts of grazing intensification on dairy cow welfare as discussed in Chapter 5 would benefit from further examination in a commercial setting. While the observed effects of grazing pressure treatments were minor, replication with a larger group of animals, and in a real-world rather than experimental setting would be beneficial to support or challenge these findings. Furthermore, a longer term evaluation of grazing intensification, would provide valuable information on any potential long-term impacts of intensification. Including welfare indicators in a system study over multiple years could also account for the influence of years with abnormal weather as experienced during my study. Although as a result of climate change, unprecedented or extreme weather is likely to become the new normal, which is further motivation for the use of studies which monitor effects over a longer period.

With more attention focused on the sustainability of livestock systems, currently and in the future, pasture-based dairy research in general could benefit from greater integration of animal welfare indicators into all manner of studies. The numerous welfare risk-factors identified in Chapters 3 and 4 emphasize the interconnection of welfare to various aspects of pasture-based dairy production management, and resources. The study of animal welfare encompasses health, behaviour and affective state, thus the focus on only individual components such as milk yield or BCS in grazing studies should no longer be considered sufficient to draw conclusions about the impact on overall dairy cow welfare.

Finally, the most important tool going forward to ensure continued improvement of dairy cow welfare in pasture-based systems is the regular implementation of a standardised welfare assessment protocol. As discussed in Chapter 2, to generate the most complete and accurate picture of welfare within this system, the assessment should evaluate animal-based measures of welfare during both the grazing period as well as the housing period whenever present. The results of such an assessment will facilitate the benchmarking of welfare indicators and provide a valuable source of information on the current state of dairy welfare. This knowledge will enhance our ability to make decisions that can improve dairy cow welfare, to maintain consumer confidence, and to monitor effects of intensification and changes in on-farm management practices in the future.

MAIN CONCLUSIONS

- A welfare assessment protocol was developed and implemented that targets the animal-based welfare indicators most relevant to spring-calving, pasture-based dairy production.
- The use of performance benchmarking highlighted the great variability in herd-level prevalence of welfare indicators between farms.
- More than double the number of welfare risk factors were identified during the housing period (n = 35) as during the grazing period (n = 14), emphasising the influence that indoor housing conditions can have on dairy cow welfare in a pasture-based system
- Multiple welfare risk factors related to housing were identified during the grazing period, including length of the previous housing period, inadequate cubicle dimensions, and presence of a brisket board in cubicles, highlighting the carry-over effects of the housing period into the grazing period.
- Several risk factors (cow comfort index, cubicle width, shed floor slipperiness, shed light level, shed passage width and both presence and absence of collecting yard backing gates) were each associated with multiple welfare indicators during the housing period; the associated indicators were primarily one or both of tail injury or integument damage, suggesting these are areas of particular welfare concern during housing.
- Tail injury (broken or incomplete tails) is occurring frequently among a subset of farms, necessitating the identification of the causes and methods of prevention to improve dairy cow welfare.
- Nasal discharge and integument alterations were the two most commonly affected welfare indicators in the Irish pasture-based system.
- Increasing levels of grazing pressure due to variation in pasture allowance and stocking rate had only minor impact on indicators of welfare.
- Across the examined levels of grazing pressure, all measured welfare indicators except rumen fill and locomotion score demonstrated improvement between the early (spring) and late grazing (autumn) period, highlighting the positive impact of pasture access on dairy cow welfare.

SUMMARY

Animal welfare is an integral part of sustainable dairy production. Well-cared for animals are healthier, have less impact on the environment, are better able to sustain the livelihood of farmers, and provide consumers with confidence in the food those animals produce. With the trend towards greater intensification of dairy production worldwide, even among pasture-based dairy production systems such as those common in Ireland, the challenge of maintaining good animal welfare becomes increasingly important to the sustainability of dairy production. This is of particular importance to the pasture-based production systems in Ireland, which have undergone considerable expansion and intensification since the elimination of the European milk quota system in 2015. While pasture-based production is often believed to provide cows the best welfare due to its apparently more natural environment, there are still challenges to dairy cow welfare within this system, such as greater exposure to inclement weather, long daily walking distances to paddocks, reduced daily lying times, and the potential for nutritional stress. Little large-scale research has been conducted to provide information on the current welfare state of dairy cows within this system, which is vital to identify areas where dairy cow welfare can be improved.

There were three aims in this thesis: 1) to conduct a welfare assessment to identify the current state of welfare among spring-calving, pasture-based dairy farms in Ireland, 2) to use the data collected through this welfare assessment to identify risk factors for welfare during both the grazing and housing periods, and 3) to examine how measures of welfare are influenced by increasing levels of grazing intensity on spring-calving pasture based dairy farms.

Data collection for Chapters 2 to 4 was derived from a welfare assessment conducted on over 100 spring-calving, pasture-based farms across the primary dairy-producing counties in southern Ireland, during both the grazing (April – September 2019) and housing periods (October 2019 – February 2020). The welfare assessment examined seven indicators of welfare: locomotion score, body condition score integument damage, ocular discharge, nasal discharge, tail injury (consisting of lacerated, broken or incomplete/docked tails), and the fearful avoidance response to human approach. In addition, data was collected directly regarding the farm facilities (e.g. milking parlour and holding areas, roadways to paddocks, winter housing sheds) as well as the farm management practices through a survey with the farmer.

Utilising the data collected through this welfare assessment, Chapter 2 discusses the herd-level prevalence of each welfare indicator during both the grazing and housing periods. These prevalence values were compared between periods to identify potential differences in welfare over time and under different management

conditions. The majority of farms were able to meet the respective body condition targets for both grazing and housing periods. Locomotion scores were relatively low (9-10% of cows categorised as clinically lame at either period). Ocular discharge was uncommon at both periods, while nasal discharge was somewhat common (5-7% of cows affected at either visit), which indicates a potential welfare concern to address. Integument damage was minor, involving primarily hair loss, and was concentrated to the hindquarter region during the grazing period, and to both the hindquarters and head-neck-back region during housing. Potential causes discussed were impacts with elements of the indoor facilities, such as cubicles and feed rails during housing, as well as potential carry-over effects of housing paired with mounting behaviour due to breeding season during the grazing period. A concerning amount of broken and incomplete tails were observed regardless of period, with an average of 8% of cows affected, suggesting tail injury is a considerable welfare issue, due to either accidental (e.g. poor facility design or animal handling practices) or intentional (e.g. tail docking) causes. There was also a high proportion of cows displaying a fearful avoidance response to an approaching human at both grazing and housing visits; although the average prevalence was lower when tested within the pen or at the feed-face during housing, compared to when tested in the paddock during grazing. Thus this may be associated with less regular interaction with humans during grazing. It was concluded that there are opportunities for welfare improvement surrounding the prevention of tail injury, identification of the cause of nasal discharge, and the management of indoor facilities to reduce the occurrence of integument damage. The results of this welfare assessment were also used to establish performance benchmarks for the examined welfare indicators. The performance for all farms in each indicator were ranked from best to worst and the top and bottom performing 20% of farms were identified. These benchmarks can provide farmers with a tool for comparison of their farm's performance against what can be achieved by other farms within the same system, and encourage continued improvement of welfare indicators.

On Irish pasture-based dairy farms, cows spend the majority of the year grazing at pasture, so it is important to consider the potential risk factors for good welfare during this period. In Chapter 3, a risk factor analysis was performed based on the herd-level data collected from the welfare assessment of 93 dairy farms during the grazing period. A zero-inflated beta regression model was used to analyse potential associations between categorical management and resource factors collected as part of the welfare assessment and the seven animal-based welfare indicators. These analyses identified 14 risk factors associated with one or multiple indicators of welfare. Factors associated with lameness were: length of the previous housing period, all cubicles outside recommended lengths, and frequency of roadway repairs. The previous housing period length was also associated with integument damage, although the direction of the association was not apparent from the analysis. One factor, not participating in elective herd disease testing in the past year, was associated with a below target body condition score (<2.75). Associated with tail lacerations were the use of a single breeding method (either artificial insemination or a bull), not employing part-time staff and not using cubicle brisket boards. Collecting yard holding time was associated with nasal discharge, while health record-keeping method and collecting yard area were associated with ocular discharge. Factors associated with an avoidance response distance > 1 m were herding cows without a dog present and not employing additional full-time staff. Because multiple risk factors for welfare during the grazing period were, in fact, related to the housing period, it was concluded that carry-over effects of the housing period may be persisting into the grazing period. This highlights the importance of also considering the housing period in addition to the grazing period when assessing dairy cow welfare in a pasture-based system.

The housing period in a spring-calving pasture-based system presents a different set of challenges to dairy cow welfare than the grazing period. In Chapter 4, herd-level data collected from 82 farms during the housing visit of the welfare assessment were utilised to identify risk factors for welfare during the housing period. A zero-inflated beta regression model was used to assess potential associations between aspects of housing facilities and management and the seven indicators of animal welfare. Analyses identified 35 risk factors for welfare during the housing period (more than double the number identified in Chapter 3). In total, four risk factors were identified for each of ocular discharge, nasal discharge, avoidance response of > 1 m from human approach, and body condition above the housing period target of 3.5. A further six risk factors were associated with lameness and with integument damage to either the head-neck-back or hindquarter regions. The greatest number of risk factors, 11 in total, were identified as associated with tail injury of either lacerated, broken or incomplete tails. It was concluded in Chapter 4 that the high amount of risk factors associated with tail injury indicate this is an area in need of considerable research focus to improve dairy cow welfare. Several identified risk factors were associated with multiple indicators of welfare, the majority of which were related to either tail injury or integument damage. Tail lacerations were associated with cow comfort index and shed light-level; broken tails with cubicle width, shed passage width and the absence of a collecting yard backing gate; and incomplete tails with cubicle width and the presence of a collecting yard backing gate. Integument damage to the head-neck-back region was associated with shed floor slipperiness and shed passage width, while damage to integument of the hindquarters was associated with cow comfort index. Additionally, it was noted that multiple risk factors associated with negative indicators of welfare were frequently related to housing features that met recommended guidelines from the literature. This suggests the facility recommendations may not accurately reflect the needs of cows when housed, and may benefit from re-evaluation.

Pasture-based dairy production in Ireland has undergone considerable expansion over the last decade; however, studies related to intensification within this system have seldom had the potential effects on animal welfare as their primary focus. In Chapter 5, the aim was to investigate the potential impact of three differing levels of increased grazing pressure on indicators of welfare during both the early and late grazing periods of a single lactation. Data collection for this study was part of a larger system study taking place on the Curtins research farm (Teagasc, Fermoy, Cork, Ireland), and took place over a five week period in spring (early grazing) and a seven week period in autumn (late grazing). The examined indicators of welfare were locomotion score, hoof health (digital dermatitis and white line disease), rumen fill, ocular and nasal discharge, and integument damage to the neck-back and hock regions. The treatments represented a lower pressure grazing strategy (LOW; high pasture allowance and 2.75 cow/ha stocking rate), a moderate pressure grazing strategy (MOD; medium pasture allowance and 2.75 cow/ha stocking rate), and a higher pressure grazing strategy (HIGH; low pasture allowance and 3.25 cow/ha stocking rate. The results of Chapter 5 show only a minor impact of increased grazing pressure treatments on indicators of welfare. Small yet significant increases in nasal discharge and damage to integument of the neck-back region as well as reduced impairment of the locomotion score were observed at greater levels of grazing pressure. However, there were considerable effects of grazing period on welfare indicators, with all except rumen fill and locomotion score demonstrating notable improvements during the late grazing period compared to the early grazing period. These findings were not entirely unexpected due to the considerable difference in environments preceding each of these grazing periods; cows experience a prolonged period of housing prior to the early grazing period, in contrast to a prolonged period on pasture prior to the late grazing period. However, uncharacteristically cool wet spring weather during the study period may have influenced the results somewhat as it resulted in more days housed during the early grazing period than would be typical under usual weather conditions.

In Chapter 6, I reflect on the challenges of developing a welfare assessment protocol that includes welfare indicators reflective of the specific needs of a pasture-based dairy system. The welfare assessment conducted as a part of this thesis collected valuable data that enabled the identification of risk factors for welfare during both the grazing and housing periods. Tail injury was identified as a key area in need of welfare improvement, where until now, there has been little research focus. The results of the risk factor analyses also emphasize the important impact that even a short housing period can have on dairy cow welfare. It would be wise in future welfare assessments of pasture-based systems to similarly include evaluation of dairy cow welfare during both grazing and housing periods. Future welfare assessments would also benefit from incorporating regular performance benchmarking into the protocol to improve the ability to visualise the variability among farms, monitor progress made and motivate farmers. Even with the promising results of this thesis which suggest cows were able to cope well under increased grazing pressure, in light of the ongoing intensification of dairy production worldwide, it is vital to continue to monitor the impact these changes may have on animal welfare in the future. Striving for continued improvement, even in regards to welfare indicators which many be deemed "acceptable" will help to maintain consumer confidence and contribute to the overall sustainability of the system.

In conclusion, conducting a welfare assessment specifically designed for a pasture-based production system has improved our understanding of the current state of cow welfare on Irish dairy farms and enabled the identification of risk factors for welfare. These risk factors will aid in guiding future research and focusing recommended changes to on-farm management practices towards the continued improvement of dairy cow welfare during both the grazing and housing periods. It has also been shown that cows in a spring-calving pasture-based dairy production system were able to cope well with increasing levels of grazing pressure, and that even under greater intensification, more time on pasture led to improvements in indicators of welfare.

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APPENDIX

Appendix A. Description of categorical scales for animal-based and resource-based measures described in Chapters 3 and 4.

Measure	Level	Description
Ocular discharge[1]	0	Normal, no discharge.
	1	Small amount of ocular discharge.
	2	Moderate amount of ocular discharge.
	3	Heavy ocular discharge.
Nasal discharge[1]	0	Normal serous discharge.
	1	Small amount of cloudy discharge.
	2	Bilateral, cloudy or excessive mucus discharge.
	3	Copious bilateral mucopurulent discharge.
Integument damage[2]	0	No missing, thinning or broken hair. No swelling.
	1	Bald area. None or very mild swelling.
	2	Medium swelling (1 - 2.5 cm) and/or lesion (scab or open wound).
	3	Major Swelling (> 2.5 cm).
Avoidance response[3]	1	Retreat at > 2 m.
	2	Retreat between 1 – 2 m.
	3	No retreat at 1 m, avoids extended hand.
	4	Accepts hand, but not touch.
	5	Accepts touch.
Surface condition	Very Smooth	Even surface. Well maintained with no broken or damaged surface, no large rocks or signs of erosion.
	Smooth	Mostly even surface, no broken sections. Occasional holes or bumps etc. May have signs of machinery use or erosion.
	Rough	Somewhat uneven, larger stones, bumps and holes are common. Signs of wear or erosion.
	Very Rough	Extremely bumpy and uneven, with coarse and broken surface. Many large, protruding rocks, holes etc.
Water source cleanliness	Clean	Water is clear, with minimal debris.
	Partly Dirty	Water not perfectly clear, but still can see to bottom. Some debris.
	Dirty	Difficult to see bottom. Lots of debris.
Floor slipperiness[4]	Slippery	Little to no grip, easy spinning
	Somewhat slippery	Some grip but can still slide/spin
	Not slippery	Good grip, abrasive surface, can't slide/spin.
Light level[4]	Bright	Can read easily with no strain.
	Dim	Can read but with some strain.
	Dark	Very difficult/impossible to read.
Cubicle condition	Very good	< 5% of cubicles damaged or in disrepair (e.g. broken cubicles, torn mats)
	Good	< 25% of cubicles damaged or in disrepair.
	Poor	25 - 50% of cubicles damaged or in disrepair.
	Bad	> 50% of cubicles damaged or in disrepair.
Cubicle hardness	Hard	Like concrete or bare floor. Too painful to drop to knees voluntarily.
	Medium	Like foam or rubber. Dropping to knees is unpleasant, but not painful.
	Soft	Like a mattress or deep bedding. Pain-free drop to knees.
Cubicle bedding coverage	Full	Thick coating. Cannot see cubicle base through bedding material.
	Partial	Can see cubicle base through bedding material in some areas.
	Minimal	Bare sprinkling of bedding material. Cubicle base clearly seen through bedding material.
	None	No bedding material.
Cubicle or loose yard bedding cleanliness	Clean	< 25% soiled with manure.
	Partly Dirty	25 - 50% soiled with manure.
	Dirty	> 50% soiled with manure.
Loose yard bedding depth	Sparse	Minimal coverage. Floor visible through bedding. Drop to knees would be painful.
	Thin	Floor just covered but not visible through bedding. Drop to knees would be painful.
	Thick	Medium amount of coverage. Dropping to knees would be unpleasant but not painful.
	Very Thick	Dense and soft coverage. Pain-free drop to knees.

[1] 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

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Appendix B. Description of categorical predictor variables and corresponding levels included in regression analyses for each welfare indicator in Chapter 3. The visit when each factor was collected is indicated. Also indicated is the number of farms included in each analysis which involves that factor for both the complete cases (CC) and substitution (SUB) methods of analysis. Welfare indicators include locomotion score 2 and 3 (LS), body condition score < 2.75 (BCS), tail lacerations and breaks (TL), ocular discharge score 1-3 and nasal discharge score 2-3 (OSNS), integument damage score 2 and 3 (INT), avoidance response > 1 m (AR).

Visit	Variable	Variable description	Level	Level Description	Number of Farms per level by indicator – CC (SUB)[1]					
					LS	**BCS**	**TL**	**OSNS**	**INT**	**AR**
1	Cubicle length	Front of cubicle to curb[1]	Recommended	Recommended length of 2.3-2.6 m for wall facing or 2.21-2.45 m for head-to-head/passage facing	7 (8)	7 (8)			8 (8)	
			Non-recommended	Above or below the recommended length	54 (67)	52 (67)	60 (67)		57 (67)	
			Mixed	> 50% herd housed with mix of recommended and non-recommended cubicles	16 (18)	13 (18)	25 (26)		16 (18)	
1	Cubicle width	Between partitions at cubicle opening[1]	Non-recommended	All outside recommended cubicle width for partition type	65 (78)	61 (78)	71 (78)		67 (78)	
			Mixed	Sheds with mixture of cubicles outside and within recommended width of 1.15 ± 0.025 m (1.125-1.175 m for cubicles with no partition attachment (e.g. cantilever, mushroom) and 1.225-1.275 for cubicles with attached partitions (e.g. Newton-Rigg)	12 (15)	11 (15)	14 (15)		14 (15)	
1	Brisket board	Presence of a brisket board in cubicles	No	No brisket board	60 (74)	56 (74)	67 (74)		63 (74)	
			Yes	Brisket board present	17 (19)	16 (19)	18 (19)		18 (19)	
1	Neck-rail height	Cubicle floor to bottom of neckrail[1]	Recommended	Within recommended height of 1.1 - 1.2 m	29 (32)	29 (32)			30 (32)	
			Non-recommended	Above or below the recommended height of 1.1-1.2 m	43 (55)	37 (55)			45 (55)	
			Mixed	Shed contains mixture of cubicles with recommended and non-recommended neck-rail heights	5 (6)	6 (6)			6 (6)	
1	Collecting yard area	Sufficient[2] collecting yard area/cow	No	Below recommended 1.4 m^2/cow	32 (41)			33 (41)	35 (41)	
			Yes	Above recommended 1.4 m^2/cow	45 (52)			44 (52)	46 (52)	
1	Collecting yard flooring	Primary floor type (> 50%)	Concrete		42 (53)			46 (53)		
			Slats		24 (28)			22 (28)		
			Mixed concrete and slats		11 (12)			9 (12)		
1	Max holding time	Max time a cow could be in collecting yard before milking	≤ 60 min		21 (29)			22 (29)		
			> 60 ≤ 90 min		39 (42)			37 (42)		
			> 90 min		17 (22)			18 (22)		
1	Backing gate	Backing or crowd gate in collecting yard	No		61 (74)		68 (74)		65 (74)	
			Yes		16 (19)		17 (19)		16 (19)	
1	Parlour slipperiness-Entrance	Measured in front of parlour entrance	Not Slippery	Good grip, abrasive surface, can't slide/spin.	52 (63)				55 (63)	
			Slippery & Somewhat slippery	Little to no grip, easy spinning or some grip but can still slide/spin	25 (30)				26 (30)	

1	Parlour slipperiness-Exit	Measured where cows exit milking units in parlour	Not Slippery	Good grip, abrasive surface, can't slide/spin.	54 (66)		56 (66)	
			Slippery & Somewhat slippery	Little to no grip, easy spinning or some grip but can still slide/spin	23 (27)		25 (27)	
1	Parlour turns - Entrance	Sharp turn to enter parlour (≤ 90 degree)	No		45 (56)		49 (56)	
			Yes		32 (37)		32 (37)	
1	Parlour turns – Exit 90	Sharp (≤ 90 degree) turn at parlour exit	No		7 (11)			
			Yes		70 (82)			
1	Parlour turns – Exit 180	Sharp (≤ 90 degree) turn at parlour exit, then second sharp turn within one cow length	No		54 (64)			
			Yes		23 (29)			
1	Parlour end distance	Distance from milking row exit to end of parlour	< 2 m		19 (27)		23 (27)	
			≥ 2 < 3 m		31 (34)		30 (34)	
			≥ 3 m		27 (32)		28 (32)	
1	Parlour Light - Entrance	Light level measured at parlour entrance	Low light	Dim or dark	19 (22)		20 (22)	
			Bright light	Bright	58 (71)		61 (71)	
1	Parlour Light - Exit	Light level measured at parlour exit	Low light	Dim or dark	27 (34)		29 (34)	
			Bright light	Bright	50 (59)		52 (59)	
1	Parlour Step - Entrance	Step up or down to parlour at entrance	No		48 (60)			
			Yes		29 (33)			
1	Parlour Step - Exit	Step up or down from parlour at exit	No		56 (70)			
			Yes		21 (23)			
1	Furthest paddock	Distance between furthest paddock and parlour	< 1 km		31 (37)	27 (37)		
			≥ 1 km		46 (56)	45 (56)		
1	Max walking time	Maximum time for cows to return to parlour from paddock (min)	< 20 min		40 (48)	33 (48)		
			≥ 20 min		37 (45)	39 (45)		
1	Droving method	Method of bringing cows from paddock to parlour	On-foot	Cows collected on-foot or on-own always	41 (51)			30 (36)
			Vehicle	Cows collected with motorised vehicle always	24 (29)			20 (22)
			Combination	Mix of vehicle and on-foot or on-own to collect cows	12 (13)			8 (10)
1	Cows to parlour	How cows are brought into parlour from collecting yard	On own		45 (54)			33 (39)
			Assisted	Herded always, herded when required, backing gate	32 (39)			25 (29)
1	Average farm size	Based on average dairy farm size of approx. 38 Ha[3]	Below average	< 40 Ha	30 (39)			
			Above average	≥ 40 Ha	47 (54)			
1	Dog	Whether a dog is present when herding cattle	No		48 (60)			37 (43)
			Yes		29 (33)			21 (25)

Visit	Variable	Variable description	Level	Level Description	Number of Farms per level by indicator – CC (SUB)[1]					
					LS	BCS	TL	OSNS	INT	AR
1	Consider walking distance	Whether total walking distance is a factor in grazing order	No		56 (69)					
			Yes		21 (24)					
1	Footbath	Whether a footbath is used on-farm	No		33 (39)			31 (39)		
			Yes/If required		44 (54)			46 (54)		
1	Herd biosecurity Status	Whether farms purchase or bring in any outside stock (Includes, cows, calves, heifers, bulls)	Closed	No outside stock brought onto farm	12 (17)	12 (17)		12 (17)		
			Open	Yes, outside stock brought onto farm	65 (76)	60 (76)		65 (76)		
1	Health recording	Health record-keeping method	Manual	Paper, notebook, whiteboard etc.	33 (40)	33 (40)		35 (40)		
			Digital	Computer, phone, software etc.	44 (53)	39 (53)		42 (53)		
1	Herd health plan	Whether farms follow a herd health plan	No		34 (41)	31 (41)		33 (41)		
			Yes, Self-made		15 (17)	14 (17)		15 (17)		
			Yes, Vet-made		28 (35)	27 (35)		29 (35)		
1	Enrolled HMP	Enrolled in any health management program (e.g. Munster herd health, Animal health Ireland, Irish Johnes control program, etc.)	No		18 (20)			15 (20)		
			Yes		59 (73)			62 (73)		
1	SLG	Maintain a separate lame cow group (SLG) within the herd	No		52 (66)					
			Yes		14 (15)					
			Sometimes		11 (12)					
1	Lameness pain control	Specified lameness or hoof problems as a condition requiring/ receiving pain medication	No		46 (56)					
			Yes		31 (37)					
1	Regular LS	Regularly locomotion score cows	No		64 (78)					50 (60)
			Yes	Formally or informally	13 (15)					8 (8)
1	Time to treat	Time from noticing a cow with a mobility or hoof problem to the time the cow is treated	≤ 24 h	24 h or more before treatment	39 (46)					
			≤ 48 h	more than 24 h, up to and including 48 h	18 (22)					
			WK+	week or more before treatment	20 (25)					
1	Months housed	Previous housing period length	3 months		31 (38)	29 (38)	35 (38)	32 (38)	32 (38)	19 (25)
			< 3 months		25 (33)	26 (33)	29 (33)	27 (33)	28 (33)	21 (23)
			≥ 4 months		21 (22)	17 (22)	21 (22)	18 (22)	21 (22)	18 (20)
1	Herd size	Farmer reported herd size	≤ 80 cows	equal or less than the national herd average of 80 cows	17 (21)	14 (21)	19 (21)	18 (21)	19 (21)	13 (16)
			≤ 125 cows	> national average, ≤ study average of 125 cows	28 (33)	26 (33)	32 (33)	27 (33)	28 (33)	17 (23)
			> 125 cows	> study average of 125 cows	32 (39)	32 (39)	34 (39)	32 (39)	34 (39)	28 (29)

1	Pasture stocking rate	Number of cows per Ha of grazing area (total cows/total grazing area Ha)	≤ 2 cows/Ha		13 (16)	12 (16)				
			≤ 3 cows/Ha		30 (32)	26 (32)				
			≤ 4 cows/Ha		24 (33)	24 (33)				
			> 4 cows/Ha		10 (12)	10 (12)				
1	PT Staff	Farmer reported employing part-time staff	No		22 (25)	19 (25)	25 (25)	18 (25)	22 (25)	14 (17)
			Yes		55 (68)	53 (68)	60 (68)	59 (68)	59 (68)	44 (51)
1	Road repair frequency	Farmer reported frequency of paddock roadway repairs	Yearly	Once or twice/year	18 (22)					
			Occasionally	Once every 2-3 years	20 (25)					
			Rarely	4 years or more, as required or never	39 (46)					
1	Road crossing	Cows must cross an off-farm road to reach paddock from parlour	No		32 (41)					
			Yes		45 (52)					
1	CY roadway width	Whether average width of roadway along 50 m stretch to collecting yard is sufficient[4]	No	< 3.7 m/150 cows, < 4.2 m for 150-250 cows	22 (28)					
			Yes	> 3.7 m/150cows, > 4.2 m for 150-250 cows	55 (65)					
1	CY roadway verge width	Whether average verge width along 50 m of roadway to collecting yard is sufficient[4]	Recommended	Approximately recommended width (0.5 ± 0.1m)	21 (25)					
			Below recommended	Below recommended width (< 0.4 m)	39 (49)					
			Above recommended	Above rec width (> 0.6 m)	17 (19)					
1	CY roadway - surface type	Primary (> 50%) surface material type along 50 m of roadway to collecting yard	Subsoil		27 (35)					
			Concrete		23 (25)					
			Mixed	No surface type > 50%	27 (33)					
1	CY roadway - surface condition	Primary (> 50%) surface condition along 50 m of roadway to collecting yard	Smooth	Smooth or very smooth	44 (51)					
			Rough	Rough or very rough	16 (21)					
			Mixed	Equal parts rough and smooth	17 (21)					
1	CY roadway – sharp turns	Sharp turns (≤ 90 degree) along 50 m of roadway to collecting yard	No	All roads to the collecting yard have no sharp turns	13 (19)					
			Yes	All roads to the collecting yard have sharp turns	35 (41)					
			Mixed	Some have sharp turns, some do not	29 (33)					
1	CY roadway – Stones	Average percentage of loose stones along 50 m of roadway to the collecting yard	≤ 25%		17 (20)					
			≤ 50%		18 (23)					
			≤ 75%		21 (24)					
			>75%		21 (26)					
1	Roadway width	Average paddock roadway width is sufficient[4]	No	< 3.7 m/150 cows, < 4.2 m for 150-250 cows	43 (53)					
			Yes	> 3.7 m/150cows, > 4.2 m for 150-250 cows	34 (40)					

Visit	Variable	Variable description	Level	Level Description	Number of Farms per level by indicator – CC (SUB)[1]					
					LS	BCS	TL	OSNS	INT	AR
1	Roadway verge width	Average verge width of paddock roadway is sufficient[4]	Recommended	Approximately recommended width (0.5 ± 0.1m)	25 (32)					
			Below recommended	Below recommended width (< 0.4 m)	20 (25)					
			Above recommended	Above rec width (> 0.6 m)	32 (36)					
1	Roadway surface type	Primary (> 50%) roadway surface material type	Subsoil		45 (54)					
			Non-subsoil	Mix of surfaces, none > 50% (includes 3 farms where primary surface was concrete)	32 (39)					
1	Roadway surface condition	Primary (> 50%) roadway surface condition	Smooth	Smooth or very smooth	33 (39)					
			Rough	Rough or very rough	21 (23)					
			Mixed	Equal parts rough and smooth	23 (31)					
1	Roadway cow track	Obvious cow track on paddock roadway	No	Not at either point	63 (76)					
			Yes	Yes for at least one recorded point on the roadway	14 (17)					
1	Roadway stones	Average percentage of loose stones on paddock roadway	≤ 50%		10 (14)					
			≤ 75%		21 (26)					
			> 75%		46 (53)					
1	CY majority covered	Collecting yard is > 50% covered	No					46 (52)		
			Yes					31 (41)		
2	Open sides	Whether sheds have open sides	No	All sheds fully enclosed				13 (16)		
			Yes	All sheds have at least 1 open side				43 (54)		
			Mixed	Mix of sheds with open sides and fully enclosed				21 (23)		
1	Paddock water	Number of water points available in paddocks	Single	Single water point in paddock		56 (67)		59 (67)		
			Multiple	Multiple water points		16 (21)		18 (21)		
			None			0 (5)		0 (5)		
1	Paddock water clean	Cleanliness of paddock water points	Clean	All water points clean		15 (17)		16 (17)		
			Dirty	All water points dirty		17 (21)		18 (21)		
			Partly Dirty	All water points partly dirty		30 (44)		32 (44)		
			Mixed	Mixture of clean, dirty and partly dirty water points		10 (11)		11 (11)		
1	Water clean frequency	Farmer reported frequency of water point cleaning	Once/yr			37 (51)		42 (51)		32 (38)
			< Once/yr			21 (26)		20 (26)		18 (21)
			> Once/yr			14 (16)		15 (16)		8 (9)
1	Water function frequency	Farmer reported frequency of checking water point function	Regularly	Daily/weekly/monthly		61 (75)		65 (75)		50 (58)
			Irregularly	Yearly/when there is a problem/never		11 (18)		12 (18)		8 (10)
1	Water test	Whether water quality is tested	No			6 (10)		7 (10)		
			Yes			66 (83)		70 (83)		
1	Open water access	Whether cows have access to open water (e.g. lake, stream etc.) in at least one paddock	No					66 (78)		
			Yes					11 (15)		

1	Paddock water height	Paddock water source height from floor to top edge	< 0.7 m			32 (40)		
			0.7 - 0.8 m			25 (32)		
			> 0.8 m			20 (21)		
1	Disease test	Whether farms participated in elective herd disease testing in past year	No		17 (24)	19 (24)	19 (24)	
			Yes		55 (69)	58 (69)	62 (69)	
1	Routine parasite dose	Routine use of anti-parasitics/ de-wormers	No		10 (11)	11 (11)	10 (11)	7 (8)
			Yes		62 (82)	66 (82)	71 (82)	51 (60)
1	Separate pens	Separate sick pens	No			33 (41)		
			Yes			44 (52)		
1	Enrolled PB	Farms enrolled in the Pasture Base (Irish grass recording system)	No		30 (41)			
			Yes		42 (52)			
1	Measure grass	Whether paddock grass growth is measured routinely	No		31 (44)			
			Yes		41 (49)			
1	Regular BCS	Whether regular body condition scoring is practiced	No		35 (48)			31 (37)
			Yes		37 (45)			27 (31)
1	Partition type	Primary (> 50%) cubicle partition type	Cantilever and Double front fixed				51 (62)	
			Front-Rear-Fixed/Newton Rigg				20 (20)	
			Mushroom				10 (11)	
2	Multiple groups	Cows are housed in multiple groups	No					13 (19)
			Yes					45 (49)
2	Shed lighting	Shed light level	Bright	All bright light				17 (19)
			Low	All dark/dim				26 (31)
			Mixed	Mixed bright, dark and dim light				15 (18)
2	Lights left on	Lights purposely left on for the cows during housing	No					9 (12)
			Yes					49 (56)
1	CY yard entrance	Collecting yard entrance width	< 4 m				25 (29)	
			4 – 5 m				25 (29)	
			> 5 m				31 (35)	
1	Feed pass width	Width of shed feed passage is sufficient (cow-side)[5]	No	Lower than minimum recommended feed passage width of 4.6 m				32 (35)
			Yes	Meets or exceeds minimum recommended feed passage width of 4.6 m				11 (15)
			Mixed	Mixture of feed passage widths above and below minimum of 4.6 m				15 (18)

Visit	Variable	Variable description	Level	Level Description	Number of Farms per level by indicator – CC (SUB)[1]					
					LS	BCS	TL	OSNS	INT	AR
1	Passage width	Width of passages within shed are sufficient[5]	No	All passages below recommended minimum of 3 m						42 (52)
			Mixed	Mixture of passages above and below recommended minimum of 3 m (includes 3 farms all ≥ 3 m)						16 (16)
2	Feed delivery frequency	Frequency of fresh feed delivery	≥ Once/d							46 (56)
			< Once/d							12 (12)
2	Feed push-up	Frequency of remaining feed push-up to the feed face	≤ Once/d							30 (37)
			> Once/d							28 (31)
2	Grazing season	2019 grazing season length	8 months (approx. average)							26 (30)
			< 8 months							17 (20)
			9 months or more							15 (18)
1	Breeding	Breeding method	Single method	Either artificial insemination or stock bull only			15 (15)		15 (15)	9 (11)
			Combined methods	Both artificial insemination and stock bull			70 (78)		66 (78)	49 (57)
1	No. Farmers	Number of full time farmers	1							43 (49)
			≥ 2							15 (19)
1	Additional FT staff	Whether full-time staff in addition to the primary farmer(s) are employed	No							43 (51)
			Yes							15 (17)
2	Avg. farmer age	Average age of all farmers	≤ 40 yr							17 (17)
			≤ 50 yr							21 (26)
			>50 yr							20 (25)
2	Improve animal care	Farmers identified an aspect of animal care they wish to improve	No							13 (14)
			Yes							45 (54)
2	Welfare rating	How farmers rate their own farm's welfare	A	Average						12 (13)
			AA	Above average						38 (46)
			E	Excellent						8 (9)
1	Pain meds	Pain medication is used for cows on-farm	No							9 (11)
			Yes							49 (57)
2	Freeze brand	Whether freeze-branding is performed on farm	No							16 (17)
			Yes							42 (51)
2	Tail tape	Tail-tape is used for marking cows	No							24 (28)
			Yes							34 (40)

2	Cubicle cleaning	Cubicle cleaning frequency during housing	OAD	Once/day	32 (35)
			< OAD	Less than once/day	6 (6)
			TAD	Twice/day	20 (27)
2	Cubicle bedding	Cubicle bedding/liming frequency during housing	OAD	Once/day	30 (35)
			< OAD	Less than once/day	11 (12)
			TAD	Twice/day	17 (21)
1	Number of milkers	Number of people milking at a time	1		30 (36)
			1.5	Farms with 1 main milker and a part-time or seasonal second milker	9 (11)
			≥ 2		19 (21)
2	Cows held	Cows regularly held after milking during grazing	No		27 (29)
			Yes, everyday		16 (19)
			Yes, sometimes		15 (20)

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[1] Clarke, P., 2016. Winter Facilities, in: Moore, M. (Ed.), Teagasc Dairy Manual. Teagasc, Oak Park,Carlow, Ireland, pp. 143–156.

[2] Department of Agriculture Food and the Marine, 2020. Minimum Specification For Milking Premises And Dairies (S 106). Available from www.agriculture.gov.ie.

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[4] Teagasc, 2017. Dairy Farm Infrastructure Handbook. Tuohy, P., Upton, J., O'Brien, B., Dillon, P., Ryan, T., O'Huallachain, D. (Ed.). Teagasc Moorepark, Fermoy, Cork.

[5] Agriculture and Horticulture Development Board, 2012. Section 7: Cubicles, in: Dairy Housing - A Best Practice Guide. pp. 23–34. Available from https://www.farmhealthonline.com/wp-content/uploads/2013/10/Cubicles-DairyCo.pdf.

Appendix C. Description of categorical predictor variables and corresponding levels included in regression analyses for each welfare indicator in Chapter 4. The visit when each factor was collected is indicated. Also indicated is the number of farms per level included in analyses involving each variable for both the complete cases (CC) and substitution (SUB) methods of analysis. Welfare indicators include locomotion score 2 and 3 (LS), body condition score > 3.5 (BCS), broken, lacerated or incomplete tails (TL), ocular and nasal discharge score 1-3 (OSNS), integument damage score 1-3 to the head-neck-back (INT-HNB) and hindquarter regions (INT-HNB), avoidance response > 1 m (AR).

Visit	Variable	Variable description	Levels	Level description	Number of Farms per level by indicator – CC (SUB)							
					LS	BCS	TL	OS	NS	INT-HNB	INT-H	AR
1	Total cubicle length	Front of cubicle to curb[1]	Mixed	All or some cubicles within recommended length of 2.3-2.6 m for wall facing or 2.21-2.45 m for head-to-head/passage facing	22 (26)	21 (26)	22 (26)			20 (26)	20 (26)	
			Non-recommended	All outside (above or below) recommended length	46 (56)	46 (56)	47 (56)			45 (56)	45 (56)	
1	Cubicle width	Between partitions at cubicle opening[1]	Recommended	Sheds with all or some cubicles within recommended width of 1.15 ± 0.025 m (1.13-1.18 m for cubicles with no partition attachment (e.g. cantilever, mushroom) and 1.23-1.28 for cubicles with attached partitions (e.g. Newton-Rigg)	12 (14)	11 (14)	11 (14)			11 (14)	11 (14)	
			Non-recommended	All outside recommended cubicle width for partition type	56 (68)	56 (68)	58 (68)			54 (68)	54 (68)	
1	Diagonal cubicle length	From top of curb to neck-rail[1]	Recommended	within recommended length of 1.9-2.05 m	42 (51)	39 (51)	41 (51)			38 (51)	38 (51)	
			Non-recommended	above or below recommended length of 1.9-2.05 m	26 (31)	28 (31)	28 (31)			27 (31)	27 (31)	
1	Brisket board	Presence of a brisket board in cubicles	No	No brisket board	52 (63)	51 (63)	54 (63)			50 (63)	50 (63)	
			Yes	Brisket board present	16 (19)	16 (19)	15 (19)			15 (19)	15 (19)	
1	Neck-rail height	Cubicle floor to bottom of neck-rail[1]	Recommended	Within recommended height of 1.1 - 1.2 m	27 (31)	26 (31)	26 (31)			26 (31)	26 (31)	
			Non-recommended	All or some cubicles with neck-rail outside(above or below) recommended height of 1.1-1.2 m	41 (51)	41 (51)	43 (51)			39 (51)	39 (51)	

1	Curb height	Height of step up to cubicle[5]	Recommended	Within recommended levels of 0.15 - 0.2 m	11 (11)	10 (11)	9 (11)			9 (11)	9 (11)
			Non-recommended	Above or below recommended curb height of 0.15 - 0.2 m	57 (71)	57 (71)	60 (71)			56 (71)	56 (71)
1	Lunge space		Recommended	At or above recommended lunge space of 0.6 - 0.7 m	27 (21)	17 (21)	17 (21)			15 (21)	15 (21)
			Non-recommended	Below recommended lunge space of 0.6 m	41 (61)	50 (61)	52 (61)			50 (61)	50 (61)
2	Cubicle hardness		Soft	Soft, easily drop to knees without pain	7 (7)						
			Hard	Combined medium and hard scored surfaces. Uncomfortable or painful drop to knees	61 (75)						
2	Mat	Thickness of mat on cubicle surface	Thin	All cubicles with <2 cm thick mat or none	26 (31)	26 (31)	26 (31)			25 (31)	25 (31)
			Thick	All cubicles with mat >2cm thick (top 25% of cubicle mats)	19 (21)	16 (21)	18 (21)			16 (21)	16 (21)
			Mixed	Cubicles have combination of mat types (none with >50%)	23 (30)	25 (30)	35 (30)			24 (30)	24 (30)
2	Absorb. material on cubicles	Absorbent material (e.g lime) has been applied to cubicles	Mixed	None or some cubicles				16 (23)	16 (23)		
			Yes	Yes, all cubicles				48 (59)	48 (59)		
2	Cubicle stocking rate	Ratio of cows to cubicles in housing pens[6]	Non-recommended	Below recommended 1 cubicle/cow or 5 m^2/cow	36 (44)	39 (44)	37 (44)			35 (44)	35 (44)
			Recommended	Meets or exceeds recommended 1 cubicle/cow or 5 m^2/cow	32 (38)	28 (38)	32 (38)			30 (38)	30 (38)
1	Collecting yard area	Sufficient[2] collecting yard area/cow	No	Below recommended 1.4 m^2/cow	30 (34)			27 (34)	27 (34)	29 (34)	29 (34)
			Yes	Above recommended 1.4 m^2/cow	38 (48)			37 (48)	37 (48)	36 (48)	36 (48)
1	Collecting yard flooring	Primary floor type (> 50%)	Concrete		38 (46)			36 (46)	36 (46)		
			Slats		19 (25)			20 (25)	20 (25)		
			Mixed concrete and slats		11 (11)			8 (11)	8 (11)		

Visit	Variable	Variable description	Levels	Level description	Number of Farms per level by indicator – CC (SUB)							
					LS	BCS	TL	OS	NS	INT-HNB	INT-H	AR
1	Max holding time	Maximum time a cow could be in collecting yard before milking	≤ 60 min		19 (24)			18 (24)	18 (24)			
			> 60 ≤ 90 min		33 (38)			31 (38)	31 (38)			
			> 90 min		16 (20)			15 (20)	15 (20)			
1	Backing gate	Backing or crowd gate in collecting yard	No				54 (65)			51 (65)	51 (65)	
			Yes				15 (17)			14 (17)	14 (17)	
1	Parlour slipperiness-Entrance	Measured in front of parlour entrance	Non-slippery	Good grip, abrasive surface, can't slide/spin.	45 (54)					45 (54)	45 (54)	
			Slippery & somewhat slippery	Little to no grip, easy spinning or some grip but can still slide/spin	23 (28)					20 (28)	20 (28)	
1	Parlour slipperiness- Exit	Measured where cows exit milking units in parlour	Non-slippery	Good grip, abrasive surface, can't slide/spin.	48 (58)					46 (58)	46 (58)	
			Slippery & somewhat slippery	Little to no grip, easy spinning or some grip but can still slide/spin	20 (24)					19 (24)	19 (24)	
1	Parlour turns - Entrance	Sharp turn to enter parlour (≤ 90 degree)	No		39 (50)					37 (50)	37 (50)	
			Yes		29 (32)					28 (32)	28 (32)	
1	Parlour turns – Exit 180	Sharp (≤ 90 degree) turn at parlour exit, then second sharp turn within one cow length	No		49 (57)					45 (57)	45 (57)	
			Yes		19 (25)					20 (25)	20 (25)	
1	Parlour end distance	Distance from milking row exit to end of parlour	< 2 m		17 (21)					18 (21)	18 (21)	
			≥ 2 < 3 m		26 (31)					22 (31)	22 (31)	
			≥ 3 m		25 (30)					25 (30)	25 (30)	

1	Parlour light - Entrance	Light level measured at parlour entrance	Low light	Dim or dark	15 (18)			15 (18)	15 (18)	
			Bright light	Bright	53 (64)			50 (64)	50 (64)	
1	Parlour light - Exit	Light level measured at parlour exit	Low light	Dim or dark	23 (29)			20 (29)	20 (29)	
			Bright light	Bright	45 (53)			45 (53)	45 (53)	
1	Parlour step - Entrance	Step up or down to parlour at entrance	No		46 (53)					
			Yes		22 (29)					
1	Parlour step - Exit	Step up or down from parlour at exit	No		51 (61)					
			Yes		17 (21)					
1	Droving method	Method of bringing cows from paddock to parlour	On-foot	Cows collected on-foot or on-own always						34 (41)
			Vehicle	Cows collected with motorised vehicle always						22 (25)
			Combination	Mix of vehicle and on-foot or on-own to collect cows						7 (9)
1	Cows to parlour	How cows are brought into parlour from collecting yard	On own							37 (45)
			Assisted	Herded always, herded when required, backing gate						26 (30)
1	Average farm size	Based on average dairy farm size of approx. 38 Ha^3	Below average	< 40 Ha	26 (32)					
			Above average	≥ 40 Ha	42 (50)					
1	Dog	Whether a dog is present when herding cattle	No							40 (47)
			Yes							23 (28)
1	Footbath	Whether a footbath is used on-farm	No		30 (36)	28 (36)	28 (36)			
			Yes/If required		38 (46)	36 (46)	36 (46)			

Visit	Variable	Variable description	Levels	Level description	Number of Farms per level by indicator – CC (SUB)							
					LS	BCS	TL	OS	NS	INT-HNB	INT-H	AR
1	Herd Bio-security Status	Whether farms purchase or bring in any outside stock (Includes, cows, calves, heifers, bulls)	Closed	No outside stock brought onto farm	12 (15)	13 (15)		11 (15)	11 (15)			
			Open	Yes, outside stock brought onto farm	56 (67)	54 (67)		53 (67)	53 (67)			
1	Health recording	Health record-keeping method	Manual	Paper, notebook, whiteboard etc.	29 (36)	30 (36)		29 (36)	29 (36)			
			Digital	Computer, phone, software etc.	39 (46)	37 (46)		35 (46)	35 (46)			
1	Herd health plan	Whether farms follow a herd health plan	No		30 (39)	30 (39)		30 (39)	30 (39)			
			Yes, self-made		13 (14)	13 (14)		12 (14)	12 (14)			
			Yes, vet-made		25 (29)	24 (29)		22 (29)	22 (29)			
1	Enrolled HMP	Enrolled in any health management program (e.g. Munster herd health, Animal health Ireland, Irish Johnes control program, etc.)	No		15 (20)			14 (20)	14 (20)			
			Yes		53 (62)			50 (62)	50 (62)			
2	Antibiotic treatment	Whether cows are treated with antibiotics at dry-off	Always	Yes, all				42 (52)	42 (52)			
			Selectively	Yes, selectively or no				22 (30)	22 (30)			
1	SLG	Maintain a separate lame cow group (SLG) within the herd	No		43 (55)							
			Yes		14 (15)							
			Sometimes		11 (12)							

1	Lameness pain control	Specified lameness or hoof problems as a condition requiring/ receiving pain medication	No		42 (48)							
			Yes		26 (34)							
1	Regular LS	Regularly locomotion score cows	No		58 (70)							53 (65)
			Yes	Formally or informally	10 (12)							10 (10)
1	Time to treat	Time from noticing a cow with a mobility or hoof problem to the time the cow is treated	≤ 24 h	24 h or more before treatment	32 (41)							
			≤ 48 h	more than 24 h, up to and including 48 h	17 (19)							
			≥ 7 d	week or more before treatment	19 (22)							
1	Herd size	Farmer reported herd size	≤ 80 cows	equal or less than the national herd average of 80 cows	16 (20)	16 (20)	16 (20)	17 (20)	17 (20)	15 (20)	15 (20)	13 (15)
			≤ 125 cows	> national average, ≤ study average of 125 cows	22 (27)	21 (27)	21 (27)	20 (27)	20 (27)	18 (27)	18 (27)	18 (26)
			> 125 cows	> study average of 125 cows	30 (35)	30 (35)	32 (35)	27 (35)	27 (35)	32 (35)	32 (35)	32 (34)
1	CY majority covered	Collecting yard is > 50% covered	No					35 (46)	35 (46)			
			Yes					29 (36)	29 (36)			
1	Water clean frequency	Farmer reported frequency of water point cleaning	Once/yr			35 (45)		33 (45)	33 (45)			35 (41)
			< Once/yr			19 (23)		17 (23)	17 (23)			17 (21)
			> Once/yr			13 (14)		14 (14)	14 (14)			11 (13)
1	Water function frequency	Farmer reported frequency of checking water point function	Regularly	Daily/weekly/monthly		57 (68)		56 (68)	56 (68)			53 (62)
			Irregularly	Yearly/when there is a problem/never		10 (14)		8 (14)	8 (14)			10 (13)

Visit	Variable	Variable description	Levels	Level description	Number of Farms per level by indicator – CC (SUB)							
					LS	BCS	TL	OS	NS	INT-HNB	INT-H	AR
1	Open water access	Summer access to open water	No					54 (68)	54 (68)			
			Yes					10 (14)	10 (14)			
2	Shed water points	Number of water points in the shed	Single			27 (30)		27 (30)	27 (30)			
			Multiple			40 (52)		37 (52)	37 (52)			
2	Shed water clean-liness	Cleanliness of shed water points	Clean	All water points clean		15 (19)		17 (19)	17 (19)			
			Partly dirty	All water points partly dirty, or a mixture of partly dirty and clean water points		39 (47)		35 (47)	35 (47)			
			Dirty	All water points partly dirty or dirty		13 (16)		12 (16)	12 (16)			
2	Shed water height	Height above floor of shed water points (weighted average across sheds)	Below	Below average height of 0.81 m		31 (37)		30 (37)				
			Above	Equal or above average height of 0.81 m		36 (45)		34 (45)				
1	Disease test	Whether farms participated in elective herd disease testing in past year	No			15 (20)		14 (20)	14 (20)			
			Yes			52 (62)		50 (62)	50 (62)			
1	Routine parasite dose	Routine use of anti-parasitics/ de-wormers	No			8 (10)		8 (10)	8 (10)	8 (10)	8 (10)	8 (9)
			Yes			59 (72)		56 (72)	56 (72)	57 (72)	57 (72)	55 (66)
1	Separate pens	Separate sick pens	No					28 (37)	28 (37)			
			Yes					36 (45)	36 (45)			
1	Regular BCS	Whether regular body condition scoring is practiced	No			33 (43)						30 (39)
			Yes			34 (39)						33 (36)

1	Partition type	Primary (> 50%) cubicle partition type	Cantilever and Double front fixed							41 (52)	41 (52)	
			Front-Rear-Fixed/Newton Rigg							15 (19)	15 (19)	
			Mushroom							9 (11)	9 (11)	
2	Multiple groups	Cows are housed in multiple groups	No			15 (21)	16 (21)	14 (21)	14 (21)	15 (21)	15 (21)	12 (19)
			Yes			52 (61)	53 (61)	50 (61)	50 (61)	50 (61)	50 (61)	51 (56)
2	Shed lighting	Shed light level	Bright	All bright light	17 (21)	17 (21)	17 (21)			17 (21)	17 (21)	16 (20)
			Low	All dark/dim	27 (36)	26 (36)	29 (36)			26 (36)	26 (36)	27 (31)
			Mixed	Mixed bright, dark and dim light	24 (25)	24 (25)	23 (25)			22 (25)	22 (25)	20 (24)
2	Lights left on	Lights purposely left on for the cows during housing	No		12 (15)	12 (15)	12 (15)			12 (15)	12 (15)	12 (15)
			Yes		56 (67)	55 (67)	57 (67)			53 (67)	53 (67)	51 (60)
1	CY yard entrance	Collecting yard entrance width	< 4 m							20 (26)	20 (26)	
			4 – 5 m							19 (25)	19 (25)	
			> 5 m							26 (31)	26 (31)	
1	Feed pass width	Width of shed feed passage is sufficient (cow-side)[5]	No	Lower than minimum recommended feed passage width of 4.6 m		36 (43)	37 (43)			35 (43)	35 (43)	36 (41)
			Yes	Meets or exceeds minimum recommended feed passage width of 4.6 m		12 (18)	12 (18)			11 (18)	11 (18)	9 (13)
			Mixed	Mixture of feed passage widths above and below minimum of 4.6 m		19 (21)	20 (21)			19 (21)	19 (21)	18 (21)

Visit	Variable	Variable description	Levels	Level description	Number of Farms per level by indicator – CC (SUB)							
					LS	BCS	TL	OS	NS	INT-HNB	INT-H	AR
1	Passage width	Width of passages within shed are sufficient[5]	No	All passages below recommended minimum of 3 m			51 (62)			48 (62)	48 (62)	46 (57)
			Mixed	Mixture of passages above and below recommended minimum of 3 m (includes 3 farms all ≥ 3 m)			18 (20)			17 (20)	17 (20)	17 (18)
1	Dead-ends	Passages end in dead-ends	No		9 (13)					10 (13)	10 (13)	
			Yes		59 (69)					55 (69)	55 (69)	
2	Feed delivery frequency	Frequency of fresh feed delivery	≥ Once/d			51 (65)		49 (65)	49 (65)	49 (65)		47 (58)
			< Once/d			16 (17)		15 (17)	15 (17)	16 (17)		16 (17)
2	Feed push-up	Frequency of remaining feed push-up to the feed-face	≤ Once/d			31 (42)		31 (42)	31 (42)	32 (42)		32 (39)
			> Once/d			36 (40)		33 (40)	33 (40)	33 (40)		31 (36)
2	Feed-rail height	Height of feed-face head/neck rail[1]	Recommended	At or above the recommended height of 1.18 m		47 (59)				46 (59)		
			Non-recommended	Below the recommended level of 1.18 m		20 (23)				19 (23)		
2	Feed partitions	Partitions present at the feed-face	No			21 (23)				20 (23)		
			Yes			36 (46)				37 (46)		
			Mixed			10 (13)				8 (13)		
2	Feed crowding	Amount of overcrowding at the feed-face	None	Meets or exceeds minimum space of 0.6m/cow	12 (13)	12 (13)		13 (13)	13 (13)	11 (13)		
			Overcrowded	Feed space > 0.3 < 0.6 m/cow	46 (57)	45 (57)		44 (57)	44 (57)	44 (57)		
			Severely overcrowded	Feed space < 0.3 m/cow	10 (12)	10 (12)		7 (12)	7 (12)	10 (12)		

2	Grazing season	2019 grazing season length	8 months	Approximately average	31 (35)	30 (35)	31 (35)	29 (35)	29 (35)	29 (35)	29 (35)	26 (31)
			< 8 months	Below average	18 (22)	18 (22)	16 (22)	18 (22)	18 (22)	16 (22)	16 (22)	17 (21)
			9 months or more	Above average	19 (25)	19 (25)	22 (25)	17 (25)	17 (25)	20 (25)	20 (25)	20 (23)
1	Breeding	Breeding method	Single method	Either artificial insemination or stock bull only						10 (14)	10 (14)	8 (10)
			Combined methods	Both artificial insemination and stock bull						55 (68)	55 (68)	55 (65)
1	Breeding (AI)	Breeding method	Combined	Combined methods or SB only			60 (72)					
			AI only	Only artificial insemination used			9 (10)					
1	Number of farmers	Number of full time farmers	1	Sole primary farmer	52 (61)	50 (61)	54 (61)	49 (61)	49 (61)	50 (61)	50 (61)	47 (54)
			≥ 2	Two or more primary farmers	16 (21)	17 (21)	15 (21)	15 (21)	15 (21)	15 (21)	15 (21)	16 (21)
1	PT staff	Farmer reported employing part-time staff	No		20 (22)	18 (22)	19 (22)	15 (22)	15 (22)	17 (22)	17 (22)	16 (20)
			Yes		48 (60)	49 (60)	50 (60)	49 (60)	49 (60)	48 (60)	48 (60)	47 (55)
1	Additional FT staff	Whether full-time staff in addition to the primary farmer(s) are employed	No		49 (62)	50 (62)	51 (62)	48 (62)	48 (62)	48 (62)	48 (62)	47 (56)
			Yes		19 (20)	17 (20)	18 (20)	16 (20)	16 (20)	17 (20)	17 (20)	16 (19)
2	Average farmer age	Average age of all farmers	≤ 40 yr		17 (19)	17 (19)	17 (19)	17 (19)	17 (19)	16 (19)	16 (19)	16 (18)
			≤ 50 yr		26 (31)	25 (31)	26 (31)	22 (31)	22 (31)	24 (31)	24 (31)	24 (29)
			>50 yr		25 (32)	25 (32)	26 (32)	25 (32)	25 (32)	25 (32)	25 (32)	23 (28)
2	Improve animal care	Farmers identified an aspect of animal care they wish to improve - GENERAL	No		18 (21)	16 (21)	18 (21)	16 (21)	16 (21)	18 (21)	18 (21)	17 (19)
			Yes		50 (61)	51 (61)	51 (61)	48 (61)	48 (61)	47 (61)	47 (61)	46 (56)

Visit	Variable	Variable description	Levels	Level description	Number of Farms per level by indicator – CC (SUB)							
					LS	BCS	TL	OS	NS	INT-HNB	INT-H	AR
2	Improve BCS	Farmers identified BCS as an aspect of animal care they wish to improve	No			61 (75)						
			Yes			6 (7)						
2	Improve lameness	Farmers identified LAMENESS as an aspect of animal care they wish to improve	No		59 (73)							
			Yes		9 (9)							
2	Improve facilities	Farmers identified FACILITIES as an aspect of animal care they wish to improve	No		50 (58)		50 (58)	45 (58)	45 (58)	48 (58)	48 (58)	
			Yes		18 (24)		19 (24)	19 (24)	19 (24)	17 (24)	17 (24)	
2	Improve disease	Farmers identified DISEASE as an aspect of animal care they wish to improve	No					57 (75)	57 (75)			
			Yes					7 (7)	7 (7)			
2	Lameness problem	Farmers reported lameness was a problem in their herd	No		39 (46)							
			Yes		29 (36)							
1	Pain meds	Pain medication is used for cows on-farm	No									11 (14)
			Yes									52 (61)
2	Freeze brand	Whether freeze-branding is performed on farm	No									14 (17)
			Yes									49 (58)
2	Tail tape	Tail-tape is used for marking cows	No				27 (31)					22 (27)
			Yes				42 (51)					41 (48)
2	Shed floor type		C	All concrete	11 (15)			11 (15)	11 (15)			
			M	Mix of all slats, or slats and concrete	57 (67)			53 (67)	53 (67)			

2	Shed floor slipperiness		Not slippery	All flooring types recorded as not-slippery	12 (14)					11 (14)	11 (14)	
			Slippery	All flooring types recorded as slippery or somewhat slippery	35 (43)					33 (43)	33 (43)	
			Mixed	Flooring types are mixed, slippery and non-slippery	21 (25)					21 (25)	21 (25)	
2	Shed roof height	Weighted average of mean roof height of sheds	Below	Below average (< 4.5m)				36 (45)	36 (45)			
			Above	Equal or above average (≥ 4.5)				28 (37)	28 (37)			
2	Open-sides	Whether sheds have open sides	No	All sheds fully enclosed				11 (15)	11 (15)			
			Yes	All sheds have at least 1 open side				38 (49)	38 (49)			
			Mixed	Mix of sheds with open sides and fully enclosed				15 (18)	15 (18)			
	Passage cleaning frequency	Average passage cleaning frequency in sheds	< 6	< 6 times in 24 hr	32 (37)		30 (37)	31 (37)	31 (37)	30 (37)	30 (37)	
			< 8	6 to < 8 times in 24hr	24 (29)		26 (29)	22 (29)	22 (29)	25 (29)	25 (29)	
			≥ 8	≥ 8 times in 24 hr	12 (16)		13 (16)	11 (16)	11 (16)	10 (16)	10 (16)	
1	Auto alley scraper	Shed use automatic alley scrapers	No	None or <50% of sheds use automatic alley scrapers	12 (17)		11 (17)	12 (17)	12 (17)	11 (17)	11 (17)	
			Yes	All or >50% of sheds use automatic alley scrapers	56 (65)		58 (65)	52 (65)	52 (65)	54 (65)	54 (65)	
2	Cubicle condition		VG	Very Good						39 (49)	39 (49)	
			G	Good						19 (25)	19 (25)	
			P	Poor/Bad						7 (8)	7 (8)	
2	Cubicle cleaning frequency	Cubicle cleaning frequency during housing	OAD	Once/day	36 (43)	35 (43)	37 (43)					36 (40)
			< OAD	< Once/day	7 (8)	7 (8)	6 (8)					6 (8)
			TAD	Twice/day	25 (31)	25 (31)	26 (31)					21 (27)

Visit	Variable	Variable description	Levels	Level description	Number of Farms per level by indicator – CC (SUB)							
					LS	BCS	TL	OS	NS	INT-HNB	INT-H	AR
2	Cubicle bedding frequency	Cubicle bedding/liming frequency during housing	OAD	Once/day	36 (43)	35 (43)	35 (43)					34 (40)
			< OAD	< Once/day	12 (14)	12 (14)	12 (14)					9 (11)
			TAD	Twice/day	20 (25)	20 (25)	22 (25)					20 (24)
2	Cubicle cleanliness	Cleanliness of cubicle surfaces – original score	Clean	All cubicles clean or partly clean			24 (29)					
			Dirty	All cubicles partly dirty or dirty			7 (10)					
			Mixed	Mixture of clean, dirty and partly clean/dirty cubicles			38 (43)					
2	Cubicle cleanliness - binary	Cleanliness of cubicle surfaces – binary score	Clean	All cubicles clean or partly clean	24 (29)	23 (29)		23 (29)	23 (29)			
			Mixed	All or some cubicles dirty, partly dirty	44 (53)	44 (53)		41 (53)	41 (53)			
1	No. milkers	Number of people milking at a time	1	Farms with one regular milker								33 (41)
			1.5	Farms with one regular milker and a part-time or seasonal second milker								12 (13)
			≥ 2	Farms with more than one regular milker								18 (21)
2	Cows held	Cows regularly held after milking during grazing	No									28 (33)
			Yes, everyday									17 (19)
			Yes, sometimes									18 (23)
2	Cow Comfort Index - binary	Ratio of cows lying in cubicles: cows perching or standing in cubicles (loose housing omitted)	Below	< Average and median value of 0.55	32 (40)	32 (40)	34 (40)			31 (40)	31 (40)	
			Above	≥ Average and median value of 0.55	36 (42)	35 (42)	35 (42)			34 (42)	34 (42)	

2	Cow Comfort Index	Ratio of cows lying in cubicles: cows perching or standing in cubicles (loose housing omitted)	≤ 25%									12 (16)
			> 25% ≤ 50%									18 (19)
			> 50% ≤ 75%									16 (20)
			>75%									17 (20)
2	Silage quality tested		No		20 (28)	19 (28)		18 (28)	18 (28)			
			Yes		48 (54)	48 (54)		46 (54)	46 (54)			
2	Feed advice		No		38 (49)	37 (49)		35 (49)	35 (49)			
			Yes		30 (33)	30 (33)		29 (33)	29 (33)			
1	Brush	Cow brush present in shed	No							56 (72)	56 (72)	
			Yes							9 (10)	9 (10)	
2	Heifer intro	When heifers were introduced to the main herd	Before	Before calving (at or during housing)			38 (45)					
			After	After calving, when they go out to grass			31 (37)					
2	Heifers familiar	Are heifers familiar with cubicles when housed with main group	No				20 (25)					
			Yes				49 (57)					

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About the Author

Robin Elizabeth Crossley grew up on a dairy farm in Maple, Ontario, Canada, which helped to foster her love of animals and the natural environment. After completing her initial BSc degree in marine and freshwater biology at the University of Guelph (2009), her interest in science and working with animals lead her to complete an MSc degree in animal behaviour and welfare at the same institution (2016), where she focused on competitive feeding behaviour in dairy cows.

Excited by the opportunity to experience life in a new country while working to improve the lives of dairy cows, Robin moved to Ireland in 2017 to pursue this PhD in dairy cattle welfare in pasture-based systems. As a Teagasc Walsh Scholar, her research was a joint project between Teagasc, Moorepark in Fermoy, Cork, Ireland, and the WUR Animal Production Systems group in Wageningen, Netherlands, which has allowed her to work and explore in both amazing countries. Robin has also presented her PhD research at international conferences in Ireland, Netherlands, Canada, and Norway.

PUBLICATIONS

Refereed Scientific Journals

Crossley, R.E., E.A.M. Bokkers, N. Browne, K. Sugrue, E. Kennedy, B. Engel, and M. Conneely. 2022. Risk factors associated with the welfare of grazing dairy cows in spring-calving, hybrid pasture-based systems. Prev. Vet. Med. (204) 105640. doi: 10.1016/j.prevetmed.2022.105640.

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Crossley, R.E., E.A.M. Bokkers, N. Browne, K. Sugrue, E. Kennedy, I.J.M. de Boer, and, M. Conneely. 2021. Assessing dairy cow welfare during the grazing and housing periods on spring-calving, pasture-based dairy farms. J. Anim. Sci. 99 (5): 1-15.

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Crossley, R.E., E.A.M. Bokkers, N. Browne, K. Sugrue, E. Kennedy, and M. Conneely. Avoidance response to an unfamiliar human by dairy cows on pasture. In: Proceedings of the 8th International Conference on the Assessment of Animal Welfare at Farm and Group Level. Boyle, L., and O'Driscoll, K., eds. Wageningen Academic Publishers. Virtual WAFL Conference, 16th -19th August (2021), p. 50.

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Technical Articles

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Crossley, R.E., N. Browne, and M. Conneely. How do we measure dairy cow welfare on-farm? In: Proceedings of Moorepark Open Day – Irish Dairying, Growing Sustainably. Fermoy, Cork, Ireland, 3rd July (2019), p. 172 – 173.

Education Certificate

Completed training and supervision plan[1]

Basic Package **3.0 ECTS**

- WIAS Introduction Day (2017)
- Course on philosophy of science and/or ethics (2017)
- Course on essential skills (2017)

Disciplinary Competences **14.5 ECTS**

- Laboratory Animal Science and Training (LAST) course (2017)
- WIAS proposal (2018)
- The Fundamentals of Animal Emotion (2019)
- Statistics for the Life Sciences (2019)
- SYRCLE Workshop - Systematic Reviews of Animal Studies (2020)

Professional Competences **7.3 ECTS**

- Communicating for Impact, University College Dublin (2020)
- Scientific Writing (2020)
- Introduction to LaTex (2020)
- WGS Workshop Carousel (2021)

Presentation Skills **4.0 ECTS**

- ISAE 2018, Charlottetown, PEI, Canada – Poster
- ISAE 2019, Bergen, Norway – Poster
- ECPLF 2019, Cork, Ireland – Poster
- WIAS Annual Conference 2020, Lunteren, Netherlands – Poster
- WIAS Annual Conference 2021, Virtual – Oral Presentation
- WAFL 2021, Virtual – Oral Presentation

Teaching Competences **2.0 ECTS**

- Supervising MSc student (2019) - Tognola, L. "Air quality and light intensity in relation to animal welfare in Irish dairy farms during winter housing"

Total **30.8 ECTS**

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[1] With the educational activities listed, the PhD candidate has complied with the educational requirements set by the graduate school Wageningen Institute of Animal Sciences (WIAS) of Wageningen University & Research, which comprises a minimum of 30 ECTS (European Credit Transfer and accumulation System). One ECTS equals a study load of 28 hours.

Colophon

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