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A review of factors affecting the welfare of dairy calves in pasture-based production systems

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ABSTRACT

Current research on factors affecting the welfare of dairy calves is predominantly based on indoor, year-round calving systems. Calf rearing in these systems differs from that in more seasonal, pasture-based dairy production, meaning that risks to the welfare of dairy calves may not always be comparable between the two systems. The aim of this review was to consolidate the scientific literature relating to calf welfare in pasture-based dairy systems from birth until weaning, allowing for (1) the identification of current and emerging risks to calf welfare and (2) the formation of recommendations to mitigate these risks. Many of the risks to calf welfare discussed in this review are not exclusive to pasture-based dairies. This includes a global trend for increasing perinatal mortalities, a significant number of calves failing to achieve effective passive transfer of immunity, the low uptake of best practice pain relief when calves are disbudded, and the feeding of restricted milk volumes. In addition to these persisting welfare risks, two factors discussed in this review pose an immediate threat to the social license of dairy farming; the separation of cow and calf soon after birth and the management of surplus calves (i.e. calves not needed by the dairy industry). Several recommendations are made to improve the uptake of best-practice calf rearing and progress the development of alternative pasture-based rearing systems that accommodate changing community expectations. These include communication strategies that strengthen farmer beliefs regarding the welfare and productivity benefits achieved by best practice calf rearing and challenge beliefs regarding the associated costs. Farmers should also be encouraged to benchmark their rearing practices through improved record keeping of key rearing inputs and outcomes. Biological research is needed to advise the development of new calf rearing recommendations and the evolution of existing recommendations. Research priorities identified by this review include the effects of dystocia on the neonate and strategies to mitigate these effects, relationships between features of pen design and calf health and welfare, feasibility of dam rearing in large pasture-based dairy systems, and strategies that increase the value of the surplus calf.

Keywords: animal welfare, calf, cow, dairy, farm blindness, growth, rearing, seasonal calving.

Introduction

A recent report commissioned by the Australian Federal Government found that 95% of Australians view farm animal welfare as a concern, 91% want to see some reform to better protect farm animal welfare and there is a general distrust in agricultural industries when it comes to the welfare of farm animals (FutureEye 2018). Community concern for the welfare of dairy animals appears to be largely focussed on calves. For example, considerable public opposition to the practice of separating calves from their dam soon after birth has been reported in Brazil, USA and Germany, and is not improved by providing reasoning as to why early separation is performed (Busch *et al*. 2017; Hötzel *et al*. 2017). While comparable data do not exist from more seasonal pasture-based dairy regions such as Australia, 80% of Australians recognise that good animal welfare is more nuanced than the simple absence of harm (VoconiQ 2020).

Dairy production is a predominantly pasture-based industry in temperate climates such that occur in parts of Australia and New Zealand, but current research on management regimes that affect calf welfare is largely based on indoor, year-round calving systems. Some of this research is applicable to pasture-based systems as calves are typically group-housed indoors until weaning. However, differences in management, housing and feeding mean that welfare risks, and solutions to common risks, may differ among the dairy systems. For instance, in temperate climates, pasture-based dairy farms often have concentrated calving patterns, with up to 90% of the herd calving within a 50–60-day period (Roche *et al.* 2017). These seasonal calving patterns produce large numbers of calves within a short period of time, which vastly differs from the housed dairy systems that practice year-round calving. Seasonal dairy farmers are required to manage large numbers of calves as well as the freshly calved cows during this short and busy calving period. The resulting time pressures may cause a de-prioritisation of the management of calves who present a less immediate financial return than do the lactating cows.

Previous scientific reviews of the factors affecting the welfare of dairy calves predominantly relate to indoor dairy systems that practice year-round calving. To the best of my knowledge, the available scientific information on the welfare of dairy calves in pasture-based systems has not been summarised. The aim of this review is to consolidate the scientific literature relating to calf welfare in pasture-based dairy systems from birth until weaning, allowing for (1) the identification of current and emerging risks to their welfare and (2) recommendations for future research. While prioritising research directly relating to the seasonal pasture-based systems of temperate Australia and New Zealand, studies on less seasonal pasture-based and housed systems have been included when relevant or when there is a paucity of information relating to calves in seasonal systems.

Factors affecting the welfare of calves

Routine calving induction

Declining cow fertility has resulted in higher numbers of seaonal calving cows calving late, which disrupts the synchrony between feed supply and demand (Roche *et al.* 2018). When this occurs, farmers can regain control over their calving pattern by hormonally inducting parturition in late-calving cows (Macmillan 2002; Roche *et al.* 2018).

Calf mortality is the biggest welfare concern of routine calving inductions. A study of 62 Australian dairy herds found that cows being induced at an average of 7.5 months of gestation resulted in 64.6% liveborn calves (Mansell *et al.* 2006). By contrast, the authors found that 96% of calves from non-induced cows were born alive. Earlier research from the same region found that 72% of calves induced between 6.2 and 8 months of gestation died before 7 days of age, compared with 7% of non-induced calves born to term (Morton and Butler 1995). Both studies reported mortalities increasing with earlier inductions. Some pre-term calves that are born alive are euthanised on farm, sometimes by blunt force trauma. This practice poses a significant welfare and social license risk, as discussed later in this review (see section on surplus calves). Pre-term calves that are born alive and are not euthanised are lighter at birth, achieve ⅓ the commercial value of non-induced calves, and are at an increased risk of failure of passive transfer of immunity and hypothermia (Beardsley *et al.* 1974; Peters and Poole 1992; Mansell *et al.* 2006; Arnott *et al.* 2012). There is also evidence that inductions can negatively affect cow health, productivity and subsequent reproduction (Beardsley *et al.* 1974; Peters and Poole 1992; McDougall 2001; Mansell *et al.* 2006).

The Australian dairy industry has committed to voluntarily phase out routine calving inductions by 2022, while in New Zealand the practice has been banned since 2015 (ADIC 2020*b*). A 2017 Australian survey reported that 89% of farmers did not perform routine calving induction (Abuelo *et al.* 2019). Industry surveys of Australian veterinarians indicate that the number of farms using calving induction reduced by nearly 40% from 2015 to 2018, and the median percentage of the herd being induced on these farms declined from 10.4% to 7.1% over the same period (ADIC 2020*b*). While the phasing out of induction is a positive outcome for calf welfare, the transition needs to be carefully managed to avoid an inadvertent increase in welfare risks to cows due to higher culling rates for poor reproductive performance. Improving cow fertility is therefore essential to eliminating the practice of routine hormonal inductions. This requires a multifaceted approach that must include excellent cow management during transition from pregnancy to lactation ('transition' period) and genetic selection for improved fertility. As reviewed by Roche *et al.* (2018), maladaptation in the physiologically demanding transition period can result in disorders relating to negative energy balance, immune dysfunction and mineral deficiency. Any of these can negatively affect pre- and post-ovulatory processes (Roche *et al.* 2018). Further, recent New Zealand research found that genetic selection for fertility traits improves the reproductive performance of pasture-based cows in seasonal calving systems in terms of uterine health, calving to ovulation interval, submission rate for artificial insemination and pregnancy rate (Meier *et al.* 2021). In addition to improvements in genetics and transition cow management, technologies such as activity monitors can assist in more precise detection of oestrus while hormonal treatments may be used to aid the resumption of cyclicity and for heifer synchronisation programs (Fisher and Webster 2013; Crowe *et al.* 2018). It is important to note, however, that hormonal treatments are costly and may become unacceptable by consumers in the future (discussed by Meier *et al.* 2021).

Selective mating of bulls with short gestation length 'estimated breeding values' (EBVs) is an alternative strategy to calving induction that may help maintain a tight calving pattern (Haile-Mariam and Pryce 2019; Lucy 2019). It is unclear whether the incorporation of short gestation length genetics into dairy systems will reduce gestations to the point of increased calf mortality and morbidity. Even in normal calving herds (i.e. those without induction), calves from the 5% shortest gestation lengths (e.g. 265–273 days; Jenkins *et al.* 2016) or from gestation lengths that fall 1 standard deviation below the average gestation (e.g. 256–269 days; Vieira-Neto *et al.* 2017) are more likely to die in the perinatal period than those that are gestated for the average length of time. The risk of perinatal mortality should be monitored over future years to ensure advances made in the phasing out of inductions are not lost by increased reliance on short gestation genetics.

Perinatal mortality

The generally agreed definition of perinatal mortality is the 'death of the perinate prior to, during or within 48 h of calving, following a gestation period of at least 260 days' (Mee 2013, p. 1037). Perinatal mortality rates for calves housed in indoor dairy systems lie between 5% and 8% (Brickell *et al.* 2009; Barrier *et al.* 2013; Raboisson *et al.* 2013; Winder *et al.* 2018), which is marginally higher than levels reported in pasture-based systems (3–7%; Diesch *et al.* 2004; McClintock *et al.* 2005; Mansell *et al.* 2006; Mee *et al.* 2008; Mee 2013; Cuttance *et al.* 2017; Chuck *et al.* 2018). Although recent data relating to the prevalence and risk factors for perinatal mortality in Australia is lacking (see review by Cuttance and Laven 2019), data from other countries suggest that the perinatal mortality of dairy calves is increasing in both indoor and pasture-based dairy systems (Bicalho *et al.* 2007; Mee 2008, 2013; Mee *et al.* 2008; Compton *et al.* 2017).

Regardless of dairy system, difficult or abnormal calving, known as dystocia, is the primary cause of mortality in the perinatal period (Bicalho *et al.* 2007; Gulliksen *et al.* 2009; Mee 2013; Raboisson *et al.* 2013). Dystocia increases the risk of hypoxaemia in the neonate (Arnott *et al.* 2012; Mee *et al.* 2019) and, consequently, death during or soon after birth (e.g., Diesch *et al.* 2004; Brickell *et al.* 2009; Hoedemaker *et al.* 2010; Barrier *et al.* 2013). Mellor and Stafford (2004) argued that perinatal mortality due to hypoxaemia *per se* may not present a risk to calf welfare. Severe dystocia-induced hypoxaemia does not elevate arterial oxygen tensions to levels compatible with consciousness, and an unconscious animal cannot suffer (Mellor and Stafford 2004). Physical injury and trauma due to dystocia and assisted delivery may have more serious welfare consequences. Documented traumatic injuries suffered by the assisted calf include fractures, organ ruptures, diaphragmatic tears, severe bruising and haemorrhage (Barrier *et al.* 2012; Mee 2013). Up to 40% of veterinary-assisted deliveries can result in rib fractures and up to 10% in vertebral fractures, with 13% of animals delivered with a calving aid suffering a traumatic injury (discussed by Mee 2008). The conscious newborn can feel and, thus, pain associated with this physical trauma can be a serious welfare concern (Mellor and Stafford 2004). A single dose of ketoprofen (a non-steroidal anti-inflammatory drug, NSAID) to calves from assisted births increased the time they spent walking and reduced the time spent in lateral recumbency in the first 48 h of life (Gladden *et al.* 2019). In the same experiment, calves that received ketoprofen spent more time playing regardless of assistance, suggesting that there may be pain even following a eutocic birth.

Similar factors contribute to the risk of perinatal mortality in pasture-based and indoor dairy systems (Mee *et al.* 2008). Animal-related factors include dam age at first calving (particularly in heifers less than 24 months of age), sire-predicted transmitting ability for perinatal mortality, fetal gender (males are associated with greater risk of mortality) and twinning (Mee *et al.* 2008; Mee 2013; Cuttance *et al.* 2017). The relationship between herd size and perinatal mortalities is not clear; there is no evidence that perinatal mortality is related to herd size in the pasture-based systems of Ireland (Mee *et al.* 2008), but herd size may contribute to regional variation in perinatal mortality in New Zealand (Cuttance *et al.* 2017) and Norway (Gulliksen *et al.* 2009). Fetal–maternal size mismatch is one general cause of dystocia (Arnott *et al.* 2012), and is likely to be a contributing factor to the high rates of stillbirths in the heifer compared with the multi-parous cow (e.g., McClintock *et al.* 2005; Mee *et al.* 2011; Brickell *et al.* 2009; Gulliksen *et al.* 2009). A less considered contributing factor may be related to the maternal environment (see review by Arnott *et al.* 2012). For example, Barrier *et al.* (2013) found stillborn calves to be longer and thinner than their surviving counterparts independently of dystocia, suggesting altered fetal growth due to placental insufficiency, inadequate nutrition or maternal stress as factors increasing the risk of stillbirth.

Most farms experience low or zero perinatal mortalities, with fewer numbers reporting high mortalities (Mee 2013; Raboisson *et al.* 2013; Cuttance *et al.* 2017). This suggests a significant human effect on the death of the perinatal calf. Indeed, Cuttance *et al.* (2017) found that the risk of perinatal mortality decreased with increasing farmer experience. A survey of veterinarians returned unanimity that better calving management would reduce the incidence of mortality in the neonate calf (see Mee 2013). That at least half of the calves that die during birth are alive at the start of calving suggests that many of these deaths are preventable (Mee 2008; Barrier *et al.* 2013), and both increased frequency of observations and more timely interventions reduce stillbirths (Mee *et al.* 2014). Some researchers suggest that perinatal mortalities have been de-prioritised in recent years and high mortalities have been normalised on some farms (Mee 2013; Murray and Leslie 2013; Santman-Berends *et al.* 2014). To rectify this, Mee *et al.* (2014) recommended that dairy producers focus on factors that are within their control, and particularly those that can reduce the incidence of dystocia. These include the quality and quantity of calving supervision, implementing a calving intervention and assistance policy, ensuring high maternal health status, and reducing maternal–calf mismatch through sire selection and sexed semen.

Hypothermia

Many seasonal pasture-based dairy enterprises achieve peak milk production in the middle of spring, requiring calving to begin in winter (e.g. Chuck *et al.* 2018). Winter calving increases the risk of mortality (Diesch *et al.* 2004; Mee *et al.* 2008; Gates 2013; Raboisson *et al.* 2013), which may be associated with hypothermia due to cold exposure. Risk of hypothermia is exacerbated in dystocial calves (see reviews by Mellor and Stafford 2004; Roland *et al.* 2016). The temperature below which the heat loss from calves' body exceeds heat production (resulting in a hypothermic state) varies from 0°C to 18°C, depending on the age of the calf and weather conditions (Roland *et al.* 2016; Silva and Bittar 2019). New Zealand research found that calves that were born during windy and wet weather with air temperatures below 10°C had lower rectal temperatures, took longer to stand and had higher plasma glucose concentrations than did those born in dry weather with air temperatures above 10°C (Diesch *et al.* 2004). More recent New Zealand data indicate greater perinatal mortality on days with greater rainfall (Cuttance *et al.* 2017), while a study from Norway found that winter calving increased the risk of calf mortality in the first month of life (Gulliksen *et al.* 2009). There is an argument that hypothermia is not as noxious as it first appears, as it is typically accompanied by impaired cerebral function followed by unconsciousness (Mellor and Stafford 2004). Nonetheless, providing wind protection and dry lying areas helps protect cows and calves from adverse climatic conditions (Roland *et al.* 2016; Silva and Bittar 2019), but the adoption of windbreak shelter is low in Australia (Baker *et al.* 2018) and in some regions shelterbelts are being removed to facilitate pivot irrigation (Fisher *et al.* 2019).

Colostrum management

The newborn calf depends almost entirely on the absorption of the maternal immunoglobulins through colostrum (i.e. passive transfer of immunity) for protection against diseases, until its own immature immune system becomes functional (see reviews by Godden 2008 and Roche *et al.* 2015 for detailed descriptions of passive transfer of immunity). The classification of failed passive transfer (FPT) varies, but FPT is generally defined as calf serum IgG concentrations <10 mg/mL at 24–48 h of age (Godden 2008) or of serum total protein concentrations <5.2 g/L in calves less than 7 days of age (Windeyer *et al.* 2014; Urie *et al.* 2018), with a good agreement between the two measures (Hernandez *et al.* 2016; McCracken *et al.* 2017; Urie *et al.* 2018; Wilm *et al.* 2018). Calves with FPT have an increased risk of disease and death pre-weaning (Weaver *et al.* 2000; Godden 2008; Windeyer *et al.* 2014; Cuttance *et al.* 2017). Those with FPT that do not die have reduced feed intakes and growth up to 6 months (see review by Roche *et al.* 2015) and increased mortality up to 12 months of age (Cuttance *et al.* 2017), but FPT does not appear to adversely affect the productivity, performance or mortality of pasture-reared heifers over 12 months of age (Chuck *et al.* 2018; Cuttance and Laven 2019). Despite these welfare and economic consequences, and despite significant extension efforts, a large proportion of newborn calves is failing to receive adequate levels of high-quality colostrum early enough in life to ensure successful passive transfer of immunity (Roche *et al.* 2015; Abuelo *et al.* 2019). Data from around the world indicate between 11% and 49% of dairy calves have FPT (Vermunt *et al.* 1995; Wesselink *et al.* 1999; Vogels *et al.* 2013; Windeyer *et al.* 2014; Chuck *et al.* 2018; Urie *et al.* 2018; Abuelo *et al.* 2019; Cuttance *et al.* 2019)

The Australian dairy industry outlines four factors of colostrum management that affect the chances of successful transfer of immunity, colloquially known as the four Qs (Dairy Australia 2017). These are Quality, Quickly, Quantity and sQueaky clean. In general, high-quality colostrum (IgG concentration of >50 mg/mL) should be supplied within 6 h but no later than 12 h postpartum at about 10% of birth weight (~3.5–4 L; Godden 2008; Roche *et al.* 2015), and opportunities for contamination with bacteria or other pathogens should be minimised (Dairy Australia 2017). However, research suggests that up to 80% of Australian calves could be receiving colostrum with elevated bacterial counts and low IgG content, and less than half of farmers routinely check colostrum quality by using a validated method (Phipps *et al.* 2018; Abuelo *et al.* 2019). While most calves in pasture-based systems are fed colostrum within 6 h of birth (Phipps *et al.* 2018; Abuelo *et al.* 2019), 30–60% of Australian dairy farms (Vogels *et al.* 2013; Abuelo *et al.* 2019) and 50% of New Zealand dairy farms (Cuttance *et al.* 2018) collect calves two or fewer times per day, meaning that some animals may not receive supplemental colostrum in the first 12 h of life (Vogels *et al.* 2013; Abuelo *et al.* 2019). Moreover, up to one-fourth of Australian dairy farms rely on calf suckling from the dam for colostrum transfer (Vogels *et al.* 2013; Chuck *et al.* 2018; Phipps *et al.* 2018; Abuelo *et al.* 2019). This strategy is known to increase the risk of FPT in housed cattle (Beam *et al.* 2009) but may not do so in pasture-based systems (Cuttance *et al.* 2018). The relationship between consuming colostrum through dam suckling and passive transfer of immunity in pasture-based systems requires further investigation.

There is some evidence of geographical variation in the quantity of colostrum being fed to calves in Australia. Farmer surveys suggest that the majority of dairy producers from Victoria feed inadequate volumes of colostrum (2–2.5 L, Vogels *et al.* 2013; 2 L, Phipps *et al.* 2018), but a nationwide survey found that calves are fed close to recommendation (3.7 L, Abuelo *et al.* 2019). Similarly, 58–67% of Victorian farms are reported to always pool colostrum (Vogels *et al.* 2013; Phipps *et al.* 2018), a practice that dilutes high-quality colostrum (Beam *et al.* 2009) and increases the risk of spreading bacteria (Dairy Australia 2017), compared with only 11% of Australian farms in the nationwide survey (Abuelo *et al.* 2019). These differences could be attributed to regional variation in dairy systems, with more seasonal pasture systems in the temperate areas of Victoria and Tasmania than in hotter and drier parts of Australia. This geographical variation could have implications for industry training and communication strategies, so needs to be confirmed with further research.

Separation from the cow

It is common practice for commercial dairy farms to separate calves from their dams soon after birth. This typically occurs within 6–24 h postpartum in pasture-based dairy systems (Vogels *et al.* 2013; Phipps *et al.* 2018; Abuelo *et al.* 2019). The early removal of the calf is thought to reduce the risk of disease transmission from the cow to the calf (e.g., Johne's disease, cryptosporidium), allow for better control over the quality and quantity of colostrum fed, increase the cow's return to oestrus and the volume of saleable milk harvested, allow for close monitoring of calf health and prevent the formation of a strong maternal bond that becomes progressively traumatic to break (Flower and Weary 2003; Godden 2008; Beaver *et al.* 2019; Meagher *et al.* 2019).

Separating cows and calves soon after birth is falling out of step with public expectations (Weary and von Keyserlingk 2017), and two recent systematic reviews of the scientific literature have cast doubts over some of these previously accepted benefits (Beaver *et al.* 2019; Meagher *et al.* 2019). For example, protecting cow and calf health has been one of strongest arguments for early separation, particularly to reduce the risk of transfer of Johne's disease (e.g. Maunsell and Donovan 2008; Stromberg and Moon 2008), but a recent systematic review of the scientific peer-reviewed literature found no consistent evidence in support of early separation on the basis of cow and calf health (Beaver *et al.* 2019). Remarkably, none of the 14 available research articles examined found an increased prevalence of *Mycobacterium avium* ssp. paratuberculosis (MAP, the causal agent of Johne's disease) among herds permitting cow–calf contact. As MAP is predominantly transferred through the fecal–oral route, the authors stipulate that early removal of the calf cannot be considered a substitute for proper hygiene and housing management (Beaver *et al.* 2019).

Cows and their calves exhibit reinstatement behaviour following a temporary separation (e.g. allogrooming) and, when permitted, stay in close proximity to one another, even in the absence of a nursing relationship (Hudson and Mullord 1977; Das *et al.* 2001; Fröberg and Lidfors 2009; Jensen 2011; Johnsen *et al.* 2015*a*; Wenker *et al.* 2020). These behaviours are suggestive of bonding between dam and calf (Newberry and Swanson 2008). This maternal bond is observed after just 5 min of contact immediately following parturition (Hudson and Mullord 1977) and can survive at least 2 years of separation (Wagner *et al.* 2012). One recent experiment found that cows that were separated from their calves within 2 h of parturition were just as motivated to reunite with their offspring 5–8 days later as cows that were not separated (Wenker *et al.* 2020). Behavioural and physiological evidence suggests that that the acute distress, which is observed after breaking the cow–calf bond, lasts for up to 3 days (Sandem and Braastad 2005; Daros *et al.* 2014; Johnsen *et al.* 2016; Meagher *et al.* 2019).

Separating the bonded cow and calf will have some negative welfare effects regardless of when it occurs, but the intensity and duration of this varies with age of the calf at separation and management of separation (Flower and Weary 2003). While preventing contact between dam and calf immediately following parturition appears to limit cow distress at separation (Hudson and Mullord 1977), such a timely intervention is rarely practical on the pastoral dairy farm. Separating cows and calves within 24 h of birth elicits a lower behavioural and physiological response than does separation up to 14 days postpartum (Weary and Chua 2000; Flower and Weary 2001; Stěhulová *et al.* 2008), but separation at 25 days evokes a stronger behavioural and physiological response than separation at 45 days (Pérez-Torres *et al.* 2016). Thus, for the bonded cow and calf, distress may be reduced by postponing separation until nursing frequency declines and calves start becoming socially independent from the cow (Wood-Gush *et al.* 1984; Newberry and Swanson 2008; Fröberg and Lidfors 2009; Costa *et al.* 2016).

Extended dam suckling

Keeping calves and cows together for an extended period of suckling followed by late separation (i.e. at least 7 weeks of age) is gaining increasing attention among scientists and dairy industries, particularly in the northern hemisphere (see reviews by Johnsen *et al.* 2016; Beaver *et al.* 2019; Meagher *et al.* 2019). Calves that suckle their dam gain more weight and remain heavier for weeks to months after separation (reviewed by Meagher *et al.* 2019). There is evidence that dam rearing positively affects the development of cognition, stress resilience and social behaviour while reducing the development of abnormal behaviour (Meagher *et al.* 2019). The positive social effects can remain evident years after weaning (Krohn *et al.* 1999; Wagner *et al.* 2012, 2015). Extended suckling also benefits dam welfare by improving postpartum recovery (Krohn 2001; Flower and Weary 2003), udder health (reviewed by Beaver *et al.* 2019) and allowing the expression of highly motivated maternal behaviour (Johnsen *et al.* 2016). Generally, both dairy farmers that employ an extended suckling period (Grøndahl *et al.* 2007) and animal welfare researchers (Flower and Weary 2003; Johnsen *et al.* 2015*b*) consider the positive effects of an extended suckling period to outweigh the distress associated with separation from the cow at an older age.

The commercial reality of extended suckling systems faces several challenges. For example, there is a danger that leaving the calf unsupervised with the dam will be considered a replacement for careful colostrum management (Beaver *et al.* 2019). Grain and concentrate consumption are also lower in suckled calves, meaning that their energy intake substantially reduces after weaning, resulting in a negative emotional affect (Rushen *et al.* 2016) and reduced growth (Meagher *et al.* 2019). Research is needed to confirm whether the low grain consumption pre-weaning increases the risk of poor rumen development in extended suckling systems, such as reported in artificially reared calves (Stobo *et al.* 1966). Allowing the calf to achieve nutritional independence before breaking the emotional bond with the dam reduces the behavioural response to separation following an extended suckling period (Weary *et al.* 2008; Johnsen *et al.* 2018). Gradually reducing the duration of contact with the cow (Johnsen *et al.* 2015*b*, 2018) or preventing nursing by covering the udder or using an anti-suck device (von Keyserlingk and Weary 2007; Newberry and Swanson 2008), are the most effective at reducing distress. In terms of managing the later separation *per se*, maintaining restricted fenceline or audio and visual contact following abrupt weaning from the dam increases distress compared with complete audio, visual and tactile separation (Solano *et al.* 2007; Stěhulová *et al.* 2008).

Milk letdown during mechanical milking is impaired in cows that are nursing a calf (Krohn 2001; Fröberg *et al.* 2011; Johnsen *et al.* 2016; Zipp *et al.* 2018) and cannot be enhanced by presenting the hair or playing the call of the dam's own calf, or by teat massage (Zipp *et al.* 2018). Although there is no consistent evidence of reduced milk production over a longer period (Johnsen *et al.* 2016; Meagher *et al.* 2019), the quantity of milk available for sale is reduced during the suckling period (Zipp *et al.* 2018; Meagher *et al.* 2019). Indeed, the 10 L of milk a suckling calf consumes per day (Jasper and Weary 2002; De Passillé *et al.* 2011; Rosenberger *et al.* 2017) constitutes a considerable proportion of daily milk production for lower-yielding dairy cattle common in pasture-based systems. The associated loss of income may challenge the feasibility of extended suckling in pasture-based systems (Johnsen *et al.* 2016), particularly if calves are weaned beyond 7 weeks of age (Asheim *et al.* 2016). There is a valid argument that any reduction in saleable milk can only truly be considered a loss if the calves' intake exceeds what calves would have been fed otherwise (Meagher *et al.* 2019). Considering that feeding increased milk volumes to calves is now recommended (discussed later in this review), and also considering the positive benefits of dam suckling on calf health and growth (and consequently, longevity and productivity as adults), the reduction in mastitis, the reduced labour required to feed suckling calves and the reports of improved farmer satisfaction, economising extended suckling systems based on milk sales alone provides a reductive comparison to conventional dairy systems (Grøndahl *et al.* 2007; Wagenaar and Langhout 2007; Asheim *et al.* 2016; Meagher *et al.* 2019).

Most research on extended suckling has been conducted in barn systems, with smaller herd sizes than those found in pasture-based dairies and where year-round calving means that there are fewer calves to manage at any one time. Of the 70 peer-reviewed studies examined by Beaver *et al.* (2019), only two were conducted in Australia and one in New Zealand. Half-day contact with once a day milking may be a more practical alternative to fulltime suckling on pasture-based dairies. Calves maintain high milk intakes and weight gains in half-day compared with fulltime contact systems, while their development continues to benefit from suckling and dam–calf bonding (Johnsen *et al.* 2016; Meagher *et al.* 2019). The daily separation and reunion in half-day suckling systems also provide increased opportunities for positive human handling that can reduce fear of humans later in life (Johnsen *et al.* 2016). Published research suggests that nursing does not significantly reduce delivered milk over the whole lactation for low-yielding cows in half-day contact systems (Johnsen *et al.* 2016). Cows give more milk at the morning after overnight separation from the calf than do cows with fulltime contact to calves (discussed in Johnsen *et al.* 2016). Thus, separating cows and calves overnight and milking in the morning prior to reunion may be more easily managed and yield more saleable milk during the suckling period than a fulltime suckling system, while also encouraging independence from the dam, which may ease the transition at weaning (Johnsen *et al.* 2016; Meagher *et al.* 2019). The feasibility and effects of dam rearing need to be established in pasture-based dairy systems using a scalable management regime.

Surplus calves

Male dairy calves that are not required by the dairy industry and female calves that are produced in excess to that required to replace the cows that are leaving the herd can be described as "surplus calves". These animals are commonly grown out for beef in countries such as Ireland, mainland Europe and the USA, making Australia and New Zealand two of few countries in the world where their slaughter for low value veal can be more profitable than rearing them for meat production (Moran 2002). The large number of calves produced by seasonal calving patterns may present logistical challenges in terms of the capacity of farmers to rear surplus calves for the red meat market. A recent industry survey estimated that 38% (approximately 570 000) of Australian calves are processed as bobby calves through abattoirs each year (a bobby calf is a bovine calf less than 30 days old and not accompanied by its mother; Dairy Australia 2020). Just under 2 million bobby calves were processed in New Zealand in 2016 (Ministry for Primary Industries (MPI) 2017). There are two general approaches to improving the welfare of surplus calves, namely, optimising their care and management until death or sale (including euthanasia and transportation) and redirecting them from premature slaughter to the veal or beef industries. These are discussed below.

Unpublished Australian research indicates that 26% of surplus calves born in the state of Tasmania are euthanised on farm (Snare 2020). Five per cent of Canadian farms euthanise an average of 19% (range 1–100% per farm) of their male calves, despite this country having a more established pathway for surplus calves to enter the veal or beef market than does Australia (Renaud *et al.* 2017). Economics is the major factor affecting the decision of farmers to euthanise surplus calves soon after birth (Renaud *et al.* 2017), that is, whether the cost of rearing calves to minimum age for transport outweighs the price being paid for calves. Both Australian (Snare 2020) and Canadian (Renaud *et al.* 2017; Roche *et al.* 2020) research has found that the management of surplus calves is associated with geographical variation. Thus, factors such as economic conditions and logistics (e.g. distance from processor) may be important in the decision to euthanise. Australian industry reports show that 25% of Australian dairy farms had euthanised calves by blunt force trauma (Dairy Australia 2016, 2020), whereas Canadian research reports show that blunt force trauma to the head had been used to euthanise male dairy calves on 34% of farms (Renaud *et al.* 2017; Roche *et al.* 2020). Of the Canadian dairy farms using blunt force trauma, 53% of farmers indicated it was their primary method of calf euthanasia (Roche *et al.* 2020). Blunt force trauma is not an acceptable method of euthanasia in bovine (Stull and Reynolds 2008; Roche *et al.* 2020). In Canada, more frequently consulting welfare codes and guidelines and a larger farm size are associated with lower odds of euthanising calves with blunt force trauma (Renaud *et al.* 2017). In Australia, an industry focus on appropriate euthanasia practices has seen the release of policies advising against the use of blunt force trauma to euthanise young calves, except in emergency situations (ADIC 2020*a*). These new policies also encourage dairy farmers to provide euthanasia training for staff; however, a 2016 industry survey found that only 13% of Australian farms include someone that has attended a euthanasia course (Dairy Australia 2016).

Surplus calves that are not euthanised are typically reared on farm to at least 5 days of age before being sold and transported. Transportation involves an extended period off feed (i.e. milk) and may also include an indirect consignment through an intermediate facility (Fisher *et al.* 2014). The naïve immune systems, low body fat reserves and developing physiological stress responsiveness of young calves makes them especially vulnerable to transport stress (Trunkfield and Broom 1990; Swanson and Morrow-Tesch 2001; Stull and Reynolds 2008). A study of abattoir records found a total calf transport mortality of 0.64%, although mortality on individual trucks reached 25% (Cave *et al.* 2005). Risk of morbidity and mortality increase with a decreasing age and an increasing distance transported (Trunkfield and Broom 1990; Cave *et al.* 2005). The Australian Animal Welfare Standards and Guidelines for the Land Transport of Livestock stipulate that bobby calves be at least 5 days old when transported to an abattoir, must have been fed within 6 h prior to transport, be alert, able to stand and not ill at the time of transport, and be transported for a maximum duration of 12 h (AHA 2012). These recommendations align with research that has found the transport of 5–9-day-old dairy bulls for 6 or 12 h does not in itself exert a significant effect on calf welfare, but blood glucose declines steadily beyond 18 h from the withdrawal of feed (Fisher *et al.* 2014).

It is the ethical prerogative of dairy producers to ensure surplus calves receive appropriate care prior to transportation despite their low monetary value. Evidence suggests that this is not always the case. Canadian research found that 18% of young calves arrive at the rearing facility in an emaciated state (Renaud *et al.* 2018*a*) and 12% had clinical signs of dehydration (Renaud *et al.* 2018*b*). In total, 10% and 17% of farms do not provide colostrum or the same quantity of feed to male calves as to heifer calves respectively, particularly in larger herds (Renaud *et al.* 2017). Similar findings have been reported in the USA (Shivley *et al.* 2019). The proportion of Australian farms that always feed colostrum is twice as high for dairy heifers than for dairy bull calves (34 vs 62%), while dairy × beef calves are three times more likely to experience agammaglobulinemia than are heifer calves (Vogels *et al.* 2013). Similarly, 30% of New Zealand dairy farmers fail to feed colostrum to bull calves (Cuttance *et al.* 2018). A recent Australian survey found that some farmers continue to sell and transport calves before 5 days of age (Phipps *et al.* 2018). In 2019, 9% of Australian dairy farmers claim to have transported calves before 5 days old, down from 22% in 2016 (Dairy Australia 2020).

Increasing the utilisation of surplus calves is one approach to reducing or even eliminating welfare and social licence risks associated with the euthanasia, transportation and slaughter of the young dairy animal. The low monetary value and high cost of rearing and finishing surplus calves in Australia appears to be failing to incentivise their rearing for the beef market. Strategies that increase the value of a finished calf while reducing their cost of rearing may increase utilisation of these animals. For example, inseminating dairy cows with beef semen (once a sufficient number of pure dairy replacement females have been generated with dairy semen) can maximise the value of surplus calves being produced in terms of carcase quality and feed conversion ratio (McHugh *et al.* 2010; Berry *et al.* 2018; Vestergaard *et al.* 2019), while best-practice calf rearing (regarding colostrum feeding, milk allowance and the management of sick calves) may further improve value by reducing disease and death while also improving growth rates. Research, development and extension is required to support Australian dairy producers seeking to rear surplus dairy calves for the beef market.

Group housing

Dairy calves are predominantly reared in groups in seasonal pasture-based production systems (Abuelo *et al.* 2019), which contrasts the individual housing used in many year-round calving systems (Costa *et al.* 2019). The recommendation for calves to be individually housed until after weaning is made on the basis that it reduces the risk of disease transmission among calves through infected respiratory secretions or faeces (Maunsell and Donovan 2008; Stull and Reynolds 2008). Good health is obviously fundamental to good welfare, but it is reductive to equate good health with good welfare (e.g. Dawkins 2008). Proponents of individual housing prioritise calf health and trade this for other factors such as the calf's social needs (Stull and Reynolds 2008; Sumner and von Keyserlingk 2018). There is ample evidence that individual housing of calves impairs the development of social behaviour (Duve *et al.* 2012; Jensen and Larsen 2014), cognition (Gaillard *et al.* 2014), stress resilience (Duve and Jensen 2011; De Paula Vieira *et al.* 2012; Jensen and Larsen 2014), emotionality (Bučková *et al.* 2019) and feeding behaviour (Arave *et al.* 1974; De Paula Vieira *et al.* 2010; Costa *et al.* 2014, 2015; Miller-Cushon and DeVries 2016), even if fenceline contact to neighbouring calves is permitted (also see reviews by Bøe and Færevik 2003 and Costa *et al.* 2016). Conversely, calves form strong social bonds with their rearing-pen mates (Ewbank 1967; Bøe and Færevik 2003; Færevik *et al.* 2006; Raussi *et al.* 2010; Duve and Jensen 2011; Mandel *et al.* 2016), and group housing produces calves of a higher positive emotional affect (Duve *et al.* 2012; Valníčková *et al.* 2015), that gain more weight pre-weaning (Costa *et al.* 2015; Pempek *et al.* 2016) and that experience reduced growth check post-weaning (Chua *et al.* 2002; De Paula Vieira *et al.* 2010). While the expression of negative social behaviours such as aggression can be facilitated by group housing, the baseline prevalence of agonistic behaviour appears to be low (Veissier *et al.* 2001; Chua *et al.* 2002; O'Driscoll *et al.* 2006).

Group-housed calves are typically reared with conspecifics that are homogenous in age and size. This reduces the risk of smaller calves being displaced from the feeder, and thus variation in intake and growth (Bøe and Færevik 2003). Research in dairy cattle (De Paula Vieira *et al.* 2012) and in other species (rats, see review by McCarty 2017; horses, Bourjade *et al.* 2008; pigs, Verdon *et al.* 2019) suggests that interactions with older conspecifics during rearing may also be important in the development of stress resilience and social behaviour, although there are concerns that this could increase the risk of disease transfer (Bøe and Færevik 2003; Stromberg and Moon 2008; Medrano-Galarza *et al.* 2018). This concept requires further investigation.

Housing calves in groups clearly provides a more socially enriched environment than does individual housing, but animals continue to be kept in pens that lack environmental complexity. A more enriched environment (e.g. increased space, provision of toys or hay) can improve welfare by preventing frustration and increasing fulfillment of behavioural needs (Mandel *et al.* 2016). For example, individually housed calves provided with nutritional (e.g. chopped hay, artificial teats), sensory (e.g. brush) or physical enrichments (e.g. rubber chain) show improved cognition, are less reactive to novelty, perform less pen-directed suckling and spend more time playing (Horvath *et al.* 2017, 2020; Pempek *et al.* 2017). Both individually and group-housed calves use a brush more frequently than they use artificial teats, toys, chains and ropes (Pempek *et al.* 2016; Zobel *et al.* 2017) and their interest in the brush does not wane over time (Horvath and Miller-Cushon 2019). Thus, a brush may be a more effective enrichment than are other objects in terms of facilitating the expression of highly motivated behaviours. The effectiveness of various enrichments on the physical or mental state of group-housed calf is yet to be demonstrated.

Pre-weaning morbidity and mortality

Disease is the most significant cause of mortality in dairy calves outside of the perinatal period (Maunsell and Donovan 2008; McGuirk 2008; Johnson *et al.* 2011). Recent data suggest that the risks of calf morbidity and mortality on Australian dairy farms are 23.8% and 5.6% respectively (Abuelo *et al.* 2019), while a 4.1% calf mortality rate from 24 h postpartum until weaning has been reported in New Zealand (Cuttance *et al.* 2017). Neonatal calf diarrhea (NCD) and bovine respiratory disease (BRD) are the two most common diseases experienced by the calf regardless of dairy system, and account for most of the mortalities (Svensson *et al.* 2006; McGuirk 2008; Gulliksen *et al.* 2009; Windeyer *et al.* 2014; Abuelo *et al.* 2019; Zhang *et al.* 2019). The pathogenic agents that are implicated in NCD and BRD have been reviewed by Stromberg and Moon (2008) as well as Maunsell and Donovan (2008). The reported prevalence of diarrhoea and respiratory illness in group-housed calves is between 5% and 23% and 6% and 17% of calves respectively (Hough and Sawyer 1993; Chuck *et al.* 2018; Medrano-Galarza *et al.* 2018; Abuelo *et al.* 2019). Economic and welfare impacts of calf disease can extend beyond mortality, culling and clinical treatment, to include reduced growth or weight loss, suppressed appetite, depression, and long-term impacts such as delayed age at first calving (Maunsell and Donovan 2008; McGuirk 2008; Stromberg and Moon 2008; Heinrichs and Heinrichs 2011; Boulton *et al.* 2015; Shivley *et al.* 2018).

Reviews of the scientific literature caution against housing calves in groups larger than seven or eight animals due to increased transmission of infectious disease (Barkema *et al.* 2015; Mandel *et al.* 2016); however, experimental research from indoor dairy systems studying the effects of group size on calf morbidity are conflicting. One study indicated a greater risk of BRD (but not NCD) in calves transferred from individual housing to groups of 12–18 animals at 35 days of age, than in calves transferred to groups of 6–9 animals (Svensson and Liberg 2006). Other research has found no evidence that the health of calves housed in groups of 10 (range 8–13; Medrano-Galarza *et al.* 2018) or groups of two (Chua *et al.* 2002; Jensen and Larsen 2014) is worse than that of individually housed calves. The all-in-all-out systems that characterise seasonal calving systems may reduce some of the health risks associated with group housing (see review Barkema *et al.* 2015); however, the relationships among group size, herd size and calf morbidity require further investigation.

Regardless of the farming system, significant variation exists among farms in reported prevalence of calf morbidity and mortality (Johnson *et al.* 2011; Raboisson *et al.* 2013; Compton *et al.* 2017; Cuttance *et al.* 2017; Abuelo *et al.* 2019). A farmer survey by Abuelo *et al.* (2019) found that 68% and 75% of Australian dairy farms exceeded industry targets for calf mortality (target <3%) and morbidity (target <10%); however, the authors stipulated that the targets must be achievable, since they were being met by a proportion of farmers. Mortality and morbidity rates were not related to herd size or geographical location in the survey study by Abuelo *et al.* (2019), suggesting that other factors, such as those relating to the management of calves, may be more important in determining the risk of disease. Potential management factors that may affect the risk of calf morbidity and mortality are discussed below.

First, optimising nutrition through best-practice colostrum and milk collection, storage and feeding protocols (Johnson *et al.* 2011; Klein-Jöbstl *et al.* 2014; Windeyer *et al.* 2014; Seppä-Lassila *et al.* 2016; Medrano-Galarza *et al.* 2018; Abuelo *et al.* 2019), vaccinating dams against common pathogens prior to calving (Abuelo *et al.* 2019) and reducing stress (Stull and Reynolds 2008; Uetake 2013; Hulbert and Moisá 2016) increase immune functioning and thus calf resistance to infection. Despite this, many Australian calves are at risk of receiving colostrum with elevated bacterial counts and a low IgG content, while only 23% of farmers use vaccination of the dam as a preventative calf health program (Abuelo *et al.* 2019). Second, frequently providing fresh bedding (McGuirk 2008; Medrano-Galarza *et al.* 2018) and cleaning the feeder, pen and other equipment remove reservoirs of infection (Maunsell and Donovan 2008; Klein-Jöbstl *et al.* 2014) and can confer to a 10-fold reduction in the risk of NCD (Johnson *et al.* 2011). Abuelo *et al.* (2019) found that 74% of Australian dairy farmers use the same plastic calf feeder in multiple pens, with no or only water-cleaning between groups and 36% clean pens only at the beginning of the calving season. Finally, the early identification, separation and diagnosis of sick calves reduces the risk of further infection and allows for timely, and thus more effective, treatment (McGuirk 2008; Seppä-Lassila *et al.* 2016). Phipps *et al.* (2018) found that nearly 90% of farmers have established protocols for managing sick calves, but 60% fail to routinely isolate sick calves, while Abuelo *et al.* (2019) found that only 55% of dairy farmers have at least one pen for sick calves, 72% diagnose NCD themselves and 56% do not regularly consult a veterinarian for treatment of NCD.

Therefore, while aspects of shed design (e.g. air flow, drainage, separating partitions) are certainly implicated in the spread of disease among housed calves (e.g. Nordlund 2008), the success of dairy farms in controlling calf morbidity and mortality is also dependent on the farm's calf management and biosecurity protocols, and the training and competency of staff who are responsible for the care of calves.

Painful procedures

Disbudding (preventing horn growth before it becomes advanced) and dehorning (amputation of horns beyond the early budding stage; Stafford and Mellor 2011) are painful procedures that are routinely conducted on dairy farms. Castration may also increase in prevalence as Australia explores the viability of growing out of male dairy calves for the beef market (see previous section on surplus calves). The welfare significance of castration has been reviewed by Stafford and Mellor (2005*a*, 2005*b*).

Disbudding and dehorning are performed to minimise the risk of injury to other stock and to stockpersons and to reduce carcase and hide damage (Stull and Reynolds 2008; Petherick 2010). All methods of dehorning involve restraint of the animal and, because the horn bud and surrounding tissue is very innervated, varying degrees of pain (Phillips 2002). Caustic chemicals can be used to destroy the horn bud if the calf is very young (<7 days) but is a less common method of disbudding than is using a hot iron to destroy the bud and surrounding tissue (Dairy Australia 2020). Attachment of the horn tissue to the skull means that amputation of the horn is required if the calf is older than 2 months (Petherick 2010). Disbudding by hot iron cauterisation produces less acute pain than disbudding by caustic chemicals (Stafford and Mellor 2011) and a lower cortisol response to dehorning by amputation (Stafford and Mellor 2005*a*), making it the method of choice for disbudding by farmers (Boulton *et al.* 2015).

Pain is the primary assault to animal welfare associated with disbudding and dehorning. Some calves may even experience depressive-like symptoms (i.e. pessimism) in the hours after cautery disbudding (Lecorps *et al.* 2019). The inflammation and psychological stress associated with the procedure can suppress immune responsiveness and represents a secondary impact on welfare, particularly for young calves that have a developing immune system (reviewed by Hulbert and Moisá 2016). Administration of a local anaesthetic reduces the effects of disbudding on cortisol for approximately 2 h, but the stress hormone increases rapidly once the anaesthetic wears off (McMeekan *et al.* 1998), while behavioural evidence suggests calf aversion to hot-iron disbudding even with the use of a local anaesthetic (Ede *et al.* 2019). Local anaesthesia in combination with a non-steroidal anti-inflammatory drug (NSAID) is more effective at reducing pain and stress in the hours and days following disbudding than is a local anaesthetic alone (Allen *et al.* 2013; Mintline *et al.* 2013; Ede *et al.* 2019). Similarly, sedatives provide some short-term protection from disbudding pain (Stafford *et al.* 2003; Stilwell *et al.* 2010), but when combined with a local anaesthetic or NSAIDs, they virtually eliminate the acute behavioural and physiological response to hot-iron disbudding (Stafford *et al.* 2003; Caray *et al.* 2015; Cuttance *et al.* 2019) and can improve growth in the weeks post-procedure compared with calves given no pain relief or an NSAID alone (Bates *et al.* 2016). While Cuttance *et al.* (2019) found that the administration of a local anaesthetic and a sedative reduced behavioural indicators of pain in the 24 h post-procedure, the combination of sedative, local anaesthesia and an NSAID reduced pain sensitivity of the wound. More research that compares the effect of administering all three classes of drug (sedative, NSAID, local anaesthesia) to a combination of any two classes of drug may help define best-practice care for the disbudded calf. Further, wound sensitivity has been detected up to 75 h following hot-iron cautery disbudding (Mintline *et al.* 2013), while administration of a local anaesthetic 11 days post-disbudding reduces behaviours indicative of pain (Adcock *et al.* 2020). Long-term treatment plans may be required to fully protect the calf from pain due to disbudding.

Most dairy producers disbud calves before 8 weeks of age (Boulton *et al.* 2015; Winder *et al.* 2016; Phipps *et al.* 2018; Urie *et al.* 2018; Winder *et al.* 2018). This proportion increases if a veterinarian conducts the procedure (Winder *et al.* 2016) and as herd size increases (Beggs *et al.* 2019). Australian research has shown that 37% of farms with <300 cows (which make up approximately 15% of all Australian farms) dehorn after 8 weeks of age (Beggs *et al.* 2019), while some calves are dehorned up to 120 days old (Phipps *et al.* 2018). Despite consensus among dairy workers, veterinarians, researchers, animal advocates and the general public that pain relief should be provided when dehorning (Robbins *et al.* 2015), the uptake of best-practice pain relief provided by local anaesthetic plus an NSAID remains low (Boulton *et al.* 2015; Winder *et al.* 2016, 2018; Urie *et al.* 2018; Beggs *et al.* 2019). Canadian research has reported that the use of a local anaesthetic, sedation and NSAID increases when a veterinarian conducts the procedure, but 75% of dairy farmers disbud or dehorn themselves (Winder *et al.* 2016). Comparable data from Australian dairy systems are not available. The use of anaesthetic and analgesic increases with herd size in Australia, with only 13% and 6% of small herds (<300 cows) using a local anaesthetic or an analgesic when disbudding (Beggs *et al.* 2019). The larger Australian farms may have more developed operating procedures and a greater financial buffer, allowing them to engage veterinary services.

Calls to ban mutilating procedures are increasing (e.g. Hulbert and Moisá 2016; Nordquist *et al.* 2017). If a painful husbandry procedure is deemed to be necessary and there are no alternatives to the procedure, then it needs to be conducted in a way that minimises trauma. In the case of disbudding and dehorning, there is a phenotypic group of cattle that do not grow horns (i.e. are polled). Selective breeding of animals with polled genetics would completely remove the necessity of disbudding and dehorning (Petherick 2010; Stafford and Mellor 2011). The percentage of Australian farmers using polled genetics increased from 11% in 2016 to 30% in 2019 (Dairy Australia 2020), but a more rapid incorporation of polled genetics into the dairy population is challenged by the low frequency of the polled allele in dairy breeds, which increases the risk of inbreeding (Mueller *et al.* 2019). Gene editing to produce polled sires of high genetic merit would rapidly reduce the frequency of the horned allele in the dairy population, while constraining inbreeding to acceptable levels (Mueller *et al.* 2019). In general, genetic modification of animals is negatively perceived by the public; however, consumers are more likely to accept it if it will effectively improve animal welfare (McConnachie *et al.* 2019; Ritter *et al.* 2019). For example, Canadian research suggests that most consumers are supportive of spreading the polled gene through genetic modification and would be willing to consume products from polled animals (McConnachie *et al.* 2019).

Feeding

Common methods of milk feeding calves include individually from a bucket, from a teat (individually or in groups) and from an automatic calf feeder (ACF). The proportion of farmers utilising each method varies with country and dairy system (e.g. Hough and Sawyer 1993; Staněk *et al.* 2014; Boulton *et al.* 2015; Abuelo *et al.* 2019). Individually feeding calves from a bucket prevents competition for drinking space but thwarts the calf's strong motivation to suck, which may interfere with digestive processes and feelings of satiety (de Passille 2001). In group-housed calves, redirection of sucking behaviour towards peers (i.e. cross-sucking) appears to be related to sucking behaviour per se rather than milk volumes (Jasper and Weary 2002; De Passillé *et al.* 2011; Mandel *et al.* 2016). Cross-sucking can lead to injuries (Rushen and de Passille 2010) and may increase the risk of disease transfer, although there is no published research confirming the latter relationship. Group feeding calves from a trough with teats attached allows calves to fulfil their motivation to suck, but variation in the rate of milk consumption can result in larger calves displacing and poaching the milk of smaller calves (Moran 2002). Automated calf feeders deliver milk via a teat at individualised volumes and allow for the greatest possible control over calf intake (Barkema *et al.* 2015). The ACF also generates data regarding individual milk intake and frequency of feeding events that may be useful indicators of calf health (Barkema *et al.* 2015). While competitive displacements from the ACF are rare (O'Driscoll *et al.* 2006), particular attention needs to be paid to younger and smaller calves that may take longer to learn how to use the technology and, consequently, have reduced milk intakes (e.g. Fujiwara *et al.* 2014).

The milk intake of pre-weaned calves is conventionally restricted to ~10% of body weight. These volumes represent half of what scientists recommend as best practice (discussed by Palczynski *et al.* 2020), but are thought to encourage early intake of solid feed, which accelerates rumen development and minimises labour and feed costs (Drackley 2008; Khan *et al.* 2011; Palczynski *et al.* 2020). The average restrictively fed calf is provided approximately 2.5 L of milk twice per day (Hough and Sawyer 1993; Pettersson *et al.* 2001; Boulton *et al.* 2015; Urie *et al.* 2018; Abuelo *et al.* 2019), while the *ad libitum* intake of heifer calves is 9–11 L of milk per day (Jasper and Weary 2002; De Passillé *et al.* 2011; Schäff *et al.* 2016; Rosenberger *et al.* 2017). In bull calves, the *ad libitum* intake approaches 13 L per day (Miller-Cushon *et al.* 2013). While dairy advisors express concern about widespread underfeeding of calves, dairy farmers express confusion about what constitutes best-practice feeding (Palczynski *et al.* 2020).

Restricted milk volumes during rearing are generally sufficient for maintenance and limited growth (Drackley 2008), suggesting that calves are not in negative energy balance. However, it results in behavioural signs of hunger such as increased frequency of unrewarded visits to the milk feeder (De Passillé *et al.* 2011; Korst *et al.* 2017; Rosenberger *et al.* 2017; Jongman *et al.* 2020), decreased play (Duve *et al.* 2012; Jongman *et al.* 2020) and increased motivation to compete for access to concentrate (Duve *et al.* 2012). High milk volumes reduce solid feed consumption, but the daily energy intake of calves on increased milk volumes remain higher than those that are restrictively fed, and consequently they gain more weight during the milk feeding period (De Passillé *et al.* 2011; Bach *et al.* 2013; Miller-Cushon *et al.* 2013; Rosenberger *et al.* 2017; Jongman *et al.* 2020). There is little experimental evidence that the weight advantage of high milk-volume calves persists beyond 1 month post-weaning (De Passillé *et al.* 2011; Bach *et al.* 2013); however, farms that rear faster-growing heifers before weaning also rear faster-growing heifers to breeding (Bond *et al.* 2015). The accelerated growth achieved by high milk volumes pre-weaning is positively associated with milk production during the first lactation (reviewed by Roche *et al.* 2015, but also see Chuck *et al.* 2018) and survival to the second lactation (Bach 2011). For example, Soberon *et al.* (2012) found that every megacalorie of additional energy consumed from milk replacer in the pre-weaning period produced 235 kg more milk in the first lactation, and that pre-weaning average daily growth accounted for 22% of the variation in first-lactation milk yield. Thus, the benefits of increased milk volumes can represent a significant return on the investment of additional milk (Boulton *et al.* 2015; Roche *et al.* 2015; Chuck *et al.* 2018).

Very young calves (i.e. <3 days) should be fed multiple times per day as they only consume up to 2 L of milk in each meal (Jongman *et al.* 2020) and their blood glucose concentrations decline from approximately 18 h after their last meal (Fisher *et al.* 2014). It may be possible to feed calves older than 3 days larger milk volumes in fewer meals (Ellingsen *et al.* 2016; Jongman *et al.* 2020). Research by Ellingsen *et al.* (2016) reported that 67% of 3-week-old calves consume more than 5 L in a single meal and no milk was observed entering the rumen, nor were there any behaviours indicating abdominal pain or discomfort, while other research has found no effect of high (8–10 L/day) or low (4.5–6 L/day) milk consumptions on the incidence of diarrhoea (Jasper and Weary 2002; Bach *et al.* 2013; Schäff *et al.* 2016). Calves are physiologically primed for rapid growth in the first few weeks of life (Jasper and Weary 2002; Roche *et al.* 2015), thus one opportunity to reduce the economic impacts of increased milk volumes is to feed high volumes for the first 5–6 weeks of life, followed by more restricted volumes until weaning. Such feeding regimes have been shown to achieve positive effects on heifer growth without negatively affecting solid feed consumption (Schäff *et al.* 2016; Korst *et al.* 2017; Cantor *et al.* 2019). Indeed, the *ad libitum* milk consumption of calves increases from birth until it reaches a plateau at approximately 5 weeks of age (De Passillé *et al.* 2011; Korst *et al.* 2017) and little solid feed is consumed before 5 weeks (Jasper and Weary 2002; De Passillé *et al.* 2011; Rosenberger *et al.* 2017).

Weaning

Weaning calves off milk needs to be carefully managed to maintain energy intake and prevent a growth check, particularly if calves are being weaned off high milk volumes. The Australian dairy industry recommends that weaning be delayed until the rumen is adequately developed, as indicated by 1–2 kg concentrate consumption per day for at least three consecutive days (Dairy Australia 2017). A prospective study conducted by Heinrichs and Heinrichs (2011) found that for every increase of 1 kg of solid feed intake at weaning, there was a corresponding increase of 287 kg of milk produced in the first lactation. Australian research similarly found that calves provided with 1 kg or more of concentrate per day until weaning had an increased weight for age growth trajectory through to calving than did those offered less than 1 kg per day (Spence and Woodhead 2000). The average age of weaning in seasonal calving dairy systems is greater than that reported in the northern hemisphere, providing calves a longer period to adapt to concentrates (about 8 vs 12 weeks; Hough and Sawyer 1993; Pettersson *et al.* 2001; Boulton *et al.* 2015; Urie *et al.* 2018; Abuelo *et al.* 2019). While 43% of Australian dairy farmers consider age, weight and grain consumption when making decisions about weaning, 34% wean on the basis of age alone (Phipps *et al.* 2018).

Diluting, substituting or reducing the amount of milk offered over a period of days slowly transitions calves from a high-volume liquid diet to a solid diet (Khan *et al.* 2011). Compared with abrupt weaning, diluting milk with warm water increases the amount of solid food calves consume during weaning, but not their behavioural response to complete weaning (Jasper *et al.* 2008), while substituting milk with warm water for the first 2 days of weaning reduces the behavioural response to weaning, but has no effect on solid food consumption or the post-weaning growth check (Budzynska and Weary 2008). Heifers on high milk volumes that are gradually weaned continue to consume less solid feed and, consequently, have reduced growth during weaning compared with heifers on a restricted milk diet (De Passillé *et al.* 2011; Bach *et al.* 2013; Rosenberger *et al.* 2017), but post-weaning solid intake and growths are comparable (Khan *et al.* 2011). Gradually weaning calves off high milk volumes through incremental daily reductions of milk or through step-wise reductions every few days result in similar performance and behaviour of calves (Parsons *et al.* 2020); however, gradually reducing the volume of milk offered as a percentage of individual calf *ad libitum* intake improves growth performance during weaning compared with a step-wise of fixed volume (Welboren *et al.* 2019). These studies have been conducted in systems where calves are weaned at a relatively young age compared with most pasture-based systems (e.g. 35 days) and results need to be confirmed in calves weaned at an older age. Limited research suggests that weaning 12-week-old calves off high milk volumes by using a gradual weaning process reduces any negative effects of weaning on solid feed intake and growth (De Passillé *et al.* 2011).

Farm blindness

In his recent review on de-normalising poor dairy youngstock management, Mee (2020) defined farm blindness as 'a misperception by farmers that what they see every day on their own farm is normal' (Page S140). This phenomenon may be implicated in the continuation of suboptimal calf management practices, which are a recurrent theme of this review (e.g. such as those related to the management of the perinatal calf, colostrum feeding, hygienic calf rearing practices, pain relief at dehorning, milk volumes and weaning). According to Mee (2020), farm blindness can be attributed to (1) farmers failing to recognise the problem on their farm, or (2) farmers recognising the problem but being blind to it. The former arises when a problem (e.g. perinatal mortalities) is not visible to the farmer or they do not perceive the practice or outcome to be a problem, whereas the latter results from a desensitisation to the problem or a slowly changing trend where 'bad becomes normal' (Grandin 2015; Mee 2020). A combination of regular record keeping and benchmarking (i.e. comparison among farms) are key to combatting farm blindness. These are discussed below.

Problems relating to calf rearing become visible when outcomes such as disease, mortality, passive transfer of immunity and weights are recorded (Mee 2020). A recent survey found that UK cattle farmers rated their calf rearing practices highly and felt that their youngstock got enough attention, but levels of disease often were not measured and were failing to meet industry standards (Baxter-Smith and Simpson 2020). In New Zealand, Cuttance *et al.* (2018) reported that 7–80% of calves had failed passive transfer of immunity (FPT) on dairy farms where the farmer did not think there was any FPT. In addition to making a problem visible, regularly recording outcomes can combat desensitisation and change blindness by identifying whether practices are improving, staying the same or becoming worse over time (Grandin 2015). Providing farmers with peer benchmarks allows them to compare their performance to that of similar farms, which shows what constitutes 'normal' or 'abnormal' performance (Mee 2020). Benchmarking also provides physical evidence of the existence or extent of a problem, which gives farmers the confidence to assess practice change without relying on reactive or emotive decision making (Turner *et al.* 2018). This has been corroborated by Canadian research that found that benchmarking motivated farmers to make changes in their calf management by identifying areas of improvement and promoting peer discussion about best practice (Sumner *et al.* 2018). Another Canadian study found that 83% of farmers that participated in benchmarking for passive transfer of immunity made at least one change in their management of colostrum or milk feeding practices and, subsequently, recorded a decline in the rate of FPT (Atkinson *et al.* 2017).

Extension and communication programs that create awareness of good (and bad) calf management practices compliment improved record keeping and involvement in benchmarking. For example, the prevalence of cow lameness is reduced when farms start to monitor its occurence, but reductions are greater when additional advice and support is provided (Main *et al.* 2012). The success of communication efforts depends on what information is being delivered, but also on who is delivering the information and how. The latter two factors are integral to reducing emotive reactivity or defensiveness that risk cessation of farmer engagement, particularly when a problem is not perceived to be as important by the farmer as it is by others (e.g. by veterinarians; Mee 2020). Canadian dairy farmers were most open to animal welfare advice when delivered from a trusted consultant with whom they had an established relationship, and particularly veterinarians (Croyle *et al.* 2019), while engagement in benchmarking programs can further enhance the farmers' perceived value of their veterinarian's capacity to advise on calf management (Sumner *et al.* 2020). A personal communicative style that accounts for the individual farmers' beliefs, goals and constraints is recommended (Ritter *et al.* 2017), and is preferred by farmers (Croyle *et al.* 2019).

While raising awareness of what constitutes best practice calf rearing is obviously an essential component of communication programs, extension efforts need to move beyond simple education to also support farmers in starting and sustaining record keeping, in interpreting and applying data in decision-making around change, and to facilitate participation in benchmarking programs (Turner *et al.* 2018).

Collaboration with other industry stakeholders, such as milk processors, to provide economic incentives for good calf rearing practices may further reinforce communications that highlight the productive and social benefits of good calf management.

Conclusions and recommendations

Many of the risks to calf welfare discussed in the present review are not exclusive to pasture-based dairy systems. For example, there is a global trend for increasing calf mortalities during or within 24 h of birth, and a significant number of calves are failing to receive adequate levels of high-quality colostrum, are not provided with analgesic in addition to anaesthetic when disbudded and are fed restricted volumes of milk. The persistence of these welfare risks across dairy systems, despite scientific advice to the contrary and considerable extension efforts, suggests a normalisation of poor practices and/or a general de-prioritisation of the management of calves. This may arise from the fact that dairy producers have finite resources (e.g. time, labour) to distribute between the care of their cows and that of their calves. With cows presenting a more immediate financial return than calves, they may be attracting the bulk of these resources. Logistical difficulties in managing large numbers of calves on seasonal pasture-based dairy farms may be further challenging the uptake of best-practice calf management in these systems.

In addition to these persisting welfare risks, two factors discussed in the present review pose an immediate threat to the social license of dairy farming; the separation of cow and calf soon after birth and the management of surplus calves. The latter is of particular importance to countries with seasonal calving systems such as Australia and New Zealand, where these animals are predominantly slaughtered as low-value veal ~7 days old. Addressing these risks requires the development of alternative systems that will challenge traditional calf rearing practices. To be commercially viable, it is essential that such alternative calf rearing systems are based on science and are developed and tested in consultation with producers and other industry (e.g. processors) and community stakeholders. Expectations of rapid change brought on by a 'silver bullet' alternative calf rearing system should be moderated. Rather, a range of options for managing cow–calf systems on pasture-based dairies or rearing and finishing surplus calves need to be available to producers, allowing them to make decisions as to what strategy is best suited for their business.

A multifactorial approach comprising social and biological research in collaboration with extension may improve the uptake of best-practice calf rearing. First, as put by Grandin (2008), 'you manage what you measure' (pp. 242). Within- and among-farm benchmarking of calf rearing practices, outcomes and performance can combat farm blindness, showing areas of improvement. Farmers should therefore be encouraged and supported by advisors and processors to improve record keeping of key rearing inputs (e.g. colostrum management, milk volumes, grain consumed, labour, weaning practices) and outcomes (e.g. calf morbidities, treatments and mortalities, growth). Second, social research needs to provide a better understanding of the barriers to adoption of best-practice calf rearing, including whether these barriers are subject to geographical and demographical variation. This understanding could guide the development of industry and extension communication strategies that (1) strengthen farmer beliefs regarding the welfare and productivity benefits achieved by best-practice calf rearing and (2) challenge beliefs regarding the associated costs. Such communication strategies also need to be delivered to those that provide advice and support to farmers, i.e. dairy consultants, veterinarians and processors. Third, biological research is needed to advise both the development of new calf rearing recommendations and the evolution of existing recommendations. The following areas have been identified as research priorities: (1) prevalence and causes of dystocia in pasture-based dairy systems, as well as its effect on the neonate and strategies to mitigate these effects, (2) the effect of features of pen design and management on calf health and welfare in 'all-in, all-out' group-housing systems (e.g. group size, herd size, stocking density, environmental enrichment, technologies to aid in early identification of illness), (3) feasibility and effects of dam rearing in large pasture-based dairy systems and (4) feeding, rearing and finishing strategies that increase the value of a finished surplus calf.

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