

# Early weaning: new insights on an ever-persistent problem in the dairy industry

Tomislav Mikuš<sup>1</sup>, Rok Marzel<sup>2</sup> and Ornella Mikuš<sup>3</sup>

<sup>1</sup>Department of Hygiene, Technology and Food Safety, Faculty of Veterinary Medicine, University of Zagreb, Zagreb, Croatia; <sup>2</sup>GO-KO farm Ltd., Kočevje, Slovenia and <sup>3</sup>Department of Agricultural Economics and Rural Development, University of Zagreb, Faculty of Agriculture, Zagreb, Croatia

## Research Reflection

**Cite this article:** Mikuš T, Marzel R and Mikuš O (2020). Early weaning: new insights on an ever-persistent problem in the dairy industry. *Journal of Dairy Research* **87**(S1), 88–92. <https://doi.org/10.1017/S0022029920000503>

Received: 21 October 2019

Revised: 20 February 2020

Accepted: 25 February 2020

### Keywords:

Calf housing; consumers; economic effects; early weaning; environmental enrichment; policy

### Author for correspondence:

Tomislav Mikuš, Email: [tmikus@vef.hr](mailto:tmikus@vef.hr)

## Abstract

It is common practice in the dairy industry to separate the calf from the cow immediately after parturition, and in most parts of the world calves are housed individually during the milk-feeding period. Early and abrupt separation has major implications for the calf's physical and psychological development. In this Research Reflection short review we present and discuss the main housing systems and management practices regarding early weaning in today's dairy industry. Main benefits and disadvantages are critically addressed, and possible future research suggested. Furthermore, major policy issues related to consumers, scientific recommendations and economic performance of farms have been identified, as well as future drivers for more viable housing solutions for neonatal calves. This review serves as an introduction and preamble to the second section of this Special Issue, which is dedicated to cow-calf contact management systems.

## Introduction

Cattle are historically one of the most researched animal species in the context of animal welfare (Mikuš *et al.*, 2018), yet there are still significant welfare issues which are not nearing resolution. One of those issues for the last couple of decades has been early weaning which is still a predominant practice in the dairy industry (EFSA, 2006, 2009; Cantor *et al.*, 2019).

Weaning of calves in natural conditions occurs at the age of 6–9 months, and it is characterized by a decrease in the frequency of suckling, with a more frequent intake of solid foods and development of more complex social interactions (Weary *et al.*, 2008). By contrast, in the present-day dairy industry calves are typically separated from their dams immediately or during the first hours after calving, whereby the maternal behaviour of cows is hampered and milk production continues without the calves. This practice is called early weaning and it has been shown to be stressful for both calves and cows (Mandel and Nicol, 2017).

Early weaning is implemented in order to improve cow productivity, facilitate herd management and avoid possible neonatal enteric and respiratory infections, which are still a significant problem in calves (Svensson *et al.*, 2003; Bolt *et al.*, 2017). Council Directive (97/2/EC) state that a single housed calf must be able to make direct visual contact through the pen barrier with other calves, which means that the calf, although single housed, can still share pathogen microorganisms through direct contact with its peers (Kung *et al.*, 1997).

Due to the complex natural hierarchies recognized among cattle, it is important that calves learn how to interact socially with their peers, as studies suggest that early social contact facilitates positive social responses and decreases agonistic behaviour (Veissier *et al.*, 1997; Pempek *et al.*, 2013). Abrupt separation of dam and calf has a number of physiological and behavioural consequences for both animals, which can be recognized immediately after separation, during several weeks after separation and some of which can even be transferred to next-generation heifers (Mandel and Nicol, 2017).

Several review papers focused on weaning and housing of calves have already been published (Weary *et al.*, 2008; Johnsen *et al.*, 2016; Beaver *et al.*, 2019), but given that early weaning and individual housing of calves is still persistent and common practice in the dairy industry, the authors decided to investigate and present new practices and potential new approaches in the housing and managing of neonatal calves, their benefits and disadvantages as well as policy drivers, economic performance and market trends. The methodology employed in the literature search is described in the online Supplementary File. Selected papers were grouped into the three major categories *Calves-only Systems*, *Policy and Economics* and *Cow-Calf Rearing Systems*. The remainder of this review will focus on the first two categories, since these are directly related to early weaning. The third category together with its references is covered in the online Supplementary File but is also the focus of the papers contained in the second section of this Special Issue, which is dedicated to the issue of cow-calf contact. As such, this Research Reflection also provides an introduction and preamble to that section.

© The Author(s), 2020. Published by Cambridge University Press on behalf of Hannah Dairy Research Foundation. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution, and reproduction in any medium, provided the original work is properly cited.



CAMBRIDGE  
UNIVERSITY PRESS

### Calves-only systems

In this section, the authors will focus primarily on group and pair housing of calves. In addition, possibilities of environmental enrichment as a tool to raise the minimum standard of individually and group managed calves will be investigated.

#### Group housing systems

Group housing system implies that calves are kept in groups of three or more animals depending on the space allowance and farm management system. Groups can be small (3–8) or large (9–30), and to avoid health issues, calves grouped together should be approximately of the same age, entering the group at the same time (Pedersen *et al.*, 2009). Due to increasing farm animal welfare concerns in the general public as well as among dairy farmers and other stakeholders involved in the dairy industry (Ventura *et al.*, 2013), group housing of calves has become more prevalent in recent years (Cobb *et al.*, 2014b). These housing systems are interesting to the industry as they provide easier management for the farmer (Hötzel *et al.*, 2014), bring benefit to the social development of calves and increase productivity (Costa *et al.*, 2016).

Although a few decades ago rearing calves in groups might have been challenging and time-consuming, technological advancement and development of automated feeding systems made group housing easily accessible to a large number of farmers (Kung *et al.*, 1997; Costa *et al.*, 2016). Thus, increased economic benefit for the farmers is at the same time a great benefit for the calves. As reviewed by Costa *et al.* (2016) young animals are more likely to start tasting solid food earlier when reared in groups than when kept individually. In addition, if joined earlier in life, calves tend to show frequent positive social interactions and smaller incidence of stressful behaviours (Abdelfattah *et al.*, 2018).

Major differences between large and small group rearing systems are connected to potential health and welfare risks. As reported by Svensson *et al.* (2003) calves housed in larger groups (10+ individuals) had a significantly higher mortality rate than individually housed calves or calves in smaller groups. In the same research, the incidence of sickness and mortality due to respiratory and digestive infections in smaller groups was similar to that in individually housed calves (Svensson *et al.*, 2003). Similar results have been observed in studies conducted by Cobb *et al.* (2014a). Furthermore, calves kept in larger groups face greater social challenges around feeding time when aggression and general behavioural disturbance most often occur (Jensen, 2003; von Keyserlingk *et al.*, 2004; de Passillé *et al.*, 2011). These behavioural issues can be avoided, or at least minimized, through proper feeding management. This involves smaller groups of calves feeding through a sufficiency of available teats, and more frequent availability of milk (Jensen, 2003; Costa *et al.*, 2016; Mahmoud *et al.*, 2016).

#### Pair housing systems

Pair housing systems imply that calves are kept in pairs for the first several weeks, thus joined immediately after birth or within the first neonatal days. Rearing of calves in pairs reduces potential health risks in early life due to easy access and monitoring of each animal pair and it lowers the potential welfare problems such as cross-suckling and feeding time disturbance. Moreover, the pairing system provides calves with more space for everyday interactions and social development (De Paula Vieira *et al.*, 2010).

A recent study by Morgan (2018) shows that pair housing has positive effects on the calves' immune system, under well-managed conditions. There were no differences in humoral immunity potential between single and pair-housed animals, thus increasing the resistance to potential neonatal infections. Overvest *et al.* (2018) found that in the pair housing system, the presence of another animal promoted greater feeding rates of both solid feed and water, which translated into greater daily intake of feed in general. Results of the same study also suggest that calves joined in pairs from birth, rather than a few days later, may exhibit fewer behavioural disruptions in the post-weaning period. Pempek *et al.* (2016) confirmed similar results regarding increased feed intake, while Whalin *et al.* (2018) also concluded that calves kept in pairs are less fearful towards novel foods.

Furthermore, Whalin *et al.* (2018) have not recorded any differences in body weight gain compared to individually housed calves. The authors explain the increased feed intake without gaining body weight with an increased social activity of the paired calves. Behavioural problems such as cross suckling which Pempek *et al.* (2016) have recorded can be explained by low milk allowances and bucket feeders used in their research. Using a better feeding management system, cross-suckling issues are scarce (Whalin *et al.*, 2018). In general, the findings of the reviewed studies regarding pair housing of neonatal calves, reveal that the keeping of calves in this rearing system is beneficial in terms of health, performance and behaviour.

#### Enriched systems

Environmental enrichment in the dairy industry is almost non-existent in contrast to some other livestock productions (pigs in particular), and as such it does not follow the needs of the animals reared in indoor housing systems (Mandel *et al.*, 2016). Enrichment should provide appropriate stimuli to promote normal behaviours, improve welfare and biological functioning of animals (Newberry, 1995; Mandel *et al.*, 2016). For the purpose of this review, the authors will consider only pen enrichments as potential benefit for the housing of calves.

Several published studies regarding enrichment of the calves' pens suggest that some practices can benefit the social and behavioural development of the animal, but others remain inconclusive. Thus, the study conducted by Jensen *et al.* (2015) in which calves had access to an increased space allowance concluded that providing increased space can elevate the level of playing behaviour. Dividing the enclosure of group housed calves can increase opportunities for calves to avoid antagonistic behaviours and provide additional opportunity for exploratory behaviour (Newberry, 1995; Ninomiya and Sato, 2009). Some other additions to the enclosure such as fresh bedding in connection with a feeding routine can also stimulate playing behaviour (Jensen *et al.*, 1998). However, as both stimuli were presented to calves at the same time it is not possible to separate individual effects of the two. When offered in the enclosure, calves will suckle a dry rubber teat, which can reduce cross-suckling behaviour by over 75% (de Passillé and Caza, 1997), but as later argued by de Passillé *et al.* (2011), the negative repetitive behaviour of cross-suckling did not vanish, it was merely diverted from a calf to the dry teat. A better possibility is to offer calves teat-feeders, which will provide functional purpose and decrease the incidence of negative behaviour (Jensen *et al.*, 2008).

Several studies researching the effect of enriched environments on individually housed calves and cows have inconclusive results.

In the experiment conducted by Mandel *et al.* (2019) cows were isolated in enclosures with a mirror, an automated grooming brush, or with both items at the same time, and they found no reduction of stress indicators compared to the non-enriched environment. A similar study which involved housing individual calves in a fully furnished pen (with two artificial teats, a stationary brush, a calf 'lollie', and a rubber chain link for calves to manipulate) came to a similar conclusion. Although calves were interacting with all of the items offered, the enrichment did not affect growth, starter intake, nor behavioural response to social and environmental novelty after weaning (Pempek *et al.*, 2017). Results of the studies reviewed in this section suggest that providing some physical complexity to standard individual housing can have minor or no significant benefits for cattle, compared to social enrichment in the sense of the presence of another calf.

### Policy and economics

Conflicting research results about the effects of early and postponed cow-calf separation demand additional effort in gathering empirical data as this is an important area of public and policy concern (Ventura *et al.*, 2013; Hötzel *et al.*, 2017). Different countries have used different instruments to raise questions and improve farm animal welfare standards. As reviewed by von Keyserlingk and Hötzel (2015) legislation has played an important role in the implementation of improved animal welfare in industrialized countries such as parts of the EU, New Zealand, Canada and some states in the USA. At the same time, a lack of appropriate enforcement in some countries undermined confidence in this legislative approach (von Keyserlingk and Weary, 2017). The EU was the first region in the world to recognize the importance of animal welfare and to translate initiatives into reality by establishing concrete rules. The EU animal welfare rules for dairy cows are derived from the Council Directive 98/58/EC concerning the protection of animals kept for farming purposes and requiring that owners or keepers of dairy cows take all reasonable steps to ensure the welfare of animals (EC DG SANTE, 2017). Still, the requirements are general and nonspecific. There are no requirements on postponed or non-separation of calf and mother in the EU legal regulations of dairy animal welfare (Grethe, 2017), and the European Food Safety Authority (EFSA) is rather equivocal on the topic, stating: 'There are conflicting research data as to whether it is best for the welfare of the cow to leave the calf with the cow for a prolonged lactation period or to remove it within 24 h' (EFSA, 2009).

The question of cow-calf separation can evoke strong feelings of empathy in the public which is usually supportive of a more natural way of rearing that would prevent unnecessary stress for both cow and calf. Natural behaviour or naturalness appear to be idealized concepts of animal wellbeing created by the lay public outside the livestock industry (Hötzel *et al.*, 2017). The public opinion towards animal production is a result of negative connotations connected to farm practices that are rated as adverse to animal welfare (Boogaard *et al.*, 2010). According to a study conducted by Ventura *et al.* (2013), research participants with more knowledge and experience with dairy farming expressed their support of early separation and evaluated the practice considering the larger picture. In contrast, participants with no experience or interaction with farmers had little understanding for early separation (Ventura *et al.*, 2013).

Producers and specialists in dairy farming are in the minority in relation to consumers, who are the providers of budget support for agricultural production and whose interest for animal welfare

is increasing. That is why the decision-making process should address scientific evidence of best practices, as well as industry and non-industry stakeholders' feedback in order to be received and implemented properly. Although EU member states stakeholders have recently been giving great attention and importance to animal welfare support practices on dairy farms, good health and productivity are in focus, while affective states and natural living are less frequent worries. This is partially due to the cross-compliance mechanism of the Common Agricultural Policy which represents a series of mandatory requirements which farmers must respect in their agricultural practice when exercising the right to direct subsidies in agriculture. As animal welfare is only one of them and respective indicators are not clear or detailed, it is difficult to monitor and conclude to what extent the farming community implements various initiatives, especially behavioural issues (EC DG SANTE, 2017). Furthermore, it is difficult to prescribe animal welfare practices which would potentially cause higher production costs and an increase in domestic prices. There is no unambiguous and definitive answer on the economic questions as regards an extended period of suckling. Asheim *et al.* (2016) studied the profitability of different calf-feeding strategies in Norwegian organic dairy farms. Results indicated that heifer calves fed high amounts of milk also have higher milk yield in their first lactation. Additionally, suckling for several weeks may be considered an economically viable option for calf rearing, but it could lower the milk fat content and negatively affect the price. However, an increase of price could be justified by labelling the product as goods produced according to a certain animal welfare practice (Grethe, 2017). On the other hand, Kišac *et al.* (2011) examined the impact of the length of a calf suckling milk from its own mother on the calf growth and cow production on a Slovak non-organic dairy farm. The results showed that prolonged nursing positively influenced the growth of calves, but reduced the mothers' milk production. Therefore, if the farmer's goal is high-yielding dairy cows, keeping calves with the dam for 21 d after birth is not recommended.

In terms of facilities, most modern farm buildings are not designed for keeping cows and calves together (Asheim *et al.*, 2016) and such reorganization would call for new investments not welcomed by farmers. Furthermore, separation and weaning of suckling dairy calves is a question of animal ethics rather than one of animal health and production. Consumers will continue to force changes in industry practices and argue for a reform of legislation based on morality rather than economics, especially in modern and rich societies. As market-oriented producers listen to consumer demands they will have to at least offer a compromise to raise the level of care for dairy cows and calves. Policy support will have to follow this trend and ensure new ways of compliance. However, there is no 'one size fits all' policy framework to respond to all animal welfare aspects, especially to its ethical dimension. Countries and even regions differ among each other with respect to all aspects of agricultural structure (e.g. structure and value of production, socioeconomic characteristics of farmers, implemented policy instruments). Economies will have to adapt to new market rules and demands, but will each have to walk their own path considering the characteristics of their respective agricultural sector.

### Conclusions

Although modern farms are organized in such a way that different categories of dairy cattle are grouped separately and general

management of farms does not allow much interaction, new scientific evidence presented in this review suggests that there are some management possibilities achievable with minimum investment which can improve the welfare of calves. As a final remark, the authors would like to stress that farmers and policy makers will soon need to recognize and recommend a viable way of managing neonatal calves, not only because of scientific advancement, but also due to public expectations which are growing stronger by the day.

**Supplementary material.** The supplementary material for this article can be found at <https://doi.org/10.1017/S0022029920000503>

**Acknowledgements.** This article is based upon work from COST Action FA1308 DairyCare, supported by COST (European Cooperation in Science and Technology, [www.cost.eu](http://www.cost.eu)). COST is a funding agency for research and innovation networks. COST Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation.

## References

- Abdelfattah EM, Karousa MM, Lay Jr DC, Marchant-Forde JN and Eicher SD (2018) Short communication: effect of age at group housing on behavior, cortisol, health, and leukocyte differential counts of neonatal bull dairy calves. *Journal of Dairy Science* **101**, 596–602.
- Asheim LJ, Foske Johnsen J, Havrevoll Ø, Mejdell CM and Grondahl AM (2016) The economic effects of suckling and milk feeding to calves in dual purpose dairy and beef farming. *Review of Agricultural, Food and Environmental Studies* **97**, 225–236.
- Beaver A, Meagher RK, von Keyserlingk MAG and Weary DM (2019) Invited review: a systematic review of the effects of early separation on dairy cow and calf health. *Journal of Dairy Science* **102**, 5784–5810.
- Bolt SL, Boyland NK, Mlynski DT, James R and Croft DP (2017) Pair housing of dairy calves and age at pairing: effects on weaning stress, health, production and social networks. *PLoS ONE* **12**, 1–18.
- Boogaard BK, Bock BB, Osting SJ and Krogh E (2010) Visiting a farm: an exploratory study of the social construction of animal farming in Norway and the Netherlands based on sensory perception. *International Journal of Sociology of Agriculture and Food* **17**, 24–50.
- Cantor MC, Costa JHC and Neave HW (2019) Current perspectives on the short- and long-term effects of conventional dairy calf raising systems: a comparison with the natural environment. *Translational Animal Science* **3**, 549–563.
- Cobb CJ, Obeidat BS, Sellers MD, Pepper-Yowell AR and Ballou MA (2014a) Group housing of Holstein calves in a poor indoor environment increases respiratory disease but does not influence performance or leukocyte responses. *Journal of Dairy Science* **97**, 3099–3109.
- Cobb CJ, Obeidat BS, Sellers MD, Pepper-Yowell AR, Hanson DL and Ballou MA (2014b) Improved performance and heightened neutrophil responses during the neonatal and weaning periods among outdoor group-housed Holstein calves. *Journal of Dairy Science* **97**, 930–939.
- Costa JHC, von Keyserlingk MAG and Weary DM (2016) Invited review: effects of group housing of dairy calves on behavior, cognition, performance, and health. *Journal of Dairy Science* **99**, 2453–2467.
- Council Directive 97/2/EC of 20 January 1997 amending Directive 91/629/EEC laying down minimum standards for the protection of calves.
- Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes.
- de Passillé AM and Caza N (1997) Cross-sucking by calves occurs after meals and is reduced when calves suck a dry teat. *Journal of Dairy Science* **80**, 229.
- de Passillé AM, Borderas F and Rushen J (2011) Cross-sucking by dairy calves may become a habit or reflect characteristics of individual calves more than milk allowance or weaning. *Applied Animal Behavior Science* **133**, 137–143.
- De Paula Vieira A, von Keyserlingk MA and Weary DM (2010) Effects of pair versus Single housing on performance and behavior of dairy calves before and after weaning from milk. *Journal of Dairy Science* **93**, 3079–3085.
- EFSA (2006) Opinion of the scientific panel on Animal Health and Welfare (AHAW) on a request from the Commission related with the risks of poor welfare in intensive calf farming systems. *EFSA Journal* **4**, 366, n/a.
- EFSA (2009) Scientific opinion on the overall effects of farming systems on dairy cow welfare and disease. *EFSA Journal* **1143**, 3–38.
- European Commission DG Health and Food Safety (EC DG SANTE) (2017) Overview report Welfare of Cattle on Dairy Farms. *Ref. Ares* (2017) 5623870–17/11/2017
- Grethe H (2017) The economics of farm animal welfare. *Annual Review of Resource Economics* **9**, 75–94.
- Hötzel MJ, Longo C, Balcão LF, Cardoso CS and Costa JHC (2014) A survey of management practices that influence performance and welfare of dairy calves reared in southern Brazil. *PLoS ONE* **9**, 1–17.
- Hötzel MJ, Cardoso CS, Roslindo A and von Keyserlingk MAG (2017) Citizens' views on the practices of zero-grazing and cow-calf separation in the dairy industry: does providing information increase acceptability? *Journal of Dairy Science* **100**, 4150–4160.
- Jensen MB (2003) The effects of feeding method, milk allowance and social factors on milk feeding behaviour and cross-sucking in group housed dairy calves. *Applied Animal Behavior Science* **80**, 191–206.
- Jensen MB, Vestergaard KS and Krohn CC (1998) Play behaviour in dairy calves kept in pens: the effect of social contact and space allowance. *Applied Animal Behavior Science* **56**, 97–108.
- Jensen MB, de Passillé AM, von Keyserlingk MAG and Rushen J (2008) A barrier can reduce competition over teats in pair-housed milk-fed calves. *Journal of Dairy Science* **91**, 1607–1613.
- Jensen MB, Duve LR and Weary DM (2015) Pair housing and enhanced milk allowance increase play behavior and improve performance in dairy calves. *Journal of Dairy Science* **98**, 2568–2575.
- Johnsen JF, Zipp KA, Kälber T, de Passillé AM, Knierim U, Barth K and Mejdell CM (2016) Is rearing calves with the dam a feasible option for dairy farms? – current and future research. *Applied Animal Behavior Science* **181**, 1–11.
- Kišac P, Brouček J, Uhrinčar M and Hanus A (2011) Effect of weaning calves from mother at different ages on their growth and milk yield of mothers. *Czech Journal of Animal Science* **56**, 261–268.
- Kung L, Demarco S, Siebenson L, Joyner E, Haenlein G and Morris R (1997) An evaluation of two management systems for rearing calves fed milk replacer. *Journal of Dairy Science* **80**, 2529–2533.
- Mahmoud ME, Mahmoud FA and Ahmed AE (2016) Impacts of self- and cross-sucking on cattle health and performance. *Veterinary World* **9**, 922–928.
- Mandel R and Nicol CJ (2017) Re-direction of maternal behaviour in dairy cows. *Applied Animal Behavior Science* **195**, 24–31.
- Mandel R, Whay HR, Klement E and Nicol CJ (2016) Environmental enrichment of dairy cows and calves in indoor housing. *Journal of Dairy Science* **99**, 1695–1715.
- Mandel R, Wenker ML, van Reenen K, Keil NM and Hillmann E (2019) Can access to an automated grooming brush and/or a mirror reduce stress of dairy cows kept in social isolation? *Applied Animal Behavior Science* **211**, 1–8.
- Mikuš T, Radeski M, Ciszter LT, Dimitrov I, Jurkovich V, Nenadović K, Ostović M, Zupan M and Kirchner MK (2018) The Danube region – on stream with animal welfare assessment in the last 35 years: a review of research on animal welfare assessment in a multi-lingual area in Europe. *Journal of Agricultural and Environmental Ethics* **31**, 511–526.
- Morgan CK (2018) *Evaluation of Single vs. Pair Housing Holstein Calves on Specific Antibody Concentrations to KLH* (Honors Thesis Projects). University of Tennessee, Knoxville, USA
- Newberry RC (1995) Environmental enrichment: increasing the biological relevance of captive environments. *Applied Animal Behaviour Science* **44**, 229–243.
- Ninomiya S and Sato S (2009) Effects of 'Five freedoms' environmental enrichment on the welfare of calves reared indoors. *Animal Science Journal* **80**, 347–351.

- Overvest MA, Crossley RE, Miller-Cushon EK and DeVries TJ** (2018) Social housing influences the behavior and feed intake of dairy calves during weaning. *Journal of Dairy Science* **101**, 8123–8134.
- Pedersen RE, Sørensen JT, Skjøth F, Hindhede J and Nielsen TR** (2009) How milk-fed dairy calves perform in stable versus Dynamic groups. *Livestock Science* **121**, 215–218.
- Pemek JA, Eastridge ML, Botheras NA, Cronney CC and Bowen Yoho WS** (2013) Effects of alternative housing and feeding systems on the behavior and performance of dairy heifer calves. *The Professional Animal Scientist* **29**, 278–288.
- Pemek JA, Eastridge ML, Swartzwelder SS, Daniels KM and Yohe TT** (2016) Housing system may affect behavior and growth performance of Jersey heifer calves. *Journal of Dairy Science* **99**, 569–578.
- Pemek JA, Eastridge ML and Proudfoot KL** (2017) The effect of a furnished individual hutch pre-weaning on calf behavior, response to novelty, and growth. *Journal of Dairy Science* **100**, 4807–4817.
- Svensson C, Lundborg K, Emanuelson U and Olsson S-O** (2003) Morbidity in Swedish dairy calves from birth to 90 days of age and individual calf-level risk factors for infectious diseases. *Preventive Veterinary Medicine* **58**, 179–197.
- Veissier I, Chazal P, Pradel P and Le Neindre P** (1997) Providing social contacts and objects for nibbling moderates reactivity and oral behaviors in veal calves. *Journal of Animal Science* **75**, 356–365.
- Ventura BA, von Keyserlingk MAG, Schuppli CA and Weary DM** (2013) Views on contentious practices in dairy farming: the case of early cow-calf separation. *Journal of Dairy Science* **96**, 6105–6116.
- von Keyserlingk MAG and Hötzel MJ** (2015) The ticking clock: addressing farm animal welfare in emerging countries. *Journal of Agricultural and Environmental Ethics* **28**, 179–195.
- von Keyserlingk MAG and Weary DM** (2017) A 100-year review: animal welfare in the journal of dairy science – The first 100 years. *Journal of Dairy Science* **100**, 10432–10444.
- von Keyserlingk MAG, Brusius L and Weary DM** (2004) Competition for teats and feeding behavior by group-housed dairy calves. *Journal of Dairy Science* **87**, 4190–4194.
- Weary DM, Jasper J and Hötzel MJ** (2008) Understanding weaning distress. *Applied Animal Behavior Science* **110**, 24–41.
- Whalin L, Weary DM and von Keyserlingk MAG** (2018) *Short Communication*: pair housing dairy calves in modified calf hutches. *Journal of Dairy Science* **101**, 5428–5433.