Preventive Veterinary Medicine 184 (2020) 105154

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

# Factors associated with calf mortality and poor growth of dairy heifer calves in northeast Germany

A. Tautenhahn[a,*], R. Merle[b], K.E. Müller[a]

[a] Clinic for Ruminants and Swine, Department of Veterinary Medicine, Freie Universität Berlin, Königsweg 65, D-14163 Berlin, Germany
[b] Institute for Veterinary Epidemiology and Biostatistics, Department of Veterinary Medicine, Freie Universität Berlin, Königsweg 67, D-14163 Berlin, Germany

ARTICLE INFO

*Keywords:*
herd
management
average daily weight gain
failure of passive transfer
animal needs index
serum albumin

ABSTRACT

A cross-sectional study was conducted on fifty German dairy farms to identify risk factors for high mortality and poor growth in calves. Between 2012 and 2014, farm visits took place and a questionnaire on farm management practices was completed by in-person interview. In addition, heart girth measurements of calves around weaning were performed to estimate average daily weight gain. Furthermore, blood and faecel samples of calves were collected and a score addressing calf welfare was determined. The epidemiological associations between risk factors and high mortality and poor growth were estimated using two regression models. The factors significantly associated with high calf mortality (> 5%) were a high rate of calves with failure of passive transfer (> 25%) and the metaphylactic use of halofuginone lactate. A small amount of concentrates consumed around weaning, relocating calves more than twice until weaning and a low incidence risk of milk fever (< 5%) were found to be significantly associated with poor growth (median: 675 grams). Although the fifty farms cannot be considered as a representative sample for North-East Germany, the results indicate that the farm management has a big impact on growth and survival of dairy calves and needs to be addressed more t horoughly when raising the future dairy cow.

## 1. Introduction

Calf health and animal welfare are of interest to producers, consumers and policy-makers (Amon et al., 2014). In detail, high rates of morbidity and mortality lead to huge economic losses, are at odds with animal welfare and with food safety (Bostelmann, 2000; Böckel, 2008). In addition, high rates of morbidity are related to increased use of antibiotics and a marked rise in antimicrobial resistance (World Health Organization, 2014). As a reaction to the importance of the topic the "New Common Animal Health Strategy 2007-2013" was adopted by the European Union in 2007 (European Commission, 2007). In their "One Health" strategy, the European Union perceives human health, animal health and animal welfare as an inseparable complex. With the guiding principle "prevention is better than cure", the purpose of the strategy is to enhance animal health by improving husbandry conditions. Key indicators for fair calf health and welfare are required, because calf health and welfare are difficult to determine. Growth and mortality rates in calves were shown to be suitable indicators to assess calf health and welfare on herd level (Quigley et al., 1996; Santman-Berends et al., 2019).

Growth rates reflect appropriate nutrition and proper feeding strategies of calves on the one hand, but on the other hand, growth rates can be hampered when calves are sick or stressed (Donovan et al., 1998; Roland et al., 2016; Shivley et al., 2018). Furthermore, poor nutrition can cause immune suppression, which can result in disease or even death (Nonnecke et al., 2003; Foote et al., 2005; Fox et al., 2005). Multifactorial diseases as Neonatal Calf Diarrhoea (NCD) and Bovine Respiratory Disease (BRD) form the main threats to calf health and welfare (Reinhardt et al., 2009; Hoedemaker, 2018; Urie et al., 2018a). The latter diseases arise as a result of interactions between husbandry conditions, host factors and pathogens (Mayr, 2002). In particular, NCD and BRD have been shown to be controlled by improving housing conditions as well as enhancing the host's immune defence, by improvement of colostrum management and nutrition as well as minimizing stress by professional stockman ship in animal handling and by reducing the number of pathogens in the calf's environment (Lago et al., 2006;

*Abbreviations:* NCD, Neonatal Calf Diarrhoea; BRD, Bovine Respiratory Disease; ADG, average daily weight gain; FPT, failure of passive transfer; ANI, Animal Needs Index.

* Corresponding author.
*E-mail address:* Annegret.Tautenhahn@fu-berlin.de (A. Tautenhahn).

https://doi.org/10.1016/j.prevetmed.2020.105154
Received 17 December 2019; Received in revised form 7 September 2020; Accepted 15 September 2020
Available online 24 September 2020
0167-5877/

Windeyer et al., 2014; Al Mawly et al., 2015; Urie et al., 2018b).

Previous studies reported average calf mortality rates between 3.3% and 5.3% for Norway, Canada, Switzerland, United States and the Netherlands (Gulliksen et al., 2009; Bleul, 2011; Windeyer et al., 2014; Urie et al., 2018a; Santman-Berends et al., 2019). Few current data is available on calf mortality rates in Germany. Zitzmann et al. (2019) reported an average calf mortality rate of 7.7% for Thuringia in 2006/2007, Hoedemaker (2018) 8.1% for Lower Saxony in 2016 and Sanftleben (2009) 6,4% for Mecklenburg-Western Pomerania in 2007. No data is available on growth rates of preweaned dairy calves and calf rearing practices on German dairy farms.

Identifying risk factors for high dairy calf mortality and poor growth, will contribute to improve housing, feeding and management strategies on German dairies. Therefore, the objective of the present study was to identify factors associated with high mortality (> 5%) in dairy calves during the first six months of life and with poor growth in calves in the first three months of life.

## 2. Materials and methods

### 2.1. Study design and selection of herds

The study was designed as an observational study and consisted of two models. In both models, the herd was the unit of concern. In the model “Risk factors associated with high calf mortality”, a cross-sectional study was conducted with calf mortality, defined as mortality of calves between the second day and sixth month of life, as the dependent variable. At herd level calf mortality was not normally distributed and was therefore dichotomized in herds with high risk of calf mortality (> 5%) and herds with a low risk (≤ 5%). The classification of herds was based on the median calf mortality in the study population in 2012, which is in agreement with the target value for calf mortality of 5% proposed by Roy (1990). In the model “Risk factors associated with median ADG from birth to weaning”, average daily weight gain (ADG) of calves from birth until twelve weeks of life was the dependent variable at herd level.

Due to the limited study period and resources, we decided to enrol a total of 50 dairy herds in the study. For logistical reasons farms had to be located in northeastern Germany (Brandenburg, Saxony, Lower Saxony and Mecklenburg-Western Pomerania). Inclusion criteria for the study were an average herd size of ≥ 50 dairy cows and in-house rearing of calves and heifers. Most farms were enrolled in the projects “Brandenburger Testherden” of the cattle breeders’ association Brandenburg (visited/contacted: n = 20/58) and “Veredelungsland Sachsen 2020” of the state control association of Saxony (visited/contacted: n = 10/10) and were invited to participate in the study by letter (Müller et al., 2016). Additional farms belonged to the clientele of the Clinic for Ruminants and Swine of the Freie Universität Berlin (visited/contacted: n = 15/15) and the Educational and Experimental Institution for Animal Husbandry Echem (visited/contacted: n = 5/5) and were contacted by phone. The first ten letters with invitations were sent out by the project collaborators of the project “Veredelungsland Sachsen 2020” in August 2012 to farms in the project in Saxony. All these farms were visited once until the end of the year. Just seven farms of the clientele of the clinic were contacted by the staff of the clinic and were visited until September 2013 by the corresponding author. Some of these farms have been working together with the clinic for several years; others contacted the clinic due to problems with calf rearing. We offered them to participate in the study as a first diagnostic step. During the study visits no other investigations than on the purpose of this study were made. In October 2013, members of the project “Brandenburger Testherden” and of the Educational and Experimental Institution for Animal Husbandry Echem were asked for help with farm acquisition. Between October 2013 and October 2014 the remaining 33 farms were visited.

Overall, 88 farms were invited to participate in the study. In detail, 68 farms were contacted by letter and 20 farms by phone with a response rate of 44% and 100%, respectively. The overall response rate was 57%, which can be considered a high response rate. All farms entered the study voluntarily.

### 2.2. Data collection

Each herd was visited on a single occasion by the same veterinarian (corresponding author) between September 2012 and October 2014. A questionnaire on farm management practices, morbidity and calf mortality was completed by in-person interview. In addition, blood und faecel samples were obtained to evaluate for failure of passive transfer (FPT), selected metabolic parameters (serum albumin, globulin) and enteropathogens often observed in calves with NCD. Heart girth measurements were conducted around weaning (12th week) to estimate ADG from birth to weaning. Additionally, a score addressing calf welfare (Animal Needs Index by Winckler et al. (1994)) was determined.

All variables were collected and retrieved on farm by a single investigator at a single farm-visit. This made a separate data collection of exposure and outcome variables impossible and therefore rules out blinding of the study. This could lead to biased data what should be in mind when interpreting the results of this study.

### 2.3. Questionnaire

The questionnaire was created hypothesis driven and corresponding to literature (Taffe et al., 2006; Schäffer et al., 2007; Bundesministerium, 2009; Lorenz et al., 2011a; Lorenz et al., 2011b) and comprised 315 mostly open or semi-closed questions. These dealt with the topics: general herd data (16 questions), dry cow management (50), calving and colostrum management (45 + 21), feeding and housing routines (57 + 56) and health management of calves (70). The questionnaire was pretested on two on bovine health specialised veterinarians and adapted afterwards. The visiting veterinarian interviewed herd managers and staff responsible for the animals. Questions were always expressed in the same way, but were explained if the respondent asked for further clarification. The interview lasted approximately two hours. The questionnaire (in German) is available from the corresponding author upon request.

### 2.4. Heart girth measurements

For the determination of ADG, heart girth measurements were used to determine the weight of calves. Depending on farm size up to eleven calves per farm aged around the twelfth week of life were included. Primarily, female calves were selected as male calves are usually sold by dairy farms at an age of two weeks. Male calves or calves 84 days ± 14 days were only included, if no sufficient number of calves fulfilling the inclusion criteria was available. On average 10.6 (SD = 1.16) calves were measured per farm, the lowest number was 6 calves and the highest 11 calves. 16.3% of the farms did not have 11 calves (most common number) in a suitable age belonging to the breed German Holstein at the date of the visit. In particular, on smaller farms the target number of calves was not achieved ($p = 0.051$). The measuring tape Animeter (Albert Kerbl GmbH, Buchbach, Germany) was used. The Animeter has two types of scale: centimetre and kilogramme. In this study we applied the centimetre scale. As described by Heinrichs et al. (1992), heart girth measurements were carried out and the described formula was used to estimate life weight in kilograms for the breed German Holstein. One herd kept mainly the breed Jersey and was excluded from the model “Risk factors associated with median ADG from birth to weaning”, because the calculation of ADG is not suitable for this breed.

### 2.5. Sample collection

Colostral antibody transfer was estimated on basis of serum total protein levels. Samples of up to eleven calves aged two to seven days, regardless of their health or hydration status, were obtained at each farm. On average 7.6 (SD = 3.30) calves were tested per farm, the lowest number was 0 calves and the highest 11 calves. 68% of the farms could not provide the target number of 11 calves (most common number) in an age required for estimation of the success or failure of passive transfer on basis of serum total protein levels at the day of the visit. This was in particular true for smaller farms ($p < 0.001$). The blood samples were obtained from the jugular vein using a blood collection tube without anticoagulant (S-Monovette®, Sarstedt, Nümbrecht, Germany). Samples were transported refrigerated to the Clinic for Ruminants and Swine (FU Berlin) and centrifuged for ten minutes at 3725 rpm and 20 °C (centrifuge: Megafuge 3.0R, Heraeus Holding GmbH, Hanau, Germany). The serum was transferred to another tube and stored at −24 °C until further processing. For examination of appropriate nutrition and health status (albumin, total protein and globulin) of calves before weaning, serum samples were collected from the same calves that were measured for weight.

Faecel samples for detection of enteropathogens as Cryptosporidium parvum, Bovine Rotavirus, Bovine Coronavirus and *E.coli* (F5) were obtained from the rectum of calves, regardless of their faecel consistency and health status of the calf. Gloves were changed between calves. Up to eleven calves on each farm aged from 5 to 28 days, but preferably 8 to 14 days old, were sampled. Sex or breed of the calves were no selection criteria. On average 9.9 (SD = 2.11) calves were tested per farm, the lowest number was 3 calves and the highest 11 calves. 30% of the farms did not have 11 calves (most common number) in the target age at the day of the visit. Age of the sampled calves ranged from 5 to 26 days, on average calves were 11.3 (SD = 3.90) days old. 67.0% of the calves were

| Animal Needs Index | | Age category/ | | | Compartements and age category | | | |
|---|---|---|---|---|---|---|---|---|
| Area of influence | Evaluation point | evaluation type | Maximum points | Given points | 1 E | 2 G1 | 3 G2* | 4 G2* |
| Movement behavior | Movement space per animal | E/ L | 7 | 0 | 0 | | | |
| | Movement space per animal | G1/ L | 7 | 0 | | 0 | | |
| | Movement space per animal | G2/ L | 7 | 2 | | | 2 | 2 |
| | Ground conditions (Slippriness) | E/ L | 4 | 4 | 4 | | | |
| | Ground conditions (Slippriness) | G1/ L | 4 | 0 | | 0 | | |
| | Ground conditions (Slippriness) | G2/ L | 4 | 0 | | | 4 | 0 |
| | Outlet | E-G2/ L | 7 | 0 | 0 | 0 | 0 | 0 |
| | Pasture | E-G2/ L | 7 | 0 | 0 | 0 | 0 | 0 |
| | Number of functional areas | G1/ L | 3 | 2 | | 2 | | |
| | Number of functional areas | G2/ L | 3 | 2 | | | 2 | 2 |
| | **Subtotal** | | **53** | **10** | | | | |
| Feeding behavior | Milk feeding method | E/ L | 7 | 5 | 5 | | | |
| | Milk feeding method | G1/ L | 7 | 6 | | 6 | | |
| | Access to water | E-G1/ L | 4 | 4 | 4 | 4 | | |
| | Access to roughage | E-G2/ L | 5 | 0 | 0 | 0 | 0 | 0 |
| | Animal:feeding place ratio | G1-G2/ L | 5 | 5 | | 5 | 5 | 5 |
| | Width feeding place | G1-G2/ L | 4 | 4 | | 4 | 4 | 4 |
| | Hight feeding place | G1-G2/ L | 4 | 4 | | 4 | 4 | 4 |
| | **Subtotal** | | **36** | **28** | | | | |
| Social behavior | Movement space per animal | G1/ L | 5 | 0 | | 0 | | |
| | Movement space per animal | G2/ L | 5 | 2 | | | 2 | 2 |
| | Contact opportunity 2nd week of life | E/ L | 7 | 1 | 1 | | | |
| | Contact to mother | E/ L | 7 | 0 | 0 | | | |
| | **Subtotal** | | **24** | **3** | | | | |
| Resting behavior | Softness of lying surface | E-G2/ M | 7 | 7 | 7 | 7 | 7 | 7 |
| | Cleanliness of lying surface | E-G2/ M | 5 | 5 | 5 | 5 | 4 | 4 |
| | Slippriness of lying surface | E-G2/ M | 5 | 5 | 5 | 5 | 5 | 5 |
| | Lying space per animal | G1/ L | 4 | 1 | | 1 | | |
| | Lying space per animal | G2/ L | 4 | 2 | | | 4 | 2 |
| | **Subtotal** | | **25** | **20** | | | | |
| Comfort behavior | Cow brush | G1-G2/ L | 2 | 0 | | 0 | 0 | 0 |
| | Group-hoosing 2nd week of life | G1/ L | 5 | 0 | | 0 | | |
| | Access to outlet or pasture | G1-G2/ L | 3 | 0 | | 0 | 0 | 0 |
| | **Subtotal** | | **10** | **0** | | | | |
| Hygiene | Housing system (Stable climate) | G1/ L | 4 | 4 | | 4 | | |
| | Housing system (Stable climate) | G2/ L | 4 | 2 | | | 4 | 2 |
| | Daylight in the stable | G1/ L | 4 | 4 | | 4 | | |
| | Daylight in the stable | G2/ L | 4 | 2 | | | 4 | 2 |
| | Stable smell | G1/ L | 4 | 1 | | 1 | | |
| | Stable smell | G2/ L | 4 | 3 | | | 4 | 3 |
| | Quality bedding | E-G2/ L | 3 | 3 | 3 | 3 | 3 | 3 |
| | Access to outlet/ pasture | E-G2/ L | 3 | 0 | 0 | 0 | 0 | 0 |
| | **Subtotal** | | **30** | **19** | | | | |
| Supervision | Functionality of stable equipemnt | A | 3 | 3 | | | | |
| | Cleanliness feeding/drinking places | A | 3 | 3 | | | | |
| | Cleanliness of animals and skin | A | 3 | 3 | | | | |
| | Cleanliness outlet | A | 2 | 0 | | | | |
| | Body condition | A | 2 | 1 | | | | |
| | Dehorning status | A | 3 | 0 | | | | |
| | Documentation | A | 4 | 3 | | | | |
| | **Subtotal** | | **20** | **13** | | | | |
| **ANI** | **Total** | | **198** | **93** | | | | |

**Fig. 1.** Summary of the ANI** result of one farm showing the seven areas of influence and all evaluation points and their impact on final results.
E - individual housing (first two weeks); G1 – group housing (until weaning); G2 – group housing (until six month of life); A – all calves; L – lowest count; M - mean.
* Each compartment in an age group was assessed separately.
** Winckler et al. (1994).

between 8 and 14 days, 15.1% were younger and 17.9% were older. The samples were transported refrigerated into the Clinic for Ruminants and Swine (FU Berlin) and stored at −24 °C until further analysis.

### *2.6. Laboratory analyses of samples*

All laboratory analyses were performed at the laboratory of the Clinic for Ruminants and Swine (FU Berlin). Thawed serum samples were analyzed at a temperature of 20 °C using an open random access chemistry analyzer (Cobas Mira Plus, Hoffmann La Roche, Basel, Switzerland). Serum albumin levels were determined by bromocresol green test and serum total protein levels by biuret test. The globulin concentration was calculated by subtraction of albumin content from total protein content.

For the detection of Cryptosporidium parvum, Bovine Rotavirus, Bovine Coronavirus and *E.coli* (F5) antigen the enzyme linked immunosorbent assay (ELISA) BIO K348 (Bio-X Diagnostics, Rochefort, Belgium) was used. The test was carried out following the operating instructions.

### *2.7. Animal Needs Index*

For evaluation of husbandry conditions with respect to calf welfare a modified version of the Animal Needs Index 94 for calves (Tiergerechtheitsindex 94 für Kälber) described by Winckler et al. (1994) was applied. The Animal Needs Index (ANI) for calves covers seven areas of influence: movement behavior, feeding behavior, social behavior, resting behavior, comfort behavior, hygiene and supervision. In each area of influence, several parameters are graded using a score. A farm can achieve a maximum of 198 points for very suitable conditions with respect to animal welfare. Except "supervision", that is evaluated just once over all calves (A), all areas of influence have to be assessed in three age categories: first two weeks of life (E), third week of life until weaning (G1) and weaning until calves are six months old (G2). Evaluation points that were assessed in different compartments and age groups were summarized to one value by just counting the lowest allocated points (L) or by building the average number of points (M). An example of the ANI results of a farm is presented in Fig. 1, showing all evaluation points of the area of influences and how these are summarized.

For determination of physical dimensions of stall and stall facilities, an electronic distance meter (BOSCH DLE 40 Laser-Entfernungsmesser, Robert Bosch GmbH, Gerlingen-Schillerhöhe, Germany) and a carpenter's rule were used. The modified version of the Animal Needs Index (in German) is available from the corresponding author upon request.

### *2.8. Data analyses*

#### *2.8.1. Data management*

Calf mortality risk was calculated as follows:

$$\text{Calf mortality } (\%) = \frac{\text{number of dead calves (2nd day until six month of life) in 2012}}{\text{number of born and alive calves in 2012}} \cdot 100\%$$

The number of born and alive calves as well as the number of dead calves were exported from herd management programs (big farms) or if not available from the farm book (small farms). Farmers in Germany have to report all movement notifications (arrival and exit of all farm animals; e.g. birth, death) to a central database (HI-Tier). Most herd management programs are linked to HI-Tier, so that retrieved data should correspond to official records in HI-Tier. Data concerning birth and death, that are noted in farm books, needs to be transferred to the database HI-Tier within seven days.

ADG was calculated as follows:

$$\text{ADG (gramm per day)} = \frac{\text{measured body weight (kg)} - 43\text{ kg}}{\text{age of the calf (days)}} \cdot \frac{1000\,g}{kg}$$

The average birth weight of 43 kg refers to Trilk and Münch (2008), who determined the birth weights for the breed German Holsten in Northern Germany.

Data at individual calf level from blood and faecel testing as well as from heart girth measurements were transformed into data at herd level using the herd median or percentage of calves. The cut-off value for FPT and successful antibody transfer was set at $< 55$ g/l and $\geq 55$ g/l, respectively, as recommended by Vandeputte et al. (2011) when the biuret-test for serum total protein examination is applied. At herd level, the percentage of calves with FPT was used for further analyses. Serum albumin levels in calves around the twelfth week of life was used to evaluate appropriate nutrition and health status before weaning. The authors assumed a threshold value of $< 33$ g/l serum albumin to be an indicator for malnourishment (and chronic disease) of preweaned calves. At herd level, the percentage of calves with low serum albumin was used for further analyses.

After execution of the ANI, the results were transferred into score values for each area of influence. At herd level results were expressed as percentage of the achieved score from maximum possible score value in each area of influence. For example: a farm with 13 points in the area of influence "supervision" (maximum possible score value: 20 points) achieved 65% of all possible points in this area of influence.

Due to possible information bias, we excluded the incidence risks of NCD, BRD and navel-ill as outcome variables. Diseases were treated at very different degrees of severity and most farmers estimated all incidence risks freely. Others counted the cases out of the treatment register (herd management program or stable book) and calculated incidence risks by dividing counted cases by the number born alive calves for NCD, BRD and navel-ill and by the number of calvings for milk fever and ketosis in the past twelve month before farm visit. Because of the importance of these variables for the outcome variables calf mortality and ADG we kept them in these models. Due to the convenience sampling strategy of farms selection bias cannot be ruled out. Confounding was controlled by including potential confounders in the multivariable regression models.

Before statistical analyses the data set was revised by using data cleaning techniques as removing duplicate data and correcting or marking obviously incorrect data. Missing or incorrect data was marked as missing values.

### *2.9. Statistical analyses*

All statistical analyses were performed using the software SPSS (Version 20.0, SPSS Inc. 2012, USA). For the investigation of associations between potential risk factors with calf mortality and ADG from birth to weaning a multivariable model each was built.

At first, the large data set was reduced. Therefore, descriptive analyses of all data at herd level were performed. Continuous not normally distributed data was dichotomized or categorized. Potential risk factors were eliminated from further analyses if they were lacking variance ($<$ 5% observations per category in binary outcomes), were missing biological causality or had too many missing values ($>$ 20%, except for

**Table 1**
List of potential risk factors included in risk analyses, their categorization and observed frequencies at herd level.

| variable | category | number of herds | missing |
|---|---|---|---|
| Calf mortality risk 2012 | ≤ 5.0% | 25 | 0 |
| | > 5.0% | 25 | |
| ADG from birth to weaning | Normally distributed | 50 | 0 |
| **Blood samples** | | | |
| Serum total protein concentration in the first week of life | Normally distributed | 48 | 2 |
| Percentage of calves with FPT | ≤ 25% | 9 | 2 |
| | > 25% | 39 | |
| Serum albumin concentration around weaning | Normally distributed | 49 | 1 |
| Percentage of calves with a concentration of serum albumin < 33 g/l around weaning | ≤ 25% | 30 | 1 |
| | > 25% | 19 | |
| Serum globulin concentration around weaning | Normally distributed | 49 | 1 |
| **ANI for calves** | | | |
| Area of influence: movement behavior in % | Normally distributed | 50 | 0 |
| Area of influence: feeding behavior in % | Normally distributed | 50 | 0 |
| Area of influence: hygiene in % | Normally distributed | 50 | 0 |
| Area of influence: supervision | ≥ 65% | 31 | 0 |
| | < 65% | 19 | |
| **Faecel samples** | | | |
| Percentage of faecel samples tested positive for *Bovine Rotavirus* | ≤ 20% | 30 | 0 |
| | > 20% | 20 | |
| **General farm characteristics** | | | |
| Cow number at visit | < 300 | 8 | 0 |
| | 300 - 800 | 33 | |
| | > 800 | 9 | |
| Average age at first calving | ≤ 26 month | 39 | 0 |
| | > 26 month | 11 | |
| Average milk yield per year | ≤ 9800 kg | 22 | 8 |
| | > 9800 kg | 20 | |
| **Dry cow management** | | | |
| Incidence risk of ketosis (treatment) | ≤ 5.0% | 30 | 4 |
| | > 5.0% | 16 | |
| Incidence risk of milk fever (treatment) | ≤ 5.0% | 30 | 0 |
| | > 5.0% | 20 | |
| **Calving management** | | | |
| Moving dry cows in to the maternity pen in days before expected parturition | ≤ 2 days | 21 | 0 |
| | > 2 days | 29 | |
| Cleaning interval of the maternity pen | ≤ 7 days | 33 | 0 |
| | > 7 days | 17 | |
| Disinfection of the maternity pen | no | 21 | 0 |
| | yes, but not against cryptosporidia | 17 | |
| | yes, against cryptosporidia | 12 | |
| Separation of maternity pen and box for sick cows | no | 13 | 0 |
| | next to each other | 15 | |
| | yes | 22 | |
| Time per day without staff at the farm | ≤ 2 hours | 15 | 1 |
| | > 2 hours | 34 | |
| Availability of a guideline on how to do calving assistance | no | 29 | 0 |
| | yes | 21 | |
| Average time interval before moving the calf out of the maternity pen | ≤ 2 hours | 33 | 0 |
| | > 2 hours | 17 | |
| **Colostrum management** | | | |
| Maximal time interval between calving and harvesting first colostrum of the dam | ≤ 2 hours | 13 | 0 |
| | > 2 - 8 hours | 16 | |
| | > 8 hours | 21 | |
| Use of heifer colostrum for the first meal | never | 7 | 0 |
| | sometimes | 15 | |
| | always | 28 | |
| Conservation of colostrum | yes, frozen | 29 | 0 |
| | no | 11 | |
| | yes, refrigerated | 10 | |
| Latest feeding of first colostrum to newborn calves (hours post natum) | | | 1 |

**Table 1** (*continued*)

| variable | category | number of herds | missing |
|---|---|---|---|
| | ≤ 2 hours | 20 | |
| | > 2 - 4 hours | 9 | |
| | > 4 hours | 20 | |
| Volume of first colostrum offered at first meal | ≥ 3.0 l | 32 | 0 |
| | < 3.0 l | 18 | |
| First colostrum offered at second meal | no | 21 | 0 |
| | partly | 16 | |
| | yes | 13 | |
| **Feeding management** | | | |
| Maximum volume of milk/ milk replacer per day before weaning | ≥ 9.0 l | 23 | 0 |
| | < 9.0 l | 27 | |
| Composition of liquid feed in the third and fourth week of life | milk replacer < 30% skim milk or dilution of whole milk with > 15% water | 9 | 0 |
| | milk replacer ≥ 30% skim milk or dilution of whole milk with ≤ 15% water | 41 | |
| Adoption of milk replacer | no adoption or not earlier than the fourth week of life | 8 | 0 |
| | adoption in the second or third week of life | 21 | |
| | adoption in the first week of life | 21 | |
| Interval between calibration checks of automated milk feeding systems | at least once a week or no use of automated milk feeding systems | 18 | 0 |
| | at least once a month | 15 | |
| | less than once a month | 17 | |
| Age at weaning (days) | Normally distributed | 50 | 0 |
| Age at first offer of water to calves (all-season) | ≤ 7 days | 22 | 0 |
| | > 7 days | 28 | |
| Age at first offer of hay to calves | ≤ 7 days | 14 | 0 |
| | > 7 days | 27 | |
| | not before weaning | 9 | |
| Age at first offer of concentrates to calves | ≤ 14 days | 36 | 0 |
| | > 14 days | 14 | |
| Amount of concentrates consumed around weaning in kg | Normally distributed | 34 | 16 |
| **Housing management** | | | |
| Age at moving calves to group pens in days | Normally distributed | 50 | 0 |
| Cleaning interval in group pens of the youngest calves | ≤ 14 days | 32 | 0 |
| | > 14 days | 18 | |
| Frequency of relocation of calves between birth and weaning | ≤ 2 relocations | 24 | 0 |
| | > 2 relocations | 26 | |
| Air space per calf in group pens of the youngest calves | ≥ 8 $m^3$ | 28 | 1 |
| | < 8 $m^3$ | 21 | |
| Change between stalls with warm climate and outdoor climate housing before weaning | change | 31 | 0 |
| | no change | 19 | |
| **Health management** | | | |

(*continued on next page*)

**Table 1** (*continued*)

| variable | category | number of herds | missing |
|---|---|---|---|
| Incidence risk of NCD (treated calves) | ≤ 15% | 26 | 3 |
| | > 15% | 21 | |
| Incidence risk of BRD (treated calves) | ≤ 15% | 23 | 3 |
| | > 15% | 24 | |
| Incidence risk of navel-ill (treated calves) | ≤ 2% | 25 | 5 |
| | > 2% | 20 | |
| Preventive treatment of the navel | no | 11 | 0 |
| | Chlortetracycline spray | 13 | |
| | Iodine | 26 | |
| Manipulation of the navel at birth | no manipulation | 45 | 0 |
| | manipulation (cut) | 5 | |
| Use of halofuginone lactate | no | 27 | 0 |
| | yes | 23 | |
| Interruption of milk feeding for calves with NCD | maximum one meal | 31 | 0 |
| | more than one meal | 19 | |
| Dehorning method | hot iron | 31 | 2 |
| | caustic paste or liquid | 17 | |
| Vaccination against respiratory pathogens | no | 24 | 1 |
| | yes | 25 | |
| Vaccination against ringworm | no | 13 | 0 |
| | yes | 37 | |

"Amount of concentrates consumed around weaning in kg" in the model for poor growth). Then all variables were tested for correlation using the Spearman's rank correlation coefficient. If the correlation coefficient was above 0.6, only the factor with the better biological plausibility was selected for further analyses. The remaining potential risk factors as well as categories and observed frequencies are summarized in Table 1.

The associations of calf mortality (binary: ≤ 5%, > 5%) with potential risk factors (n = 52) were tested in univariable analyses. Candidate variables with binary outcome were tested using chi-square-test and those with categorical or continuous outcome using logistic regression. Factors with a p-value ≤ 0.2 (n = 16) qualified for multivariable analysis. Due to a limited number of herds (n = 50) in the study the number of candidate variables was reduced according to the p-value to a maximum of seven candidate variables. In the first step, the multivariable logistic regression model was reduced by using a manual stepwise backward procedure, with $p < 0.1$ as criterion for retention. In the second step, excluded variables were re-entered one by one. The final model only included variables that were significant at a significance level of $p < 0.05$. Confounding and interaction effects were considered in the model. In the end, no confounders were discovered in the model and none of the two-way interactions were significant in the model and therefore, all interaction terms were removed. The fit of the model "Risk factors associated with high calf mortality" was evaluated with the Omnibus test of model coefficients based on Chi-square test with a significant test result proving that the null hypothesis can be rejected and the Cox & Snell R-squared indicating an acceptable fit of the model with $R^2 > 0.2$.

In the model "Risk factors associated with median ADG from birth to weaning" the associations of median ADG at herd level (continuous) with potential risk factors (n = 53) were tested in univariable analyses. Candidate variables with binary outcome were tested using Student's t-test, those with categorical outcome using analysis of variance (ANOVA) and with continuous outcome using linear regression. Factors with a p-value ≤ 0.2 (n = 25) qualified for multivariable analysis. As described in the previously model a maximum of seven candidate variables were included in a multivariable linear regression model. The potential risk factor "amount of concentrates consumed around weaning" was used in the model with an adjusting factor to weight the observations, to account for heteroscedasticity of the data (weighting was done using "weighted least squares"). Further analysis was performed as described above. In the model "Risk factors associated with median ADG from birth to weaning", the fit of the model was evaluated with the adjusted R-squared and by assessing the residuals. Plots of the standardized residuals against the predicted values were observed for their pattern and distribution and for outliers.

## 3. Results

### 3.1. Descriptive data

Herd size ranged from 70 to 1414 cows (median: 419 cows) with a median milk yield of 9800 kg per cow and year (range: 7680 – 12000 kg). Median calf mortality risk in 2012 was 5.0% (range: 0.0% - 17.7%). Herd characteristics of low and high mortality herds are presented in Table 2.

Median herd level incidence risk for NCD, BRD and navel-ill in calves (treatment) was 12.0% (range: 0.0% - 90.0%, Q 25%: 5.0%; Q 75%: 27.0%), 17.5% (range: 0.1% - 90.0%, Q 25%: 9.4%; Q 75%: 30.0%) and 1.6% (range: 0.0% - 30.0%, Q 25%: 1.0%; Q 75%: 4.2%), respectively. Median herd level incidence risk for milk fever and ketosis treatment of dairy cows was 4.6% (range: 1.0% - 35.0%, Q 25%: 3.0%; Q 75%: 6.7%) and 3.1% (range: 0.5% - 46.0%, Q 25%: 1.5%; Q 75%: 6.6%), respectively.

Median ADG from birth to weaning was 675 grams (range: 414 – 1027 grams). 51.1% of herds had ADGs at herd level of less than 700 grams and 8.2% of 900 grams and more. Median ADG was tested for seasonal effects, but no differences between seasons were observed.

378 calves of 48 farms were tested for FPT in their first week of life. Two farms had no calf aged seven days or less at the day of visit. At herd level, a median of 63.6% calves had FPT (range: 0.0% - 100.0%). 81.3% of the herds had at least 25% calves per herd with FPT indicating insufficient colostrum management on the farm. FPT at herd level was tested for seasonal effects. Farms visited in autumn had a higher proportion of calves with FPT compared to farms visited in winter (p = 0,077).

Serum albumin, total protein and globulin levels were determined in 518 calves around weaning with a herd median of 34.7 g/l (range: 29.5 g/l – 37.4 g/l), 60.9 g/l (range: 52.0 g/l – 72.1 g/l) and 25.5 g/l (range: 18.7 g/l – 37.6 g/l), respectively. 40.0% of the herds had at least 25% calves per herd with a serum albumin concentration < 33.0 g/l. The authors assume a threshold value of ≥ 33 g/l serum albumin to be an indicator for malnourishment of preweaned calves.

497 faecel samples from calves between 5 and 28 days of life were tested for enteropathogens. At herd level, a median of 72.7% (range: 0.0% - 100.0%), 15.4% (range: 0.0% - 72.7%), 0.0% (range: 0.0% - 28.6%) and 0.0% (range: 0.0% - 25.0%) were tested positive for Cryptosporidium parvum, Bovine Rotavirus, Bovine Coronavirus and *E. coli (F5)* antigen, respectively. Relevant descriptive data of the questionnaire and the ANI is presented in a summarized form in Table 1.

**Table 2**
Herd characteristics of herds with low calf mortality (≤ 5%) and high calf mortality (> 5%) in 50 German dairy herds, visited between September 2012 and October 2014.

| Herd characteristics | Low calf mortality | High calf mortality |
|---|---|---|
| Number of herds | 25 | 25 |
| Median calf mortality risk | 2.9 (Q 25%: 2.2; Q 75%: 4.0) | 7.1 (Q 25%: 5.5; Q 75% 8.7) |
| Median herd size | 447 (Q 25%: 327; Q 75%: 602) | 402 (Q 25%: 340; Q 75%: 493) |
| Median milk yield (kg per cow and year) | 9920 (Q 25%: 9384; Q 75%: 10922) | 9798 (Q 25%: 9425; Q 75%: 9873) |
| Mean age at weaning (days) | 76.7 (SD = 10.5) | 76.4 (SD = 11.2) |

**Table 3**
Results from univariable analyses of candidate variables with respect to their association with type of herd (high calf mortality > 5% and low calf mortality ≤ 5%) in 50 German dairy herds, visited between September 2012 and October 2014.

| Variable | category | Low calf mortality | High calf mortality | p-value |
|---|---|---|---|---|
| ADG from birth to weaning in g/day [b,c] | Median | 739 | 663 | 0.096 |
| Serum total protein concentration in the first week of life in g/l [b] | Median | 53.9 | 52.8 | 0.110 |
| Percentage of calves with FPT [a,c] | ≤ 25% | 7 | 2 | 0.068 |
| | > 25% | 16 | 23 | |
| Serum albumin concentration around weaning in g/l [b] | Median | 34.8 | 34.2 | 0.141 |
| Disinfection of the maternity pen [b,c] | no | 13 | 8 | 0.111 |
| | yes, but not against cryptosporidia | 9 | 8 | |
| | yes, against cryptosporidia | 3 | 9 | |
| Separation of maternity pen and box for sick cows [b,c] | no | 5 | 8 | 0.090 |
| | next to each other | 11 | 4 | |
| | yes | 9 | 13 | |
| Time per day without staff at the farm [a] | ≤ 2 hours | 10 | 5 | 0.146 |
| | > 2 hours | 15 | 19 | |
| Maximal time interval between calving and harvesting first colostrum of the dam [b] | ≤ 2 hours | 8 | 5 | 0.130 |
| | > 2 - 8 hours | 10 | 6 | |
| | > 8 hours | 7 | 14 | |
| Latest feeding of first colostrum to newborn calves (hours post natum) [b] | ≤ 2 hours | 12 | 8 | 0.140 |
| | > 2 - 4 hours | 2 | 7 | |
| | > 4 hours | 11 | 9 | |
| First colostrum offered at second meal [b] | no | 7 | 14 | 0.130 |
| | partly | 10 | 6 | |
| | yes | 8 | 5 | |
| Age at first offer of water to calves (all-season) [a,c] | ≤ 7 days | 14 | 8 | 0.087 |
| | > 7 days | 11 | 17 | |
| Age at first offer of hay to calves [b,c] | ≤ 7 days | 11 | 3 | 0.033 |
| | > 7 days | 10 | 17 | |
| | not before weaning | 4 | 5 | |
| Amount of concentrates consumed around weaning in kg [b] | Normally distributed | 1.5 | 1.0 | 0.072 |
| Change between stalls with warm climate and outdoor climate housing before weaning [a] | change | 18 | 13 | 0.145 |
| | no change | 7 | 12 | |
| Use of halofuginone lactate [a,c] | no | 19 | 8 | 0.002 |
| | yes | 6 | 17 | |
| Interruption of milk feeding for calves with NCD [a] | maximum one meal | 18 | 13 | 0.145 |
| | more than one meal | 7 | 12 | |

a – chi-square-test; b – logistic regression; c – candidate variables for multivariable model.

### 3.2. Risk factors associated with high calf mortality

Results from univariable analyses are presented in Table 3. Seven of these variables were introduced to the model "*Risk factors associated with high calf mortality*" chosen by the lowest p-value in univariable analysis. The factor "Amount of concentrates consumed around weaning" ($p = 0.072$) was not introduced in the model, because it had too much missing data (16 farms). At the end of the manual backward selection process, the variables "Use of halofuginone lactate" ($p = 0.002$) and "Percentage of calves with FPT" ($p = 0.040$) remained in the multivariable logistic regression model (Table 4). The R-squared of 0.376 showed that a substantial part of the differences between farms could be explained by this model. Farms that used halofuginone lactate to control for cryptosporidiosis in newborn calves had 10.0 times higher odds to have a calf mortality risk above 5% (95% confidence interval 2.3 – 43.4). FPT in calves proofed to be a risk factor for high calf mortality. More than 25% of calves with FPT in the herd increased the odds of having a high calf mortality risk by 8.1 times (95% confidence interval 1.1 – 58.7).

**Table 4**
Results from multivariable binary logistic regression model showing the association between various risk factors and type of herd (high calf mortality > 5% and low calf mortality ≤ 5%) in 50 German dairy herds, visited between September 2012 and October 2014.

| Variable | category | *b* | SE (*b*) | OR | 95% CI | p-value |
|---|---|---|---|---|---|---|
| Intercept | | −2.639 | 0.749 | 0.07 | | 0.012 |
| Percentage of calves with FPT* | ≤ 25% | referent | 1.014 | 8.05 | 1.10-58.70 | 0.040 |
| | > 25% | 2.303 | | | | |
| Use of halofuginone lactate | no | referent | 1.049 | 10.00 | 2.31-43.37 | 0.002 |
| | yes | 2.086 | | | | |

* 2 missing values.

### 3.3. Risk factors associated with median ADG from birth to weaning

Results from univariable analyses are presented in Table 5. Seven of these variables were introduced into the model "*Risk factors associated with median ADG from birth to weaning*" selected by the lowest p-value in univariable analyses. After manual backward selection, the variables "Amount of concentrates consumed around weaning" ($p < 0.001$), "Frequency of relocation of calves between birth and weaning" ($p < 0.001$) and "Incidence risk of milk fever" ($p = 0.001$) remained in the final multivariable linear regression model (Table 6) and explained 72.8% of the variance between herds (adjusted R-squared). The amount of consumed concentrates around weaning was associated with ADG until weaning. Median ADG increased by 160 grams (95% confidence interval 107 – 213) at herd level. Frequent relocation of calves turned out to be a risk factor for poor growth until weaning. Calves that were relocated on the same farm more than twice from birth until weaning gained 119 grams per day less until weaning than calves that were relocated not more than twice (95% confidence interval -172 – -67). Farms with a high incidence risk of milk fever treatment in periparturient cows (> 5%) had 115 grams more ADG until weaning than farms with a lower incidence risk (95% confidence interval 55 – 175).

## 4. Discussion

### 4.1. Risk factors associated with calf mortality above 5%

#### 4.1.1. Multivariable model for risk factors associated with high calf mortality

FPT of more than 25% of the neonatal calves in a herd was associated with high calf mortality. This finding is in accordance with results of previous studies demonstrating that total serum protein levels below 55 g/l in neonatal calves are a risk factor for lethal outcome (Rea et al., 1996; Tyler et al., 1998; Torsein et al., 2011).

In the present study, Cryptosporidium parvum was detected in faecel samples obtained from calves on 49 (98%) farms with a median percentage of 72.7% of calves between 5 and 28 days of age. Halofuginone lactate was administered to all neonatal calves on nearly half (46%) of the farms visited. Farms on which routine administration of halofuginone lactate was performed had 10.0 times higher odds for calf mortality risk above 5%. Similar observations were made by Fourichon et al. (1997), who observed a higher mortality in neonatal calves on

**Table 5**
Results from univariable analyses of candidate variables with respect to median ADG of calves from birth until weaning (herd level) in 50 German dairy herds, visited between September 2012 and October 2014

| Variable | Category | Median ADG in grams per day | p-value |
|---|---|---|---|
| Calf mortality risk 2012 [a] | ≤ 5.0%<br>> 5.0% | 739<br>663 | 0.092 |
| Serum total protein concentration in the first week of life [c] | Median | +8 g/day per g/l | 0.116 |
| Serum albumin concentration around weaning [c] | Median | +46 g/day per g/l | < 0.001 |
| Percentage of calves with a concentration of serum albumin < 33 g/l around weaning [a] | ≤ 25%<br>> 25% | 719<br>631 | 0.029 |
| Serum globulin concentration around weaning [c] | Median | - 8 g/day per g/l | 0.141 |
| ANI for calves - area of influence: feeding behavior in % [c] | Normally distributed | +3 g/day per % | 0.093 |
| ANI for calves – area of influence: supervision [a,d] | ≥ 65%<br>< 65% | 738<br>571 | 0.002 |
| Incidence risk of ketosis (treatment) [a] | ≤ 5.0%<br>> 5.0% | 662<br>745 | 0.178 |
| Incidence risk of milk fever (treatment) [a,d] | ≤ 5.0%<br>> 5.0% | 608<br>745 | 0.002 |
| Cleaning interval of the maternity pen [a,d] | ≤ 7 days<br>> 7 days | 663<br>795 | 0.001 |
| Separation of maternity and box for sick cows [b] | no<br>next to each other<br>yes | 795<br>734<br>647 | 0.060 |
| Time per day without staff at the farm [a] | ≤ 2 hours<br>> 2 hours | 738<br>635 | 0.024 |
| Maximal time interval between calving and harvesting first colostrum of the dam [b] | ≤ 2 hours<br>> 2 - 8 hours<br>> 8 hours | 739<br>631<br>652 | 0.019 |
| Volume of first colostrum at first meal [a] | ≥ 3,0 l<br>< 3,0 l | 736<br>629 | 0.031 |
| Age at weaning (days) [c] | Normally distributed | - 3 g/day per day | 0.141 |
| Age at first offer of hay to calves [b] | ≤ 7 days<br>> 7 days<br>not before weaning | 671<br>652<br>770 | 0.025 |
| Age at first offer of concentrates to calves [a,d] | ≤ 14 days<br>> 14 days | 719<br>581 | 0.015 |
| Amount of concentrates consumed around weaning in kg [c,d] | Normally distributed | +130 g/day per kg | 0.004 |
| Cleaning interval in group pens of the youngest calves [a,d] | ≤ 14 days<br>> 14 days | 635<br>754 | 0.018 |
| Frequency of relocation of calves between birth and weaning [a,d] | ≤ 2 relocations<br>> 2 relocations | 739<br>632 | 0.017 |
| Incidence risk of NCD (treated calves) [a] | ≤ 15%<br>> 15% | 731<br>663 | 0.120 |
| Preventive treatment of the navel [b] | no<br>Chlortetracycline spray<br>Iodine | 590<br>671<br>737 | 0.139 |
| Interruption of milk feeding for calves with NCD [a] | maximum one meal<br>more than one meal | 725<br>671 | 0.051 |
| Dehorning method [a] | hot iron<br>caustic paste or liquid | 713<br>633 | 0.061 |
| Vaccination against ringworm [a] | no<br>yes | 630<br>675 | 0.125 |

a – Student's t-test; b – ANOVA; c – linear regression; d – candidate variables for multivariable model.

farms applying medical prevention for digestive disorders. One explanation could be that farms with high risk of calf mortality due to NCD use halofuginone lactate more often than farms with less problems with NCD. In contrast to these observations, other researchers demonstrated the beneficial effect of metaphylactic halofuginone treatment (Keidel and Daugschies, 2013). A toxic effect of halofuginone lactate as reason for increased calf mortality is unlikely as Villacorta et al. (1991) observed toxic side effects at much higher dosages (500 μg/kg BW) than those recommended by producers (5-10 μg/kg).

**Table 6**
Results from multivariable linear regression model showing the association between various risk factors and median ADG of calves from birth until weaning (herd level) in 50 German dairy herds, visited between September 2012 and October 2014.

| Variable | category | B | SE (B) | 95% CI (B) | p-value |
|---|---|---|---|---|---|
| Intercept | | 587 | 37.9 | 509 - 664 | < 0.001 |
| Incidence risk of milk fever (treatment) | ≤ 5.0%<br>> 5.0% | referent<br>115 | 29.6 | 54 - 175 | 0.001 |
| Amount of concentrates consumed around weaning in kg*,** | Normally distributed | 160 | 26.0 | 107 - 213 | < 0.001 |
| Frequency of relocation of calves between birth and weaning | ≤ 2<br>> 2 | referent<br>-119 | 25.7 | −172 - -67 | < 0.001 |

* 16 missing values.
** Weighted regression with least squares (-1.9 x amount of concentrates$^2$).

### 4.2. Univariable analyses for risk factors associated with high calf mortality

Risk factors that did not remain in the multivariable model for high calf mortality, but showed a significant ($p < 0.05$) association with calf mortality, are discussed in this section.

The risk factor “age at first offer of hay” did not remain in the model although no offer of hay in the first days of life compared to early supply was associated with higher calf mortality in the univariable analysis ($p = 0.033$). Torsein et al. (2011) and Perez et al. (1990) observed lower calf mortality rates on farms that offered roughage to calves from the first week of life onwards compared to those farms that offered roughage shortly before weaning. Perez et al. (1990) assumed that the supply of roughage to neonatal calves enhances early rumen development. In practice, feeding concentrates to young calves is preferred to offering hay as concentrates were proven to enhance rumen development more efficiently than hay (Noci, 2010). In addition, hay feeding was shown to reduce the amount of concentrates consumed (Žitnan et al., 1998). Early supply of high amounts of concentrates without any roughage was shown to cause hyperkeratosis and clumping of rumen papillae. To this end, the hay provided is thought to prevent hyperkeratosis of rumen papillae by evoking a scratching effect on the rumen epithelium (Suárez et al., 2007; Noci, 2010).

### 4.3. Risk factors associated with median ADG from birth to weaning

#### 4.3.1. Multivariable Model for risk factors associated with median ADG from birth to weaning

Promoting solid feed intake of calves during the pre-weaning period has a positive effect on rumen development and facilitates the transition from milk to solid feed at weaning (Khan et al., 2011b). The intake of high amounts of concentrates in the pre-weaning period was associated with high ADG until weaning (+ 130 ADG per kg concentrates). This is in line with the results of Bateman et al. (2012) who noted up to 430 grams extra weight gain for each kg of concentrate intake. Place et al. (1998) did not observe a relation between ADG before weaning and the amount of concentrates consumed, however a relation was demonstrated between ADG and the amount of dry matter intake. Especially on farms with restricted milk feeding, an early and abundant offer of concentrates could be crucial for successful transition of the weaning period (Roth et al., 2009).

Relocating calves more than twice from birth until weaning was related to lower ADG. Corresponding observations were made by Mormède et al. (1990) and Siegel and Latimer (1975) in rats and chickens. As a result of repeated regrouping and relocation, animals showed signs of chronic stress such as aggression against herd mates and insufficient ADG. Veissier et al. (2001) did not observe adverse effects on ADG due to regrouping and relocating of calves but measured an increased stress response compared to controls. They suspected a negative effect of regrouping and relocation on ADG and calf health under field conditions when more than two calves form a group. More research is needed to confirm their assumptions.

The association between incidence risk of milk fever in dairy cows and ADG in calves was an unexpected result. Calves showed higher ADG on farms with a higher milk fever incidence risk. This result is in contrast to former publications that describe significant health implications for both dams and calves on farms with a high milk fever incidence risk, among these, dystocia and the weak calf syndrome (Gröhn et al., 1989; Houe et al., 2001; Wilhelm et al., 2017). Weak calves consume less first colostrum, fall ill more often and have reduced ADG (Besser et al., 1990; Wittum and Perino, 1995; Weaver et al., 2000). One explanation for our findings could be a higher percentage of cows with $\geq 3$ parities on farms with higher incidence risk of milk fever treatment. Milk fever is usually a disease of dairy cows in their third lactation or beyond (Correa et al., 1993). At the same time multipara have richer first colostrum (Tyler et al., 1999; Scholz et al., 2011) and therefore their offspring has a decreased risk of FPT, sickness and reduced ADG (Robison et al., 1988; Wittum and Perino, 1995; Windeyer et al., 2014).

#### 4.3.2. Univariable analyses for risk factors associated with median ADG from birth to weaning

Risk factors that did not remain in the multivariable model for median ADG, but showed a significant ($p < 0.05$) association with ADG, are discussed in this section.

As expected the risk factors “time per day without staff at the farm” ($p = 0.024$) and “maximal time interval between calving and harvesting first colostrum of the dam” ($p = 0.019$) were associated with ADG. A precondition for early first colostrum harvesting is that staff members are present to take over the latter task. In our study, collecting first colostrum within two hours after calving at maximum versus a more extended period was associated with better growth in neonatal calves. Several studies proved before, that a delay in first colostrum harvesting leads to reduced immunoglobulin G concentrations due to the diluting effect of milk synthesis in the freshly calved cow (Moore et al., 2005; Morin et al., 2010; Scholz et al., 2011). Calves that consume first colostrum with low concentrations of immunoglobulin G have a higher risk of FPT (Besser et al., 1991) and thus are at risk for diseases and poor growth (Robison et al., 1988; Wittum and Perino, 1995; Windeyer et al., 2014).

Feeding at least three litres of first colostrum at first meal was associated with higher weight gains before weaning ($p = 0.031$). This finding is in accordance with observations by others (Faber et al., 2005; Trotz-Williams et al., 2008; Beam et al., 2009). Early and sufficient colostrum supply is one of the main protective factors against FPT, which is connected to poor growth, as described above.

Farms that started offering concentrates to calves beyond two weeks of life had lower ADG from birth to weaning than farms that fed concentrates earlier ($p = 0.015$). Most of the study farms reared their calves with a restricted milk feeding routine und tried to wean calves as early as possible to reduce feeding costs. In particular, calves fed restricted depend on early rumen development for sufficient growth. Therefore, concentrates that are supposed to be the most effective feed for early rumen development need to be offered to calves as early as possible (Tamate et al., 1962; Forbes, 1971; Noci, 2010).

Farms that abandoned hay from the diet of preweaned calves had higher ADG in this study than farms that fed hay unchopped and separately ($p = 0.025$). This result is in line with studies (Warner et al., 1956; Jahn et al., 1970; Kertz et al., 1979) in which calves were exposed to a restricted milk feeding routine. Pre-ruminant calves consumed less concentrates when they were fed hay separately. The authors concluded that limited rumen capacity in young calves determines the amount of solid feed intake. To this end, the simultaneous offer of hay and concentrates would reduce ADG due to the lower energy density of hay compared to concentrates. In further studies, pre-ruminant calves were fed chopped hay either separately, or mixed with concentrates (Coverdale et al., 2004; Suárez et al., 2007; Khan et al., 2011a). None of these authors could show a negative effect of hay on ADG. Taking the protective effect of hay on calf mortality into account hay feeding to calves seems to be recommendable.

Evaluating the data from the Animal Needs Index, we observed higher ADG on those farms that fulfilled the requirements of calves more efficiently than farms with insufficient ADG. Farms with more than 65% of points in the area of influence “supervision” in the Animal Needs Index had higher ADG than farms with less points ($p = 0.002$). Differences between farms relied mainly on differences in documentation of symptoms and treatment of diseases. This corresponds to the results of Lundborg et al. (2005). They found a positive correlation between proper documentation and good calf health and draw the conclusion that thoroughness in documentation reflects a good quality of calf raising management.

### 4.4. Other findings

In our study, we found a strong positive correlation of median serum albumin concentrations and ADG until weaning ($p < 0.001$). At herd level, each one-gram increase in serum albumin concentration was associated with a rise in ADG by 46 grams. Low serum albumin levels are a constant finding in malnourished and underweight children (Clarke et al., 2006; Cripps et al., 2008). In piglets and calves, the predictive capacity of serum or plasma albumin concentrations has been examined in the context of different rearing intensities (restricted vs. ad libitum feeding) in the first month of life (Hammon et al., 2002; Liu et al., 2015; Maccari et al., 2015). A positive association between body weight and plasma albumin concentration was detected in mature humans by Jeejeebhoy et al. (2015). Although in individual animals low serum albumin concentrations can be the consequence of either malnutrition or a variety of disorders (protein loosing enteropathy, liver degeneration), on herd level, we consider low serum albumin ($< 33$ g/l) as predicting indicator for malnourishment or for an elevated proportion of calves with chronic diseases leading to insufficient ADG from birth to weaning. Its suitability as indicator, however, has to be investigated in subsequent studies.

### 4.5. Statistical methods

Our statistical analyses included dealing with data challenges such as multicollinearity, finding associations ‘due to chance alone’, confounding and interaction effects (Dohoo et al., 1997). We used techniques to reduce the number of independent variables and to select for variables with the highest explanatory power before inserting them into multivariable models. Furthermore, confounding and interaction effects were considered for in the models. Due to the limited number of farms in this study, the number of independent variables per final multivariable regression model had to be reduced to a maximum of seven variables to reduce the possibility to find associations just due to chance alone. Since more than seven risk factors may effect multifactorial diseases in calves, we had to select the variables carefully.

### 4.6. Conclusions

The results of the present field study indicate that high calf mortality ($> 5\%$), FPT in the neonate (serum protein $< 55$ g/l) and low ADG from birth to weaning ($< 700$ g/day) are still a problem on dairy farms under livestock production conditions in northeast Germany. As the welfare of food producing animals and in particular of young stock comes more and more into the focus of society, the management of calf rearing should be systematically evaluated and improved in the light of recent insights into nutrition, husbandry conditions, animal handling and disease prevention. Especially colostrum and feeding management routines on most farms need to be revised and checked more frequently. Feeding routines should focus on high rates of ADG until weaning. Offering water and concentrates right from the start enables calves to consume sufficient amounts of concentrates at weaning and leaves them prepared for the milk deprivation at weaning. Animal handling and husbandry conditions should be reviewed from an animal perspective to reduce unnecessary stressful routines as frequent relocating of calves until weaning.

## Author's roles

The corresponding author, Annegret Tautenhahn, is responsible for study design, data collection and analysis and drafting the manuscript. The author Kerstin Elisabeth Müller was involved in creating the study design, connected with the funding associations, helped with the farm acquisition and supervised the corresponding author in this study. The author Roswitha Merle supported the study with the development of the assessment strategy and by performing data analysis.

## Ethical approval

All examinations and sample collections were performed in line with legal regulations on the performance of experiments on animals (Bundesministerium, 2010).

## Quality standards

In conduct with this research quality standards like standard operating procedures for peripheral venous blood sampling and faecel sampling of the Clinic for Ruminants and Swine of the Freie Universität Berlin and 'Safeguarding Good Scientific Practice' of the German Research Foundation (DFG) were taken into account.

## Declaration of Competing Interest

The authors report no declarations of interest.

## Acknowledgements

The study was supported by the cattle breeders' association Brandenburg "Brandenburger Testherden", the managers of the project "Veredelungsland Sachsen 2020" of the state control association of Saxony and the Educational and Experimental Institution for Animal Husbandry Echem by helping with the farm acquisition. The authors thank the participating farmers for their interest and support.

## References

Al Mawly, J., Grinberg, A., Prattley, D., Moffat, J., Marshall, J., French, N., 2015. Risk factors for neonatal calf diarrhoea and enteropathogen shedding in New Zealand dairy farms. Vet. J. 203, 155–160.

Amon, T., Bergschmidt, A., Hessel, E., Kemper, N., Knierim, U., Schrader, L., Schumacher, U., von Borell, E., Breitschuh, G., 2014. Tiergerechtheit bewerten. Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL) Darmstadt, Germany.

Bateman II, H.G., Hill, T.M., Aldrich, J.M., Schlotterbeck, R.L., Firkins, J.L., 2012. Meta-analysis of the effect of initial serum protein concentration and empirical prediction model for growth of neonatal Holstein calves through 8 weeks of age. J. Dairy Sci. 95, 363–369.

Beam, A.L., Lombard, J.E., Kopral, C.A., Garber, L.P., Winter, A.L., Hicks, J.A., Schlater, J.L., 2009. Prevalence of failure of passive transfer of immunity in newborn heifer calves and associated management practices on US dairy operations. J. Dairy Sci. 92, 3973–3980.

Besser, T.E., Gay, C.C., Pritchett, L., 1991. Comparison of three methods of feeding colostrum to dairy calves. J. Am. Vet. Med. Assoc. 198, 419–422.

Besser, T.E., Szenci, O., Gay, C.C., 1990. Decreased colostral immunoglobulin absorption in calves with postnatal respiratory acidosis. J. Am. Vet. Med. Assoc. 196, 1239–1243.

Bleul, U., 2011. Risk factors and rates of perinatal and postnatal mortality in cattle in Switzerland. Livest. Sci. 135, 257–264.

Böckel, V., 2008. Investigation about quantitative benchmarking of animal health. Dissertation. University of Veterinary Medicine Hannover, Hannover, Germany.

Bostelmann, N., 2000. An examination of the influence of marketing organisations on animal health and meat quality of fattening pigs on the basis of collected slaughter check results, pH-values and meat temperature of the ham. Dissertation. Free University Berlin, Berlin, Germany.

Bundesministerium, 2009. In: Bundesgesetzblatt (Ed.), Verordnung zum Schutz landwirtschaftlicher Nutztiere und anderer zur Erzeugung tierischer Produkte gehaltener Tiere bei ihrer Haltung: TierSchNutzV.

Bundesministerium, 2010. In: Bundesgesetzblatt (Ed.), Tierschutzgesetz: TierSchG.

Clarke, M., Locker, D., Berall, G., Pencharz, P., Kenny, D.J., Judd, P., 2006. Malnourishment in a population of young children with severe early childhood caries. Pediatr. Dent. 28, 254–259.

Correa, M.T., Erb, H., Scarlett, J., 1993. Path analysis for seven postpartum disorders of Holstein cows. J. Dairy Sci. 76, 1305–1312.

Coverdale, J.A., Tyler, H.D., Quigley I.I.I., J.D., Brumm, J.A., 2004. Effect of various levels of forage and form of diet on rumen development and growth in calves. J. Dairy Sci. 87, 2554–2562.

Cripps, A., Otczyk, D.C., Barker, J., Lehmann, D., Alpers, M.P., 2008. The relationship between undernutrition and humoral immune status in children with pneumonia in Papua New Guinea. P. N. G. Med. J. 51, 120–130.

Dohoo, I.R., Ducrot, C., Fourichon, C., Donald, A., Hurnik, D., 1997. An overview of techniques for dealing with large numbers of independent variables in epidemiologic studies. Prev. Vet. Med. 29, 221–239.

Donovan, G.A., Dohoo, I.R., Montgomery, D.M., Bennett, F.L., 1998. Calf and disease factors affecting growth in female Holstein calves in Florida, USA. Prev. Vet. Med. 33, 1–10.

European Commission, 2007. New Common Animal Health Strategy 2007-2013.

Faber, S.N., Faber, N.E., McCauley, T.C., Ax, R.L., 2005. Case study: effects of colostrum ingestion on lactational performance 1. Prof. Anim. Sci. 21, 420–425.

Foote, M.R., Nonnecke, B.J., Waters, W.R., Beitz, D.C., Fowler, M.A., Miller, B.L., Johnson, T.E., Perry, H.B., 2005. Effects of increased dietary protein and energy on composition and functional capacities of blood mononuclear cells from vaccinated, neonatal calves. Int. J. Vitam. Nutr. Res. 75, 357–368.

Forbes, J.M., 1971. Physiological changes affecting voluntary food intake in ruminants. In, The Nutrition Society 135–142.

Fourichon, C., Beaudeau, F., Seegers, H., 1997. Critical points related to housing and management in control programmes for calf morbidity and mortality in French dairy herds. 9 th International Congress in Animal Hygiene. Helsinki, Finland 37–40.

Fox, C.J., Hammerman, P.S., Thompson, C.B., 2005. Fuel feeds function: energy metabolism and the T-cell response. Nat. Rev. Immunol. 5, 844–852.

Gröhn, Y.T., Erb, H.N., McCulloch, C.E., Saloniemi, H.S., 1989. Epidemiology of metabolic disorders in dairy cattle: Association among host characteristics, disease, and production. J. Dairy Sci. 72, 1876–1885.

Gulliksen, S.M., Lie, K.I., Loken, T., Osteras, O., 2009. Calf mortality in Norwegian dairy herds. J. Dairy Sci. 92, 2782–2795.

Hammon, H.M., Schiessler, G., Nussbaum, A., Blum, J.W., 2002. Feed intake patterns, growth performance, and metabolic and endocrine traits in calves fed unlimited amounts of colostrum and milk by automate, starting in the neonatal period. J. Dairy Sci. 85, 3352–3362.

Heinrichs, A.J., Rogers, G.W., Cooper, J.B., 1992. Predicting body weight and wither height in Holstein heifers using body measurements. J. Dairy Sci. 75, 3576–3581.

Hoedemaker, M., 2018. Verminderung von Aufzuchtverlusten in niedersächsischen Milchviehbetrieben. Hannover, Germany, pp. 1–66.

Houe, H., Østergaard, S., Thilsing-Hansen, T., Jørgensen, R.J., Larsen, T., Sørensen, J.T., Agger, J., Blom, J., 2001. Milk fever and subclinical hypocalcaemia–an evaluation of parameters on incidence risk, diagnosis, risk factors and biological effects as input for a decision support system for disease control. Acta Vet. Scand. 42, 1–29.

Jahn, E., Chandler, P.T., Polan, C.E., 1970. Effects of fiber and ratio of starch to sugar on performance of ruminating calves. J. Dairy Sci. 53, 466–474.

Jeejeebhoy, K.N., Keller, H., Gramlich, L., Allard, J.P., Laporte, M., Duerksen, D.R., Payette, H., Bernier, P., Vesnaver, E., Davidson, B., 2015. Nutritional assessment: comparison of clinical assessment and objective variables for the prediction of length of hospital stay and readmission. Am. J. Clin. Nutr. 101, 956–965.

Keidel, J., Daugschies, A., 2013. Integration of halofuginone lactate treatment and disinfection with p-chloro-m-cresol to control natural cryptosporidiosis in calves. Vet. Parasitol. 196, 321–326.

Kertz, A.F., Prewitt, L.R., Everett Jr., J.P., 1979. An early weaning calf program: summarization and review. J. Dairy Sci. 62, 1835–1843.

Khan, M.A., Weary, D.M., Von Keyserlingk, M.A.G., 2011a. Hay intake improves performance and rumen development of calves fed higher quantities of milk. J. Dairy Sci. 94, 3547–3553.

Khan, M.A., Weary, D.M., Von Keyserlingk, M.A.G., 2011b. Invited review: Effects of milk ration on solid feed intake, weaning, and performance in dairy heifers. J. Dairy Sci. 94, 1071–1081.

Lago, A., McGuirk, S.M., Bennett, T.B., Cook, N.B., Nordlund, K.V., 2006. Calf respiratory disease and pen microenvironments in naturally ventilated calf barns in winter. J. Dairy Sci. 89, 4014–4025.

Liu, Y., Kong, X., Jiang, G., Deng, J., Yang, X., Li, F., Xiong, X., Yin, Y., 2015. Effects of dietary protein/energy ratio on growth performance, carcass trait, meat quality, and plasma metabolites in pigs of different genotypes. J. Anim. Sci. Biotechnol. 6, 36–45.

Lorenz, I., Earley, B., Gilmore, J., Hogan, I., Kennedy, E., More, S.J., 2011a. Calf health from birth to weaning. III. housing and management of calf pneumonia. Ir. Vet. J. 64, 14–22.

Lorenz, I., Mee, J.F., Earley, B., More, S.J., 2011b. Calf health from birth to weaning. I. General aspects of disease prevention. Ir. Vet. J. 64, 10–17.

Lundborg, G.K., Svensson, E.C., Oltenacu, P.A., 2005. Herd-level risk factors for infectious diseases in Swedish dairy calves aged 0-90 days. Prev. Vet. Med. 68, 123–143.

Maccari, P., Wiedemann, S., Kunz, H.J., Piechotta, M., Sanftleben, P., Kaske, M., 2015. Effects of two different rearing protocols for Holstein bull calves in the first 3 weeks of life on health status, metabolism and subsequent performance. J. Anim. Physiol. Anim. Nutr. 99, 737–746.

Mayr, A., 2002. Multikausale Infektionskrankheiten. In: Rolle, M., Mayr, A., Büttner, M. (Eds.), Medizinische Mikrobiologie, Infektions- und Seuchenlehre. Enke, Stuttgart, pp. 19–20.

Moore, M., Tyler, J.W., Chigerwe, M., Dawes, M.E., Middleton, J.R., 2005. Effect of delayed colostrum collection on colostral IgG concentrationin dairy cows. J. Am. Vet. Med. Assoc. 226, 1375–1377.

Morin, D.E., Nelson, S.V., Reid, E.D., Nagy, D.W., Dahl, G.E., Constable, P.D., 2010. Effect of colostral volume, interval between calving and first milking, and photoperiod on colostral IgG concentrations in dairy cows. J. Am. Vet. Med. Assoc. 237, 420–428.

Mormède, P., Lemaire, V., Castanon, N., Dulluc, J., Laval, M., Le Moal, M., 1990. Multiple neuroendocrine responses to chronic social stress: Interaction between individual characteristics and situational factors. Physiol. Behav. 47, 1099–1105.

Müller, K.E., Englisch, A., Tautenhahn, A., Gäbler, E., Forkmann, A., Rösler, U., Kühl, N., Friese, A., Ullrich, E., 2016. Bewertung von Hygiene, Tierwohl und Tiergesundheit. Schriftenreihe des LfULG. Heft 5/2016.

Noci, B., 2010. Effects of different rations on growth and rumen development of calves. Dissertation. Free University Berlin, Berlin, Germany.

Nonnecke, B.J., Foote, M.R., Smith, J.M., Pesch, B.A., Van Amburgh, M.E., 2003. Composition and functional capacity of blood mononuclear leukocyte populations from neonatal calves on standard and intensified milk replacer diets. J. Dairy Sci. 86, 3592–3604.

Perez, E., Noordhuizen, J.P.T.M., Vanwuijkhuise, L.A., Stassen, E.N., 1990. Management Factors Related to Calf Morbidity and Mortality-Rates. Livest. Prod. Sci. 25, 79–93.

Place, N.T., Heinrichs, A.J., Erb, H.N., 1998. The effects of disease, management, and nutrition on average daily gain of dairy heifers from birth to four months. J. Dairy Sci. 81, 1004–1009.

Quigley, J.D., S.T, N., Benedictus, G., Brand, A., Kloosterman, B., 1996. Monitoring replacement rearing. In: Brand, A., Schukken, Y.H., Noordhuizen, J.P. (Eds.), Herd health and production management in dairy practice. Wageningen Pers., Wageningen, pp. 75–102.

Rea, D.E., Tyler, J.W., Hancock, D.D., Besser, T.E., Wilson, L., Krytenberg, D.S., Sanders, S.G., 1996. Prediction of calf mortality by use of tests for passive transfer of colostral immunoglobulin. J. Am. Vet. Med. Assoc. 208, 2047–2049.

Reinhardt, C.D., Busby, W.D., Corah, L.R., 2009. Relationship of various incoming cattle traits with feedlot performance and carcass traits. J. Anim. Sci. 87, 3030–3042.

Robison, J.D., Stott, G.H., Denise, S.K., 1988. Effects of Passive-Immunity on Growth and Survival in the Dairy Heifer. J. Dairy Sci. 71, 1283–1287.

Roland, L., Drillich, M., Klein-Jöbstl, D., Iwersen, M., 2016. Invited review: Influence of climatic conditions on the development, performance, and health of calves. J. Dairy Sci. 99, 2438–2452.

Roth, B.A., Keil, N.M., Gygax, L., Hillmann, E., 2009. Influence of weaning method on health status and rumen development in dairy calves. J. Dairy Sci. 92, 645–656.

Roy, J.H., 1990. The calf: Volume 1 Management of health. Butterworths Kent (UK).

Sanftleben, P., 2009. Vorbeuge von Kälberkrankheiten durch richtige Aufzucht und Fütterung in der Milchviehhaltung. 27. Fachtagung LKV/RGD. Güstrow, Germany.

Santman-Berends, I.M.G.A., Schukken, Y.H., van Schaik, G., 2019. Quantifying calf mortality on dairy farms: Challenges and solutions. J. Dairy Sci. 102, 6404–6417.

Schäffer, D., von Borell, E., Richter, T., 2007. Critical control points (CCP) for the housing and management of calves. Zuchtungskunde 79, 363–393.

Scholz, H., Knutzen, G., Fischer, B., Wähner, M., 2011. Factors of influence on the quality of colostrum from dairy cows. Zuchtungskunde 83, 396–405.

Shivley, C.B., Lombard, J.E., Urie, N.J., Kopral, C.A., Santin, M., Earleywine, T.J., Olson, J.D., Garry, F.B., 2018. Preweaned heifer management on US dairy operations: Part VI. Factors associated with average daily gain in preweaned dairy heifer calves. J. Dairy Sci. 101, 9245–9258.

Siegel, H.S., Latimer, J.W., 1975. Social interactions and antibody titres in young male chickens (Gallus domesticus). Anim. Behav. 23, 323–330.

Suárez, B.J., Van Reenen, C.G., Stockhofe, N., Dijkstra, J., Gerrits, W.J.J., 2007. Effect of roughage source and roughage to concentrate ratio on animal performance and rumen development in veal calves. J. Dairy Sci. 90, 2390–2403.

Taffe, B., Baumgart, S., Fischer, B., Zehle, H.-H., Pollandt, G., 2006. Kälbersterblichkeit senken, Aufzuchtverluste minimieren. In: Sachsen-Anhalt, T. (Ed.), Tierseuchenkasse Sachsen-Anhalt, pp. 1–16. Magdeburg, Germany.

Tamate, H., McGilliard, A.D., Jacobson, N.L., Getty, R., 1962. Effect of various dietaries on the anatomical development of the stomach in the calf. J. Dairy Sci. 45, 408–420.

Torsein, M., Lindberg, A., Sandgren, C.H., Waller, K.P., Tornquist, M., Svensson, C., 2011. Risk factors for calf mortality in large Swedish dairy herds. Prev. Vet. Med. 99, 136–147.

Trilk, J., Münch, K., 2008. Connections between health of calves, growth and later yields of dairy cattle. Zuchtungskunde 80, 461–472.

Trotz-Williams, L.A., Leslie, K.E., Peregrine, A.S., 2008. Passive immunity in Ontario dairy calves and investigation of its association with calf management practices. J. Dairy Sci. 91, 3840–3849.

Tyler, J.W., Hancock, D.D., Wiksie, S.E., Holler, S.L., Gay, J.M., Gay, C.C., 1998. Use of serum protein concentration to predict mortality in mixed-source dairy replacement heifers. J. Vet. Intern. Med. 12, 79–83.

Tyler, J.W., Steevens, B.J., Hostetler, D.E., Holle, J.M., Denbigh, J.J.L., 1999. Colostral immunoglobulin concentrations in Holstein and Guernsey cows. Am. J. Vet. Res. 60, 1136–1139.

Urie, N.J., Lombard, J.E., Shivley, C.B., Kopral, C.A., Adams, A.E., Earleywine, T.J., Olson, J.D., Garry, F.B., 2018a. Preweaned heifer management on US dairy operations: Part I. Descriptive characteristics of preweaned heifer raising practices. J. Dairy Sci. 101, 9168–9184.

Urie, N.J., Lombard, J.E., Shivley, C.B., Kopral, C.A., Adams, A.E., Earleywine, T.J., Olson, J.D., Garry, F.B., 2018b. Preweaned heifer management on US dairy operations: Part V. Factors associated with morbidity and mortality in preweaned dairy heifer calves. J. Dairy Sci. 101, 9229–9244.

Vandeputte, S., Detilleux, J., Rollin, F., 2011. Comparison of four refractometers for the investigation of the passive transfer in beef calves. J. Vet. Intern. Med. 25, 1465–1469.

Veissier, I., Boissy, A., dePassillé, A.M., Rushen, J., Van Reenen, C.G., Roussel, S., Andanson, S., Pradel, P., 2001. Calves' responses to repeated social regrouping and relocation. J. Anim. Sci. 79, 2580–2593.

Villacorta, I., Peeters, J.E., Vanopdenbosch, E., Ares-Mazas, E., Theys, H., 1991. Efficacy of halofuginone lactate against Cryptosporidium parvum in calves. Antimicrob. Agents Chemother. 35, 283–287.

Warner, R.G., Flatt, W.P., Loosli, J.K., 1956. Ruminant nutrition, dietary factors influencing development of ruminant stomach. J. Agric. Food Chem. 4, 788–792.

Weaver, D.M., Tyler, J.W., VanMetre, D.C., Hostetler, D.E., Barrington, G.M., 2000. Passive transfer of colostral immunoglobulins in calves. J. Vet. Intern. Med. 14, 569–577.

Wilhelm, A.L., Maquivar, M.G., Bas, S., Brick, T.A., Weiss, W.P., Bothe, H., Velez, J.S., Schuenemann, G.M., 2017. Effect of serum calcium status at calving on survival, health, and performance of postpartum Holstein cows and calves under certified organic management. J. Dairy Sci. 100, 3059–3067.

Winckler, C., Schneider, H., Sundrum, A., 1994. Tiergerechtheitsindex für Kälber. In: Sundrum, A., Andersson, R., Postler, G. (Eds.), Tiergerechtheitsindex - 200 ein Leitfaden zur Beurteilung von Haltungssystemen, pp. 41–55. Köllen, Bonn.

Windeyer, M.C., Leslie, K.E., Godden, S.M., Hodgins, D.C., Lissemore, K.D., LeBlanc, S.J., 2014. Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. Prev. Vet. Med. 113, 231–240.

Wittum, T.E., Perino, L.J., 1995. Passive immune status at postpartum hour 24 and long-term health and performance of calves. Am. J. Vet. Res. 56, 1149–1154.

World Health Organization, 2014. Antimicrobial resistance global report on surveillance: 2014 summary. World Health Organization.

Žitnan, R., Voigt, J., Schönhusen, U., Wegner, J., Kokardova, M., Hagemeister, H., Levkut, M., Kuhla, S., Sommer, A., 1998. Influence of dietary concentrate to forage ratio on the development of rumen mucosa in calves. Arch. Anim. Nutr. 51, 279–291.

Zitzmann, R., Pfeffer, M., Söllner-Donat, S., Donat, K., 2019. Risk factors for calf mortality influence the occurrence of antibodies against the pathogens of enzootic bronchopneumonia. Tierärztl. Prax. Ausg. G Großtiere Nutztiere 47, 151–165.