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Master of research project

Effect of enteric disorders on the growth, age at first calving and first lactation performance and survival of Holstein Friesian dairy heifers

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By

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Declaration

I hereby declare that this thesis is my own and the work herein has not been submitted for any other degree or award and additional sources of information and assistance during the preparation of this thesis have been acknowledged.

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Frequently used abbreviations

ADG	average daily gain
AFC	age at first calving
ARP	acute phase response
BC	bovine colostrum
BRD	bovine respiratory disease
BW	birth weight
CH_4	methane
CI	calving interval
CO2-eq.	carbon footprint
CR	conception rate
CSC	calf starter concentrate
d	day
DH	dairy heifers
DM	dry matter
DMI	dry matter intake
ECM	energy-corrected milk
ED	enteric disorders
ET	environmental temperature
FA	fatty acids
FCE	feed conversion efficiency
FL	first lactation
FPCM	fat and protein-corrected milk
FLM	first lactation milk
FPT	failure of passive transfer
FS	faecal score
g	gram
GHG	greenhouse gas
GIT	gastrointestinal tract
HF	Holstein Friesian
IGF	insulin growth factor
kg	kilogram
L	litre
MG	mammary gland
mo.	month

MY	milk yield
LPM	lifetime milk production
LW	live weight
MR	milk replacer
MW	mature weight
NSAID	non-steroidal anti-inflammatory drugs
NTED	not treated for ED
n-3 FA	omega fatty acid
ORT	oral rehydration therapy
OS	oligosaccharides
PIT	passive immunity transfer
pp	postpartum
PPI	postpartum interval
POW	postweaning
PR	pregnancy rate
PRW	preweaning
RR	replacement rate
SAA	serum amyloid A
SHp	serum haptoglobin
SR	survival rate
TED	treated for enteric disorders
WM	whole milk
/	per

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Effect of enteric disorders on the growth, age at first calving and first lactation performance and survival of Holstein Friesian dairy heifers

Abstract

The UK dairy industry needs to work toward net zero greenhouse gas emissions and elimination of antimicrobial treatment of livestock by 2050. Dairy herd replacements are one of the greatest economic, feed, and carbon footprint (CO_2-eq.) costs of milk production, which can be lowered by reducing the age at first calving (AFC), and herd replacement rate (RR) by improving preweaning (PRW) calf health, average daily growth (ADG), feed conversion efficiency (FCE) first lactation milk (FLM) yield and survival. This study aimed to evaluate the incidence and effect of enteric disorders (ED), which required oral rehydration therapy PRW, on the ADG, FCE, AFC, FLM yield, and survival of Holstein Friesian dairy heifers (DH) using 60 DH calves (n-30) that were not treated for ED (NTED) and (n=30) that were treated for ED (TED) PRW. Milk replacer (MR) intake ($P=0.030$), dry matter intake ($P=0.037$), ADG ($P<0.001$), FCE ($P=0.047$) PRW and weaning weight (WW) ($P<0.001$), mature weight (MW) ($P=0.002$) and live weight (LW) ($P=0.003$) at 12 mo., MW and LW ($P=0.002$) at first calving, FLM yield ($P=0.018$), and survival from birth to second lactation ($P=0.031$) was greater in DH NTED than TED. The AFC ($P=0.004$), postpartum (pp) interval to first insemination ($P=0.007$), pp insemination per conception ($P=0.066$), cost ($P=0.004$) and CO_2-eq./ d calving interval ($P=0.049$) were lower in DH calves NTED than TED. Calf starter concentrate, chopped cereal straw, and water intake, age at first insemination and conception, body condition score (BCS) at parturition, and pp change in BCS did not differ between DH NTED and TED PRW. In conclusion, the incidence of ED was high, but DH NTED had greater PRW MR, DMI, and ADG, WW. LW and MW at 12 mo. of age, a lower AFC and greater LW and MW first calving, FLM, component yield, and survival rate to second lactation than DH TED PRW.

Keywords: Enteric disorders; Heifers, Growth, Milk yield, Survival, Carbon footprint

Introduction

The UK aims to achieve net-zero greenhouse gas (**GHG**) emissions in the agricultural sector and eliminate the use of antimicrobials in livestock by 2050 (European Commission, 2019). This poses a significant challenge to the dairy industry, given that milk production needs to continually increase to meet consumer demands for a safe and healthy diet (Shalloo et al., 2020; Clay et al., 2020). One of the largest contributors to the economic (Heinrichs et al., 2013), feed (Boulton et al., 2017), and carbon footprint (**CO_2-eq**.) costs (Bell and Winson, 2018) in dairy farming are herd replacements. Reducing the age at first calving (**AFC**) (Boulton et al., 2017) can lower these costs. Increasing the average daily gain (**ADG**) of dairy heifers

(**DH**) preweaning (**PRW**) has been shown to result in greater first lactation milk (**FLM**) yield (Tozer and Heinrichs, 2001; Zanton and Heinrichs 2005; Soberon and Van Amburgh, 2013; Margerison et al., 2013; Gelsinger et al., 2016; Chuck et al., 2018), longevity and lifetime milk yield and lower herd replacement rate (**RR**) (Zanton and Heinrichs, 2005; Boulton et al., 2017), costs (Overton et al., 2013) and CO2-eq. of milk production (Bell and Winson, 2018). The maintenance of good dairy herd health and fertility is essential in lowering herd RR (Garnsworthy et al., 2004). Even a small reduction in RR, such as from 20 to 18 %, has been shown to lower the CO_2-eq. per kg of fat and protein-corrected milk (**FPCM**) yield by 1.7% (Herron et al., 2022) and 48.5 kg CO_2-eq. per percentage of herd replacement rate (Bell and Wilson, 2018). One of the leading causes of calf mortality is ED (Donovan et al., 1998; Windeyer et al., 2014; Umaña Sedó et al., 2023), with between 34% and 56.5% of calves reported to suffer ED preweaning (Urie et al., 2018; Abuelo et al., 2021; NAHMS, 2021; Goh et al., 2024). However, few studies have assessed the longer-term potential effects of enteric disorders (**ED**), necessitating treatments such as oral rehydration therapy (**ORT**), on DH performance, economic impact (Virtala et al., 1996; Aghakeshmiri et al., 2017), feed conversion efficiency (**FCE**) and CO_2-eq. emissions in herd replacements and milk production. A greater understanding of the impact of how early-life health and common calf diseases, such as **ED,** affect ADG, FCE, and FLM yield, fertility, and survival rate (**SR**) of DH is essential. This knowledge could help in lowering calf mortality, antimicrobial treatment, herd RR, and ultimately contribute to the strategic plans aims at minimizing antibiotic use and achieving net-zero emissions by 2050. Nevertheless, only few studies have assessed the impacts of ED PRW on **DH** health, ADG, feed intake, FCE, AFC, live weight (**LW**) at first calving, FLM yield, survival, and the overall CO_2-eq. of herd replacements and milk production.

Literature review

Calf mortality and disease

The leading cause of pre-weaned calf mortality is diarrhoea (Barkley et al., 2021), which is primarily triggered by gastrointestinal tract (**GIT**) pathogenic enteritis, diarrhoea (Urie et al., 2018), along with bovine respiratory disease. Furthermore, these conditions constitute significant welfare and economic concerns (Gomes et al, 2021). The incidence of ED that results in diarrhoea can lead to decreased absorption and increased loss of water and electrolytes in the GIT of calves, which begins with the ingestion of single or multiple pathogens (Table 1), signalling pathogenic physiological pathways that cause dehydration (Cho and Yoon, 2014). Due to the multifactorial aetiology of ED, including calving management, immunity, environmental stress, and both infectious and non-infectious pathogens, mitigation remains challenging (Whon et al., 2021). Variation in environmental temperature (**ET**) can increase the risk of disease because neonatal calves have a narrow thermo-neutral comfort and body temperature regulation range, due to a relatively large surface area, amniotic fluid evaporation, and limited adipose tissue reserves (Dantas et al., 2019). In thermoneutral conditions, a 40 kg calf consuming 4 L/d of whole milk can achieve an ADG of 0.35 kg/day. However, ET can lower FCE (NRC, 2001), including ET at birth, and calves born in warmer seasons can achieve ADG that are 0.047 kg/d greater than those born in cooler seasons (Johnson et al., 2017) and minimising the exposure to ET below thermoneutral has the potential to increase energy available for ADG and immunity, thereby potentially lowering the incidence of disease.

Table 1: Main pathogens causing enteric disorders in dairy calves

Infectious agent	Age, d	Clinical symptoms
Escherichia coli	1 to 7	Effortless passing of yellow and/or white faeces
Rotavirus	3 to 21	Watery brown to light green faeces, with blood, and mucus
Coronavirus	5 to 21	Watery yellow faeces
Coccidia	≥ 7	Blood-tinged faeces
Cryptosporidium	7 to 21	Watery brown to light green faeces, blood, and mucus

Adapted from Huvepharma, (2019).

Enteric disorders, calf growth and development

One of the most significant risk factors related to the occurrence of ED in calves is the failure of passive immunity transfer (Shivley et al., 2018; Godden et al., 2019; Renaud et al., 2020). Diarrhoea, regardless of aetiology, results in a variety of complications that include acid-base and electrolyte imbalance and increased lumen-fluid volume with consequent dehydration (Gomez et al., 2017; Trefz et al., 2017), all of which contribute to calf mortality. The application of ORT, following physical assessment of even mild dehydration in diarrhetic neonatal calves, has been shown to increase calf LW by 2% (Constable et al., 1998). This rehydration, using electrolyte preparations, corrects abnormalities in free water deficit, acid-base, and plasma osmolality abnormalities (Constable et al., 2021) and is critical in lowering neonatal calf mortality. Other factors for diseases like ED include low birth weight, environmental contamination, pathogen infection, and lower nutrient intake, all of which contribute to a higher incidence of diarrhoea, poor calf health, and weakened immunity contribute to greater incidence of ED, diarrhoea, poor calf health, and immunity (Mee, 2023). Studies have shown that calves that experienced ED and diarrhoea, even with ORT, had lower preweaning ADG and lower WW (Donovan et al., 1998; Soberon et al., 2012; Abeulo et al., 2021). However, these studies did not evaluate the effect on subsequent heifer performance.

The intake of milk can be negatively affected by PRW calf vigour, and health status, and calves that suffer ED for 6 to 28 d consume less milk, especially during the initial 2 to 4 d following the onset of diarrhoea, leading to reduced ADG and a higher likelihood of other diseases compared to healthy calves (de Passille et al., 2016). Lower milk intake is linked to weakened immune function (Ockenden et al., 2023), as shown by elevated white blood cell count (WCC) and neutrophil count (Foote et al., 2007) and increased neutrophil activity in PRW calves (Obeidat et al, 2013). In neonatal calves, ADG is typically deprioritized relative to gut immunity, where immune responses are equally important. Thus, achieving higher ADG and ensuring adequate nutrient intake are crucial for building strong immunity and maintaining health, particularly in adverse environmental conditions. Calves not treated for ED and/or other diseases exhibit greater ADG, feed, and energy intake, and faster tissue repair and recovery from diseases (Lochmiller and Deerenberg, 2000).

Immune response to disease and inflammation

Pathogenic infections and diseases in calves trigger an immune and inflammatory response, referred to as the acute phase response (**APR**), which occurs due to tissue damage and/or stress. During APR, acute phase proteins (**APP**) are produced (Gruys et al., 2005; Schrodl et al., 2016) with the main APPs In ruminants being serum amyloid A (**SAA**) and haptoglobin (**SHp**) (Ceciliani et al., 2012; Tothova et al., 2015). The concentrations of these proteins fluctuate within the first two weeks of life, influenced by factors such as clinical and sub-clinical infections, colostrum intake, and the age of the calf (Peetsalu et al., 2022). This early adaptation of APPs is crucial for neonatal calves to adjust to their new environments (Tothova et al., 2015). For example, *Cryptosporidium* infections has been shown to rigger inflammation and increase in acute phase protein such as SAA (Pourjafar et al., 2011). However, because the incubation period for *Cryptosporidium* infection is very short (5 to 7 d), the adaptive immune response cannot prevent the development of such an infection (Petry et al., 2010; Abeywardena et al., 2015). Greater SAA concentrations in the first 2 to 3 weeks of life have been associated with lower ADG in calves PRW (Seppa-Lassila et al., 2017) and postweaning (**POW**) LW up to 250 d of age (Loch et al., 2023). Equally, higher SHp concentrations have been associated with a lower ADG in dairy calves at 3 mo. of age (Niine et al., 2018). While the mechanism is not fully known, the early development of a diverse GIT microbiome is thought to initiate an inflammatory response, which primes the immune system and enhances liver function, which can affect future productivity (Byrne et al., 2022; Dorbek-Kolin et al., 2022). However, more persistent disease infection results in higher SHp concentrations, dysregulation of innate immune responses, and lower adaptive immune response efficacy and responsiveness to vaccination (Gomes et al., 2023).

Calf morbidity associated with diarrhoea and respiratory disease

A greater incidence of morbidity is associated with diarrhoea and respiratory disease including the highest neonatal mortality rate which highlights significant welfare and economic issues (Gomes et al, 2021). At birth, calves must transition from umbilical nutrient supply to milk digestion, thermoregulate temperature, and adapt to an environment likely to be of a greater pathogenic load than the in-utero environment (Osorio, 2020). This occurs when calves rely on the acquisition of passive immunity and the development of active immunity, assessed by faecal cell culture to assess messenger ribonucleic acid (Rosa et al., 2018), which occurred at approx. 2 weeks of age and was accompanied by poorer faecal score (Chase, 2018) (Figure 1). Ockenden et al. (2023) specifically examined the impact of intake levels (high vs low) on calf growth and found that reduced intake due to disease would limit milk consumed with an attendant impact on overall growth and development.

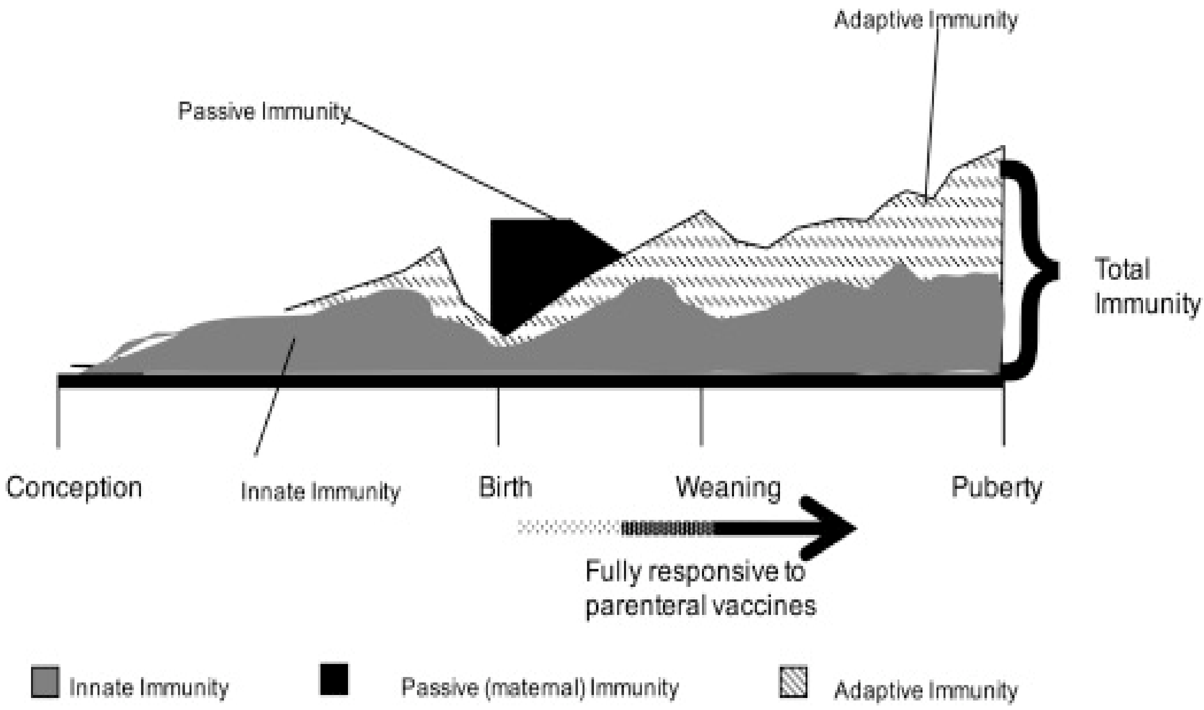

Fig. 1: Neonatal immune development in the calf and its impact on vaccine response, within the GIT healthy enterocytes provide an initial defence against colonisation by pathogenic microorganisms and are essential for the secretion and absorption of nutrients and greater growth (adapted from Chase, 2018)

Gastrointestinal tract microbiome

The gastrointestinal microbiome within the neonatal calf has specific and important metabolic and nutritional functions (Ren et al., 2019) on which the development of the intestinal barrier relies (Vacca, 2017). It has long been considered the uterus is a sterile environment with the first exposure to bacteria occurring at birth (Rehbinder et al., 2018; de Goffau et al., 2019). The sterility of the rumen is reported at birth because it is not anatomically and physiologically developed, minimal papillae on the internal surface of the rumen, and the rumination function does not begin until approximately 2 weeks of age (Khan et al., 2016). However, research by Elolimy et al. (2019), Scott (2017), and Collado et al. (2016) detected microbiota in amniotic fluid, placenta, and umbilical cord of humans during pregnancy and hindgut of calves before first colostrum feeds, suggesting the vertical transmission of microbiome from host to offspring (Quercia et al., 2019; He et al., 2020). In bovine, Klein-Jobstl et al. (2019) and Alipour et al. (2018) discovered the possibility of colonisation of the calf faecal microbiota was maternally related. Low faecal microbiota bacterial diversity richness is the most apparent factor associated with greater severity of diarrhoea, that was related to greater intestinal permeability and a dysbiosis within gut microbiota that led to pathogenic-induced diarrhoea, especially in calves of lower birth weight that had poor faecal score attributed to foetal development and gut health (Fan et al., 2021). A major source of bacterial colonisation is colostrum, containing species from *Lactobacillus*, *Bifidobacterium*, *Staphylococcus*, *E. coli,* and *Streptococcus uberis* within the GIT of the calf, and initiation of early colonisations are *Staphylococcus*, *Streptococcus, Enterococcus,* and *Enterobacteria*, utilising oxygen to create an anaerobic environment within the intestines (Malmuthuge et al., 2015). Lactic acid bacteria, i.e., *Lactobacillus*, *Bifidobacterium* spp. *Enterococcus* and *Pediococcus* spp. multiply and spread rapidly following colostrum provision to ferment sugars, contributing to the production of acids, e.g., lactic or propionic (Rozanska et al., 2013). *Lactobacilli* are the dominant bacteria within the digestive system of the calf during the first week of life and colonisation may be affected by pH (close to neutral), also considered beneficial as they can break down proteins, carbohydrates, and fats and contribute to improved nutrient absorption (Puppel et al., 2020). *Bifidobacterium* spp. is also a dominant bacterium and this aids in establishing an immune response, which is an important factor in the T cell differentiation process and proliferation (Chung et al., 2012) (Fig. 2).

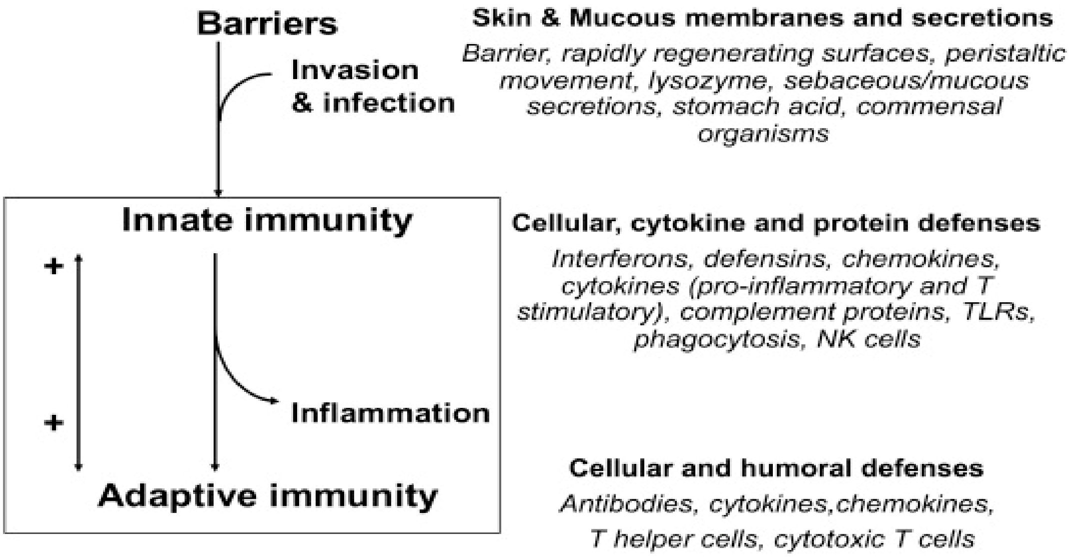

Fig. 2: Gut immune responses: the barrier, innate, and adaptive immune components (adapted with permission from D. Topham, PhD, Rochester, NY)

As the microbiome in the calf matures there is a change in the composition of the GIT microbiota and initial pathogenic bacterial species which tend to be facultative anaerobes able to utilise oxygen but are replaced by more beneficial species that are strict anaerobes (Fonty and Chaucheyras-Durand, 2006) (Figure 3).

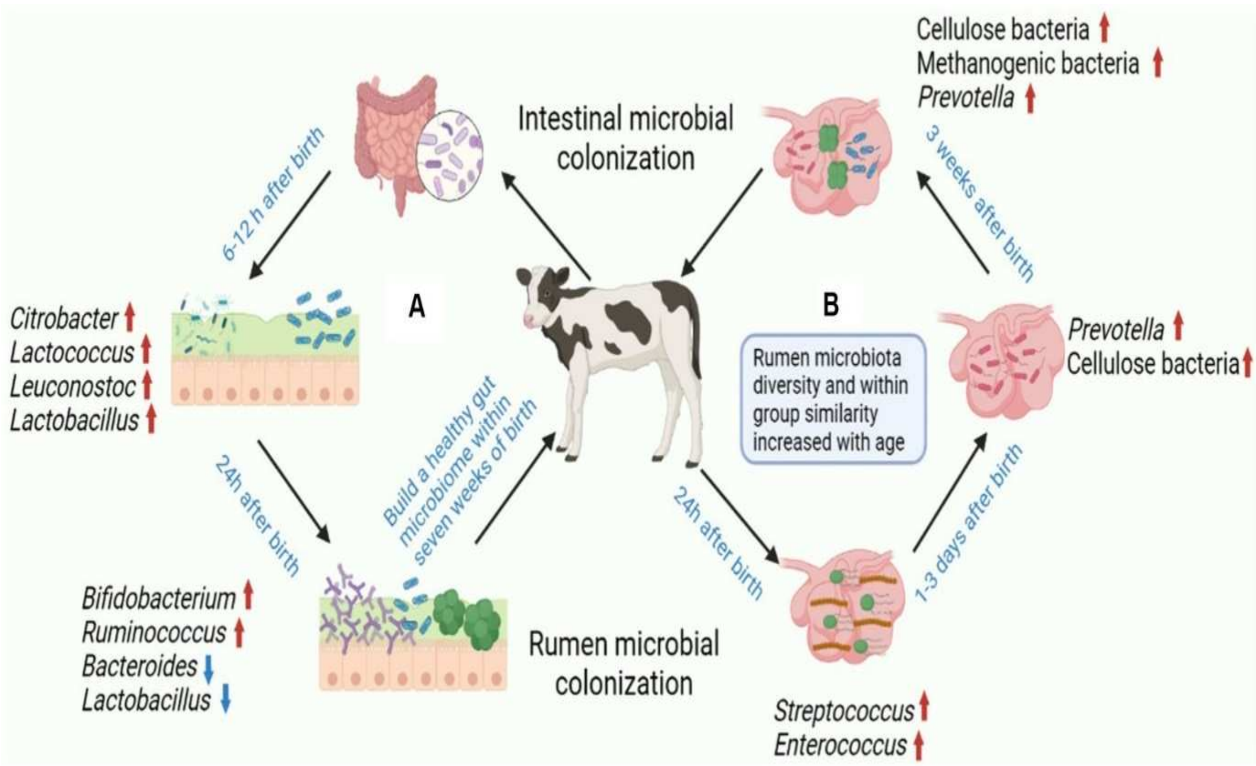

Fig. 3: Colonisation and development of the gut microbiome in calves (reproduced from Du et al., 2023)

The change in bacteria causes the rumen environment to become anaerobic, with very few species including fungi being able to utilise oxygen. These more beneficial bacterial species (e.g. amylotic bacteria, lactate bacteria) are initially at much lower concentrations but soon begin to dominate the ruminal environment as early as three days of age (Mizrahi, 2013). The microbial colonisation of the GIT plays a significant role in the ADG of pre-weaned calves, and a greater ADG and FCE are associated with a greater abundance of propionate-producing and carbohydrate-degrading bacteria, which raises serum concentrations of insulin and glucose in calves pre-weaning, but not post-weaning (Xu et al., 2023). Moreover, early bacterial colonisations of the GIT and subsequently of the rumen result in greater FE and nutrient utilisation, which can lead to increased milk yield at first lactation (Paz et al., 2018). A proposal put forward by Yanez-Ruiz et al. (2015) refers to the rumen programming concept in which nutrition in early life can be used to manipulate the microbiome of calves in early life to achieve long-term optimal production. A study, based on this concept and the knowledge of greater rumen development in calves > 3 weeks of age was performed to accelerate development via oral fiber administration at 3 d post-birth (Kodithuwakku et al., 2022) based on the presence of fibrolytic bacterial species in the calf rumen at birth. Offering calves fiber before starter concentrate may accelerate the development and colonisation of microbial activity with effects lasting into adulthood and the results confirmed a higher milk yield average in the first 30 d of lactation in cows that received early dietary intervention. The achievement of optimal productivity and performance relies on a critical understanding of neonatal health and development which allows manipulation of the gut microbiome (Bischoff et al., 2011; Malmuthuge and Guan, 2016). Such can be achieved by utilising host physiology, diet, and environment to assist in a stable rumen environment thus encouraging optimum health and future performance (Wallace et al., 2019). The protective barrier of the intestinal tract consists of mechanical, chemical, and immune components, which ensure the development and differentiation of the intestinal epithelium and immunity, regulating both innate and acquired immunity within the intestine (Du et al., 2023). This microbiota in the gut is closely related to the health, ADG, and development of calves (Malmuthuge and Guan, 2016). A rapidly forming colony post-birth becomes established during early life, specifically during weaning (Tanaka and Nakayama, 2017). Whilst genetics and age play a vital role within the rumen microbiota of calves (Lv et al., 2019; Xie et al., 2020), the balance of other factors such as host physiology, diet, and environment can directly alter and enhance the initial establishment, progress, and long-term rumen stability (Jami et al., 2013). Mitigation of the economic losses reduced culling rates and prevalence of antimicrobial resistance, and biological adaptations within the GI tract during the onset of diarrhoea need to be recognised and better understood (Slanzan et al., 2022).

Preweaning calf feeding practices

The failure of passive transfer (**FPT**) is one of the most significant risk factors related to the occurrence of ED, due to the local action and anti-pathogenic function of colostrum within colostrum in the GIT (Shivley et al., 2018; Godden et al., 2019; Renaud et al., 2020). The importance of colostrum is not only to secure an adequate plasma passive immunity status but also to prove specific antibodies within the gut lumen that are responsible for the rapid neutralisation of pathogenic bacteria (Viidu and Motus, 2022) that may gain entry to the GIT. The achievement and maintenance of optimal calf health is the successful passive immunity transfer (**PIT**) is a key focal point in reducing pre-weaning calf morbidity and mortality, as well as long-term health benefits (AHDB, nd). The importance of colostrum in securing adequate plasma passive immunity status (Viidu and Motus, 2022) can be achieved by offering colostrum as soon as possible following birth with sufficiently high IgG concentration to provide necessary concentration of immunoglobulins within the limited volume that young calves can ingest (Margerison and Downey, 2005). This has been referred to as the three Qs; quickly, quality, and quantity (Quigley, 2005). Godden et al. (2019) recommended feeding colostrum within the first 1 to 2 h after birth, due to the potential for greater absorption and serum IgG concentrations compared with calves offered colostrum at 6 and 12 h after birth (Fischer et al., 2018) despite the GIT remaining permeable to IgG 12 h post birth (Louis and Lin, 2009). Greater success in the transfer of passive immunity has been demonstrated when calves were offered a sufficient volume of colostrum that has a greater concentration of Ig, defined as serum IgG > 25 g/L directly after birth (Lombard et al., 2020). The amount (**L**) of colostrum offered at the first opportunity following birth is recommended to be between 10 to 12% of birth weight (Lago et al., 2018) and/or approx. 3 L (Mokhber-Dezfooli et al., 2012; Desjardins-Morrissette et al., 2018) to 4 L (Godden et al., 2019; Armengol, and Fraile, 2016). Colostrum and milk pasteurization improve health status and decrease mortality in neonatal calves receiving appropriate colostrum ingestion (Rafiei et al., 2019) in the first feed, which may reflect the variation in birth weight of differing breeds. Feeding larger amounts of colostrum has been shown to slow down abomasal emptying, which would delay Ig reaching the small intestine and site of absorption, which may lower the opportunity for IgG absorption (Mokhber-Dezfooli et al., 2012). This is supported by work that showed a 4-fold greater likelihood of PIT by calves that received one meal of 3 L directly following birth, compared with those that received an additional second feed of 2 L of colostrum at 5 to 6 h later (Abeulo et al., 2021). The heat treatment of colostrum at 60℃ was found not to affect IgG concentration and have a positive effect on IgG absorption (Godden et al., 2012; Gelsinger et al., 2014; Armengol and Fraile, 2016). In terms of the method of colostrum feeding, no differences in PIT and IgG absorption were found between the application of oesophageal tube and nipple bottle feeders as delivery methods for colostrum (Bonk et al., 2016). This was corroborated by Desjardins-

Morrissette et al. (2018) who offered 3 L of colostrum replacement via tube and/or nipple and found no difference in the rate of abomasa emptying. Shivley et al. (2018) found that the rate of PIT failure for colostrum delivered via an oesophageal tube and/or nipple bottle was 9% and 14% respectively, potentially showing a little more success in PIT from the application of an oesophageal tube feeder. However, there is a physiological limit that may restrict the total IgG absorption by the GIT enterocytes (Conneely et al., 2014; Lopez et al., 2020) due to the saturation of IgG receptors (Leece, 1973; Jaster, 2005). Overall, studies reported a low level of association between the success of PIT and ED and diarrhoea, with the majority of studies claiming this was not a risk factor (Sivula et al., 1996; Donovan et al., 1998; Virtala et al., 1996; Trotz-Williams et al., 2007) and Curtis et al. (2016) found 37% of calves contracted bovine respiratory disease (**BRD**) despite only 5% having a failure of PIT. The importance of colostrum is not only to secure an adequate plasma PIT status but also to prove specific antibodies within the gut lumen that are responsible for the rapid neutralisation of pathogenic bacteria (Viidu and Motus, 2022) that may gain entry to the GIT. Moreover, calves must rely on the effective colonisation of microbes to help aid immunity, combat disease, and provide overall health benefits. Such colonization occurs before birth and continues to establish throughout the early stages of life (Funkhouser and Bordenstein, 2013). Historically, colostrum is known as the most important for neonates with IgG levels determining its quality and therefore impact on the calf, however, scientific advances have recognized proteins that have important bioactive properties (Zhang et al., 2015; Le et al., 2011) such as lactoferrin, lactoperoxidase, osteopontin, and butyrophilin (Le et al., 2011) that play a key role in priming the humoral immune system (Nissen et al., 2017). Greater omega fatty acid (**n-3 FA**) in colostrum is known to increase precursors that produce anti-inflammatory compounds, increase the antioxidant capacity of calves, and alleviate oxidative stress following birth (van Niekerk et al., 2021). In bovine colostrum, there are numerous fatty acids and bioactive compounds, including insulin growth factor (**IGF**) IGF-1, growth hormones, insulin, and oligosaccharides (**OS**), which are in lower concentrations in transition / wate milk (McGrath et al., 2016; Van Soest et al., 2022; Pyo et al., 2020). Bovine colostrum contains up to 72x more OS than milk (Fischer-Tlustos et al., 2020), which enhances the intestinal uptake of IgG (Feeney et al., 2019) and prevents the adhesion of pathogens in the GIT (Martin et al., 2002). The milk fat concentration is greater (5.7 to 6.4%) in BC than in WM (4.3%) and the FA profile of BC is distinct, having far greater polyunsaturated fatty acids (**FA**) and lower saturated short-chain FA concentrations than WM (O'Callaghan et al., 2020). The GI villi development of calves is as much as 50% greater in calves offered dilute bovine colostrum (**BC**) at equal volume to milk replacer (**MR**) over a 4-d period and calves offered 2.8 L within 20 minutes of birth (Van Soest et al., 2022). Calves offered a 1:1 colostrum: whole milk (**WM**) mixture for a further 3 d, after the initial colostrum feeding following birth, developed a greater intestinal surface area and increased villi height compared with calves offered whole milk, potentially due to greater concentrations of IGF 1 and 2 (Pyo et al., 2020). Moreover, greater hormone concentrations in BC, such as insulin and IGF-1, have been shown to increase GIT cell wall proliferation and intestinal volume (van Niekerk et al., 2021), which results in greater ADG. As a consequence, the continued feeding of transition milk/dilute BC for 1 to 3 d, after the initial feeding of colostrum on the day of birth, has been shown to increase PRW ADG and LW of calves (Van Soest et al., 2020; Fischer et al., 2021) and lower incidence of elevated ear, eye and nasal score (Conneely et al., 2014).

Milk feeding practices

Current milk feeding practices encourage the feeding of greater amounts of milk/MR after birth, but this need to take into consideration of osmotic threshold of neonatal calves before they develop diarrhoea (i.e., <8.9 and 6.4% of dry matter (**DM**), respectively), which increases the impact of the macronutrient composition of milk on the development of the GIT of calves offered greater amounts (7 L; 43% lactose; 150 g/L) of MR (Welboren et al., 2021). High lactose content combined with a greater percentage of solids (12.5 to 20%) leads to high osmolarity in MR (~400m mOsm/kg) compared with milk (300 mOsm/kg (Wilms et al., 2019; Wilms et al., 2020), which could exceed the maximum capacity of absorption in calves (Hof, 1980). Traditionally, MR supplied has been in alignment with bovine whole milk in terms of fat and protein solids content (≥23% DM basis) (Yohe et al., 2022; Wilms et al., 2022), while increasing the MR and/or fat concentration in the liquid lowers the amount of hunger-related behaviour (Echeverry-Munera et al., 2020), lowers faecal scores (Amado et al., 2019), reduces therapeutic interventions (Berends et al., 2020) and calf mortality (Urie et al., 2018). A study by Ollivett et al. (2012) who looked at the effect of nutritional plane on health in dairy calves, following infection with *Cryptosporidium parvum* found calves consuming increased MR (0.30 Mcal intake energy/kg metabolic body weight using 28% protein-20% fat milk replacer vs 0.13 Mcal intake energy/kg metabolic body weight using 28% protein-20% fat milk replacer) had improved faecal scores and increased ADG than those consuming less and concluded that calves consuming more MR following pathogenic challenge remain hydrated, recover quicker, and converted feed with greater efficiency. The fatty acid profile of MR differs from that of WM (Hageman et al., 2019; Mellors et al., 2023) based on the fat and protein sources used in the manufacture of the MR. Historically, MR formulations include a high lactose content based on the availability of milk byproducts which has been driven by industry targets to reduce feed costs and optimise lean growth by discouraging fat inclusion in MR formulations (Berends et al., 2020). Whilst increased fat intake has been shown to improve lean growth (Bartlett et al., 2006), decrease mortality (Urie et al., 2018), and result in greater fat deposition POW, at 4 to 9 mo. of age, which has been negatively associated with mammary development, DMI, and future milk yield (Radcliffe et al., 2000). It is also reported that faecal consistency improves when fat inclusion within MR is higher (23% vs. 17% inclusion) (Berends et al., 2020) which could make an assessment of health and disease diagnosis more reliable. The provision of a greater amounts and quality of nutrition improves calf welfare (Krachun et al., 2010), immunity (Ollivett et al., 2012), and ADG achieved can be similar to those of suckled calves (Drackley et al., 2008). Pre-weaned calves consuming 900 to 1300 g MR DM /d had a greater ADG, LW, stature, and FCE than calves offered 500 g MR DM /d (Cowles et al., 2006; Guindon et al., 2015; Chapman et al., 2016). In terms of milk volume, at weaning calves offered 8 L (MR 125 g/L) were 19 kg heavier than those offered 4 L/d and achieved an ADG of 0.83 v 0.56 kg/d respectively (Ockenden et al., 2023). In pre-weaned calves, greater DM intake is likely to enhance ADG of due to greater amounts of nutrients and energy being consumed (Kazemi-Bonchenari et al., 2022). In such calves, greater plasma insulin and IGF-1 (IGF-1) were greater in concentration, which stimulates the uptake and utilisation of glucose by tissues, encouraging greater rates of ADG and development (Leskova and Zucker, 1974; Zhao et al., 2014). Growth is stimulated by IGF-1 due to its effect on bodily organs such as the liver and skeletal muscle (Psa et al., 2019) and increases the energy supplied to calves at this critical stage of development.

Preweaning milk volume and calf concentrate starter intake

Traditionally, calf feeding programmes restricted the volume of milk (MR 125 g/L) to approx. 10% of calf birth weight (**BW**) (Vasseur et al., 2012; Hotzel et al., 2014; Stanek et al., 2014) to encourage the early consumption of calf starter feed and facilitate early weaning at 6 weeks of age, which lowered feed costs, labour requirements and risk of diarrhoea (Chapman et al., 2017; Jafari et al., 2020; Rosadiuk et al., 2021). However, this has been associated with a greater motivation to obtain milk following milk ingestion (de Passille et al., 2011), which displays behaviours indicative of hunger, associated with poor welfare (Kiezebrink et al., 2015; Yunta et al., 2015), and achieve lower ADG compared with calves offered greater milk volume (15 to 20% BW MR 125 g/L) (Jafari et al., 2020; Rosadiuk et al., 2021). Moreover, limiting milk intake to 10% BW during the pre-weaning period limits AGD imposing greater health challenges and negatively affecting future milk production (van Niekerk et al., 2021; Margerison et al., 2013) whilst feeding greater volumes of milk (15 to 20% BW at 125 g MR/L) has been associated with a greater immune response after weaning (Ballou 2021; Ballou et al., 2013). The ADG of neonatal calves is determined by multiple factors such as genetic background, nutrient composition, volume intake, and environmental variables such as temperature and housing (Lochmiller and Deerenberg, 2000). The increasing genetic merit of dairy beef and heifer calves requires greater ADG to be achieved pre-weaning, which has led to the feeding of greater volumes of milk (125 g MR/L) closer to 15 to 20% BW, is known to lower starter intake preweaning compared with restricting milk feeding volume to 10% BW (Khan et al., Molenaar et al., 2020; Rosadiuk et al., 2021; Ivemeyer et al., 2022). Calves offered greater volumes of milk (125 g MR/L) at 15 to 20% BW and had greater ADG during the first month of life, but lower starter intake during the first two months of life than calves offered a lower volume, 10 % BW, and the adoption of a 10-d step-down weaning process was sufficient to increase starter intake post-weaning (Rosadiuk et al., 2020). Some studies that found lower starter intake when calves are offered greater volumes of milk (MR 125 g/L) pre-weaning, found lower ADG post-weaning when weaning took place at < 8 weeks of age (Eckert et al., 2015; Meale et al., 2015). One study showed weaning calves at 7 weeks using a gradual step-down weaning process resulted in greater ADG and rumen VFA concentrations post-weaning compared with calves that were weaned abruptly (Steele et al., 2017). Other studies found that the gradual weaning of calves between 7 and 9 weeks of age from greater milk volumes (15 to 20% BW at MR 125 g/L) was correlated with lower post-weaning ADG, fiber digestion, and FE. High FCE is not always due to higher MR intake, and it has been reported that moderate MR intake combined with the progressive increase in calf starter concentrate (**CSC**) intake, which provides vital nutrients from solid feed can lead to increased ADG and FCE compared to those being offered higher MR feeding rates (Hu et al., 2019; van Niekerk et al., 2020). The gradual weaning of calves, at 10 to 12 weeks of age, encourages a greater rate of starter consumption before weaning, reducing weaning stress and lag between nutrient intake from starter and forage and nutrient requirements to sustain ADG post-weaning (Sweeney et al., 2010). Moreover, calves offered an increased volume of MR or whole milk (e.g. 20% of BW or 8 L/d) that were gradually weaned had greater FE (Khan et al., 2011) and a lower risk of disease (Soberon et al., 2012) due to lower amounts of starter intake not persisting post-weaning (Bach et al, 2013; Rosenberger et al., 2017) and potentially explain the lack of interaction between pre-and postweaning diets (Rosadiuk et al., 2021). The advantage of increased milk feeding pre-weaning on ADG appears to diminish as calves age. A study by Haisan et al. (2019) found no difference in ADG at week 5, 6, or 7 and suggested this could be due to calves feeding on less milk consumed more CSC by ≥ 5 weeks of age. Curtis et al. (2018) also observed calves offered MR *ad libitum* versus restricted had lower concentrate intakes PRW but increased rapidly to match those on restricted intake with no significant impact or health effects at the end of pre-weaning.

Puberty, age at first calving, first lactation, and lifetime milk yield

The onset of puberty relies on various factors including breed, nutrition, BCS, and LW (Handcock et al., 2021) and it is estimated to occur within Holstein-Friesian breeds when animals reach 43 to 55% of MW (Meier et al., 2021). In DH, a relationship between LW at 15 mo. of age and AFC has been found (Handcock et al., 2020), while Steele et al. (2022)

concluded that herd-level factors associated with puberty amongst grazing heifers equally resulted from a greater proportion of MW, which encouraged DH to reach puberty earlier than lighter heifers in herds of greater mean absolute and proportional LW greater puberty rates. Moreover, heifers that had greater MW at the beginning of first (MW: 93 vs. 82%) and second (MW: 76 vs. 62%) lactation had greater survival and LMP than heifers of lower MW (Archbold et al., 2012). Lowering an AFC that is greater than the recommended 22 to 24 mo. (Margerison and Downey, 2005) has been shown to increase first lactation milk (FLM) yield, when the AFC was lowered from AFC 37 mo. to 21 mo. (639 from 1125 d) it increased FLM yield by 1.8 kg/d in Irish HF DH (Berry and Cromie, 2009). Lowering the AFC to 23 mo. from 26 mo. (700 from 791 d) increased FLM yield by 2.9 kg/d (Storli et al., 2017) and from 31 mo. (700 from 943 d) by 3.1 kg/d in Canadian Holstein Friesian (**HF**) DH heifers (Lin et al., 1986). The increase in FLM yield to lowering of the AFC from 31 mo. to 23 mo. was found to be linear by Lin et al. (1986), however was found to be non-linear in other studies that lowered AFC from > 27 mo. (821 d) to 23 mo. in Norwegian Red (Storli et al., 2017) and American HF DH (Losinger and Heinrichs, 1997). A direct relationship has been found between greater FLM yields and lifetime milk production (**LMP**) (Stassen et al., 1991), and selecting DH based on greater daily FLM yield has been shown to result in greater LMP, but heifers with greater FLM yield may have short longevity and low profitability (Jairath et al., 1995). Calving DH at an AFC < 23 mo. (700 d) has been correlated ($R^2 = 0.65$) with a greater LMP per day and herd life profitability (Rendel and Robertson, 1950) and lifetime profit per day (Boro et al., 2016). Lowering the AFC to 23 mo. (700 d), from 30 mo. (913 d) increased the LMP, by 5,295 kg over 5 years and/or 2.7 kg/d (Cooke et al., 2013) but lowering the AFC to 21 mo. (639 d) lowers LMP (Nilforooshan and Edriss, 2004). The LMP, of DH that had an AFC of 22 mo. (669 d) have been found to yield an additional 2.4 kg/d of LMP compared to DH calving at 1095 d (36 mo.) (Eastham, 2012). Low FLM yields <15 L/d are followed by relatively low second and third-lactation milk yields and as such very low FLM yields may be used in culling decisions (Haworth et al., 2008). Increasing the ECM yield of dairy cattle improves feed efficiency (VandeHaar and St-Pierre, 2006) and lowers the number of lactating cows required to produce the same amount of energy-corrected milk (**ECM**) yield (Capper et al., 2009). Moreover, dairy herds that have a lower proportion of first lactation cows have been found to have greater ECM per cow and lower GHG emissions per kg ECM yield, modelling to show that lowering herd RR from 45 to 15% lowered GHG emissions by 9 to 14% (Liang and Cabrera, 2015), which can be achieved by greater longevity and lifetime milk production.

Age at first calving, fertility, and calving frequency

Infertility is the most common reason for the involuntary culling of dairy cows (Margerison, 2022) and first lactation (**FL**) DH (Esslemont and Kossaibati, 1999; Brickell and Wathes, 2011). A lower AFC of 23 to 25 mo. (700 to 760 d) has been found to result in greater fertility, including a lower postpartum interval (**PPI**) to conception (Ettema and Santos, 2004), calving interval (**CI**) in FL heifers (Ettema and Santos, 2004; Eastham, 2012), and greater herd longevity (Bach, 2011; Cooke et al., 2013). However, two studies showed that the AFC did not affect the fertility, reproductive performance (Simerl et al., 1992), PPI to first service, and/or conception rate (**CR**) to first service of FL DH (Cooke et al., 2013). However, Cooke et al. (2013) found that lowering the AFC to < 23 mo. from >30 mo. (<700 and >913 d) tended to lower postpartum interval (PPI) to conception and number of services per conception (2.6 v 4.7± 1.7), which was associated with a lower CI and 300 d lower age at second calving, which may be related to the greater than recommended BCS (3.8 to 3.9) of 2.5 to 3.0 (AHDB, nd) found in DH that had an AFC > 30 mo. (Cooke et al., 2013), which is related to lower pp DMI, greater risk of metabolic disorders (Bedere et al., 2018) and greater pp BCS loss, which can have a deleterious effect on fertility (Wathes et al., 2008; Bedere et al., 2018) and involuntary culling and herd replacement rates. In terms of methane (**CH_4**), dairy herd replacements have been shown to contribute 27% of dairy herd emissions, and a greater AFC can be responsible for an additional 6% more CH_4, due to the greater number of herd replacements required and the greater LW and feed intake up to and at first calving (Garnsworthy, 2004). There is evidence to support that cows suffering from disease whilst pregnant is associated with offspring performance, with heifers being born to dams who experienced disease around the time of conception having a greater incidence of disease as a calf and during first lactation (Carvalho et al., 2020). Calves born to dams of high somatic cell count have been shown to have a greater AFC, increased first and second lactation mean SCC, and lower milk yield (Swartz et al., 2021). A greater nutrient provision, both PW and POW have been shown to result in a greater rate of reproductive development (Bruinje et al., 2019; 2020) resulting in a greater number of class 2 ovarian follicles (Bruinje et al., 2020) while enhanced nutrient provision POW has been shown to increased endometrial thickness, follicular size, the number of class 3 follicles and increase the likelihood of achieving puberty by 30 weeks of age (Bruinje et al., 2019). Feeding management and strategies PRW are key factors in mammary gland (**MG**) development which is essential for long-life production within dairy herds. Studies have reported this nutritional phase can determine MG growth rate and that this rate is quicker than the remaining body (Esselburn et al., 2015; Soberon and Van Amburgh, 2017). Growth of the MG can be reduced when weaning earlier (56 vs 91 d) (de Passille and Rushen, 2016) with MG size at 100 d being 5% less in those weaned at 56 d of age versus those weaned at 91 d of age (McCoard et al., 2019). Calves fed restricted MR versus *ad libitum* had delayed growth at 62 d of age including the MG and parenchyma, Niwinska et al. (2022) concluded that an increased intake of CSC increased microbial development, but this was not efficient or effective during the first 80 d of life, when ADG and development appears most critical, as well as bovine MG being at its most active during the first 3 mo. of life (Capuco and Akers, 2010).

Age at first calving and dairy heifer survival

A lower AFC has been associated with a greater SR (Evans et al., 2006; Bach, 2011; Cooke et al., 2013) and more heifers with an AFC ≤ 22 mo. (669 d) completing FL (Wathes et al., 2014). While an AFC of 21.7 (662 d) was shown not to compromise the SR of DH during FL, delaying the AFC by as few as 13 d to 23.8 mo. (724 d) was sufficient to lower SR significantly (Bach, 2011). A greater AFC, of 24 to 27 mo. (730 to 821 d), had a greater odds ratio of mortality and being culled during FL (Archer et al., 2013) and heifers that had an AFC ≥ 30 mo. (913 d) had a 30% lower SR at third lactation than heifers that had an AFC between 23 and 25 mo. (700 and 760 d), 50 and 70% respectively (Cooke et al., 2013). Despite a lower AFC of 22 to 24 mo. of age being economically desirable for intensive and block-calving dairy production systems, several studies have shown that first lactation milk was lower when heifers had an AFC < 24 mo. of age (Castillo-Badilla et al., 2019; Meyer et al., 2004; Le-Cozier et al., 2008). One study found an AFC of <22 mo. of age was associated with greater pp infertility and lower survival rates into the second lactation which lowered lifetime milk yield (Steele, 2020). Other studies found an AFC < 22 mo. of age did not extend the pp interval (PPI) to conception and number of subsequent lactations achieved, there was a greater incidence of dystocia suggesting the optimal AFC may be between 23 and 26 mo. of age (Atashi et al., 2021). Conversely, other studies have found that AFC did not affect SR during FL (Simerl et al., 1992; Ettema and Santos, 2004) and or at third calving, but an AFC < 28 mo. (852 d) and > 38 mo. (1156 d) increased the risk of culling in Kenyan DH (Ojango et al., 2005). Bach. (2011) also reported a positive association between ADG within the first 2 mo. of life with survivability to second lactation, with a growth of 0.8 ± 0.4 g/d than those with reduced growth. There have been some inconsistencies among studies may be due to the limited variation in the AFC in some studies (Ettema and Santos, 2004) and the small number of herds evaluated in others (Simerl et al., 1992; Ettema and Santos, 2004). The lifespan of HF dairy cows has decreased (Schuster et al., 2020) which is largely due to lower fertility and survival (Miller et al., 2008; Norman et al., 2009; Dallago et al., 2021) resulting in an average dairy herd lifespan of < 3 (Pinedo et al., 2014) to 4.5 years (Kerslake et al., 2018), which are lower than the natural lifespan of ≥ 5 years (De Vries, 2020). In dairying, culling is largely due to the physiological state of the cow, which includes parity, lactation stage, energy balance, age, and infertility (Pinedo et al., 2022), which is exasperated by greater age, herd size, and season (Tsuruta et al., 2005). Dairy cow survival rates within commercial herds were greater at 84 and 80% in US organic herds in the first and second lactation (Hardie et al., 2021) and declined between the second, third, and fourth lactation from 89, to 72 and 51% (Pipino et al., 2023). Differences in survival may be related to metabolic stress in early lactation compared with late lactation, particularly due to greater milk yield (Putman et al., 2018; Lean et al., 2023a; Lean et al., 2023b) and pp depletion of body condition and tissues (Schaff et al., 2013) to support milk production (Costa et al., 2019). This has been reportedly worse amongst primiparous dairy cattle due to nutrient requirements for maintenance, ADG, FLM yield, and gestation (Ryder et al., 2023). Increasing societal pressure from consumers and industry standards make animal health, welfare, and the ethical and environmental impact of greater importance to dairy farming (De Vries and Marcondes, 2020; Infascelli et al., 2021).

Age at first calving and lifetime production

The length of the herd life and/or productive life span are defined as the period between birth and/or AFC and culling (Beaudeau et al., 1995; Tsuruta et al., 2005). A survey of UK data from 18 dairy farms (n=468) of FL DH, shows that of those culled 37% was directly related to infertility (Brickell et al., 2011), and 82.6% of first lactation cows remained in the herd through to second lactation with a median CI of 370 d (Taylor et al., 2024). Other approaches to longevity, were defined as the period from birth to culling, which was shown to be 2.2% lower in heifers that had an AFC < 24 mo. (730 d) compared with heifers that had an AFC between 24 and 30 mo. (730 and 913 d), which had 5% greater longevity than heifers that had an AFC > 30 mo. (913 d) (Haworth et al., 2008). In terms of lactation, a study showed that lowering the AFC of HF heifers to 23 mo. (700 d) from 26 mo. (791 d) increases the number of days spent lactating by 107 (Lin et al., 1988). An AFC as young as 18 to 22 mo. (548 to 669 d) resulted in the greatest percentage of total lifetime lactating (**TLL**), which was as much as 60% TLL, followed by 58 % TLL at an AFC between 22 and 26 mo. (669 and 791 d), 55% of TLL at an AFC between 26 and 30 mo. (791 and 913 d) and was as low as 48% of TLL at an AFC ≥ 30 mo. (≥ 913 d) (Froidmont et al., 2013). Moreover, in the UK Cooke et al. (2013) found that an AFC < 23 mo. (700 d) achieved a greater amount, 54% of TLL than heifers that had an AFC ≥ 30 mo. (≥ 913 d) that achieved as little as 18 % of TLL. Moreover, increasing the proportion of lifetime dairy cows spend lactating, as a heifer and/or dry cow, improves lifetime feed efficiency (Vandehaar and St-Pierre, 2006) and lowers the CO_2-eq. of dairy production.

Live weight and body condition at first calving, first lactation milk yield and fertility

The AFC has been found a more reliable method of monitoring dairy herds in terms of economic value and profitability, however lowering the AFC to ≤ 24 mo. (749 d) resulted in DH completing fewer lactations and were least economical than an AFC of 24 to 26 mo. (750 to 799 d) (Krpalkova et al., 2014). Previous studies have shown a positive relationship between milk yield (MY) and BW at FLM yield, while heifers of greater LW at first calving were 49% more likely to be culled than lighter heifers (Han et al., 2021) and a significant curvilinear relationship showed heifers calving at 656 kg LW at 21 mo. of age completed more than three lactations (Handcock et al., 2019), while one study reported LW at first calving had no impact on LMP (Heinrichs and Heinrichs, 2011). A population study of 116,369 Czech Holstein cows, found LW to be a good indicator of chest width, and depth, which as it increased negatively affected cow longevity and LMP (Zavadilova et al., 2011). However, the application of LW targets (Akins, 2016) of 55% of MW at breeding and 82 (NRC, 2001) to 85 % at first calving (Margerison and Downey, 2005) have been suggested for Holstein Friesian heifers. Other metrics include a BW of 36 kg and MW of 580 kg (Kennedy and Murphy, 2017), which require an ADG of 0.68 kg/d to obtain such AFC and LW targets. Dairy heifers that had a lower AFC between 23 and 25 mo. of age had a body condition score (BCS) closer to the recommended 2.5 to 3.0 BCS at parturition (AHDB, nd) compared with heifers that had an AFC > 30 mo. that had greater BCS of 3.8 to 3.9, which were greater than the recommended maximum of 3.0 at parturition (AHDB, nd). Lower FLM yield has been associated with increased mammary fat pad, during pre-pubertal weight gain which negatively impacts the parenchyma development in favour of adipose tissue but several studies state first lactation does benefit from a greater ADG PRW (Khan et al., 2011; Soberon et al., 2012; Geiger et al., 2016; Soberon and Van Amburgh, 2017). In contrast, Kiezebrink et al. (2015) found no association between increased ADG up to 54 days of age between calves consuming 4 L vs 8 L with a 7 kg difference which remained significant up to 52 weeks of age. After this period, a difference in weight could not be detected and there was no significant difference in first lactation production. The maintenance of good dairy cow health plays a key role in reproductive success (Ribeiro et al., 2013), greater FCE (Garnsworthy, 2011), and lower GHG (Capper et al., 2023) and CO_2-eq. of producing milk (Bell and Wilson, 2018). The BCS of dairy cattle is useful in assessing the health and nutritional status of the dairy herd (Heuer et al., 1999; Stevenson and Atanasov, 2022) especially when compared with recommended targets at parturition, 60 d pp, and drying off (AHDB, nd). Moreover, excessive loss of BCS >0.5 during early lactation between 0 and 60 d pp negatively affects the fertility, LMP (Han et al., 2021), herd RR, and the CO_2-eq. of milk production from dairy cows (Bell and Wilson, 2018). In DH, a low BW has been associated with a greater incidence of dystocia, which appeared to have no subsequent impact on reproductive performance (Kusaka et al., 2022). However, the impact of AFC on fertility during the first lactation has been associated with younger DH continuing to grow pp, requiring nutrients for FLM yield, ADG, and BCS in preference to reproduction, and an older AFC was associated with the greatest BCS, between 3.8 to 3.9, and greater BCS mobilization, longer PPI to luteal activity (Ryder et al., 2023), and infertility, concluding that optimal 5-year lifespan and LMP was achieved at an AFC of 23 to 25 mo. (Cooke et al., 2013). While DH and cows that begin the second lactation in target BCS display fewer metabolic disorders and infectious diseases (Wang et al., 2019; Siurana et al., 2023) compared with older cows that are at greater risk of being culled due to a greater incidence of clinical hypocalcaemia, mastitis, and lameness (Lean et al. (2023). Evaluation of 305 d milk yield has shown that a greater LW at first calving resulted in a greater FLM yield, equivalent to 12.6 kg /kg LW (Hermiz and Hadad, 2020), which may be related positive correlation between LW, dry matter intake (**DMI**), and milk yield (**MY**) (Petrovska and Jonkus, 2014). However, while the measurement of BW and LW are accurate ways to assess the ADG of DH, it is more labour-intensive, costly, and difficult to access limiting the availability and applicability of LW and ADG in comparison to birth date and AFC (Ferrari et al., 2024). The AFC of DH has decreased by two months from 1996 to 2020, from 28.1 (± 2.9) to 26.1 (± 3.1 mo.) (Ferrari et al., 2024) and these statistics followed the reduction of age at first insemination, observed by Ferrari et al. (2023). Hutchinson et al. (2017) discussed more intense selection criteria for productivity and reproductivity combined with improved practices, which have indirectly enhanced AFC. Some studies report that a lower AFC lowered FLM, fat, and protein yields (Mohd Nor et al., 2013; Eastham et al., 2018), with heifers calving at 36 mo. a FLM yield 735 kg greater than heifers that had an AFC ranged from 18 to 21 mo. (Ferrari et al., 2024) but this is likely due to heifers not reaching adequate LW and mature weight (**MW**), and the need to use dietary energy for ADG rather than FLM yield (Sejrsen et al., 2000; Hutchinson et al., 2017) indicating the importance of an understanding of the biological interrelationships between PRW ADG and subsequent fertility, AFC, FLM yield (Curran et al., 2013).

Carbon footprint and economic costs of milk production and dairy heifer rearing

The assessment of the impact of dairying on GHG emissions requires quantification of all emissions and removals using life cycle assessment (**LCA)** (Beauchemi and McGeough et al., 2013), which is a holistic tool that has been used agricultural systems to evaluate the inputs, outputs, and potential environmental impact of a product production system (ISO, 2006 a, b). Many LCA studies have been conducted to estimate the CO_2-eq of dairy and related co-products under specialized production systems in several developed countries (Beauchemi and McGeough et al., 2013; Marton et al., 2016) but few have related to dairy herd replacements directly. The net farm CO_2-eq. and margin are affected the cost of rearing herd replacements, and income from milk sales because herd replacements typically produce less milk than the cows that are replaced (Renkema and Stelwagen, 1979; Rogers et al., 1988). In the rearing of dairy herd replacements key performance indicators (**KPIs**) include the AFC, pregnancy rate (**PR**), calving interval (**CI)**, replacement rate (**RR**) and feed costs (AHDB, 2014). In terms of RR there can be considerable variation, ranging from as low as 18% to as high as 36% being required to maintain the herd size (AHDB, 2024), The RR can be lowered by extending the productive life of dairy cows, which equally lowers the economic cost and CO_2-eq. of milk production (Van Middelaar et al., 2014; Bell et al., 2015; Grandl et al., 2016).

In terms of costs, animal feed, forage, and supplements account most at 36.8%, followed by labour at 22.3% (Boulton et al., 2017) and herd replacements at 20% of total farm expenditure (Gabler et al., 2000). The average cost of rearing heifers in the UK has been estimated to be £1819 per heifer and average feed costs were £2.31 / d (Boulton et al., 2017). Mover, this represents 1.5 lactations to repay heifer rearing costs, but these costs vary greatly between dairy farms, and this is mainly due to AFC (Boulton et al., 2017). In the UK, the AFC ranges between 26 and 28.9 mo. of age (Brickell et al., 2009; Sherwin et al., 2016), compared with the optimal economic AFC of 22 and 24 mo. of age (Margerison and Downey, 2005; Cooke et al., 2013; Wathes et al., 2014). The break-even point for heifer rearing costs has been calculated to be at an AFC of 26 mo. (Boulton et al., 2017), showing that financial losses associated with greater AFC.

Summary and research gap

This literature review showed that the UK has continued to have greater a than optimal AFC, along with higher rates of preweaning calf mortality and morbidity, which were mainly due high rates (< 70% of calves) of enteric disorders. Moreover, many dairy heifers do not reach and/or complete first lactation, which is below the point at which it has been shown the make a financial return on the investment in rearing costs. The evaluation of the CO_2-eq. of milk production has shown that cow survival, herd replacement rate and AFC contribute to a greater CO_2-eq. of milk production and greater feed costs. Studies have evaluated heifer mortality rates, the effect of calfhood disease on ADG and effect of PRW ADG on milk production and survival. Other studies have assessed the economic cost and CO_2-eq. of milk production, which included dairy herd replacements. However, there are no studies that have directly assessed the effect of enteric disorders on the feed efficiency, survival, economic cost and CO_2-eq. of herd replacements into second lactation.

Aim, objectives, and hypothesis

This thesis aimed to evaluate the effect of ED, which required ORT, on calf health, antimicrobial treatment, ADG, FE, fertility, AFC, FLM yield, and survival of HF DH into second lactation. The objectives were to evaluate faecal score twice every daily and measure the effect of ED that required ORT on the feed intake, ADG, WW and POW ADG, and FE of dairy heifer calves and assess the effect on the ADG, age, and LW at first service, fertility, AFC, LW, FLM yield, fertility and survival of first lactation DH. The hypothesis was that ED and ORT would lower PRW DMI and WW, LW at first service and first calving, and extend the AFC and lower MW at first calving, FLM yield, and survival of DH during first lactation compared with calves not treated for ED.

Materials and methods

Location of study and ethical approval

The data used for this study was collected between October 2020 and April 2024, from the University of Nottingham Centre of Dairy Science and Innovation (CDSI), Sutton Bonnington, Leicestershire, United Kingdom. The research was completed following approval of the ethical review by the University of Nottingham Animal Ethics Committee and in alignment with the UK Animal Scientific Procedures Act 1986, Project license No.: P78FDB0C3.

Animal selection, experimental design, and treatment

The experiment was undertaken using 52 randomly selected Holstein-Friesian DH from the year-round-calving dairy herd at the University of Nottingham, Centre of Dairy Research and Innovation. The heifers were grouped retrospectively according to the pre-weaning treatment for ED, determined by faecal score (**FS**) and administration of ORT using electrolyte solutions. The animals were assigned to one of two treatment blocks: calves that were not treated for ED (**NTED**) with ORT (n=30; birth LW 44.5 ±0.80 kg) and calves that were treated for ED (**TED**) with ORT (n=22; birth LW 42.5 ±0.96 kg) before weaning.

Animal housing and management

Immediately after birth, calves were transferred to a dual-pitch calf house that housed a maximum of 36 calves, in pens containing two calves per pen. Each pen was deep-litter bedded with cereal straw and contained a milk feeding station, fitted with weigh scales (Forster Technik, Germany), separate troughs for calf starter, cereal straw, and water (JFC, Shropshire, UK). At 14 d following weaning heifers were moved into a mono-pitch building and placed into groups containing 12 per pen, which was fitted with straw beds, a feeding alley with a water trough, automated scrapers (CleanSweep, Dairymaster, Co. Kerry, Ireland) that ran every 4 h and a head-locking feed face (IAE Agriculture Ltd., Stoke-on-Trent, UK). The heifers remained in this environment until they reached 12 months of age. At 12 months of age, the DH were moved to a similar dual-pitched heifer house fitted with 72 free stalls, fitted with cantilever divisions, and rubber mats that were bedded with sawdust. The alleys were fitted with above-ground automatic scrapers that ran at 4 h intervals and a central feed passage that was fitted with head-locking bale gates. At 3 to 4 weeks before partition, heifers were moved to a deep litter straw bedded pen, that housed 8 to 10 dairy cattle and was fitted with a central feed alley that had a feed face that was fitted with head-locking bale gates (IAE Agriculture Ltd., Shropshire, UK). At parturition, the heifers were moved to a dual-pitch building fitted with 55 free stalls, cantilever divisions, and deep litter sand beds, which were accessed on slatted concrete floors. The beds were cleaned daily, to remove excreta and dirty wet sand, which was facilitated by the deposit of larger volumes of clean fresh sand each week. The slatted floors were cleaned by a robot that pushed effluent through the slats (Lely UK Ltd., St Neots, UK) and the effluent was removed from below the slats by an automatic underfloor scraper that operated every 4 h (Lely UK Ltd., St Neots, UK).

Calf health and management

Directly following birth, calves had the umbilical cord treated with a 10% iodine solution (Mole Valley Farmers Ltd, UK) and were offered 3 to 4 L of pasteurised colostrum, via an oesophageal tube, containing ≥ 50 g/L of immunoglobulins (Igs) according to a colostrometer. All calves were dressed in calf jackets and routinely vaccinated against respiratory disease (Rispoval RS+Pi3 IntraNasal, Zoetis, USA) at 9 d of age. The umbilical area was checked daily until 14 d and weekly up to 1 mo. of age. Calves with a swollen umbilical cord/area and suspected umbilical infection/septicaemia were isolated and treated with antibiotics (NuFlor; Merck Animal Health Ltd., USA) and non-steroidal anti-inflammatory drugs (**NSAID**) (2.5 ml of Metacam per 100 kg LW s.c., Boehringer Ingelheim Ltd, Germany). Calves with symptoms of BRD, including coughing, lethargy, increased respiration rate, nasal discharge, sunken eyes, and/or low ear(s) placement (Wisconsin scoring system, McGirk et al., 2008) along with an elevated rectal temperature were treated with antibiotics (2.5 ml Draxxin per 100 kg of LW s.c., (Pfizer Ltd, USA) and NSAIDs (2.5 ml of Metacam per 100 kg LW s.c., Boehringer Ingelheim Ltd, Germany), with repeat treatment 72 h later as necessary. At 4 to 6 weeks of age, all calves were disbudded using an electric hot iron (Mole Valley Farmers Ltd, UK) using local anaesthesia (Norbrook Ltd, UK) and NSAID (2.5 ml of Metacam per 100 kg LW s.c., Boehringer Ingelheim Ltd, Germany).

Diet composition and animal feeding

At 2 to 4 d of age, calves were fed 3 L /d of transition milk, which had been collected from cows and heifers between 1 and 3 d postpartum. This was offered in buckets fitted with slow-flow teats, along with *ad libitum* access to fresh clean water from a plastic trough. At 4 d of age calves were offered MR (Milkivit Energizer, Trouw Nutrition, UK) (Table 1) from automated milk feeding stations (AMFS) (Forster Technik, Germany), reconstituted with water according to manufacturer's recommendations (42°C) and offered to calves at 38°C at a rate of 6 L (150 g/L in 2 L portions) at 4 d of age, 8 L (2 to 3 L portions) at 13 d of age, and 10 L (3.5 to 4 L portions) up to 53 d of age, then reduced to 2 L at 69 d and 0 L at 70 d of age. Calves were offered *ad libitum* access to calf starter (Course Mix, Irwin Feeds, UK) and water at 1 week of age and *ad libitum* access to chopped cereal straw (CCS) from 3 weeks of age (Table 2) provided in separate plastic troughs suspended above ground level in each pen.

Table 2: Nutrient composition of diet offered to calves 1 to 84 d of age

Item (% of DM)	Milk replacer[1]	Calf starter[2]	Cereal straw
Dry matter, %	96.7	87.4	89.0
Crude protein, % DM	23.1	20.1	5.7
Crude fibre, % DM		7.4	40.3
Neutral detergent fibre, % DM		30.9	82.0
Fat, % DM	18.5	2.3	1.2
Ash, % DM	5.0	7.1	5.9
Sugars. % DM	30.2		

[1] - Milk replacer ingredients: Skimmed-milk powder, whey powder, vegetable oil (palm, coco, Rape, Soya), Wheat starch, Wheat flour, Calcium chloride, Magnesium oxide, Monopotassium phosphate, Calcium carbonate, Dextrose, Propane-1, 2-diol. [2] Calf starter ingredients: Barley, Distillers dark grains, Linseed Expeller, Micronised Beans, Micronised Peas, Sugar Beet Pulp, Cane Molasses, Flaked Maize, Hi pro Soya, Locust Beans, Wheatfeed, Sopralin, Vitamins, Minerals, and Soya Oil.

Table 3: Ingredients and chemical composition of partial mixed ration and pelleted concentrate offered to dairy heifers (3 mo. of age to 25 d prepartum)

Ingredients (kg DM/d/cow)	Partial mixed ration	Pelleted concentrate
Diet components		
Maize silage, kg DM	7.5	-
Grass silage, kg DM	4.9	-
Whole crop silage, kg DM	2.8	-
Soya: Rape seed meal, kg DM	1.6	-
Molasses, kg DM	1.0	-
Diet composition, DM		
Dry matter, %	23.8	89.0
Crude protein, %	16.8	18.0
Metabolizable energy, MJ/Kg	12.1	12.5
Neutral detergent fibre, %	2.1	0.2
Starch and sugar, %	2.1	5.2
Oil, %	0.25	0.6

Dietary minerals and vitamins; calcium, 18%; phosphorus, 10%; magnesium, 5%; salt, 17%; copper, 2,000 mg/kg; manganese, 5,000 mg/kg; cobalt, 100 mg/kg; zinc, 6,000 mg/kg; iodine, 500 mg/kg; selenium, 25 mg/kg; vitamin A, 400,000 IU/kg; vitamin D3, 80,000 IU/kg; and vitamin E, 1,000 mg/kg. Pelleted concentrate ingredients: Barley,, Distillers dark grains, Micronised Beans, Linseed Expeller, Sugar Beet Pulp, Cane Molasses, Flaked Maize, Hi pro Soya, Wheatfeed, Sopralin, Vitamins, Minerals, and Soya Oil.

Calves were gradually weaned from 7 and fully weaned at 10 weeks of age, when calves were greater than double birth weight and had been consuming ≥ 2 kg/hd/d of CSC for ≥3 consecutive days before weaning. At 70 to 84 d of age calves continued to receive *ad libitum* access to CSC, CCS, and fresh clean water for two weeks, then they offered *ad libitum* access to a partial mixed ration (PMR) (Table 3) and 1 kg pelleted concentrate. At 4 to 6 mo. of age heifers were transferred to the PMR, plus 1 kg/head/d of compound feed (CSC) up to 6 mo. of age. From 7 to 12 mo. of age, heifers were offered *ad libitum* access PMR (Table 3). At 12 to 15 mo. of age heifers were housed in a dual pitch free stall barn, where they were offered PMR 1 (Table 3) plus 2.5 kg/hd/d of a pelleted feed, which was formulated to accommodate an ADG of 1.0 kg/d (NRC, 2001). At 15 mo. of age, heifers were transferred to the adult cattle dual pitch barn, where they were offered *ad libitum* access PMR (Table 3) until 3 to 3.5 weeks prepartum when they were transferred to the transition group and offered a transition diet (Table 3) until parturition.

Table 4: Ingredients and composition of transition partial mixed ration and pelleted concentrate offered to lactating heifers

Ingredients	Partial total mixed ration
Diet components, DM	
Maize silage, kg	7.5
Grass silage, kg	4.9
Whole crop silage, kg	2.8
Wheat straw, kg	1.5
Soya: Rape seed meal, kg	1.6
Molasses, kg	1.0
Diet composition, DM	
Dry matter, %	23.8
Crude protein, %	16.2
Metabolizable energy, MJ/Kg	11.2
Neutral detergent fibre, %	3.9
Starch and sugar, %	1.6
Oil, %	0.01

Dietary minerals and vitamins; calcium, 18%; phosphorus, 10%; magnesium, 5%; salt, 17%; copper, 2,000 mg/kg; manganese, 5,000 mg/kg; cobalt, 100 mg/kg; zinc, 6,000 mg/kg; iodine, 500 mg/kg; selenium, 25 mg/kg; vitamin A, 400,000 IU/kg; vitamin D3, 80,000 IU/kg; and vitamin E, 1,000 mg/kg.

At partition, heifers were transferred to the milking cow accommodation alongside adult cows. During their first lactation, heifers were offered *ad libitum* access to lactation PMR (Table 4), which was formulated to provide enough nutrients for the maintenance of the animal, plus 30 L/d of MY. This was supplemented with a pelleted feed, which was offered by the robot milking system (RMS) and attached feed bin (Lely Astronaut A3; Lely UK Ltd., St Neots, UK) at a rate of 2 kg/d at parturition, rising to 12 kg/d at 35 DIM, and remaining at 12 kg/d until 70 DIM, after which the daily allowance was 3.5 kg/d plus 0.45 kg per L of average daily MY between 32 and 51 L/d, over the previous seven days. The daily concentrate allocation for each heifer was divided across the expected number of visits to the RMS to prevent digestive disorders by limiting the total concentrate feeding amount to 12 kg FM/d and 3 kg FM per visit to the RMS.

Table 5: Ingredients and composition of lactation partial mixed ration and pelleted concentrate offered to lactating heifers

Ingredients (kg DM/d/cow)	Partial total mixed ration	Pelleted concentrate
Diet components, DM		
Maize silage, kg	7.5	-
Grass silage, kg	4.9	-
Whole crop silage, kg	2.8	-
Wheat straw, kg	0.5	-
Soya: Rape seed meal, kg	3.6	-
Molasses, kg DM	1.3	-
Protected fat, kg DM	0.4	-
Diet composition		
Dry matter, %	23.8	89.0
CP, % DM	16.8	18.0
ME, MJ/Kg DM	12.2	12.5
NDF, % DM	2.9	0.2
Starch and sugar, % DM	2.6	5.2
Oil, % DM	0.5	0.6

Dietary minerals and vitamins; calcium, 18%; phosphorus, 10%; magnesium, 5%; salt, 17%; copper, 2,000 mg/kg; manganese, 5,000 mg/kg; cobalt, 100 mg/kg; zinc, 6,000 mg/kg; iodine, 500 mg/kg; selenium, 25 mg/kg; vitamin A, 400,000 IU/kg; vitamin D3, 80,000 IU/kg; and vitamin E, 1,000 mg/kg. Pelleted concentrate ingredients: Barley, Distillers dark grains, Micronised Beans, Sugar Beet Pulp, Cane Molasses, Flaked Maize, Hi pro Soya, Wheatfeed, Sopralin, Vitamins, Minerals, and Soya Oil.

Measurements

Calf and heifer health

Calf gastrointestinal and respiratory health was scored twice daily (7.00 and 16.00) using the Wisconsin scoring system 4-point scale was used to assess the faecal consistency (Diaz et al., 2001; McGuirk, 2008), with 1 being firm and 4 being liquid (Fig 4), which was evaluated twice daily directly before milk feeding. Calves with a faecal score of 3 were offered 2 L of milk containing 50 g of electrolyte (Lectade, UK), and severe cases with faecal score ≥3 were offered 50 g of electrolytes in 2 L of water. Calves with pneumonia symptoms such as heightened respiration rate, temperature, and congested lungs; or navel infection, with a swollen navel; were isolated. These calves were prescribed antibiotics and examined by a veterinarian and the treatments and number of days treated were recorded. The calf umbilical area was checked weekly, with one calf being treated for umbilical infection at 14 d of age and 4 calves were treated for preclinical (1) and clinical (3) pneumonia (NuFlor; Merck Animal Health Ltd., USA) for 3 to 5 d. Additionally, 1 calf was treated for a jaw abscess infection at 14 and 30 d of age (Synlox, Merk Animal Health Ltd., USA). The post-weaning health of growing and first lactation heifers was monitored twice daily and all disease incidence, severity, treatment, and reason for culling were recorded in the farm diary and transferred to a herd health management package (Uniform, Agri Professional, UK).

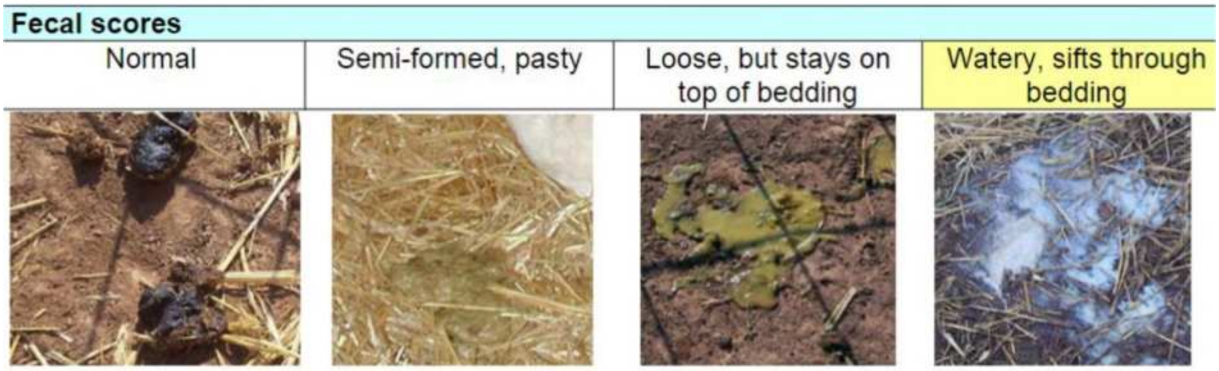

Fig: 4: Wisconsin scoring system 4-point scale used to assess the faecal consistency (Diaz et al., 2001; McGuirk, 2008)

Dry matter intake, feed samples, and nutrient concentration

The fresh matter (FM) intake for each animal was monitored by electronic feed bins, fitted with electronic animal identification gates (Hokofarm Group B.V., Marknesse, Netherlands) to assess PMR intake. Feed samples of PMR and pelleted feed, were collected weekly and used to assess PMR and pelleted feed DM. The pelleted concentrate was offered to growing heifers using the head-locking bale gates before first calving and using bins fitted to the robot milking station (Lely Astronaut A3; Lely UK Ltd., St Neots, UK) following partition. Weekly samples (500 g) of all feeds were collected and near-infrared spectroscopy (NIRS) was used to analyze maize, grass, and whole-crop cereal silages for dry matter (DM) and nutrient composition. These analyses, were undertaken using the Forage Analysis Assurance Group equations to calculate metabolizable energy (ME) using the formula ME = 0.14 x NCGD + 0.25 x OAH where NCGD = neutral cellulase plus gamanase digestibility (FSR, 2005) (Tables 2, 3 and 4). The AOAC (1990) procedures were used to determine DM, CP, NDF, sugar, starches, and fat (oil acid hydrolysis; OAH) content of feed ingredients and PMR and pelleted feed intake were recorded and used, in conjunction with feed DM, to calculate the DMI /head (hd)/day.

Milk yield and composition

Daily milk yield (kg/d) was recorded automatically by the Lely milking robot (Lely Astronaut A3; Lely UK Ltd., St Neots, UK) and used to calculate the mean weekly MY. Milk (20 ml) samples were collected every other week from pm and am milkings on two consecutive days. The milk samples were preserved using a broad-spectrum Microtabs®II (containing Bronopol and Natamycin; D&F Control Systems, Inc., USA) and were refrigerated at 3 to 5 °C until analysis for somatic cell count (SCC), milk fat, milk protein, and urea AOAC (1990) reference method No. 972.16 (National Milk Records Laboratory, Yorkshire, UK). Fat-corrected MY (MY kg x fat g/kg /40 g/kg), protein and fat-corrected milk (FPCM) yield (MY kg × ((0.1226 × *Fat* %) + (0.0776 × Protein %) + 0.2534) (Gerber, Vellinga et al., 2011), milk fat (MY kg x fat %), milk protein (MY kg x protein %) and milk solids (milk fat + milk protein) yields were calculated. Energy-corrected milk (ECM) yield was calculated in kg (0.327 x MY kg + 12.95 x milk fat kg + 7.21 x milk protein kg) according to Sjaunja et al. (1990).

Live weight and body condition

The live weight of individual calves was measured by load cells attached to the milk feeding station (Forster Technik, Germany) and used to determine the mean weekly LW and change in LW. The birth weight (1 d of age), and weaning weight (70 d of age) were recorded and ADG pre-weaning (< 70 d of age) and post-weaning (70 to 84 d of age) and double birth weight were calculated. The LW of growing heifers was measured monthly, using electronic weigh sales (Truetest, NZ). The LW was assessed at each milking using load cells attached to the platform of the robot milking station (Lely Astronaut A3; Lely UK Ltd., St Neots, UK) and used to calculate LW at first calving, 60, and 120 d pp and change between 0 and 60, 60 to 120, and 0 to 120 d pp. The proposition of mature weight was calculated by dividing the calving weight by the mean live weight of cows in ≤ 3rd lactation. The body condition score (BCS) of growing heifers and heifers during first lactation was assessed weekly by the same member of technical staff using a 5-point scale, from 1- significantly thin to 5- severely overfat, to the nearest quarter point (AHDB, 2021) and used to calculate BCS at calving, 60, and 120 d pp and change from parturition to 60, 60 to 120, and 0 to 120 d pp.

Oestrus activity, artificial insemination, and pregnancy determination

At 12 mo. of age, heifers were transferred to a free stall barn fitted with two pens, 84 cubicles fitted with rubber mats that were bedded with wood sawdust, and (5%) lime flour. The allies were cleaned automatically by overground scrapers (CleanSweep, Dairymaster Co Cork, Ireland) that ran at 4 h intervals and a central feed passage fitting with 80 head-locking bale gates (IAE Agriculture Ltd., Stoke-on-Trent, UK). Heifer reproduction was managed professional by advanced breeding systems (ABS) (Genus Breeding Ltd, Nantwich, UK), which included the synchronisation of oestrus (Estrumate, MSD Animal Health UK Limited), tail paint, observation of oestrus behaviour and/or disturbance of tail paint (Genus Breeding Ltd, Nantwich, UK).

During the first lactation oestrus was detected using activity using accelerometers that were attached to the collar of individual heifers that continuously measured horizontal movements of head and neck during walking and mounting behaviour. This activity was automatically transferred via an antenna when heifers visited the robotic milking station and used to calculate a daily activity index. This was used to separate increased activity associated with oestrous behaviour compared with typical stored activity patterns using specially developed algorithms and used by herd management software to provide lists of individual heifer oestrus and health status (Lely Astronaut A3; Lely UK Ltd., St Neots, UK). All heifers were mated by artificial insemination (AI), which took place 12 hours following the oestrus activity by a breeding technician (Genus Breeding Ltd, Nantwich, UK). Pregnancy was confirmed by a qualified veterinarian 18 to 21 d following a successful AI using a Voluson *I* ultrasound device (General Electric Healthcare Systems, Vienna, Austria) fitted with a 12L RNA linear array multifrequency transducer operated at 4 to 12 MHz and was confirmed by rectal palpation at 40 to 60 d of gestation.

Feed and treatment use, economic cost and carbon dioxide equivalents

The feed cost of heifers was estimated using the actual AFC of the DH in this study and a daily cost of £2.31/d up to calving at 791 d according to Boulton et al. (2017), by applying heifers not treated with ORT as a base of £0.00 additional feed, electrolyte and MR costs. An electrolyte treatment of £4.00 /d and MR costs of £1,500/t were used to calculate the effect of days treated with electrolytes on AFC-related feed, and electrolyte and MR costs and the total cost of these resources, excluding labour and finance. The CO_2-eq-related emissions were calculated from the CI, which was calculated using the PPI to conception with the addition of a standardised gestation period for lactating dairy cattle of 283 d. The RR related to infertility was calculated using the PR (100 – PR = RR) and the CO_2-eq related emissions were calculated using the RR, % x 48.7 kg according to the method for CO_2-eq emissions calculated per % RR for DH according to the methods described by Bell and Wilson (2018). The CO_2-eq. emission per day of CI, was calculated using 14.9 kg/d, which was representative of the average amount CO_2-eq. per d of CI for dairy cows according to the method described by Bell and Wilson (2018).

Statistical analysis

The data was collected from T4C (Lely Ltd., UK) and Uniform (Agri), and collated using Excel (Microsoft Office, 2016), weekly means were calculated and used to calculate the ADG, feed intake, FCE, feed efficiency, and water intake during the PRW up to 70 d of age, the POW period between 70 and 84 d of age, and over the whole calf rearing period between birth and post-weaning 1 to 84 d of age. Statistical analysis was completed in Minitab (Version 17.2.1, 2016, State College, PA) and data was assessed for normality of distribution using Anderson-Darling distribution assessment and found to be normally distributed applying NTED and TED as a fixed effect and animals as a random effect in the model. The live weight, feed intake, ADG, FE, and FLM yield, milk fat, protein, lactose, $\log^{base10}$ SCC, milk urea, LW, BCS, DMI, and PPI to first AI, inter oestrus cycles, were analyzed using a generalised linear mixed model (GLM) two-sided analysis of variance (ANOVA), with the confidence interval set at 0.95 with NTED and TED applied as a fixed effect and animals treated as a random effect in the model. The number of insemination numbers, conception rate, and pregnancy rate (**PR**) were assessed using Chi-square analysis. The data was presented means (± SE) along with the relevant P values. The existence of significant differences between means was expressed as $P<0.05$, while tendencies were expressed as $P<0.10$.

Results

Environmental temperature, humidity, and thermo-neutral zone

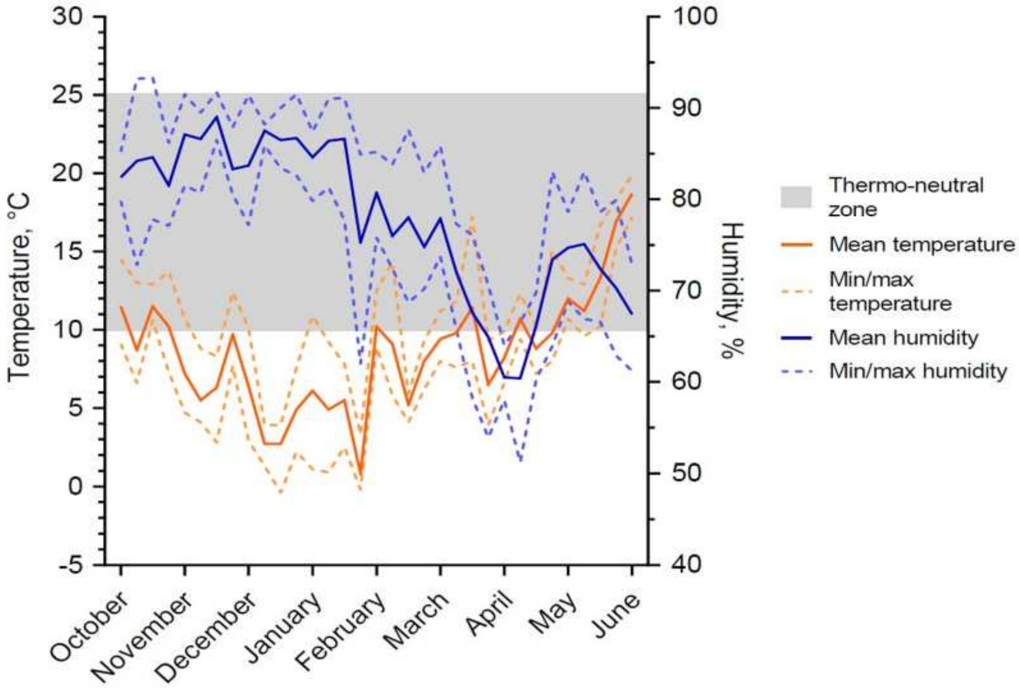

Fig. 5: Temperature, humidity, and thermo-neutral zone for pre-weaned dairy calves

The mean temperature was below the thermo-neutral zone for calves < 4 weeks of age between October and March, when the relative was above 75% (Fig 5).

Calf health, treatment, feed and water intake

Table 6: Mean faecal score, days treated, and mortality rate (± SE) of individual dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No animals	30	30	-
Faecal score (0 to 5) [1]	1.5 (0.27)	3.4 (0.32)	<0.001
Electrolyte treatment, d	0.00 (0.00)	3.2 (0.31)	0.003
Respiratory score, d	0.6 (0.26)	1.0 (0.31)	0.288
Morality rate, %	0.0 (0.01)	0.1 (0.01)	0.985

[1] – 0 to 5 point scale, with 0 being good and 5 being very poor

Table 7: Mean feed and water intake (± SE) according to pens of dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No pens [1]	15	15	-
Preweaning milk replacer intake, kg DM/d	0.90 (0.015)	0.85 (0.018)	0.030
Pre-weaning starter intake, kg DM/d	0.39 (0.021)	0.37 (0.024)	0.480
Pre-weaning straw intake, kg DM/d	0.05 (0.003)	0.05 (0.004)	0.434
Preweaning total feed intake, kg DM/d	1.34 (0.013)	1.27 (0.015)	0.037
Pre-weaning daily water intake 1 to 70 d, kg/d	0.23 (0.008)	0.24 (0.009)	0.595
Post-weaning starter intake 70 to 84 d, kg DM/d	2.52 (0.072)	2.62 (0.084)	0.379
Post-weaning straw intake 70 to 84 d, kg DM/d	0.19 (0.014)	0.18 (0.017)	0.539
Post-weaning daily water intake 70 to 84 d, kg/d	2.40 (0.045)	2.42 (0.053)	0.746
Overall mean starter intake 1 to 84 d, kg DM/d	0.75 (0.026)	0.74 (0.311)	0.954
Overall mean daily straw intake 1 to 84 d, kg DM/d	0.07 (0.005)	0.07 (0.006)	0.438
Overall mean daily water intake 1 to 84 d, kg/d	0.50 (0.008)	0.50 (0.009)	0.646

[1] – Mean intake of two calves per pen

Calves that had a FS ≥3 and were TED PRW had a 1.9 greater FS and received ORT for 3.2 d more than DH calves that had a FS <3 and were NTED (Table 6), which was equivalent to an ED incidence of 50%. The respiratory score and mortality rate of DH calves did differ between DH NTED and TED, using ORT PRW. The DH calves NTED had a 0.05 kg/d greater MR and 0.071 kg DM/d intake up to weaning (70 d of age) compared with calves TED using ORT (Table 7). There was no difference in the CSC, chopped cereal straw, and water between DH calves NTED and TED, using ORT.

Live weight and average daily weight gain

While there was no difference in birth weight, DH calves NTED had a 10.2 kg greater WW at 70 d of age and 9.2 kg greater LW at 14 d POW at 84 d of age, compared with DH calves TED (Table 8). The PRW ADG up to 70 d of age and the overall ADG up to 84 d of age were 0.08 kg/d greater in DH calves NTED compared with calves TED. The POW ADG, between 70 and 84 d of age, did not differ between calves NTED and TED.

Table 8: Live weight and average daily gain (± SE) of dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No animals	30	30	-
Birth weight (1 d), kg	44.5 (0.81)	42.5 (0.95)	0.119
Weaning weight (70 d), kg	100.3 (1.32)	91.9 (1.55)	<0.001
Live weight post-weaning (84 d), kg	114.5 (1.72)	105.3 (2.00)	0.001
Pre-weaning weight gain 1 to 70 d, kg/d	0.79 (0.014)	0.71 (0.017)	<0.001
Post-weaning weight gain 70 to 84 d, kg/d	1.03 (0.048)	0.954 (0.056)	0.291
Overall daily weight gains 1 to 84 d, kg/d	0.83 (0.016)	0.75 (0.019)	0.001

Feed conversion and feed efficiency

The FCE of DH calves NTED was 0.04 kg greater PRW up to 70 d of age and overall, between 1 and 84 d of age, compared with DH calves TED using ORT (Table 9). The POW FCE, between 70 and 84 d of age, did not differ between DH calves NTED and TED, using ORT before weaning. The FE of DH calves NTED was greater, requiring -0.13 kg of feed PRW up to 70 d of age and -0.16 kg overall, between 1 and 84 d of age, less feed compared with DH calves TED using ORT (Table 7). The POW FE, between 70 and 84 d of age, did not differ between DH calves NTED and TED, using ORT before weaning.

Table 9: Feed conversion and feed efficiency (± SE) of dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No animals	30	30	-
Live weight gain/kg intake, 1 to 70 d, kg	0.64 (0.013)	0.60 (0.015)	0.047
Live weight gain/kg intake, 70 to 84 d, kg	0.40 (0.024)	0.36 (0.028)	0.256
Live weight gain/kg intake, 1 to 84 d, kg	0.51 (0.013)	0.47 (0.015)	0.037
Feed intake/kg weight gain 1 to 70 d, kg	1.54 (0.027)	1.67 (0.032)	0.047
Feed intake/kg weight gain 70 to 84 d, kg	2.61 (0.147)	2.73 (0.175)	0.256
Feed intake/kg weight gain 1 to 84 d, kg	2.02 (0.054)	2.18 (0.063)	0.037

Reproductive performance and survival rate before first calving

The age at first insemination, and conception, conception rate to first insemination, number of inseminations per conception, pregnancy, and survival rate up to first calving did not differ between DH NTED and TED, using ORT, before weaning (Table 10).

Table 10: Mean live weight, proportion mature weight at 12 mo. of age, and reproduction performance (± SE) of individual dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No. animals [1]	30	22	-
Live weight at 12 mo. of age, kg	383 (11.8)	334 (15.5)	0.003
Average daily weight gain. 3 to 12 mo., kg	0.94 (0.008)	0.81 (0.009)	0.001
Proportion of mature live weight, %	55 (0.05)	49 (0.05)	0.002
Age at first insemination, d	414 (11.5)	425 (13.3)	0.570
Age at first insemination, mo.	13.6 (0.38)	14.0 (0.44)	0.570
Age at conception, d	427 (11.0)	433 (12.7)	0.718
Age at conception, mo.	14.0 (0.36)	14.2 (0.42)	0.718
Conception rate to first insemination, %	65 (10.9)	67 (12.6)	0.921
Insemination per conception, No.	1.9	1.9	0.943
Pregnancy rate, %	83 (8.7)	73 (10.2)	0.811
Survival rate, %	83 (9.1)	69 (8.1)	0.268

[1] – Number of animals that survived at 12 mo. of age

Mature weight and age at first calving

Table 11: Mean mature weight and age at first calving (± SE), and live weight of first lactation dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No. animals [1]	18	18	-
Age at first calving, d	704 (10.0)	747 (9.8)	0.004
Age at first calving, mo.	23 (0.3)	25 (0.3)	0.004
Parturition mature weight, %	87 (1.2)	81 (1.2)	0.002

[1] – Number of animals that survived at first calving

The AFC was lower and MW at first calving was greater in DH NTED compared with those TED, with ORT, as PRW calves (Table 11).

First lactation live weight and body condition score

Table 12: Mean during first lactation live weight and body condition score BCS (± SE) of dairy heifer calves not treated and treated for enteric disorders using electrolytes

	Electrolytes		
	Not treated	Treated	P value
Obs., No. animals [1]	18	18	-
Live weight at parturition	617 (8.2)	575 (8.8)	0.002
Live weight at 60 d pp	616 (8.2)	570 (8.8)	0.001
Live weight at 120 d pp	697 (8.3)	559 (0.3)	0.005
Change in live weight 1 to 60 d pp	-0.7 (2.20)	-5.2 (2.62)	0.120
Change in live weight 60 to 120 d pp	18.6 (3.24)	12.9 (2.91)	0.187
Change in live weight 1 to 120 d pp	19.3 (4.51)	18.1 (5.77)	0.890
Body condition at parturition, 1 d pp [1]	3.0 (0.10)	3.0 (0.12)	0.854
Body condition at 60 d pp [1]	3.0 (0.18)	2.8 (0.14)	0.297
Body condition at 120 d pp [1]	3.0 (0.11)	2.8 (0.15)	0.397
Change in body condition 1 to 60 d pp [1]	-0.1 (0.07)	-0.2 (0.09)	0.376
Change in body condition 60 to 120 d pp [1]	-0.0 (0.06)	0.0 (0.09)	0.998
Change in body condition 1 to 120 d pp [1]	-0.1 (0.11)	-0.2 (0.14)	0.532

[1] – Body condition: Assessed (0 to 5 points scale, at 0.25 point intervals) according to AHDB (2021)

The LW of DH NTED was 42 kg greater at parturition, 46 kg greater at 60 d pp, and 138 kg greater at 120 d pp than DH TED before weaning (Table 12). The BCS at parturition and change in LW and BCS between parturition and 60 d pp, 120 d pp, and 60 to 120 d pp did not differ between DH NTED and TED, with ORT before weaning.

First lactation milk yield and composition

The DH NTED had 3.6 kg/d greater 305 d milk, 4.2 kg/d greater FCM, 4.7 kg/d greater ECM, 4.3 kg/d greater FPCM, 0.17 kg/d greater milk fat, 0.08 kg/d greater protein and 0.35 kg/d greater MS yield than DH TED using ORT as calves PRW (Table 13). The milk fat, protein, lactose, urea, and $\log^{base10}$ SCC concentrations did not differ between DH NTED and TED, using ORT, before weaning. The DH TED, using ORT, as PRW calves spent 30 d more in lactation than DH NTED.

Table 13: Mean first 305-day lactation milk yield, milk composition, and days in milk (± SE) of dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No. animals	18	18	-
305 d milk yield, kg/d	34.8 (1.01)	31.2 (1.04)	0.018
FCM yield, kg/d [1]	39.0 (1.22)	34.8 (1.43)	0.035
ECM yield, kg/d [2]	40.8 (1.20)	36.1 (1.40)	0.017
FPCM yield, kg/d [3]	34.3 (1.14)	30.0 (1.33)	0.021
Milk fat, g/kg	44.9 (0.34)	44.8 (0.39)	0.966
Milk protein, g/kg	36.5 (0.31)	35.0 (0.37)	0.122
Milk lactose g/kg	47.8 (0.19)	46.7 (0.16)	0.584
Milk urea, %	0.28 (0.015)	0.27 (0.014)	0.282
Log^{base10} milk SCC, cells/ml	1.42 (0.106)	1.37 (0.124)	0.733
Milk fat yield, kg/d	1.56 (0.05)	1.39 (0.058)	0.035
Milk protein yield, kg/d	1.27 (0.039)	1.19 (0.046)	0.005
Milk solids yield, kg/d	2.83 (0.085)	2.48 (0.099)	0.012
Days in milk, d	309 (12.4)	339 (13.3)	0.045

[1] – FCM – Fat corrected milk yield, kg = Milk yield kg x milk fat kg / 40.0. [2] – ECM – Energy corrected milk yield, kg = 0.327 x milk yield kg + 12.95 x milk fat kg + 7.21 x milk protein kg (Sjaunja, 1990) [3] – FPCM – Fat and protein corrected milk yield = Milk kg × ((0.1226 × Fat %) + (0.0776 × Protein %) + 0.2534) (Gerber et al., 2010)

First lactation reproduction performance

The DH NTED had a 15 d shorter PPI to the first insemination and a 20% greater survival rate at the end of the first lactation than DH that had been TED, using ORT, as PRW calves (Table 14). The number of inseminations required per conception tended to be 0.7 fewer and CI tended to be 19 d lower in DH NTED compared with DH TED, using ORT, as calves PRW. The conception rate to first insemination, PPI to conception, PR, and RR did not differ between DH NTED and TED, using ORT, as PRW calves.

Table 14: Mean first lactation reproduction performance (± SE) of dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Obs., No. animals	18	18	-
Interval to the first insemination, d pp	56 (3.6)	71 (3.9)	0.007
Conception rate to first insemination, %	27 (13.7)	22 (15.2)	0.801
Interval to conception, 130 d pp	85 (12.2)	64 (13.2)	0.256
Insemination per conception, No.	1.8 (0.22)	2.5 (0.23)	0.066
Pregnancy rate, %	96 (5.2)	90 (3.4)	0.346
Calving interval, d [1]	368 (7.3)	387 (7.9)	0.079
Replacement rate, %	4.0 (2.5)	10.0 (3.4)	0.346
Survival birth to second lactation, %	79 (0.01)	59 (0.01)	0.031

[1] – Calving interval calculated from PPI to conception + 283 d gestation
[2] – Replacement rate calculated on an assumed replacement rate of 20% and CI 365 d
[3] – Combined replacement rate for addition days of calving interval + 100 % for replacements

Economic cost and carbon dioxide equivalents

Table 15: Mean economic and carbon footprint cost (± SE) of dairy heifer calves not treated and treated for enteric disorders using electrolytes before weaning

	Electrolytes		
	Not treated	Treated	P value
Pre-weaning milk replacer intake 1 to 70 d, kg DM	59.6 (1.02)	56.2 (1.19)	0.030
Pre-weaning starter intake 1 to 70 d, kg DM	27.3 (1.44)	25.7 (1.61)	0.480
Pre-weaning straw intake 1 to 70 d, kg DM	3.5 (0.21)	3.5 (0.28)	0.434
Preweaning feed intake 1 to 70 d, kg DM	90.4 (0.89)	85.4 (1.11)	0.037
Post-weaning starter intake 70 to 84 d, kg DM	35.4 (1.01)	36.7 (1.18)	0.379
Post-weaning straw intake 70 to 84 d, kg DM	2.7 (0.19)	2.5 (0.24)	0.539
Additional electrolyte costs, £	0.00 (0.01)	8.70 (1.23)	0.019
Replacer cost, £,	0.00 (0.55)	-5.71 (0.74)	0.017
Additional feed costs to first calving, £	0.00 (1.40)	99.60 (21.60)	0.004
CO_2-eq. calving interval, kg	5476 (100.0)	5770 (110.0)	0.049
CO_2-eq. replacement rate, kg	195 (121.8)	487 (165.6)	0.346
CO_2-eq./kg milk	0.45 (0.553)	0.45 (0.0515)	0.978

The DH calves NTED had a 3.4 kg greater MR and 5 kg DM and 0.071 kg DM/d intake up to weaning (70 d of age) compared with calves TED using ORT (Table 14). The CSC, chopped cereal straw, and water intake did not differ between DH calves NTED and TED, using ORT. The cost of feed up to first calving was £99.60 lower, electrolytes were £8.70 less and MR was 5.71 greater for DH NTED than those TED, using ORT, as PRW calves (Table 13). The accumulated total feed and electrolyte costs were £102.59 (± 16.71) (P=0.015) lower for DH NTED than those TED, using ORT, as calves PRW. The CO_2-eq. related to the CI was lower for DH NTED than those TED, using ORT, as PRW calves. The CO_2-eq. related to RR was 40 % lower, but CO_2-eq. related to RR and per kg of milk yield did not differ between DH NTED and TED, using ORT, as PRW calves.

Discussion

One of the leading causes of calf mortality is ED (Donovan et al., 1998; Windeyer et al., 2014; Umaña Sedó et al., 2023) and between 34% and 56.5% have been reported to suffer ED preweaning (Urie et al., 2018; Abuelo et al., 2021; NAHMS, 2021; Goh et al., 2024)., However, only few studies have assessed the longer-term potential effects of ED and its treatment with ORT, on DH performance and the economic (Virtala et al., 1996; Aghakeshmiri et al., 2017), FE and CO_2-eq. of dairy herd replacements and milk yield. This study found that DH NTED had better FS, consumed more MR, and achieved a greater ADG up to 70 d of age. Furthermore, NTED had higher WW and overall ADG up to 84 d of age, had a lower economic and carbon footprint cost and greater LW, MW, and FLM yield, milk component yield and survival rate up to the end of first lactation compared with DH TED PRW.

Enteric disorders

In this study, the incidence of ED was 50%, which is lower than rates reported in the United States (NAHMS, 2021), but similar to the 53.8% reported by Goh et al. (2024) and higher than the 34% (Urie et al., 2018) and 41% (Abuelo et al., 2021) reported in other studies. This variation in ED incidence highlights differences between study populations and environments. The peak in ED incidence occurs early in life, between 8 (Goh et al., 2024) and 28 d of age (Curtis et al., 2016; Urie et al., 2018), and in this study, ED peaked when calves were > 15 d of age, which can increase the potential risk of mortality even when the reported FPT was as low as 5% (Curtis et al., 2016). The calves in this study, were offered a peak of 6 L/d of MR at a concentration of 150 g/L and studies have shown that calves offered more nutrients PRW have a lower incidence and duration of ED (Ockenden et al., 2023) and calves NTED continued to consume MR, as with other studies (Knauer et al., 2017). Additionally, colder temperatures are associated with higher rates of health disorders and mortality, especially in younger calves (Windeyer et al., 2014), with a lower critical temperature of 13°C at 1 d of age, which is lowered to 6.4°C at 30 d of age (Silva and Bittar, 2019). In this study, MR was withdrawn when calves had ED resulting in a FS ≥ 3 and were given ORT, which is in agreement with others that demonstrated that withholding milk for calves TED, with ORT, enhanced the recovery from ED. This was despite some studies reporting that calves offered milk along with ORT gained more LW than those that had milk withdrawn when offered ORT (Constable et al., 2001; Goodell et al., 2012; Barry et al., 2020). Historically, literature states resting the gut during episodes of diarrhoea within PRW to prevent further pathogenic growth but has often resulted in lower ADG and overall growth (Goodell et al., 2012; Fettman et al., 1986). Heller and Chigerwe (2018) also reported that reduced MR feeding and milk being withheld from calves TED with ORT will impede recovery of diarrhoea, contributing to increased mortality (Barry et al., 2020). Mortality was not impacted in this study with 0.0 vs 0.01% rate for NTED and TED, suggesting quick diagnosis, treatment and husbandry significantly reduced risks. A better plane of nutrition can lower calf disease by improving immune function when PRW calves are receiving greater amounts of MR during cold weather that is below the lower critical limit when calves have greater metabolic demands (Nonnecke et al., 2009; Roland et al., 2016). As such, dairy producers have been encouraged to increase the amount of nutrients from milk during colder months, which usually occurs between November and March in this study. However this increased nutrient intake was not associated with a greater incidence of ED, which could potentially be due to DH calves being offered 6 L of MR reconstituted at 150 g/L, which may match nutrient requirements in the UK, but not those found in Canada, where 33% of the dairy producers offered a maximum of ≤6 L/d of milk or milk replacer at a reconstitution rate of 125 g/L (Winder et al., 2018).

Calf mortality

Calf mortality rates have been widely used as an indicator of animal health and welfare in dairy farms (Ortiz-Pelaez et al., 2008; Roche et al., 2020; Umaña Sedó et al., 2023). Preweaning mortality on dairy units has been reported to range between 5 and 11% in calves born alive between 1 d of life and weaning (Compton et al., 2017). In this study, mortality was 0.1%, which is low and in agreement with other studies that reported zero-mortality (Margerison et al., 2013; Curtis et al., 2016) and was well within the reported target mortality rate of ≤ 5% (Dairy Calf and Heifer Association, 2010) and far lower than the 12.7% reported by Mahendran et al., (2017). One potential reason for this low rate could be that only female dairy calves were included in this study. Female calves have a lower risk of perinatal mortality compared with male dairy calves, 6% v 10% respectively (Silva Del Río et al., 2007) due to factors such as shorter gestation and lower BW, which reduces the mortality compared with male calves (Johanson and Berger, 2003; Dhakal et al., 2013). Overall, this shows considerable variation in reported mortality rates, which may be due to differences in age, methods of estimation and reporting that are often due to the lack of reliable records, data collection, along with differing calculation and definitions (Compton et al., 2017; Winder et al., 2018; Santman-Berends et al., 2019; Umaña Sedó et al., 2023). Moreover, in the UK ear tagging and identification must be carried out within 20 d of birth and mortality within this period may not be recorded (Hyde et al., 2020), while in France farmers record mortality after 48 h of birth, leading to underestimations of preweaning mortality (Raboisson et al., 2013). There are other studies have equally reported low mortality rates despite a large (0.80), proportion of calves presenting at least one clinical disease between birth and 12 weeks of age (Curtis et al., 2016). Lower mortality rates may be related to greater serum IgG concentrations (Urie et al., 2018), which lowers the risk of disease and mortality (Arthington et al., 2000; Gulliksen et al., 2008; Godden et al., 2009). Moreover, the prompt and effective application of ORT is critical in lowering neonatal calf mortality, by correcting abnormalities in free water deficit, acid-base and plasma osmolality abnormalities, related to dehydration (Constable et al., 2021). In this study, the FS of calves was assessed twice every day and calves that had a FS ≥ 3 were promptly treated using ORT and TED calves were given electrolytes for 3.2 more days than NTED DH calves.

Bovine respiratory disease

In previous studies, a high proportion (58.1%) of PRW calves diagnosed with ED also presented symptoms of BRD (Guo et al., 2022). However, in this study, the number of days calves had respiratory RS ≥3 did not different between DH NTED and TED for ED. This may be due to the complex aetiology, with a coinfection of two or more pathogens being likely to be a synergistic cause of BRD (Pardon et al., 2020; Bell et al., 2021). A greater BRD score is associated antimicrobial treatment (Charmorro et al., 2017) and a lower LW (Jones et al., 2004; Yang et al. 2015), ADG and FE of calves (Kargar et al., 2020). Factors such as colostrum Ig G concentration (Klein-Jobstl et al., 2014; Meganck et al., 2015) and extending the duration of colostrum feeding can lower ear and nasal scores (Conneely et al., 2014), along with the incidence and duration of ED (Carter et al., 2022). In this study, calves NTED and TED were consistently offered 3 to 4 L of pasteurised colostrum according to BW, and colostrum was tested to ensure it contained >50 g/L of IgG, and this was offered to DH calves at < 6 h after birth using an oesophageal tube. Afterwards, calves were offered 3 L of more dilute colostrum until 3 to 4 d of age via buckets fitted slow-flow teats. This potentially eliminated differences in colostrum concentration and duration of feeding as factors that could have affected the incidence and/or duration of ED. In this study, only one calf had a navel infection (0.017%), which is far lower than the 5 to 20% of dairy calves that develop umbilical infections in the United States (Virtala et al., 1996; Mee, 2008). This disease may disseminate hematogenous into joints, lungs, kidneys, and other organs, and can cause severe complications (Virtala et al., 1996; Renaud et al., 2018b) and has been shown to increase mortality (Renaud et al., 2018a) and contribute approx. 3% of calf mortality (NAHMS, 2021). However, navel infections caused 0% mortality in this study, potentially because the infection was promptly diagnosed and successfully treated using antimicrobials.

Liveweight gain and live weight

In this study, the PRW ADG and overall ADG at 84 d of age was 0.08 kg/d greater in DH calves NTED than those TED. According to a meta-analysis by Gelsinger et al. (2016), this higher ADG may result in a greater FLM yield. The results in this study regarding the effect of PRW ED on ADG are in agreement with several studies that showed that calves that did not have PRW ED and poor FS, had greater PRW ADG (Donovan et al., 1998; Soberon et al., 2012; Abeulo et al., 2021) because calves that have a combination of ED and antibiotic treatment for other diseases can achieve as much as a 0.5 kg/d lower ADG than healthy calves (Soberon et al., 2012). This lower ADG in calves that suffer ED PRW may be related to poorer calf vigour, less milk intake, and lower health status, which lower milk intake (Ockenden et al., 2023), especially during the initial 2 to 4 d following the onset of ED, and calves that suffered ED between 6 to 28 d of age, compared with calves that remained healthy (de Passille et al., 2016). This is likely because in this study the majority (0.93) of ED occurred within the first 28 d of life.

Studies have demonstrated that increasing milk allocation from 4 to 8 L (125 g/L) increases the ADG from 0.56 to 0.83 kg/d and LW by 19.0 kg at 10 weeks of age (Ockenden et al., 2023). In this study the DH calves NTED had WW that was 10.2 kg greater at 70 d of age and LW that was 9.2 kg greater at 14 d POW at 84 d of age, compared with DH calves TED. This agrees with previous studies that showed calves NTED can achieve greater WW and LW (Donovan et al., 1998; Soberon et al., 2012; Abeulo et al., 2021), which can be as much as 55% greater (4.8 v 10.6 kg) (Strapak et al., 2013). Greater PRW health and ADG may be attributed to differences in microbial abundance and total VFA concentrations implying those calves that suffer ED may have lower GIT microbial diversity and abundance, including rumen microbes that regulate ADG PRW and POW (Xu et al., 2023). Enteric disorders, especially when caused by Cryptosporidium, can have long-term negative effects on growth, resulting in reduced ADG and up to 34 kg lower LW in calves at 6 mo. (Shaw et al., 2020) and up to 7 mo. of age of age compared with healthy calves (Bueno da Silva et al., 2019). Moreover, DH calves that have ED and lower ADG PRW, can have a greater AFC and lower FLM yield than those that did not have ED PRW (Virtala et al., 1996; Aghakeshmiri et al., 2017).

The onset of puberty, and as such age and fertility at first mating, relies on various factors such as breed, nutrition, BCS, and LW of DH (Handcock et al., 2021). In HF breeds, which were used in this study, puberty is reached at 43 to 55% of MW (Meier et al., 2021). In this study, DH NTED had a 44 kg greater LW and 6% more MW and achieved the 55% MW industry target for first mating at 12 mo. of age (AHDB, nd) while DH TED PRW did not. Greater feed and nutrient intake PRW and POW up to 25 weeks of age increase the ADG (Rosaduik et al., 2021), reproductive development and the number of class 2 ovarian follicles DH produces during the prepubertal phase (Bruinje et al., 2020). However, in this study, despite the greater ADG of DH NTED, PRW TED did not affect the age at first insemination, and conception, conception rate to first insemination, number of inseminations per conception, pregnancy rate of DH between 12 to 15 mo. of age. This was in agreement with a recent study that found no association between PRW ED and reproductive performance of DH at first mating, despite the negative effect that calfhood disease on the ADG and fertility of DH (Chuck et al., 2023). In terms of DH survival, infertility has a great effect on the survival rate of DH up to first calving. In this study, the survival rate was 14% greater and the culling rate 14 % lower in DH NTED than those TED PRW. The fertility, culling, and survival rates did not differ between DH NTED and TED potentially due to the low number of animals used in this study for these factors, which indicates the need for larger scale studies. However, the pre-first calving culling rates found in this study increase dairy herd RR by 17 % in DH NTED compared with 31% in DH TED as PRW calves, which with an estimated CO_2-eq. of 48.5 kg/% RR (Bell and Wilson, 2018), would be equivalent to 679 kg less CO_2-eq. for DH NTED compared with those TED as PRW calves.

Feed intake

A greater PRW DM intake enhances ADG, due to greater amounts of nutrients and energy being consumed (Kazemi-Bonchenari et al., 2022). The PRW MR intake, DMI, and ADG were greater in calves NTED PRW. Other studies stated that this may be related to better calf vigour, and health status, which resulted in greater milk intakes by calves between 6 to 28 d of age, compared with calves that suffered ED (de Passille et al., 2016). Healthy calves that consume more milk have been shown to have greater plasma insulin and insulin growth factor-1 (IGF-1) concentrations that stimulate greater tissue uptake and utilization of glucose, this in turn encourages greater ADG and overall development (Leskova and Zucker, 1974; Zhao et al., 2014) potentially due to its effect on bodily organs such as the liver and skeletal muscles (Psa et al., 2019). In this study, calves NTED consumed 3.4 kg more MR and achieved greater daily PRW and overall ADG than calves TED. Moreover, studies have shown that greater MR feeding rates lower FS (Amado et al., 2019), therapeutic interventions (Berends et al., 2021), and mortality (Urie et al., 2018) rates. The effect of greater MR intake on ADG is in agreement with studies that have shown that greater PRW ADG is related to greater milk intake (Zanton and Heinrichs 2005; Soberon and Van Amburgh, 2013; Margerison et al., 2013; Gelsinger et al., 2016; Chuck et al., 2018), but this impact on ADG appears to diminish in calves of 5, 6, and 7 weeks of age, potentially due to the increasing influence of the consumption of CSC (Khan et al., 2011; Haisan et al., 2019; Rosadiuk et al., 2020). However, in this study, the PRW and POW total CSC, cereal straw, and water intakes did not differ between calves NTED and TED, potentially due to the majority (0.93), of ED occurring < 28 d of age.

Episodes of ED and diarrhoea can be affected by the continued pathogenic growth, which more typically results in lower ADG (Goodell et al., 2012; Fettman et al., 1986), which occurs despite there being no difference in the severity in the FS and duration of ED (Smith and Berchtold, 2014). In this study, MR was withdrawn when calves had ED resulting in a FS ≥ 3 and were given ORT, which is in agreement with others that demonstrated that withholding milk for calves TED, with ORT, enhanced the recovery from ED and contributed to a lower mortality rate (Barry et al., 2020), which was the case in this study. This was despite some studies reporting that calves offered milk along with ORT gained more LW than those that had milk withdrawn when offered ORT (Constable et al., 2001; Goodell et al., 2012). In this study NTED consumed 3.4 kg more MR than those TED. This, at 150 g/L, is equivalent to 22.7 L total, and 0.32 L/d over the PRW period less milk, which is less than 0.6 (± 0.1) L /d less milk than healthy calves consumed by healthy calves (Knauer et al., 2017). Despite this, there was no difference in CSC, cereal straw and water intake between calves NTED and TED, despite other studies showing that greater milk feeding volumes of 15 to 20% BW lowered CSC intake and reduced ADG in the first 4 (Rosadiuk et al., 2020) to 8 weeks of life (Eckert et al., 2015; Meale et al., 2015), unless a gradual step-down process is implemented, as was applied in this study, to facilitate an increase in CSC PRW (Rosadiuk et al., 2020) and increase rumen VFA concentrations POW, compared with calves who were weaned abruptly (Steele et al., 2017).

Feed efficiency

The PRW FE of DH calves in this study was in keeping with previous studies, that showed PRW FE of calves ranged between ~0.50 (Kmicikewycz et al., 2013) and ~0.70 (Stamey et al., 2012; Montoro et al., 2013). The PRW FE of DH calves NTED was 4% greater than those TED and received ORT. The actual FE of calves is greater in calves offered a diet that contains a greater concentration of digestible nutrients to achieve an ADG >0.80 kg/d (Quigley et al., 2018; Maynou et al., 2019), which was similar to the 0.83 kg/d ADG achieved by the DH calves NTED in this study. This can be attributed to the combined effect of greater MR intake while maintaining of a similar CSC intake by DH NTED in this study. This is supported by other studies that found a greater FE in calves offered a moderate amount of MR combined with a progressive increase in starter intake that provides increasingly vital nutrients from solid feed, which leads to greater ADG and FE compared with calves offered high levels of MR (Hu et al., 2019; van Niekerk et al., 2020). The FE of livestock has become increasingly important to the dairy industry, due to the financial and environmental costs of feed, which are one of the largest for milk production (Ockenden et al., 2023). Improvements in FE can reduce feed costs and GHG and urinary nitrogen excretion (Li et al., 2020), which are required to meet the net zero carbon and lower N emissions set by the UK Government to be met by 2050. However, survey data has shown a great deal of variation in heifer rearing costs on UK farms (Boulton et al., 2009), and a closer evaluation of FE, by breaking down feed use into that used by the lactating herd and herd replacements has the potential to improve the FE of dairy herds, however, this is difficult to evaluate due to the lack of on-farm data (Garnsworthy et al., 2020) making more controlled studies and more detailed farm surveys useful.

Age, maturity, and live weight at first calving

In the UK, only 20.1% of UK HF DH calve at 23 and 25 mo. (690 to 750 d) of age (Eastham et al., 2018), which is similar to the AFC achieved by the HF DH NTED PRW in this study, indicating that lowering the incidence of ED PRW had the potential to lower the AFC of UK DH. The AFC of DH TED in this study was greater than DH NTED, and this AFC was above the industry 24 mo. (AHDB, nd) potentially due to the negative effect that calfhood disease had on the ADG and fertility of DH (Chuck et al., 2023), which was despite all calves in this study consistently receiving high-quality pasteurized colostrum according to industry recommendations (AHDB, nd) indicating the need to continually apply and improve colostrum management protocols, in addition to calving protocols (Schuenemann et al., 2013) and calving and calf housing and feeding equipment hygiene has been highlighted as sources of calf ED causing pathogens (McGuirk, 2008) and the exposure of calves to these pathogens can the reduced by routine cleaning of the calf rearing environment (Heinemann et al., 2020) and a better understanding of the pathogens involved and the interaction between an effect on the GIT microbiome and innate immunity would be useful. The AFC achieved by DH NTED was 1 mo. closer to the industry target 24 mo. AFC (AHDB, nd) and 2 mo. less than DH TED. A lower AFC of 22 to 24 mo. of age is economically desirable for intensive and block-calving dairy production systems, lowering feed costs and RR compared with an extended AFC > 24 and 30 mo. (Bouton et al., 2017). Moreover, an AFC ≤ 24 mo. of age resulted in a greater herd life (Berrie and Cromie, 2009; Sawa and Bogucki, 2010; Cooke et al., 2013) and LMP (Sawa and Bogucki, 2010; Eastham et al., 2019). Moreover, Foder et al. (2020) reported max. FLM yield at an AFC of 24 mo., while milk yield across the first 5 years of life was greater at an AFC of 22 to 23 mo., which is closer to the AFC achieved by DH NTED PRW. While some studies have shown that FLM yield was lower when heifers had an AFC < 24 mo. of age (Castillo-Badilla et al., 2019; Meyer et al., 2004; Le-Cozier et al., 2008), which may be related in part to lower LW/MW and lower DMI, and greater risk of periparturient disease, infection, NEB, and infertility (Chuck et al., 2023).

First lactation milk yield and composition

The DHs that were NTED PRW had FLM yields 3.6 kg/d milk, 4.2 kg/d FCM, 4.7 kg/d ECM, 4.3 kg/d FPCM, 0.17 kg/d fat, 0.08 kg/d protein, and 0.35 kg/d MS yield greater than DH TED PRW. The majority found that greater PRW ADG increases FLM yield (Zanton and Heinrichs 2005; Soberon and Van Amburgh, 2013; Margerison et al., 2013; Gelsinger et al., 2016; Chuck et al., 2018), except for one study (Kiezebrink et al., 2015). However, few studies have addressed the effect of ED on PRW ADG and FLM yield, but one study compared DH TED and NTED, and found that DH NTED had a 50 g/d greater, which was associated with a 325 kg increase in 305 d FLM yield (Abeulo et al., 2021). This would be equivalent to 520 L of FLM yield in this study, due to the 80 g/d greater PRW ADG, however, DH NTED had a FLM yield that was 1,098 greater than DH TED PRW. In terms of the effect of PRW ADG on FLM yield, a meta-analysis completed by Gelsinger et al. (2016) evaluated that a 100 g/d greater PRW ADG would result in an expected increase of 155 kg FLM yield. In this study, the 80 g/d greater PRW ADG in DH NTED would be equivalent to 124 L more FLM yield. At the same time, these DH achieved 1,098 L more 305 d FLM yield, which is greater than associated with PRW ADG and may be related to a lower AFC and greater MW but not differences in BCS at first calving and pp change in BCS between DH NTED and TED in this study. The PRW nutrition and ADG are key factors affecting MG development (Esselburn et al., 2015; Soberon and Van Amburgh, 2017; Molenaar et al., 2020) and greater MR intake can increase MG development by 1.9 to 3.9 times when MR intake provides more DM, CP, and ME intake (Geiger et al., 2016; Vailati-Riboni, 2018; Niwinska et al., 2022) and calves are weaned later (de Passille and Rushen, 2016; McCoard et al., 2019) at a greater LW. This increase in FLM yield in DH NTED may be related to the greater PRW MR and DMI, which was supported by other studies that found greater PRW and POW feed intake resulted in each additional kilogram of ADG between birth and breeding producing 3,281 kg of FLM yield (Soberon et al., 2012) that would be equivalent to 14,4364 L in this study, which is far more than the 1,098 L greater FLM yield achieved by DH NTED, which indicates the potential effect of greater PRW ADG, MR and DM intake and LW at breeding as factors that may have affected the FLM yield of DH that are NTED and TED PRW.

Fertility, survival, replacement, and carbon footprint costs

In this study, the DH NTED had a PPI to the first insemination that was 15 d shorter, CI 19 d shorter, and they required 0.7 fewer inseminations per conception than DH TED PRW. This agrees with other studies that showed DH that an AFC of 23 mo. had better fertility in first and subsequent lactations (Bach, 2011; Cooke et al., 2013; Atashi et al., 2021). Moreover, the shorter CI in DH that was NTED had a shorter CI in the first lactation, compared with DH TED. This agrees with a previous study that showed that greater pre-pubertal ADG of 0.85 to 0.97 kg/d, between 5 and 10 mo. of age that had shorter CI between first and second lactation compared with DH that had ADG < 0.85 kg/d (Krpalkova et al., 2014). This is in keeping with the 0.94 kg/d ADG achieved by DH NTED and 0.80 achieved by DH TED PRW between 3 and 12 mo. of age. While Bach (2011) found that the incidence of PRW diarrhoea was not associated with the chances of finishing the first lactation. The DH had a greater PRW ADG (Bach, 2011), and achieved an AFC ≤ 24 mo. (Bach, 2011; Nan et al., 2023) and those that had a greater LW at first calving achieved greater survival rates at the beginning of first (82 to 93%) and second (62 to 76%) lactation (Archbold et al., 2012) compared with those that ≥ 24 mo. (Nan et al., 2023) compared with lighter heifers (Archbold et al., 2012). These indicate the importance of ADG, MW, and AFC in the survival of DHs. The AFC and LW/MW were similar to those achieved in this study, which showed that DH NTED PRW had an AFC of 23 to 24 mo. and pp MW of 0.87% had greater survival rates of 79% at the end of first lactation compared with DH TED PRW that had an AFC of 25 mo. 59% in DH TED PRW. This reinforces the importance of AFC (Bach, 2011; Cooke et al., 2013; Atashi et al., 2021; Nan et al., 2023) and LW / MW on the longevity of DH, which may be due to a lower risk of periparturient disease, infection, NEB, and infertility (Chuck et al., 2023). The survival rate and RR DHs between birth and the end of the first lactation were greater for DH NTED than DH TED PRW.

Further research

Consistently high calf mortality rates, extended AFC, and high culling rates of DH before and during first lactation in the UK indicate the importance of this area of research in improving animal welfare and lowering the economic cost and carbon footprint of milk production. This study clearly showed that small group size, of two calves per pen, facilitated the twice daily observation of calf comportment and faecal score, using the Wisconsin scoring system by qualified and experienced staff, which allowed the timely removal of milk replacer from the diet and administration of oral rehydration therapy to achieve a low calf mortality rate, despite a high enteric disorder incidence rate. The development and application of artificial intelligence in calf observation warrants further research. This study clearly showed that a high proportion of dairy calves suffered enteric disorders, which was in keeping with previous studies and farm surveys, indicating the importance of research into the cause and prevention of enteric disorders. This study clearly showed the negative impact enteric disorders have on pre-weaning calf growth and longer-term survival of dairy heifers and indicates that more research into the economic, welfare, and environmental impact of enteric disorders is required. Further research should include the development of informed calf management protocols, knowledge and education resources, more clarity around good labour and management practices, and the application of natural pre and probiotics. These along with a better understanding of the effect of preweaning enteric disorders and treatment on the gastrointestinal microbiome, and innate immunity. Limitations of this research were the sample size and potential to have measured more factors such as the effect of enteric disorders on the gastrointestinal microbiome biodiversity, innate immunity, and acute phase proteins in response to enteric disorders. Further research should include larger animal numbers and data sets, potentially evaluating a range of farming systems, farm surveys of the incidence, cause, treatment, and impact of enteric disorders on mortality, treatment, and longer-term survival and productivity of dairy cattle and its impact on the economic and environmental impact of dairy production. Further research should include controlled studies and evaluation of the effect of enteric disorders on the gastrointestinal tract microbiome biodiversity, specific pathogenic bacteria present, and the impact on innate immunity and acute phase proteins to better understand the potential impact of enteric disorders and ways in which the gastro microbiome biodiversity can be enhanced to lower the incidence of enteric disorders and improve the feed and economic efficiency of dairy heifers on farms. Future research should apply standardised measurement methods, especially to calf mortality, morbidity, feed, and resource use, including a more detailed analysis of the economic cost and environmental impact of dairy production systems. Larger scale studies in the UK should be used to confirm the effect of pre-weaning enteric disorders on the average daily gain, feed efficiency, age at first calving, mature weight at first calving, first lactation milk yield, and survival and lifetime milk production of dairy heifers. Lower incidence rates of pre-weaning enteric disorders are essential in lowering antimicrobial use and the economic, CO_2-eq. and improving animal welfare and reducing the ethical cost of milk production. Research should be disseminated at scientific conferences and in journals, but also at the farmer level through collaboration with industry, farmer discussion groups and meetings, and industry advisory and government bodies and veterinary services.

Conclusions

The incidence rate of 50% of enteric disorder, with oral rehydration therapy, was relatively high and dairy heifers not affected by enteric disorder had greater pre-weaning milk replacer and dry matter intake, and average daily gain. Calves were not treated and treated for enteric disorder preweaning had low bovine respiratory disease, disease, antimicrobial treatment, and mortality rates, potentially due to rapid identification and administration of oral rehydration therapy and application of vaccination for bovine respiratory disease. The dairy heifers that were not treated for enteric disorder had greater weaning weight, live weight at 12 mo. of age and first calving, mature weight at first calving, and lower age at first calving than dairy heifers treated for enteric disorder pre-weaning. The first lactation milk and milk component yield, and survival rate of dairy heifers not treated for enteric disorder pre-weaning were greater than dairy heifers treated for enteric disorder pre-weaning. The feed efficiency was greater and the economic and CO_2-eq. cost was lower in dairy heifers not treated for enteric disease than in dairy heifers treated for enteric disease pre-weaning. The lower pre-weaning milk replacer intake and weaning weight of calves that were treated for enteric disorders preweaning may be better addressed by extending the pre-weaning period and/or offering these dairy heifer calves an equivalent amount and/or more milk replacer preweaning to allow them to achieve a similar weaning weight and greater potential subsequent survival rate and lifetime performance more similar to dairy heifers not treated for enteric disorder pre-weaning.

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