

Effect of dairy breed and peri-natal live weight on; feed intake, live weight gain, feed efficiency and bio-economic viability of a high milk feeding system for rearing bull calves

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1. Abstract

An estimated 101, 959 UK dairy bull calves were euthanized in 2016, mainly due to a lack of profitable bull beef schemes, particularly for the smaller Jersey crossbreed calves. This study aimed to compare the performance of Holstein Friesian and Jersey cross Holstein Friesian breeds, by allocating 60 calves into pairs ($n=30$) at $10 (\pm 3)$ d of age, according to breed and initial live weight (ILW) to one of three groups: Holstein Friesian (HF) of higher ILW (50 ± 0.9 kg); Jersey x HF of higher (JxH) ILW (51 ± 0.9 kg) and Jersey x HF of lower (JxL) ILW (44.1 ± 0.8). All calves were offered milk replacer (MR) at ≤ 10 L/d (MR: 150 g FM/L), which was offered via teat buckets twice daily, along with *ad libitum* access to cereal based starter, straw and water. Calves were all weaned at 12 weeks of age. Dairy breed and ILW had no effect on pre and post-weaning growth rates, total milk and feed efficiency. Pre-weaning starter consumption was lower for JL compared HF and JH. Initial LW, weaning and post weaning LW were greater, while the number of days taken to reach a LW of 120 kg was 7 d less for HF and JxH compared with JxL calves. It was concluded that, in terms of LW at 10 ± 3 d of age, larger (≥ 50 kg) HF and JxH calves were equally viable, while smaller (< 50 kg) JxL calves could potentially be equally viable at a lower purchase price.

Key words: Dairy, Crossbred, Bull calves, Rearing

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3. List of frequently used abbreviations

ADG	Average daily gain
BSU	Biological support unit
Conc.	Concentrate
DMI	Dry matter intake
hd	Head
FCE	Feed conversion efficiency
FE	Feed efficiency
HF	Holstein/ NZ Friesian
ILW	Initial live weight
KW	Kiwi cross
JxH	Kiwi cross higher initial weight
JxL	Kiwi cross lower initial weight
LW	Live weight
SF	Solid feed

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6. Literature review

Background

In the UK, a majority of farmers have adopted an all-year-round calving system whereby the majority of feed is conserved forage (AHDB, 2017). However, with low milk prices and the uncertainty with BREXIT, there is pressure on farmers to strive for efficiency, especially in all-year-round calving where inefficiencies can easily be overlooked (AHDB, 2018a; Redman, 2018). Farmers may consider reducing the cost of milk production in the form of better pasture management and cross bred dairy cattle to increase feed efficiency, longevity and fertility in the herd (Roche et al., 2006; Prendiville et al., 2010; Buckley et al., 2014). Crossbred cattle, such as the popular New Zealand (NZ) “Kiwi-cross” (a cross between Holstein-Friesian and Jersey), will inevitably produce a variation in the breed type and birth weight of dairy heifer and bull calves (Garrrick and Lopez-Villalobos, 1998). In NZ, dairy bred bull calves selected at 7 d of age according to colour and live weight for slaughter, are typically referred to as ‘bobby’ calves (MPI, 2015). In 2016, 361,492 dairy bulls entered into the British beef chain, whilst an estimated 101,959 calves were euthanized at birth (CHAWG, 2018b). With consumer concerns of the environmental and welfare aspect of farming growing, these numbers must be addressed (Forum, 2013; Stannard, 2018). To decrease the number of calves euthanized at birth, sufficient data detailing the growth performance, development and cost effectiveness of rearing dairy cross bred calves for beef production in the UK is required.

Current calf rearing practices

Rosé veal

Rosé veal originates from calves younger than 12 months of age, that are weaned at around 12 weeks of age and finished on solid feed (SF) (EBLEX, 2011; Berends, 2014). Rose veal was developed in the 1990s and has grown to approximately 30% of the Dutch veal sector (AND, 2014; Berends, 2014), but has become established as a product relatively recently and as such, literature on Rosé veal is limited. In the UK, labelling states that the term “rosé veal” can only be applied to meat from animals < 12 mo. of age in an approved system, i.e. calves

that were offered a diet consisting of ad-libitum concentrate or concentrated feed, with the provision of straw when animals were > 8 weeks of age and housed in a welfare-friendly environment, such as loose housed in open yards, otherwise animals > 8 mo. of age at slaughter must be labelled and marketed with the additional “beef” term, and the age at slaughter must be stated as either up to 8 mo. or 8 to 12 mo. (EBLEX, 2011).

Rosé veal production was introduced into the UK mostly to utilize unwanted bull calves from the dairy industry, following the banning of live animal transport to Europe (Forum, 2013). In the UK in 2015, the number of male calves, not registered, and euthanized on farm were estimated to be around 95,000 (CHAWG, 2018a). The most recent figures have shown an increase to 101,959 calves for 2016 (CHAWG, 2018b). Efforts have been made to reduce the number of male dairy calves by the use of sexed semen and by increasing the uptake of dairy-bred bull calves into the beef industry (Forum, 2013). The Beyond Calf Exports Stakeholders Forum (2006 to 2013), published a report containing case studies and survey statistics on the then current situation surrounding the dairy-bred bull calves. Firstly, to reduce the number of bull calves born on a dairy unit, the use of sexed semen is recommended, allowing for dairy farmers to potentially increase the number of beef-dairy male crossbreds, and therefore improve returns (Forum, 2013; Holden and Butler, 2018). Bull calves are typically reared intensively on concentrates/grain to utilize their higher growth rate, compared to steers, that are usually finished later, do not require an energy-dense diet, and usually includes grazing at pasture (Earley, 2011). Alternatively grazing can be included in bull beef systems but requires excellent pasture management to maintain high growth rates (Crosson and O’Riordan, 2011).

In the UK, the definitions of veal and beef are: rosé veal must be slaughtered at less than 8 mo. of age; rosé beef must be slaughtered at 8 to 12 mo. of age; cereal beef is typically slaughtered at over 12 mo. of age, usually at 15 to 19 mo. of age (Earley, 2011). Rose veal is reportedly growing more popular in the UK, as consumers realize it is a product with higher levels of welfare, different to the traditional white veal system which was banned in the UK in 1990 (Forum, 2013). Growing consumer concern about the animal welfare of their meat products has put pressure on farmers, the national agricultural sector and supermarket companies to be more transparent in the way the animals are reared and slaughtered (EBLEX, 2011; Forum, 2013). In making consumers more aware of Rosé veal, there is expectation that demand for the product will also increase.

White veal

White veal consumption is greatest in France, Italy and Germany, and is produced on a large scale in the Netherlands, France, Italy and Belgium, with over 600, 000 tonnes of veal produced per year (AND, 2014). The dairy and veal sectors are closely linked, because many veal calves are the surplus bull calves originating from dairy farms, either purebred dairy or a cross of dairy and beef breeds e.g. Holstein Friesian x Belgian blue (Sans and de Fontguyon, 2009; Berends, 2014; Coleman, 2016). Veal sales in the UK declined in the 1980s, when consumers became more aware of the some of the welfare-compromises involved in the rearing strategies applied to veal calves (Clarke, 2016). Some of the infringements of welfare regulations included; the limited freedom of movement within crates in which calves were housed, the iron-deficient diet that resulted in anaemia and the characteristically white meat, along with gastrointestinal issues and behavioural abnormalities developed related with the lack of fibre from forage in the diet (Cozzi et al., 2009; Brscic et al., 2011; Webb et al., 2012). The diet of white veal calves was closely linked to gastrointestinal (GI) developmental problems and abnormal behaviours, due mainly to the lack of functional fibre (Brscic et al., 2011; Webb et al., 2012). Gastrointestinal tract problems, include ruminal drinking, acidosis, ruminal plaques, abomasal lesions, poor rumen development and rumen papillae hyperkeratinisation (Brscic et al., 2011).

Ruminal drinking (RD) has been described as leakage of milk into the reticulo-rumen, typically from failure of the oesophageal groove reflex and/or from backflow of milk from the abomasum (Berends, 2014). However, a study undertaken by Ellingsen et al. (2016) demonstrated that high voluntary amounts of milk consumption (up to 6.8 L/d) did not cause ruminal drinking, showing evidence to the contrary (Berends, 2014), indicating that RD was not caused by liquid flowing back from the abomasum and thus potentially solely by failure of the oesophageal reflex. When milk enters the reticulo-rumen, it is fermented to produce volatile fatty acids and lactate and thus cases of RD are often associated with a lower pH and, in some cases, lead to metabolic acidosis and/or D-lactic acidosis, which is characterized by an increased lactic acid load in the bloodstream (Dunlop and Hammond, 1965; Gentile et al., 2004). Whilst clay-like faeces has historically been associated with RD, noticeable variable consistencies in faeces depend to a greater extent on the state of dehydration rather than directly with RD (Herrli-Gygi et al., 2008). These symptoms, along with acidosis, can be severe and even fatal (Dirr and Dirksen, 1989).

Gastrointestinal disorders associated with limited dietary forage and fibre

Gastrointestinal disorders and their prevalence in the veal industry, include ruminal plaques (31.4 %), rumen papillae hyperkeratinisation (6.1 %), and abomasal lesions (74.1 %) (Brscic et al., 2011). In a survey of 170 veal farms, from three European countries; Netherlands, France and Italy, which were considered to represent a selection of the major veal producers in Europe, Brscic et al. (2011) used trained observers to inspect the rumens and abomasa of calves to assess different intestinal disorders (ruminal plaques, abomasal lesions and rumen papillae hyperkeratinisation), and capture details of the management, housing and feeding of the calves. Brscic et al. (2011) showed that low amounts of solid feed provision, ≤ 50 kg DM/hd, over the rearing period, was associated with low rumen development (60.4%). This was in agreement with other studies, supporting the concept that SF was required to stimulate rumen development (Cozzi et al., 2002). More specifically, the fermentation of carbohydrates into volatile fatty acids (VFAs), especially butyrate and propionate (Tamate et al., 1962; Baldwin et al., 2004; Suárez et al., 2006b). In a study collating data from 2.4 million white veal calves, it was found that higher than median amounts of either milk and roughage, or milk (1.7 kg/d), concentrates (0.79 kg DM/d) and roughage (0.14 kg DM/d), were associated with lower mortality rates (Santman-Berends et al., 2018). Brscic et al. (2011) found that the provision of SF was associated with a lower incidence of ruminal plaques, hyperkeratinisation and abomasal lesions in an intensive milk feeding regime.

Table 6.1: Effect of concentrate, forage type, and concentrate : forage ratio on the prevalence of ruminal plaques in veal calves

Concentrate grain type	Forage type	Concentrate : forage ratio	Prevalence plaque, %	Reference
Corn grain	ND	ND	68	Prevedello et al. 2012
Corn grain	Wheat straw	80: 20	8.3	
Corn grain	Wheat straw and soya bean meal ¹ (20:8)	72:28	0	
None (milk diet only)	ND	ND	0	Suárez et al. 2006b
Pectin-based concentrate	ND	ND	80	
NDF-based	ND	ND	94	
Starch-based	ND	ND	73	
Mixed ²	ND	ND	100	
Mixed ³	No forage	ND	100	Suárez et al. 2007
	Corn silage	40:60	63	
	Corn silage	70:30	88	
Ad lib	Corn silage	70:30	0	
	Straw	70:30	13	
	Restricted straw and grass (50:50)	70:30	50	
	Grass, restricted	70:30	13	
Ad lib	Straw and grass (50:50)	70:30	0	

¹ Extruded soya bean meal mix
hulls, crushed barley mix

² Mixed (equal amounts of pectin, NDF and starch)
ND: No data

³ Mixed beet pulp ground, soybean hulls, broken corn, corn

Beef from the dairy industry

The Holstein-Friesian is the most prominent dairy breed in the UK, making up 82% of the national herd, followed by crossbreeds (10%) and Jerseys (3.9%) (Redman, 2018). Holstein-Friesians or the “black-and-white” type have been the focus for bull calf utilization (Forum, 2013). Dairy cows are sometimes crossed with beef bulls which offers a higher price if selling for rearing (£160 vs. £50 for a pure dairy bred bull calf (Redman, 2018)) or finishing, and is known to have better finishing characteristics than pure dairy-bred counterparts (Hickson et al., 2014; Coleman, 2016; Santman-Berends et al., 2018). Santman-Berends et al. (2018) indicated that Dutch veal farmers are more likely to ensure better health care for the beef x dairy crossbreeds such as Belgian blue crosses over “black and whites” because of their greater market value. In the current study, we measured time taken to reach 120 kg live weight as this is a target a calf rearer might aim for when selling on to finishers, or a marker for calf performance in an intensive rosé veal of cereal beef system.

In New Zealand, grazing systems are more common and Holstein Friesian/Jersey cross-breeds make up 48% of the dairy cow population (LIC and DairyNZ, 2017). Dairy bull calves are generally known as “bobby calves” and are taken from the farm usually within the first seven days of life for human consumption or pet food (Muir et al., 2001; MPI, 2015). Pure-bred dairy bull calves are tolerated in the beef industry, however, Jersey type bull calves are generally disregarded for beef production, due to lower birth weight and finishing weights, and poorer carcass characteristics compared to the other dairy and dairy cross types (Smith et al., 1976; Purchas and Morris, 2007). Berry et al. (2018) compared carcass characteristics of cattle differing in proportion of Jersey breed finding that pure-bred Jersey did not perform as well as Holstein-Friesians in terms of days to target slaughter, carcass fat classification and carcass weight. However, in a Rosé veal system, Jersey crossbred calves returned a higher margin than Friesian calves, mainly due to Jersey crossbred calves costing considerably less to purchase (€30 vs. €140), although labour costs and time to slaughter were not reported (Crosson and O’Riordan, 2011).

Cost of production

Studies on the economics of dairy beef production have noted that profit is sensitive to feed and calf prices (Muir et al., 2001; Ashfield et al., 2014). From the cost of feed and bedding to the slaughterhouse pay-outs, all have the tendency to fluctuate frequently (CHAWG, 2018a). The prices of straw this year have demonstrated this, with the prices of big barley straw bales reaching £102/t in May, compared to the average price in England and Wales last year of £55 (AHDB, 2018b). Although sale prices of young bulls can seem attractive, an expensive, concentrate-intensive system is required to get them to target weights for slaughter (Earley, 2011). The John Nix pocketbook for farm management by Redman (2018), estimates £209 variable costs per calf, for calves that are weaned early and given 20 kg of MR in total. Variable costs including feed, vet & medical, bedding and miscellaneous (e.g. ear tags) costs. If farmers were to feed 42 kg of MR as undertaken in some intensive feeding programs (Davis Rincker et al., 2011), then variable costs per calf would increase by £41. With longer finishing systems, cheaper feeds can be utilized therefore in some cases, rosé veal/beef may not be more profitable than other bull or steer finishing systems (Ashfield et al., 2014).

Table 6.2: Growth rate (kg/day) from different sire breeds between two ages (months) according to varying dairy breed types

Description	Age (months)		Growth rate, kg/d				Location	Diet	Reference
	Start	End	Holstein	Friesian	Jersey	Kiwi ¹			
Pure & cross bred steers ²	0	23		0.6	0.5	0.6	NZ	Pasture	Barton et al. 1994
Crossbred steer & bulls ²	6	13		0.5	0.4		NZ	Pasture	Baker et al. 1990
Crossbred steers	7	13			1.0		USA	Maize silage & concentrate	Smith et al. 1976
Crossbred heifers	7	31		0.4	0.4		NZ	Pasture	Burke et al. 1998
Purebred bulls	9	15		1.2	1.1		UK, EU	Barley & straw	Albertí et al. 2008
Purebred heifers	9	21		0.6	0.4		USA	Sorghum concentrate	Long et al. 1979
Pure & crossbred heifers	9	15		0.5	0.5		USA	Pasture, grain, hay	Baker et al. 1989
Pure bred bulls	3	14	1.2				UK	Cereals	Marsh 2013
Pure bred bulls	3	12	1.4				UK	Barley & straw	Marsh 2013
Pure bred steers	0	10	1.7		1.2		USA	Maize silage, high-moisture maize, soya bean	Lehmkuhler & Ramos, 2008

Amended from Coleman (2016)

¹ Friesian and Jersey cross breed

² Calculated using published weights at two ages

Restricted and/or conventional milk feeding strategy

Calves offered restricted milk amounts (8 to 10% birth weight or 454 to 568 g/d) and weaned early, starting at 4 weeks of age (Drackley, 2008), can have compromised productivity and health (Hill et al., 2005; Khan et al., 2011). Several studies have shown poorer weight gains (Flower and Weary, 2001; Jasper and Weary, 2002), higher risk of disease (Godden et al., 2005; Khan et al., 2007; Ballou, 2012) and abnormal behaviours such as cross-sucking (Rushen and de Passillé, 1995; De Paula Vieira et al., 2008; Leruste et al., 2014), with conventional milk-feeding systems, which can negatively affect future production (Drackley, 2005; Heinrichs and Heinrichs, 2011). These restricted or traditional feeding programmes typically restricting intake to around 4 L/d (Khan et al., 2011), leaving calves hungry and can consequently cause stress for the calf (Weary et al., 2008; de Passillé et al., 2011). However, a restriction on milk will initiate an appetite for SF sooner than with larger or *ad libitum* amounts of milk offered (Hill et al., 2005; Quigley et al., 2006).

Accelerated growth / enhanced milk feeding programs

Enhanced or intensive milk feeding programs offer milk at approximately twice the amount of conventional systems (Drackley, 2008). A number of systems offer calves *ad libitum* and/or relatively high at approx. 1.5 to 2% of BW as milk solids, in terms of volume of milk (Stamey et al., 2012). These include traditional white veal, rosé veal, and intensively-reared dairy heifer replacements. Rosé veal and dairy heifer rearing tend to offer *ad libitum* starter concentrate and forage alongside the milk diet (Berends, 2014; Khan et al., 2016). Due to the similarity in the milk volume offered to calves in these systems, this review will include research detailing the feeding practices and development of heifer and bull calves.

High milk intake dairy heifer calf systems

Traditionally farmers restricted milk feeding volumes in order to encourage earlier consumption of cereal and protein meal based starter feed in greater amounts. Consumption of SFs develops the rumen faster, facilitates early weaning, and reduces the costs associated with calf rearing (Kertz et al., 1979; Otterby and Linn, 1981; Anderson et al., 1987; Le Cozler et al., 2008; Soberon et al., 2012). However, studies have found that feeding greater amounts of milk and/or milk replacer leads to greater average daily liveweight gain (ADG) and body

weight (BW) targets (Appleby et al., 2001; Jasper and Weary, 2002; Cowles et al., 2006; Meale et al., 2015; Rosenberger et al., 2017; Schäff et al., 2018), feed efficiency (Blome et al., 2003) and was positively related to milk yield in first lactation in dairy heifers (Foldager et al., 1997; Drackley et al., 2007; Davis Rincker et al., 2011; Soberon et al., 2012; Soberon and Van Amburgh, 2013; Gelsinger et al., 2016). The introduction of automatic feeders helps to facilitate large milk intakes per day with several visits to the machine, which inevitably aids the gradual weaning process in intensive systems (Khan et al., 2011; de Passillé and Rushen, 2016).

Lactation performance

A meta-analysis by Soberon and Van Amburgh (2013) predicted a 42.9 kg increase in first lactation milk yield for every 100 g DM/d of milk solids, whereas the latest model from Gelsinger et al. (2016) predicted a 66.2 kg higher milk yield. Some studies did not find an increase in first lactation milk yield from higher vs. lower amounts of whole milk or MR, however these studies did not have enough animals per treatment, and therefore not enough statistical power (Terré et al., 2009; Korst et al., 2017), or had an experimental design that led to poor growth rates pre- and post-weaning (Morrison et al., 2009). Raeth-Knight et al. (2009) did not find a difference between groups of calves offered different nutrient intensities (20% CP, 20% fat; 28% CP, 16% fat), MR feeding rate (12.5, 13.9, 16.7% solids), and acidified vs non-acidified, however only standardized mature-equivalent milk production was reported as the projected 305 d mature-equivalent milk yield.

Drackley et al. (2007) did find a positive effect of MR intake on milk yield, however there were only 10 animals per treatment in that study. They offered calves a conventional (1.25% birth weight; 22% CP, 20% fat) vs an intensive (2.5% body weight; 28% CP, 20% fat) rate of MR, the calves on the intensive diet had a greater actual 305 d milk yield (10, 554 vs 9, 226 kg), 305 d protein yield (325 vs 301 kg) and total milk yield (12, 890 vs 11, 208 kg) than calves on the conventional MR diet in trial 1 (Drackley et al., 2007). When milk yield was corrected for genetic variation, dairy heifers offered higher total amounts of MR (2.1% LW) had a tendency to have a greater first lactation milk yield (10,128 kg) than those offered more conventional amounts (MR at 1.2% LW; 9,712 kg milk yield) of MR (Davis Rincker et al., 2011). Furthermore, Soberon et al. (2012) found that when feeding intensive MR rates (0.9 kg/d and

2.5% birth weight, weaned at 49 d), pre-weaning ADG achieved was positively correlated with first lactation milk yield in the Cornell (850 kg/ 1 kg pre-weaning ADG) and commercial herd (1, 113 kg/1 kg pre-weaning ADG).

Calf nutrition

Milk nutrition

The most important factor for a calf's future health and production is adequate amounts of high quality colostrum (IgG concentration >50 g/L) and within the first few days of life (McGuirk and Collins, 2004; Bateman et al., 2012). Following colostrum, calves are transferred onto a milk diet of which the three main types of milk diet are; whole saleable milk, whole non-saleable milk (waste milk) and milk replacers (MR) (Jones and Heinrichs, 2016). Whole milk generally has a higher saleable value than the cost of MR on a DM basis (Garnsworthy, 2005) due to price adjustments made by commercial companies producing MR. According to the farm gate milk price forecasted for 2018 at 27 p/L, and a MR price of £1,900 /t feeding whole milk would cost £10.40 more per calf, if feeding 40 kg of MR per calf (Redman, 2018). Waste milk on the other hand, although not saleable, should not be looked at as a free feed because there is an opportunity cost involved in producing it, and losses due to mastitis should be closely scrutinized (Drackley, 2008). Furthermore, feeding of waste milk has shown an increase in antibiotic resistant microorganisms by calves (Aust et al., 2012). A survey of 19 UK dairy farms completed in 2009 found that 42% of farms offered calves whole milk, 32% MR twice daily, while the remainder were offered a combination of whole milk and MR (Brickell et al., 2009).

The biological value of milk proteins is a function of their amino acid profile, the amount of protein offered relative to requirements, and the energy allowable gain (van Amburgh and Drackley, 2005). In the early 2000s, milk replacers were formulated with more protein from whey than skim milk or casein (Tanan, 2005). Such derivatives of whey included dried whey, whey protein isolates, whey protein concentrate and de-lactosed whey (Davis and Drackley, 1998) (Table 6.3). As edible-grade milk proteins become more sought after and prices have continued to fluctuate, alternative proteins for milk replacers have been examined (Gilbert et al., 2016). Protein sources such as fish protein (Huber and Slade, 1967; Ørskov et al., 1982),

liquid egg (Touchette et al., 2003), spray dried red blood cells and animal plasma (Quigley and Bernard, 1996; Quigley et al., 2000) have been considered. Vegetable sources such as soya, wheat, and potato have also been considered, and are of primary use in the EU where animal products in animal feeds have been banned (Terui et al., 1996; Montagne et al., 2001). However, with these alternate sources of protein in milk replacers, supplementary amino acids (mainly lysine and methionine) must be added to support growth (Hill et al., 2008a; Kertz et al., 2017). In terms of fat in milk replacers, sources vary from animal fat to palm oil, however, countries in the EU predominately use rapeseed (canola) and palm oil for the same reasons stated above (Tanan, 2005). When comparing calf nutritional studies in the pre-weaning stage, it is important for authors to state the sources of protein and fat in milk replacers, as well as any additives, as this will affect the digestive physiology of the calf and can therefore affect results, especially if comparing rumen morphology.

Modified NRC (2001) equations are an improvement on previous versions (Kertz et al., 2017). Greater refining of predicting energy and protein requirements in calves has been made possible with the data collected from studies at the University of Illinois and Cornell University (Diaz et al., 2001; Tikofsky et al., 2001; Blome et al., 2003; Bartlett et al., 2006). These studies utilized what is termed “enhanced” or “intensified” nutrition (Khan et al., 2011), using MRs relevant to modern conditions - containing whey proteins, and high CP contents. The examples of values using these modified equations (Table 6.4) support conclusions from previous studies (Diaz et al., 2001; Blome et al., 2003; Bartlett et al., 2006; Khan et al., 2011) that showed greater efficiency in terms of growth rate when feeding MR with greater concentrations of CP.

Table 6.3: Composition of whole milk (g/kg DM) and of commonly used ingredients in calf milk replacers (g/kg air dry matter)

	DM	CP	Fat	Lactose	CF	Ash	Ca	P	Reference
Whole milk	130	254	308	377	ND	63	109.0	7.6	Toullec 1989
Whole milk	130	246 to 269	254 to 362	377	ND	54	5.0	3.0	Mahaut et al. 2000
Skim milk powder	947	341	16.0	478	ND	82	14.7	10.2	INRA-AFZ 2002
Sweet whey powder	950 to 965	110 to 140	10 to 20	700 to 50	ND	80 to 90	7.6	6.8	Toullec 1989; De Wit 2001
Whey powder	950 to 965	200 to 250	15 to 25	480 to 40	ND	150 to 220	28.9	10.7	Toullec 1989; De Wit 2001
Whey protein ¹	960 to 970	340 to 800	30-80	100 to 550	ND	40 to 80	4.8	5.1	Toullec 1989; De Wit 2001
Soya protein ²	950	665	5.0	ND	40	65	3.0	8.0	INRA-AFZ 2002
Soluble wheat gluten	950	840	50	ND	11	11	0.5	2.2	INRA-AFZ 2002

Sourced from Tanan (2005)

¹ Commonly used whey protein concentrate is 340 g CP and 500 g lactose

² Concentrate

ND: No data

Table 6.4: Nutrient requirements and estimated feed efficiency (FE: gain/feed) for a 45 kg calf under thermos-neutral conditions, using the Cornell-Illinois equations

Gain	DMI	ME	CP	Crude fibre	FE
kg/d	% BW	Mcal/d	g/d	g/100 g DM	g/g
0.2	1.05	2.34	94	18.0	0.38
0.4	1.30	2.89	150	22.4	0.63
0.6	1.57	3.49	207	26.6	0.77
0.8	1.84	4.40	253	27.4	0.86
1.0	2.30	4.80	318	28.6	0.87

Sourced from van Amburgh and Drackley (2005)

Conventional MR typically contains 20 to 22% CP (Bartlett et al., 2006; Hill et al., 2008 a; Hill et al., 2010 a) however, a study by Diaz et al. (2001) challenged the early National Research Council recommendations (NRC, 1989) for beef and dairy calves and found that a MR higher in CP yielded better growth rates and composition of growth (greater skeletal and lean muscle mass) (Tikofsky et al., 2001; Blome et al., 2003). High protein MR designed for “accelerated growth” should be offered at the appropriate rate of an intensive diet (Drackley, 2008). Bartlett et al. (2006) found that an increasing CP concentration (14, 18, 22, 26% CP) correlated with an increase in ADG and body frame, however efficiency of protein use for gain was greater when calves were offered at 1.75% than 1.25% of BW daily. Milk replacer powders have slightly different compositions for different systems: for dairy heifer replacement MR powders it is recommended that a CP of 26 to 28% and a fat content of 20 to 21% be provided with additional lactose (Hill et al., 2009a; Margerison, 2011). Milk replacer nutritional composition for rearing veal calves has not been explicitly stated, yet for a lean carcass, a MR fat content of under 20% is recommended (Kertz et al., 2017). However, the higher the quality of the MR (i.e. milk-proteins used, greater than 23% CP, and low fat) the greater productivity can be expected (Diaz et al., 2001; Cowles et al., 2006; Soberon et al., 2012; Meale et al., 2015).

Intensive milk feeding programs

Elevated planes of milk feeding or intensive milk feeding programs are becoming more popular in dairy heifer rearing systems due to positive effects on growth and production. The code of practice for dairy farmers in Canada now recommend a higher plane of milk intake at 20% BW to ensure a higher standard of welfare (NFACC, 2009). Intensive programs however lower starter intake and live weight loss is sometimes observed at weaning (Sweeney et al., 2010). Bach et al. (2013) studied performance and health of dairy calves on two MR allowances (6 L/d vs 8 L/d) and found that although calves offered 8 L/d had a greater pre-weaning ADG, at 228 d of age they did not differ in terms of BW. Bach et al. (2013) weaned calves over a longer period of time (over 21 d), which is much longer than other studies reviewed here that typically weaned in a step-down method over a one week period and may be a contributing factor to there being no difference observed in the final live weight.

Automatic compared with manual feeding of milk

Automatic milk feeding machines were introduced around 1988 (Svensson and Liberg, 2006) and can be a valuable asset to any calf rearing operation (Kung et al., 1997). The primary benefits of the automated feeder are a reduction in labour time involved in feeding and the opportunity to feed greater amounts of milk by feeding calves more frequently (Marcé et al., 2010). Feeding meals more frequently follows how a dam would nurse her calf more closely, drinking up to 12 L/d over several meals (Appleby et al., 2001; Khan et al., 2011). De Passillé and Rushen (2016) demonstrated that an automatic feeder can allow calves to be weaned according to starter intake, which can be beneficial in terms of reducing signs of hunger, such as unrewarded visits to the feeder and low levels of play, and allows a smooth transition to a SF diet, without a loss in liveweight gain following weaning.

Concerns have been raised over the high risk of disease amongst calves housed in groups, such as is required when using automatic milk feeding machines (Svensson and Liberg, 2006; Cobb et al., 2014; Curtis et al., 2016). The risk of respiratory disease and enteric disorders are considered to be greater when calves are housed in groups, especially when there is a variation in age (Marcé et al., 2010). A Canadian survey completed by Medrano-Galarza et al. (2018) analysed the relationship between management practices and calf health on a sample

of farms using automatic feeders, and found a median average prevalence of 24% for calf diarrhoea (CD) and 14% for bovine respiratory disease (BRD) on farms that utilized automated milk feeders. The disease incidence found by Medrano-Galarza et al. (2018) were similar to a study completed in North America by Lago et al. (2006), in which calves were housed individually, however, an underestimation of disease prevalence is likely. Medrano-Galarza et al. (2018) measured the prevalence of disease, rather than the incidence, which was based on seasonal visits. This study, completed in Canada, identified other management factors such as separating older cattle from calves, feeding high quality milk, refreshing bedding every 2 to 3 d and adding vitamin E, selenium, probiotics to milk (Medrano-Galarza et al., 2018). In addition to this, Svensson and Liberg (2006) recommended rearing calves in groups of less than 10 to reduce the incidence of CD and BRD. These management strategies should be considered as possible preventative measures when opting for an automatic milk feeding system.

Manual feeding is more labour intensive than automatic milk feeding, but it allows more time spent observing the calves for any pre-clinical disease symptoms. Manual feeding of milk is usually undertaken twice a day, sometimes once a day closer to weaning (Kung et al., 1997; Khan et al., 2011). In the UK, according to the Welfare of Farmed Animals (England) Regulations 2007 (WOFAR), calves need to be offered milk at least twice daily until they are able to digest an adequate amount of cereal and protein based calf SF. Milk can either be consumed via an open bucket or a bucket or bottle fitted with an artificial teat attachment and studies have shown that providing milk via a teat better satisfies the calf's need to suck, thereby reducing cross-sucking and also increases milk intake (Hammell et al., 1988; Appleby et al., 2001; de Passillé, 2001; Jensen and Budde, 2006). Cross-sucking is an abnormal, non-nutritive behaviour and is usually the sucking of another pen mate, or part of their enclosure (Lidfors, 1993). Drinking milk via a teat is also thought to better ensure the milk goes through to the abomasum through efficient use of the oesophageal groove reflex (Wise and Anderson, 1939).

Weaning strategies

Greater amounts of milk intake decrease solid feed consumption and consequentially loss of weight during weaning is sometimes observed (Jasper and Weary, 2002; Cowles et al., 2006;

Raeth-Knight et al., 2009; Mirzaei et al., 2018). Therefore, to counteract this, a “step-down” strategy was studied by Khan et al. (2007) who compared the performance of calves offered a conventional milk diet (10% live weight) and weaned abruptly, to calves offered an elevated plane (20% live weight) of nutrition and weaned gradually, surprisingly the more intensive milk diet had a greater starter intake compared to the calves on the conventional diet and subsequently once the step-down protocol was found to have a positive effect on calf performance, the optimal period for reducing the milk allowance was studied.

Sweeney et al. (2010) weaned calves on 3 different gradual weaning periods (0, 4, 10 and 22 d) with the 0 d group unsurprisingly losing weight post-weaning (0.21 kg), and a gradual weaning strategy, over 10 d, obtaining the best live weights (82.9 kg, 49 d of age) during the study. Steele et al. (2017) found no difference in GI tract morphology and live weights at 60 and 90 d of calves on two different weaning strategies (abruptly and gradually over 12 d, at 48 d of age), however the step-down weaning method (12 d step down initiated at d 36 with a 50% reduction of milk until d 48) was more economical. Roth et al. (2009) compared a 12 week weaning with a concentrate intake dependent weaning strategy, however did not provide a description of the MR used or the reconstitution rate for the 6 L offered, information that would have been useful in comparing their results with others. De Passillé and Rushen (2016) had similar weaning ages (75.8 ± 10.7 d) to Roth et al. (2009) (75.9 ± 2.58 d) for calves weaned based on starter intake.

Table 6.5: Manually and automated¹ intensive feeding of differing types and amounts of milk and milk replacer types, weaning age and measurement period on the starter intake and growth rate Holstein and Holstein-Friesian dairy calves

Milk type	Milk composition and diet						Animals	Weaning	Starter	Period	Gain	References
	CP, %	Fat, %	Lactose, %	L/d	g/L	kg/d	No.	age, d	kg/d	d	kg/d	
Whole ²	ND	ND	ND	ND	ND	8.79	28	42	0.09	0 to 36	0.78	Jasper & Weary 2002
Whole ^{1,3}	4.1	3.97	3.3	12.0	ND	ND	56	76	ND	21 to 70	0.78	de Passillé & Rushen 2016
Whole ¹	3.2	3.8	3.9	9.6	ND	ND	56 ⁴	55	0.05	7 to 41	0.88	Rosenberger et al. 2017
Whey	30.6	16.1	ND	8	150	1.20	80	42	0.20	2 to 42	0.64	Davis Rincker et al. 2011
Whey ¹	26.3	17.0	ND	6.0	208	1.25	65	56	0.13	0 to 56	0.61	Morrison et al. 2012
Whey	25.0	17.9	ND	7.8	140	1.09	96 ⁵	42	0.57	0 to 56	0.62	Dennis et al. 2018
Whey	25.0	17.9	ND	7.8	140	1.09	96 ⁵	53	0.34	0 to 56	0.67	Dennis et al. 2018
Skim	24.0	18.0	45	8.0	150	1.20	12	56	0.19	7 to 56	0.77 ⁷	MacPherson et al. 2016
Skim	26.0	16.0	45	9	150	1.35	54 ⁶	48	0.09	0 to 36	1.13	Steele et al. 2017
No data	27.0	17.0	ND	5.8	150	0.87	96 ⁵	49	0.46	0 to 56	0.55	Chapman et al. 2016

¹ Automatic feeders used

² Waste milk included

³ Weaned according to starter intake

⁴ 24 male and 32 female calves

⁵ Male calves

⁶ 20 female and 34 male calves

⁷ Gain over period of d14 to 70

ND: No data

Intensive milk feeding systems can vary with the amounts, concentrations and duration of milk offered, but all are deemed an “intensive” or “elevated” nutritional regime, compared with conventional feeding, and therefore affect starter concentrate consumption and growth rate differently (Table 6.5). Liveweight gain was consistently over 0.55 kg/d in the pre-weaning period, with some conventional programmes similarly showing such gains (Raeth-Knight et al., 2009; Margerison et al., 2013) while others have not (Jasper and Weary, 2002; Davis Rincker et al., 2011). Margerison et al. (2013) weaned Holstein-Friesian heifers at 90 kg LW, offered supplemented whole milk (4 L/d), achieved weaning at a mean of 74.5 d of age, consuming more starter pre-weaning (0.66 kg/d), and achieving high growth rates of 0.8 kg/d (19 to 39 d) and 0.84 kg/d (40 to 60 d), compared to starter intakes and growth rates recorded in Table 6.5. It is important to note that as well as the amino acid and plant carbohydrate supplementation to the whole milk, probiotics were also added to each calf’s diet for the initial pre-treatment period (3 to 18 d of age) (Margerison et al., 2013), which is the main reason for data being reported from 19 days of age onwards and calves being weaned at an older age, more typical to current practices, both of which would result in a greater rate of reported liveweight gain.

Starter / concentrate feeds

As calves begin to consume solid feed alongside their liquid diet, the rumen starts to develop a microbial population, absorptive functions and structural features (Drackley, 2008). Nutrient absorption from these two sources interact, and this interaction is still not fully understood (Berends et al., 2014). The nature of SF, weaning method and management affect the calf’s eating behaviour and in turn affect gut physiology and performance (Khan et al., 2016). In a dairy heifer replacement system, calves are usually provided with *ad libitum* solid feed in the time around weaning (Hill et al., 2005). In white veal systems, however, SF is limited so as to promote high milk intakes for a pale meat product (Berends, 2014). In 1997, the EU council brought in a directive that stipulated a minimum inclusion of solid feed to veal calves: “a minimum daily amount of fibrous feed, ranging from 50 g/day at 8 weeks of age to 250 g/day at 20 weeks of age” (Council Directive 97/2/EC, 1997). This was largely due to the welfare concerns of white veal systems (Berends, 2014). Furthermore, MRs costing up to approximately 87% more than concentrate starter (Marsh and Boyd, 2010), there is a financial incentive. This legislation motivated many studies looking into the effects of forage and concentrate in a young calf’s diet, because although an amount of fibrous feed intake allocation was specified, the type and sources of feed were not.

In the past veal systems offered a diet of milk only so that the calf remains iron-deficient and can therefore produce the desired pale meat product (Berends, 2014). However, since the 1997 EU council directive stating that SF must be included in veal calf diets, research has been undertaken to investigate exactly what type and quantity of SFs are suitable. When milk is the only source of nutrients, the calf's rumen remains largely immature (Meale et al., 2017). It is only with the presence of SF that rumen development can begin, fermentation processes are initiated, and a microbial population can begin to grow (Tamate et al., 1962; Suárez et al., 2006a). Cozzi et al. (2002) showed that feeding of SF does not necessarily hinder the production of white veal meat, and that the iron content of a feed does not directly correspond with the iron levels in calves and therefore the "redness" of the meat. Farmers of both rosé and white veal are challenged with feeding calves a composition of roughage and concentrate that will maximise growth but also mitigate gastro-intestinal problems as mentioned earlier. Strategic feeding tailored for the desired end product is key in a beef industry as making a reasonable profit remains a challenge for British beef farmers (AHDB, 2016).

A calf starter should be highly palatable and digestible in order to encourage intake and therefore stimulation of the rumen (Hill et al., 2005). Starter meals come in textured or pelleted varieties, usually contain 18-20% CP, and have a low fat content (4%) (Hill et al., 2005; Montoro and Bach, 2012; Araujo et al., 2014). NRC (2001) recommended calf starters contain 18% CP, which has been supported in subsequent studies (Hill et al., 2005; Hill et al., 2007). A study by Araujo et al. (2014) found that the higher MR intake with the high-fat starter resulted in the best BW gains compared to the other feeding strategies in calves offered a MR diet of 4L/d or 6L/d with a low (4.1%) or high (11.2%) fat calf starter. Early studies that looked at fat content of starter meals, based on low milk feeding schemes, found higher fat contents to be detrimental to calf performance (Miller et al., 1959; Kuehn et al., 1994). Grain-based starters contain high proportions of rapidly fermentable carbohydrates such as starch which release high proportions of butyrate and propionate and promote growth of amylolytic bacteria (Tamate et al., 1962). Whereas more fibrous feed, leads to the production of acetate and the promotion of cellulolytic bacteria (Khan et al., 2016). There is debate on whether to include forage early on, due to increased gut fill, displacing concentrate intake and in some cases, decreased feed efficiency (Tamate et al., 1962; Hill et al., 2005; Hill et al., 2008c; b). However, these early studies offered calves a conventional milk diet, feeding milk at a rate of

approximately 4 L, and therefore limiting their relevance to farmers that utilize a more intensive milk feeding scheme.

Forages

Calves have a relatively low intake of solid feed during the milk-feeding phase, however forage inclusion pre-weaning has shown to increase ADG, total DMI, and reduce the incidence of non-nutritive oral behaviour (Thomas and Hinks, 1982; Coverdale et al., 2004; Khan et al., 2011; Montoro et al., 2013). Various types of hays, silages and straw are included in calf diets (Imani et al., 2017) and such forage types are included in Table 6.6 for comparison. In veal calves, forage inclusion helped to reduce the incidence of some gastrointestinal disorders as discussed earlier. Santman-Berends et al. (2018) associated a lower mortality rate with veal calves with a roughage intake over 0.14 kg/day. Average growth rates in Coverdale et al. (2004) tended to be higher (0.9 kg/d) for calves offered diets including a coarse starter and brome grass hay at 7.5% and 15% inclusion as opposed to calves only given a ground starter.

Understanding how feed sorting behaviour develops from a young calf can help to implement strategies to avoid this detrimental behaviour when cows enter the milking herd (Miller-Cushon and DeVries, 2017). Various behavioural studies that have observed eating patterns in young calves have detected; calves prefer familiar feeds (Miller-Cushon and DeVries, 2011), feed sorting is reduced when SF is provided as separate components in the rearing phase (Miller-Cushon et al., 2013a), and learnt feed sorting behaviour can persist post-weaning (Miller-Cushon et al., 2013b).

Table 6.6: Starter feeds and forage provision, type and ratio, starch composition, and milk program provided, and recorded intakes, weight gain and weaning age of dairy calves pre- and post-weaning

Milk diet	Animals		Cereal	Forage	Starch % DM	Cereal/ forage	Peri-weaning intake		Gain kg/d	Weaning	
	No.	Form					Pre, kg/d	Post, kg/d		Age, d	Reference
Replacer	15	Pelleted	Starter	None	ND	Ad-libitum	0.54	1.90	0.79	57	Castells et al., 2013
Restricted			Starter	Alfalfa hay		Separate	0.62	2.08	0.82	57	
amounts			Starter	Oat hay			0.66	2.61	1.29	57	
Whole milk	60	Ground	Barley	None	52.3	No forage	0.46	1.60	0.494	49	Mirzaei et al., 2017
Restricted		cereal	Barley	Alfalfa Hay	47.1	85:15 mix	0.30	1.61	0.501	49	
amounts		mixed	Barley	Maize silage	46.8	85:15 mix	0.43	2.03	0.610	49	
		ration	Maize	None	60.4	No forage	0.27	1.37	0.419	49	
			Maize	Alfalfa Hay	53.3	85:15 mix	0.31	1.60	0.489	49	
			Maize	Maize silage	52.9	85:15 mix	0.38	1.91	0.527	49	
Whole milk	64	Pelleted	Barley	Pasture hay	25%	Ad-libitum	0.22	0.98	0.69	49	Khan et al., 2007
Greater			Corn	Pasture hay	25%	Ad-libitum	0.30	1.40	1.19	49	
amounts			Oats	Pasture hay	25%	Ad-libitum	0.23	1.02	0.76	49	
			Wheat	Pasture hay	25%	Ad-libitum	0.25	1.19	1.1	49	

ND: No data

Other calf rearing factors

The pre-weaning stage of a calf's life represents a time of dramatic change physiologically, and when it is most susceptible to ill health (Howard, 2003; Svensson and Liberg, 2006). It is estimated that calves with scours or pneumonia could mean extra labour work of around 2 – 10 minutes per calf, meaning that calves with enteric or respiratory disorders can incur significant labour costs (Mohd Nor et al., 2012), and furthermore, are less likely to survive to 24 months old (Closs and Dechow, 2017). With rearing replacements in a dairy operation estimated to account for around 20% of the total expenditure on the farm (Gabler et al., 2000), calf rearing, if not undertaken efficiently can be very costly. Boulton et al. (2015) found in their survey of 101 dairy farms across the UK, the total mean cost of £195.15 from the birth to weaning period, with an average weaning age of 62 d $\pm$ 13.

The main factors in rearing a healthy calf are colostrum, housing conditions and feeding management (Wathes et al., 2008). A calf's immature immune system gradually develops with the intake of immunoglobulin-rich colostrum (> 50 g/L IgG) (Godden, 2008). Failure of passive transfer of immunity (FPT), defined as a calf serum IgG concentration that is less than 10 mg/mL when sampled between 24 and 48 hours of age (Weaver et al., 2000; Godden, 2008), is still quite common in dairy herds, in the UK and overseas (USDA, 2007; Trotz-Williams et al., 2008; Vogels et al., 2013; Macfarlane et al., 2015). Failure of passive transfer of immunity makes the calf more susceptible to disease, particularly BRD. A Canadian study estimated that over 20% of BRD cases could have been prevented if calves were given adequate colostrum (Windeyer et al., 2014). Calf housing should have adequate ventilation but provide protection from draughts at calf level (Roland et al., 2016).

Temperatures below 15°C and above 25°C are outside of what is termed the thermos-neutral zone for calves less than 21 d of age (Schrama et al., 1993; Arieli et al., 1995). When calves need to expend more energy on thermoregulation, a decrease in performance can be expected, and calves can succumb to hyperthermia and cold stress (Scibilia et al., 1987). Smaller breeds (e.g. Jersey) are more susceptible than larger breeds (e.g. Holstein) due to their larger surface area to body weight ratio (Webster, 1974). Housing as groups, pairs, or individuals also needs to be considered. Rearing calves in a group environment has positive effects on non-nutritive sucking behaviour (Pempek et al., 2016), SF intake (De Paula Vieira

et al., 2010) reduced aggression when individually housed calves are subsequently grouped (Veissier et al., 1994), and can lower the effect of exposure in cold conditions (Mellor and Stafford, 2004). The risk of infectious disease can be greater when calves that use the same feeder; are maintained in close proximity to other calves, come from differing farms, vary in age (Svensson et al., 2003; Roth et al., 2009). In the UK, individual housing was predominantly used until weaning according to a survey by Marcé et al. (2010). The risks of infection from enteric and respiratory diseases are lower (Svensson et al., 2003; Curtis et al., 2016), but individual housing can be costly and detrimental to the calf welfare (Curtis et al., 2016; Pempek et al., 2016).

Diet additives

A calf is most susceptible to disease in the first few weeks of life. Permeability of the gastrointestinal tract starts to decrease from 17 d of age suggesting an increase in barrier function (Steele et al., 2017). Including feed additives can help prevent enteric and respiratory disorders from occurring as will be discussed. Such additives can include antimicrobials, pre- and probiotics, essential oils, vitamins and minerals, and branched-chain VFAs (Hersom et al., 2015).

A survey by the national Animal Health Monitoring System in the USA found that more than half of dairy farms feed medicated milk (USDA, 2007). White veal calves especially are known to receive antimicrobials more intensively than other classes of livestock (Pardon et al., 2012). Neomycin, colistin and oxytetracycline or variants of these are common antibiotics used in milk replacers (Heinrichs et al., 2003; Berge et al., 2005; Timmerman et al., 2005; Berends et al., 2012). The nature of large-scale calf ranches, in which calves are transported from many different farms at a young age, causing undue stress when their immune system is weak, means that farmers will use medicated MR to combat these negative effects (Berge et al., 2005; Santman-Berends et al., 2018). Berge et al. (2005) recovered a serovar (*Salmonella* Newport) in some calves, with blood stained diarrhoea that was resistant to multiple-antibiotics including third-generation cephalosporin, Ceftiofur, which was the primary antibiotic used for treating calves. Cases like these encourage the growing movement away from antibiotic use on farms, especially when a higher usage of antibiotics is associated with a higher calf mortality rate (Santman-Berends et al., 2018). Higher use of antibiotics may be directly related

to the incidence of disease, or with increased usage of antibiotics, resistance has developed meaning disease is more difficult to treat (Bos et al., 2012; Jarrige et al., 2017).

Antibiotics used for growth promotion or for prophylactic purposes were banned by the European Commission in January 2006 (EC Regulation No. 1831/2003). Antimicrobial resistance (AMR) has become an increasingly important issue to the agricultural sector and poses a serious and critical threat to human health and also affects the environment, medicine, and food (Hudson et al., 2017). Although the significance of the part that agriculture has to play in the bigger picture is uncertain, a direct link between use of antibiotics in farm animals and AMR has shown in recent findings (Economou and Gousia, 2015). Pre- and pro-biotics, and combinations of the two – synbiotics, are substances which are known to increase the number of “good” bacteria (Uyeno et al., 2015). Prebiotics have been described by (Gibson and Roberfroid, 1995) as ‘non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improves host health, whereas probiotics are live microorganisms that, when administered orally, confer beneficial effects on the host (Terrill et al., 2009; Uyeno et al., 2015). Prebiotic non-digestible oligosaccharides such as fructo-oligosaccharides (FOS, oligofructose and inulin), galacto-oligosaccharides (GOS), and mannan-oligosaccharides (MOS) have been used commercially in pigs, poultry and bovines (Heinrichs et al., 2003; Gaggia et al., 2010).

Pre- and pro-biotics have yielded some positive results in the pig and poultry industries, mainly in the form of increased populations of bifidobacteria and lactobacilli, bacteria that are known to have positive effects in the gut (Abe et al., 1995; Fernandez et al., 2002; Naqid et al., 2015; Barszcz et al., 2016; Geigerová et al., 2017). Timmerman et al. (2005) reported an increase in ADG and feed efficiency in calves offered a multispecies probiotic (MSPB) and a calf-specific probiotic (CSPB), compared to groups without a probiotic added to MR. However, in the trial of Timmerman et al. (2005), antibiotics were also supplemented (neomycin and colistin, oxytetracycline and colistin) due to the high risk of infection in the winter season, which may have affected the results. In another study, calves offered a diet supplemented with prebiotics had an improved feed efficiency (0.44 gain, kg/feed intake, kg) and growth rate (0.82 kg/d) compared with the control group (Hasunuma et al., 2011).

Essential oils (EOs) are hydrophobic compounds obtained from plants with chemical properties that vary depending on factors such as species, ecological factors, climatic conditions, harvest time, the part of the plant used, and method of isolation (Màthé, 2009). Such EOs are sourced from Cinnamaldehyde, thymol, oregano, and many more, and are used singularly or in a blend (Màthé, 2009; Brenes and Roura, 2010; Froehlich et al., 2017). A review by Zeng et al. (2015) found a mean increase in weight gain in pigs (10%) and poultry (3%). Although performance results are mostly positive, because EOs are such complex compounds, combinations of different components can have positive and negative effects on their bacteriostatic ability (Brenes and Roura, 2010; Zeng et al., 2015). Santos et al. (2015) found no difference in performance and incidence of diarrhoea in dairy calves offered milk with supplemental EO blend, although higher proportions of beneficial bacteria were found in faeces and rumen fluid. Froehlich et al. (2017) tested different rates of inclusion of a commercial EO blend and prebiotics on 100 Holstein male calves, and found that the blend at a rate of 1.25 g/calf/day (EO-0.5) increased growth rate, body frame size, and decreased mean faecal scores (≥ 2 = scours).

Vitamin E is an antioxidant known to improve immune system function in young dairy calves (Cipriano et al., 1982). The most biologically-active form of vitamin E, and the most common form in animal feedstuffs is α -tocopherol. The NRC recommended 50 IU/kg DM of vitamin E, an increase of 25% from the previous edition (NRC, 2001a) in response to more definitive evidence of the positive effects when supplemented in the diet, and the possible benefits for young calves, particularly in stressful situations as are common in the US cattle industry. Vitamin E and selenium are usually supplemented together to enhance immune responses (Castillo et al., 2013; McGrath, 2016; Medrano-Galarza et al., 2018). Trace minerals such as selenium are important for the functioning of enzymes involved in immune system responses (Spears, 2000), however the practical value of these vitamins and minerals is yet to be proven (Chauhan et al., 2016)

Volatile fatty acids, primarily acetate, butyrate and propionate are the main source of energy for ruminants (Bergman, 1990). Branched-chain VFAs, isobutyrate, isovalerate and 2-methylbutyrate, enhance growth of cellulolytic bacteria (Eugène et al., 2004). Supplementation

of 2-methylbutyrate and isovalerate improved the ADG and rumen morphology of dairy calves (Liu et al., 2016a; Liu et al., 2016b). For intensively reared calves that experience stressful events early in life, addition of such dietary additives can improve functioning of the gut and immune system and therefore improve mortality and morbidity.

The issue of euthanizing bull calves on dairy farms due to the poor prospects from rearing is a deeply upsetting issue for many people. An estimated 101,959 calves were euthanized on farm in 2016 in the UK (CHAWG, 2018b). As consumer purchases trend towards animal products that are more welfare-friendly, the beef and dairy industry are encouraged to work together to alleviate this issue (Stannard, 2018). Rosé veal has seen some publicity in the UK in efforts to boost consumption but there are doubts as to whether popularity will increase enough to make it a worthwhile venture for farmers wishing to sell their bull calves to veal operations (Forum, 2013). Compared to all-year-round systems found in some parts of the UK, where the surplus of male calves can be spread throughout the year, in block-calving systems like in other parts of the UK, Ireland and New Zealand, the surplus is within the space of a few months and poses more of a problem with supply and demand. These block-calving systems also tend to utilize fresh grass as a large proportion of the diet, and the Jersey crossbreeds tend to be more efficient at utilizing that feed (Lopez-Villalobos et al., 2000). There is more literature needed to assess the growth profile of the dairy-bred youngstock, and therefore suitability for the beef industry. Beef farmers are lacking the tools to estimate a profit margin on these animals because of the uncertainty of their expected performance and the level of nutrition required for the differing dairy breeds.

European union laws have restricted calf rearing practices (milk replacers cannot contain animal fats (e.g. tallow) or antibiotics (i.e. medicated MR), and veal calves must be provided with a minimum SF allowance of 50 to 250 g/day) and therefore requires excellent feeding management, e.g. elevated milk feeding, use of diet additives, to ensure profitable operations. Elevated milk feeding has been shown to improve growth rates of young calves however studies have not evaluated the intensive milk feeding in alternative breed types such as Jersey crossbreeds. In this literature review, different feeding strategies for the un-weaned calf have been assessed, however very few have used Jersey or Jersey crossbreeds.

Aim of this research

The aim of this research was to compare the effect of 1) dairy breed (Holstein/ New Zealand Friesian (HF) and Jersey x HF (Kiwi cross)) and 2) initial purchase live weight at 10 ($\pm$ 3) d of age of Kiwi cross bred bull calves (being $\geq$ or $<$ 50 kg LW) on; feed intake, growth rate, feed efficiency, time required to meet a marketing weight of 120 kg and the economic viability of rearing pure dairy-bred bull calves in a commercial setting.

Hypothesis

The hypothesis for this research was that Kiwi cross bred bull calves, especially those of $<$ 50 kg LW at 10 ($\pm$ 3) d of age, may have lower growth rates and require significantly more time, feed and labour (d) input to reach the 120 kg, marketing, post-weaning LW required by beef and/or veal finishers, compared with Holstein/ NZ Friesian bull calves that were of $\geq$ 50 kg at 10 ($\pm$ 3) d of age.

6. Materials and methods

Location, animals, management and nutrition

This study was conducted at the University of Nottingham (UoN), Biological Support Unit (BSU), Sutton Bonington, Leicestershire, UK. All procedures were undertaken under the authority of the UK Animal (Scientific Procedures) Act 1986, with the approval of the UoN Animal Ethics Committee, which was granted prior to the commencement of the study. The experiment was completed between late February until early June 2018, when the mean relative humidity was 77.5% and temperature was 10.7 °C, ranging from -5.5 °C to 28 °C.

A total of 60 dairy-bred bull calves, were collected directly from a single source spring calving dairy herd, within 15 km of BSU, at 10 ($\pm$ 3) days of age. Prior to collection, all the calves were offered colostrum on an *ad libitum* basis from birth to 10 ($\pm$ 3) days of age. At 10 ($\pm$ 3) days of age calves were selected at random and transported in batches of 12 calves per group to BSU

on a twice weekly basis over an 18 d period. On arrival at BSU, all calves were weighed and allocated into pairs (n=30) according to breed and live weight into three treatment groups; Holstein / NZ Friesian (HF) (mean 50.0 ± 0.9 kg ILW) and Jersey x HF calves of higher (JxH) (51.0 ± 0.9 kg ILW) and lower (JxL) (44.0 ± 0.9 kg ILW) at 7 to 10 (± 3) d of age . All calves were housed under a single span roof in a naturally ventilated building, fitted with 30 pens (2.5 m²), in which two calves were kept in pairs on deep litter barley straw beds, on which straw was replenished daily as required.

The milk replacer was reconstituted at 150 g/L and mixed using automated mobile milk mixer trollies (x2) (Dairy Spares UK) and offered at 38°C in accordance to manufacturer's recommendations (Denkavit, The Netherlands). The reconstituted milk replacer was offered at <10 L/hd/d, which was measured manually using plastic jugs, to individual calves at 07.30 and 15.30, from 4.5 L capacity plastic milk feeders fitted with a single easy flow teat (Milk bar, Co. UK). All calves were offered milk replacer on an individual basis twice daily up to 84 d of age. In addition, each pen was fitted with one straw rack and 6 removable plastic buckets (10 L), which were suspended above ground level, used to offer water (n=4) and calf SF (n=2). All calves were offered *ad libitum* access to water and calf starter (Manor farm feeds, Oakham, Leicestershire, UK) which was replenished twice daily (Table 7.1). All calves were weaned at 12 weeks of age, when starter intake was confirmed to be at least 2 kg/d per pen on 3 consecutive days. All calves were de-horned at 8 weeks of age, using a subcutaneous injection of meloxicam solution (Metacam, Boehringer Ingelheim Animal Health UK Ltd), 2.5 mL per 100 kg of calf live weight. The cornual nerve block procedure in which 5 mL of Procaine Hydrochloride solution (Adrenacaine, Norbrook Laboratories Ltd, Co. Down, N. Ireland, BT35 6JP) per horn was injected 10 to 15 min before cauterizing to minimize pain.

Measurements

Live weight, starter concentrate intake, feed conversion efficiency and feed efficiency

Live weight was measured weekly using an electronic calf weigh scale (Batemans, UK). The volume of reconstituted MR offered and refused by individual calves was measured volumetrically using 2 and 4 L plastic jugs. The amount of calf starter concentrate consumed

(kg FM) was calculated by measuring the amount offered and amount remaining (kg FM) over a 24-hour period per pen on a bi-weekly basis using electronic weigh scales and using the feed analysis DM to correct this to kg DM intake daily. This was used to estimate total starter intake and calf growth per pen, which was divided by two and expressed mean intake. The total starter, total MR and total DMI (kg DM) consumed and weight gained per pen, up to 120 kg, were used to calculate FCE (intake, kg DM/gain, kg) and FE (gain, kg/intake, kg DM) from the start to 120 kg LW. The cost intervals of milk replacer, straw and starter concentrate was deduced from industry and government guides and reports (AHDB, 2018; GP feeds UK; Mole Valley Farmers UK).

Table 7.1: Nutrient composition of milk replacer, calf meals, and barley straw on a dry matter basis

Item (% of DM)	Milk Replacer ¹	Calf starter ²	Barley straw
DM	96.8	87.3	90.7
CP	23.0	20.1	7.7
Crude fibre		7.4	40.4
NDF		31.0	83.1
ADF		14.3	52.9
Fat	19.0	2.4	1.3
Ash	7.0	7.0	6.0
Sugar	30.1		

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, (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.

The composition of all feeds was assessed using 500 g samples of milk replacer, straw, and starter concentrate, which were collected on a weekly basis and frozen at -20 °C until the analysis of DM, crude protein, sugar, fat, NDF, ADF and ash according to AOAC (1990) (Table 7.1).

Health

The faecal consistency was assessed using a 4-point scale according to Diaz et al. (2001), in which 1 is solid/normal and 4 is runny/liquid state, which was assessed twice daily directly prior to milk feeding. The calves with a faecal score of ≥ 3 were offered milk with 50 g of electrolyte (ASGold, Volac, UK) mixed in 2 L of milk, or in some severe cases (3) 2 L of water. Calves with symptoms of pneumonia, such as a high temperature and respiration rate and congested lungs, umbilical infection, which had a swollen navel, were isolated. Such calves examined by a veterinarian and prescribed antibiotics as necessary. All treatments and days treated were recorded. The umbilical cords of all calves were checked weekly and 1 calf was treated for a navel infection at 14 d of age, 1 calf was treated for inner ear infections at 14 to 30 d of age (Synulox, Merck Animal Health), while 4 calves were treated for preclinical (1) and clinical (3) pneumonia (NuFlor; Merck Animal Health) for 3 to 5 d. All calves were treated early, made a rapid recovery and data was assessed with and without these calves and this made no difference to the final data and, as a consequence, all calves were included in the data.

Statistical analysis

All data were collated in Microsoft Office Excel 2016 and analysed statistically using Minitab statistical software (Version 17.2.1, 2016, State College, PA). Liveweight gain was calculated for each calf over three periods: pre-weaning, post-weaning and up-to 120 kg LW. Concentrated starter intake was measured for each pen (n=30) and divided by two in order to estimate and present feed intake per calf. Feed conversion efficiency was calculated using the mean liveweight gain per calf pair divided by the mean feed intake per calf pair, which was calculated as a mean over the period up to 120 kg of live weight. Antibiotic treatment data were assessed using Chi-squared test. The live weight, growth rate, feed intake and feed conversion efficiency data were assessed using the norm-plot command and found to be normally distributed. These data were analysed using the General Linear Mixed Models

procedure (GLM) ANOVA command, applying animal breed type (Holstein / NZ Friesian versus Jersey/ Kiwi cross) and live weight at 10 ($\pm$ 3) (high or low) as fixed effects in the model, and individual animal as a random effect in the model. Differences between means were assessed using Tukey's test for all differences except between means for pre-weaning concentrate starter intake, for which the Fisher test was used. A confidence interval of 95 % was used, and significant differences between means were reported at a $P < 0.05$. Individual treatment means for live weight, growth rate, feed intake and feed conversion efficiency of for Holstein / NZ Friesian and Jersey/Kiwi cross of greater and lower live weight at 10 ($\pm$ 3) were presented with standard errors and P Values in the data tables.

7. Results

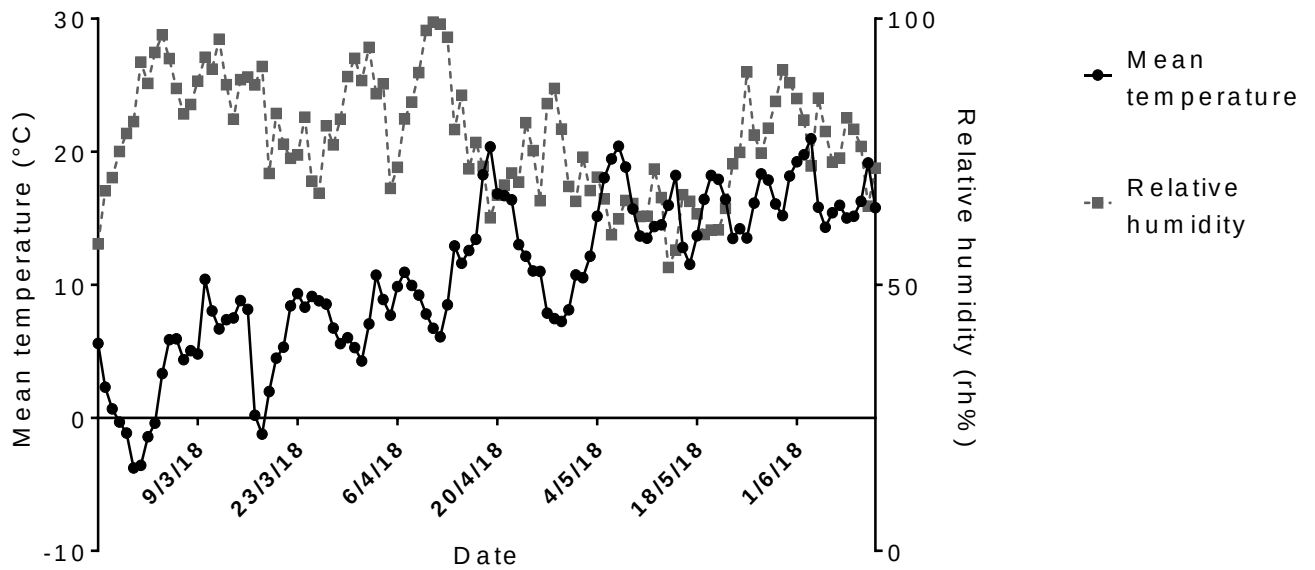


Figure 8.1: Mean daily temperature (°C) and relative humidity (RH, %) inside calf housing during experimental period

Table 8.1: Mean number of days treated with electrolytes, had a faecal score of 3 and above, and number of animals treated with antibiotics ($\pm$ SE) in Holstein / New Zealand Friesian and Jersey/Kiwi cross dairy bull calves classified as higher and lower live weight at 10 ($\pm$ 3) d of age

	Holstein / NZ Friesian	Jersey/Kiwi Higher	Cross ¹ Lower	SEMs	P value
Observations, No.	20	20	20		
Days of electrolyte treatment, No.	1.05	1.85	1.8	0.382	0.261
No. of days with faecal score ≥ 3 , d	2.05	2.35	2.10	0.424	0.867
Antibiotic use , no. of animals	4	1	1		0.189 ²

¹ Kiwi cross are cross bred dairy cattle of varying proportions of Jersey and NZ Friesian, often referred to as Holstein Friesian

² Approximate estimate of probability

The mean daily temperature was below 0°C on two occasions between during February and March (Fig 8.1). The mean relative humidity was 77.5% and temperature was 10.7 °C, ranging from -5.5 °C to 28°C.

The number of days calves had a faecal score of ≥ 3 and were offered electrolytes, and the number of animals administered antibiotics did not differ between HF, and KW of higher and lower LW at 10 (± 3) d of age (Table 8.1).

Table 8.2: Mean feed intake ($\pm$ SE) of Holstein / New Zealand Friesian and Jersey/Kiwi cross dairy bull calves classified as higher and lower live weight at 10 (± 3) d of age

	Holstein / NZ Friesian	Jersey/Kiwi Higher	Cross ¹ Lower	P value
Amount of milk consumed, L/d	8.1 (0.07)	7.9 (0.07)	8.0 (0.07)	0.298
Daily replacer intake, kg DM/d	1.14 (0.012)	1.12 (0.012)	1.13 (0.012)	0.391
Concentrate starter intake				
Pre weaning, kg DM/d	0.58 (0.178) ^a	0.61 (0.205) ^a	0.33 (0.050) ^b	0.041
Post-weaning, kg DM/d	4.04 (0.805)	3.90 (0.177)	2.85 (0.177)	0.059
Whole period, kg DM/d	1.33 (0.345)	1.29 (0.399)	0.89 (0.345)	0.105
Used to 120 kg LW, kg DM/d	0.48 (0.181)	0.48 (0.209)	0.30 (0.181)	0.215

¹ Kiwi cross are cross bred dairy cattle of varying proportions of Jersey and NZ Friesian, often referred to as Holstein Friesian

The amount of milk consumed, daily milk replacer and the pre-weaning, and total concentrate consumed up to 120 kg LW and for the whole period of the experiment did not differ between HF, JxH and JxL (Table 8.2). However, during the pre-weaning period, the daily concentrate intake was greater by HF and JxH, compared with JxL (Table 8.2).

The LW at the start, weaning, and post-weaning was greater, while the number of days required to reach a LW of 120 kg was less for HF and JxH calves compared with JxL calves. The mean LW gain up to weaning was greater in HF, compared with JxL, but did not differ between HF and JxH calves (Table 8.3). There was no difference in mean pre- and post-weaning daily LW gain and weaning age between calves of HF, JxH and JxL.

Table 8.3: Mean live weight and liveweight gain, days to weaning and achieving a live weight of 120 kg by Holstein / New Zealand Friesian and Jersey/Kiwi cross dairy bull calves classified as higher and lower live weight at 10 ($\pm$ 3) d of age

	Holstein / NZ Friesian	Jersey/Kiwi Cross ¹		P value
		Higher	Lower	
Observations, No.	20	20	20	
Starting weight, kg	50.0 (0.86) ^a	51.2 (0.86) ^a	44.1 (0.86) ^b	<0.001
Weaning weight, kg	139.7 (2.55) ^a	139.1 (2.55) ^a	129.2 (2.55) ^b	0.008
Weight gain to weaning, kg	84.3 (2.09) ^a	81.1 (2.09) ^{a, b}	77.0 (2.09) ^b	0.049
Post-weaning weight, kg ²	157.6 (3.49) ^a	153.8 (3.34) ^a	141.7 (3.21) ^b	0.005
Pre-weaning gain, kg/d	1.01 (0.031)	0.97 (0.031)	0.91 (0.031)	0.069
Post-weaning gain, kg/d	1.57 (0.105)	1.56 (0.105)	1.52 (0.105)	0.942
Weaning age, d	84.0 (1.08)	84.0 (1.08)	85.0 (1.08)	0.782
Time to 120 kg, d	69.6 (1.55) ^b	71.0 (1.55) ^b	77.7 (1.55) ^a	0.001

¹ Kiwi cross are cross bred dairy cattle of varying proportions of Jersey and NZ Friesian, often referred to as Holstein Friesian

² Live weight at 2 weeks post-weaning

Table 8.4: Mean feed conversion and feed efficiency ($\pm$ SE) up to the attainment of 120 kg live weight by Holstein / New Zealand Friesian and Jersey/Kiwi cross dairy bull calves classified as higher and lower live weight at 10 ($\pm$ 3) d of age

	Holstein / NZ Friesian	Jersey/Kiwi Higher	Cross ¹ Lower	P value
Feed conversion efficiency:				
Milk replacer, kg DM/ kg gain	1.33 (0.0192)	1.17 (0.0192)	1.16 (0.0192)	0.355
Calf starter, kg DM/ kg gain	0.498 (0.0877)	0.514 (0.1010)	0.321 (0.0877)	0.270
Total intake, kg DM/ kg gain	1.64 (0.091)	1.69 (0.105)	1.47 (0.091)	0.246
Feed efficiency:				
Gain kg/ kg DM milk replacer	0.89 (0.015)	0.86 (0.015)	0.86 (0.015)	0.248
Gain kg/ kg DM calf starter	2.54 (0.674)	3.33 (0.778)	3.55 (0.674)	0.551
Gain kg/ total intake kg DM	0.62 (0.036)	0.62 (0.041)	0.69 (0.036)	0.325

¹ Kiwi cross are cross bred dairy cattle of varying proportions of Jersey and NZ Friesian, often referred to as Holstein Friesian

Feed conversion and feed efficiency were not different between JxL, JxH and HF for milk replacer or concentrate starter for the period up to 120 kg of live weight.

In this study, a total of 33 bales (1.2 x 1.2 x 2.5 m) of straw, estimated to be 19.1 tonnes, were used uniformly amongst the three treatments. Milk replacer consumed to 120 kg of LW was greater in JxL than JxH and HF. The total milk replacer consumed over the experiment, and the total starter consumed over the entire, and 120 kg live weight period did not differ between breed/live weight categories.

Table 8.5: Total feed consumed and straw used over the entire experimental period and up to 120 kg live weight by Holstein / New Zealand Friesian and Jersey/Kiwi cross dairy calves classified as higher and lower live weight at 10 ($\pm$ 3) d of age

	Holstein / NZ Friesian	Jersey/Kiwi Higher	Cross ¹ Lower	P value
Total feed used, kg FM				
Milk replacer used, kg FM	95.7 (1.46)	95.7 (1.46)	97.2 (1.46)	0.699
Calf starter used, kg FM	154.0 (37.7)	146.5 (43.5)	101.6 (37.7)	0.138
Milk replacer to 120 kg LW, kg FM	82.39 (1.46) ^b	83.15 (1.46) ^b	91.16 (1.46) ^a	0.001
Starter feed to 120 kg LW, kg FM	40.8 (14.30)	40.3 (16.50)	28.2 (14.30)	0.397
Total straw used over whole period, t	6.37	6.37	6.37	
Milk replacer costs				
@ £1,350 / t, £	129.20	129.20	131.22	
@ £1,400 / t, £	221.48	218.54	182.00	
@ £1,450 / t, £	138.77	138.77	140.94	
Concentrate starter costs				
@ £250 / t, £	39.55	39.03	32.50	
@ £275 / t, £	43.51	42.93	35.75	
@ £300 / t, £	47.46	46.83	39.00	
Barley straw costs				
@ £65 / t, £	413.83	413.83	413.83	
@ £75 / t, £	477.50	477.50	477.50	
@ £85 / t, £	541.17	541.17	541.17	
@ £100 / t, £	636.67	636.67	636.67	

¹ Kiwi cross are cross bred dairy cattle of varying proportions of Jersey and NZ Friesian, often referred to as Holstein Friesian

9. Discussion

The aim of this research was to compare the effect of dairy breed (HF and Jersey / Kiwi cross bred) on the purchase live weight at 10 (± 3) d of age and the effect of a Kiwi cross bred bull calf being $\geq$ or < 50 kg LW at 10 (± 3) d of age on subsequent time required to meet a marketing weight of 120 kg, feed intake, growth rate and feed efficiency compared with HF bull calves of ≥ 50 kg LW at 10 (± 3) d of age. The economic viability of rearing pure dairy-bred bull calves in a commercial setting was also assessed.

9.1. Feed Intake

The mean amount of milk consumed between groups was 8.0 L/d, and the maximum was 10L/d which equates to 1.5 kg of MR/d, which qualified as an intensive milk-feeding program (Khan et al., 2011) and is comparable with other research (Table 6.5). Enhanced or intensive milk feeding programs as discussed in the review by Khan et al. (2011) are associated with greater rearing LW gains (Appleby et al., 2001; Jasper and Weary, 2002; Morrison et al., 2009; Schäff et al., 2018), feed efficiency (Blome et al., 2003) and first lactation milk yield (Davis Rincker et al., 2011; Soberon et al., 2012; Soberon and Van Amburgh, 2013).

Enhanced or intensive milk feeding programs are also associated with reduced starter intake (Hill et al., 2005; Quigley et al., 2006; Morrison et al., 2012; Chapman et al., 2016; de Passillé and Rushen, 2016; Rosenberger et al., 2017). Morrison et al. (2012) found that for every 100 g increase in MR allowance during the pre-weaning period, concentrate intake was reduced by 39 g/d. In this study, the pre-weaning concentrate starter intake ranged from 0.61 to 0.33 kg DM/d across groups (Table 8.2). This is similar to pre-weaning starter intakes recorded by Chapman et al. (2016) calves on the aggressive (AGG) treatment, and Dennis et al. (2018) calves weaned at 42 d of age (HIGH6 treatment). These studies also offered MR at a similar reconstitution rate of 150 g/L (Chapman et al. 2016) and 140 g/L (Dennis et al., 2018), and used male Holstein calves. In contrast, Davis Rincker et al. (2011) whom also offered calves MR at a rate of 150 g/L, had an average lower daily MR intake (1.03 kg DM/d), had lower starter intakes during the pre-weaning period (0.2 kg DM/d). This is most likely due to the measurement period of average starter intake starting at 2 d of age, until weaning at 42 d of age, whereas on the current study, calves came onto the study at 10 d of age and were

weaned at 84 d of age. A combination of other factors such as Holstein heifers used, and a higher content of fat (3.31%) in the starter (compared to 2.4% fat in current study starter) which is known to depress feed intake (Hill et al., 2005; Araujo et al., 2014), and the possibility of a difference in palatability are also likely to have affected the study by Davis Rincker et al. (2011).

In this study, pre-weaning concentrate intake was 85% higher for JxH than JxL calves but did not differ between HF and JxH calves, despite no differences in mean daily milk intake. Kiwi cross cattle are Jersey crossed with Holstein Friesian breed. The Jersey breed is an early maturing breed, with a slower growth rate and lighter mature weight than late maturing breeds such as Friesian (Menchaca et al., 1996; Freer et al., 2007), therefore is likely to contribute to the significantly lower intakes of the JxL calves. In the current experiment we were limited with the number of intakes recorded due to the paired housing arrangement of calves, therefore rendering the number of sample units to 20 (n=20). If the experiment were to be repeated, individual intakes and/or larger sample size would have been ideal to improve statistical power.

In some studies, forage provision has resulted in an increase in pre-weaning intake (Thomas and Hinks, 1982; Coverdale et al., 2004; Khan et al., 2011; Montoro et al., 2013; Terré et al., 2013), whilst others have shown a decrease (Hill et al., 2008c; 2009b; 2010b) or no difference (Overvest et al., 2016; Mirzaei et al., 2017; Omid-Mirzaei et al., 2018). The effect on forage intake and subsequently liveweight gain depends on the particle size and forage source (Terré et al., 2015). No significant effects have been observed in rumen-buffering capacity (Thomas and Hinks, 1982), or preference (Webb et al., 2014) for long vs. chopped straw. Long barley straw was provided as a roughage sources for calves in the current study. Straw intake unfortunately was not measured due to straw also provided as bedding, therefore making the task of quantifying straw intake difficult. However, current literature suggests that the provision of long straw was possibly beneficial to calf rumen health and live weight gains.

Offering more milk powder in terms of a more concentrated milk feed, has the potential to increase liveweight gain (Morrison et al., 2012). In the current study, the daily MR intake on

mean average, was 1.13 kg/d, with an MR inclusion rate of 150 g/L across all three groups. Morrison et al. (2012) offered a whey based MR at different rates (0.5, 0.75, 1 and 1.25 kg/d) and CP content (23 vs 27%), and maintained the volume of milk at 6 L/d. Heifers on 1 and 1.25 kg of MR/d had better growth rates and for every 100 g increase in the amount of MR offered, live weight increased by 0.76 kg (28 d) and 2.61 kg (270 d), however by 540 d, they were no longer different (Morrison et al., 2012). In a veal context, calves are finished within 8 months, therefore are able to utilize the higher growth rates and feed efficiency possible with large amounts of MR offered.

In the current study, the crude protein content of the milk replacer was 23%, which is lower than the milk replacers used in other studies compared in Table 6.5. Morrison et al. (2009, 2012) found no effects of MR CP content on ADG or frame size. However, Bartlett et al. (2006) and Blome et al. (2003) reported greater ADG with increases in CP content. Bartlett et al. (2006) found that the greatest gain:feed efficiency was for calves offered 22% CP in comparison to 14, 18 and 26% CP MRs. Drackley (2008) highlights the importance of balancing the energy and protein intake for a calf to match the expected performance of the calf. For every kilogram of liveweight gain in calves, a mean of 188 g of protein is deposited, which is estimated require 250 to 280 g of CP intake from the MR (Drackley, 2008). From this current study we achieved above satisfactory growth rates (NRC, 2001a) with the 23%, 19% fat MR. Drackley (2008) calculations account for the typical HF calf, and therefore possibly provide an overestimation for the ideal CP intake for the smaller crossbred calves used in this study.

Mean daily temperature decreased below freezing for two periods in February and March. The reported thermos-neutral zone for calves under 21 d of age is between 10°C to 0°C, whereas for calves over 21 d of age, the lower critical temperature decreases to 5°C (NRC, 2001b; Drackley, 2008). Outside the thermos-neutral zone, a calf can come under thermic stress, and therefore greater risk of morbidity and mortality is associated with rearing calves during winter months (Godden 2005). However, by providing them with adequate amounts of energy and bedding, detrimental effects on growth and health can be reduced (Hill et al. 2007; Godden 2005). In the current study, the combination of increased MR rate and thick bedding of fresh, clean straw is likely to have been a contributing factor to the impressive growth rates,

indicating enough energy was provided to account for the cold weather experienced, much above calf maintenance requirements (Table 8.3).

9.2. Growth rate

In this study, the start, weaning, and post-weaning LW were greater, while the number of days required to reach a LW of 120 kg was less for HF and JxH calves compared with JxL calves (Table 8.3). The Holstein/ NZ Friesian breed is expected to reach a higher mature live weight in bulls (770 kg) than that of the early-maturing Jersey (560 kg) or Jersey crosses (Freer et al. 2007), and is supported by literature as having higher growth rates than that of Jersey-cross cattle (Long et al., 1979; Baker et al., 1990; Freer et al., 2007; Albertí et al., 2008; Crosson and O'Riordan, 2011; Prendiville et al., 2011). In addition to this, entire males are associated with faster growth rates than females because they are growing towards a larger mature weight (Wilson et al., 1969; Menchaca et al., 1996; Lage et al., 2012). Jersey calves offered a conventional 20% CP, 20% fat MR offered at 8 to 10% of body weight, grew at modest rates of ADG, below predicted gains by NRC (2001) equations (Jones et al., 2004; Bascom et al., 2007), suggesting current NRC recommendations may not be suitable for smaller breeds in comparison to Holsteins and HF. In the current study, the HF calves were 5.4 kg heavier at the start of the experiment, but extended to a 10.5 kg greater LW than the JxL calves at weaning (Table 8.3).

Muir et al. (2001) compared the growth rates of bull calves with differing proportions of the Friesian - Jersey genotype (Friesian, $\frac{1}{4}$ Jersey/ $\frac{3}{4}$ Friesian, $\frac{1}{2}$ Jersey/ $\frac{1}{2}$ Friesian), and found that as the calf's proportion of the Jersey genotype increased, the mean live weight decreased. However, there was considerable overlap in performance, especially between the Friesian and $\frac{1}{4}$ Jersey x Friesian genotypes, suggesting prejudice against calves marked as "Jersey type" is unjustified (Muir et al., 2001). This study is the only study to have reported calf performance results on what would be considered a "Kiwi-cross" type. Our study differs from Muir et al. (2001) in that we had fed higher levels of milk for a longer period of time, resulting in large differences in live weight at 12 weeks for example (98.2 vs. 136 kg).

Pre-weaning and post-weaning average daily gains, and weaning age were not different between the three groups in the current study. The mean pre-weaning growth rate in the current study amongst all groups was 0.96 kg/d, the second highest amongst the studies listed in Table 6.5. Higher growth rates were recorded by Steele et al. (2017) than in the current study in calves weaned abruptly (1.04 kg/d) and gradually (1.13 kg/d) for the pre-weaning period (0-36d). These calves were similarly offered chopped straw, starter concentrate (22% CP, 4% fat), water *ad libitum*, and adequate colostrum, however, Steele et al. (2017) skim milk powder-based MR was lower in fat (16%) and higher in CP content (26%) than the current study MR. Possible reasons for lower growth rates in the other sources cited than in the current study is firstly, a majority used female calves, had lower maximum milk intakes and reconstitution rates, weaned calves earlier, higher morbidity recorded, and growth rate was measured from birth or an earlier age (<10 d). The high rate of growth maintained by all treatment groups suggests that firstly, feeding at the current rate of MR was beneficial for calf performance, secondly, Jersey/KW calves of a lighter weight at 10 d of age have similar weight gain and live weight to HF and/or heavier Jersey/KW calves.

There is debate on the accuracy of post-weaning growth rates due to large increases in solid feed intake typically observed at weaning (Steele et al, 2017; Khan 2011; Dennis 2018). In the current study, starter concentrate intake increased rapidly at weaning, with a mean increase of 88% pre- to post-weaning. A rapid increase in SF intake from less than 100 g/d to over 2 kg/d may represent an increase GIT fill, slowing down of passage rate and therefore increase in live weight, but not necessarily growth of body tissue (Rosenberger et al., 2017). The suggestion has been made for structural growth measurements, e.g. body length and withers height, to be included in calf studies to allow for this possible fallacy in LW measurements, especially when post-weaning live weight gains only covers, in some cases, one week post-weaning (Cowles et al., 2006; Miller-Cushon et al., 2013 a; Rosenberger et al., 2017). In the current study, the period of post-weaning gain was limited to a period of two weeks, therefore post-weaning measurements may have been influenced by the increase in SF intake. However, some studies cited in the comparison Table 6.5, lacked important parameters such as the pre-weaning period growth (de Passillé and Rushen, 2016), milk nutrient composition (Jasper and Weary, 2002) and MR ingredients (Chapman et al., 2016), and the difference between milk offered to milk consumed was sometimes ambiguous, which made it difficult to compare across calf nutritional studies.

9.3. Feed efficiency

There were no differences in feed conversion and feed efficiency between the Holstein/ NZ Friesian, Kiwi cross higher and lower groups in the current study. No other calf studies have reported feed efficiency of KW calves, therefore, the next closest in comparison is the pure-bred Jersey. Jones et al. (2004) also found no differences in feed efficiency in Holstein calves (0.391 ± 0.081 kg of gain/kg of DMI) compared to Jersey (0.244 ± 0.084 kg of gain/kg of DMI) from 0 to 29 d of age ($P=0.099$). Feed efficiency up to 120 kg LW in the current study (gain, kg/ total DMI, kg) falls within the range of values (0.35 to 0.72) reported by other researchers (Hill et al., 2008a; Chapman et al., 2016; Dennis et al., 2018).

9.4. Bio-economic viability

The lower live weight Jersey/Kiwi cross group consumed on mean average 8.4 kg more milk replacer up to 120 kg LW than the Kiwi cross (higher live weight) and Holstein/NZ Friesian group. Other total intakes measured were not different between groups in the current study. The 120 kg LW target is based on what calf rearers might aim for when selling on to finishers, or a marker for calf performance in a rosé veal of cereal beef system. In the report by Crosson and O’Riordan (2011), when Jersey and Friesian crossbreds were reared for 12 weeks and finished for veal at 8 months old, Jersey crossbreds returned a higher margin, mostly due to the calves costing significantly less to purchase. The details on the rearing phase was limited to a description of *ad libitum* concentrate and straw, however the cost-profit analysis which included an estimation of fixed costs (depreciation of buildings, machinery insurance etc.) was useful (Crosson and O’Riordan, 2011). If the smaller JxL calves consumed 8.4 kg FM of MR more than the HF and the JxH calves in the current study, at a cost of £1450/t, it would be £12.18 more to rear them to 120 kg LW. Furthermore, if the same difference in calf purchase prices from Crosson and O’Riordan (2011) was applied to the current study, it can be estimated the difference between the HF and the Kiwi cross calves would be approximately the equivalent of £96.10. Therefore, the extra cost in MR for the smaller JxL calves would be covered in the lower purchase price.

Variable costs in a calf rearing operation consist of feed (milk, concentrate, roughage), bedding, veterinary, medical and miscellaneous (e.g. ear tags) (Redman, 2018). Prices of

starter concentrate, straw and milk powder can fluctuate considerably due to changes in weather affecting crop harvests, milk prices etc. (AHDB, 2018b; d). This year (2018) has been a prime example of this with straw prices exceeding the norm. Straw costings from January to August 2018 ranged from £73 to £102/t for the big square baled barley straw (AHDB, 2018b). This year (2018) straw reached a record high at over £10/t, much higher than in recent years (AHDB, 2018c). If straw usage (feed and bedding) was approximated to 319 kg/calf over 14 weeks, like in our current study, at this year's August price of £102/T, straw usage would be £32.54/calf, compared to £22.33 when prices were at £70/T. A difference of £10.21 multiplied by 100 calves as on typical commercial calf rearing beef operations, such a difference in prices would make a substantial difference in net margin.

A minimum of 50 kg live weight at two weeks old is recommended by blade farming based on 10 years of operational data (Forum, 2013). In this study, 53.3 % of the calves collected from this spring calving herd were ≥ 50 kg at 10 (± 3) d of age. From this we can infer that the majority of the calves should reach 50 kg at two weeks old on a typical KW and HF dairy unit. In this current study, there were no differences in pre-weaning and post-weaning daily LW gain, suggesting that calves of 50 kg at two weeks and the smaller Jersey/Kiwi-cross calves should be viable for inclusion in a veal rearing operation. However, the lower LW Jersey/Kiwi-cross calves were on average 14 kg lighter post-weaning, and took 7.4 d longer to reach 120 kg than the JxH and HF. The scale and efficiency of the bull beef rearing operation would therefore determine how these differences would affect net margins.

New Zealand dairy farms, according to statistics from AHDB Dairy 2018, has the best economic cost of production despite receiving a milk price nearly a quarter lower than the average for the group of countries mentioned, due to low input costs (UK, France, Germany, Netherlands, Denmark, US, Ireland, Australia). The lower costs of feed from utilizing pasture all-year-round and dairy breeds like Kiwi crosses that can efficiently utilize that feed are factors in the differences seen. The crossbred dairy cattle, primarily Jersey x Friesian, create additional gain derived from economic heterosis (Buckley et al., 2014). In the UK, from 2016 to 2017, the number of Kiwi cross dairy cattle increased to over 4,000 hd (CHAWG, 2018b). It is likely that farm subsidies will reduce for some farmers post-BREXIT, and therefore cost efficiencies will have to be revised and may include adopting a more NZ style of farming.

In the current study, 10% of the calves were treated with antibiotics over the course of the entire study. Other studies reported higher (Heinrichs et al., 2009; Rosenberger et al., 2017), and lower morbidity rates (Hill et al., 2006b; Quigley et al., 2006; Roth et al., 2009; Bach et al., 2013). In the current study, calves responded well to the high rates of MR, with a low incidence of loose faeces (the mean number of days calves had a faecal score of ≥ 3 was 2.2 d). Loose faeces have been reported when high rates of MR are offered, or due to pathogenic scouring (Hill et al., 2006a). An increase in calf faecal scores was observed during the two cold periods. When calves experienced both diarrhoea and antibiotic treatment, pre-weaning ADG decreased by about 50 g/d (Soberon et al., 2012). Furthermore, labour time increases to treat sick calves, and this is estimated to be between 2 and 10 minutes per calf for animals with pneumonia or scours (Mohd Nor et al., 2012). Labour costs can be hard to estimate due to the variable nature of which these veal/bull beef operations are managed, e.g. as part of a dairy operation or solely a veal/bull beef rearing and finishing system. With increasing incidence of disease, an increase in costs of veterinary bills, labour requirements and a decrease in calf performance should be expected (Andrews, 2000; Mohd Nor et al., 2012).

In the UK in 2016, the number of male calves, not registered, and euthanized on farm were estimated to be around 101,959 (CHAWG, 2018b). This number can be reduced by the increased production of rosé veal, bull beef and the use of sexed semen on dairy farms (Forum, 2013). The biggest factors holding back these production systems are tight profit margins and consumer opinion, on Rosé veal especially. Compounding these issues is the uncertainty for farmer subsidies and the need for improved on-farm efficiency with the upcoming BREXIT. Dairy cross-breeds have been shown to be more profitable in terms of fertility and longevity. Buckley et al. (2014) has addressed the potential inhibitors of growth of crossbred genotypes in countries such as the UK as possibly, a fear of the unknown, or a conservative mindset in breeding cows that has long been familiar to the British countryside. However, in embracing cross-breed types, there is an opportunity to produce viable bull beef calves with high standards of management and nutrition.

In this current study, in contrast to the hypothesis, there was no difference between the HF, JxH and JxL growth rates, overall intakes, feed efficiency and health. There are several factors

to consider for the similar performance of the three groups. Possibly the elevated plane of milk nutrition used in this study was enough to equally support the KW and HF growth rates in the pre-weaning phase, or perhaps the sample size used was not enough to capture more of a performance difference between the breed types. There was significant overlap between the HF and the JxH group and requires further investigation.

Future research should focus on the effects of dairy crossbreed genotypes on higher and lower feeding rates of MR, performance measurements over an extended period of time, i.e. to 8 months, typical rosé veal finishing age, or 15 months for cereal bull beef. Very little work has been undertaken analysing the carcass characteristics of these dairy crossbreds and the associated profit margins, and the performance of rosé veal calves in the UK generally. The Jersey crossbred bull calves are generally the least preferred for beef production, however, with more research undertaken with these breed types, we can build a more accurate picture about their growth profile and optimum feeding regimes for this type of animal, and therefore guidelines for dairy and beef farmers.

10. Conclusion

Jersey/Kiwi crosses, of a higher and lower 10 d live weight, showed no differences in growth rates, overall intakes, feed efficiency and health compared with Holstein/NZ Friesians, although the lower live weight Jersey/Kiwi cross calves took 7 d longer to reach 120 kg LW compared with the Jersey/Kiwi cross calves of a higher live weight and the Holstein/NZ Friesians.

These results show that Jersey-cross bred calves should be considered for veal or beef production, especially when a lower purchase price is available for smaller calves, and calves are closer to 50 kg at 10 d of age.

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