The effect of milk replacer intake and level of crude protein in starter feed on dairy bull calf pre-weaning growth parameters and the carry-over effect on post-weaning growth and profitability

By

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Declaration

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Abstract

Title: The effect of milk replacer intake and level of crude protein in starter feed on dairy bull calf pre-weaning growth parameters and the carry over effect on post-weaning growth fed pasture and profitability.

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Currently worldwide, during the liquid phase, calves are generally fed conventional volumes (4 L/day) of milk replacer (MR) with *ad libitum* starter feed ranging between 160 g CP/kg DM and 210 g CP/kg DM. Dairy bull calves are unwanted in the dairy industry, therefore they are normally sold to feedlots where they are raised as veal or dairy beef. Calves can however consume higher volumes of MR than the conventional volume which can result in greater weight gains. A positive correlation between dietary crude protein (CP) intake and protein deposition in body tissue is also known. Thus, feeding calves higher volumes of MR combined with high CP starter can potentially increase dairy bull calves more profitable.

In practice improved feed efficiency of calves leads to higher profitability. A two part study was therefore conducted with the first phase evolving a pre-weaning MR and CP starter feed phase and a secondary part investigating the effect of pre-weaning treatments on the post-weaning backgrounding phase performance.

In the first part of the study, three different volumes of MR (4, 6 & 9 L/day) and two different CP starter feeds (210 g/kg DM & 260 g/kg DM) were fed to Holstein-Friesian bull calves to evaluate pre-weaning growth parameters. The treatments were (1) 4 L/day of MR, 210 g CP/kg DM starter feed (LL); (2) 6 L/day of MR, 210 g CP/kg DM starter feed (LM); (3) 9 L/day of MR, 210 g CP/kg DM starter feed (LH); (4) 4 L/day of MR, 260 g CP/kg DM starter

feed (HL); (5) 6 L/day of MR, 260 g CP/kg DM starter feed (HM) and (6) 9 L/day of MR, 260 g CP/kg DM starter feed (HH). All calves were weaned after 60 days of age. The MR volume of calves fed the 6 and 9 L/day were stepped down from day 46 to increase the DMI of the starter feed before weaning. Weekly body weights and allometric growth measurements were taken to evaluate body weight growth and allometric growth differences between treatments. Starter feed dry matter intake of the calves fed 4 and 6 L/day of MR were significant greater ($P < 0.05$) than for calves fed 9 L/day. No differences in ADG, growth parameters and gain over the period were observed between MR volume treatments. Average daily gain and gain over period however were significantly different ($P < 0.05$) between the two CP starter feeds. The final weight of the calves did not differ between the starter feeds, but the final weight of calves fed 6 L/day of MR were significantly ($P < 0.05$) higher than from the calves fed 4 L/day MR while the 9 L/day MR group final weight did not differ from any of the other treatments. None of the allometric growth parameters differed between treatments. The feed conversion ratio of the calves did not differ significantly among all six treatments.

During the post-weaning phase of the study, all calves were background for 80 days on *ad libitum* grazing while daily supplemented with the same concentrate feed at 2 kg per calf per day. The objective of the secondary phase was to evaluate the carry-over effects on the post-weaning growth and profitability of Holstein-Friesian steers. After 80 days of backgrounding, the calves were sold to a commercial feedlot. Based on this income, the related profitability per animal per treatment were calculated. No carry-over effects were observed for calves fed higher volumes of MR nor higher CP starter feed during the pre-weaning phase, since the gain over period during the post-weaning phase were not different amongst the treatment groups, except for treatment LL which did not differ significantly from treatments HM and HH. Treatment LL resulted in numerical slower growth both during the pre-weaning and post-weaning period. The latter treatment differed significantly ($P < 0.05$) from treatments LM, HL, HM and HH during the pre-weaning period, however only differed significantly ($P < 0.05$) from treatments LM, LH and HL during the post-weaning period. The total cost of raising the calves differed significantly ($P < 0.05$) for all treatments and this difference was mostly the result of the feed cost during the pre-weaning phase. Treatment HL was numerically, the most cost effective with the highest profit, while calves fed 9 L of MR resulted in the lowest profit. However, the profit of treatment LL and HH were significantly lower ($P < 0.05$) than treatment HL but did not differ significantly from the other treatments.

The lack of response in treatment LL during the pre-weaning period could be attributed to nutritional insult, therefore the lack of response was carried over in the post-weaning period. Feed costs vary from season to season, therefore the total cost of raising can vary over season and between geographical locations. In this trial, however feeding calves the conventional volume of MR with a high CP starter resulted in the most profitable approach to raising dairy beef.

Opsomming

Titel: Die invloed van melkvervangerinname en aanvangspilproteïeninhoud op groeiparameters van suiwelbulkalwers tydens voor-speen en die oordragingsvermoë op na-speen groeiprestasie en winsgewendheid.

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Kalwers tydens die melkfase word huidig wêreldwyd oor die algemeen ‘n konvensionele volume van (4 L/dag) melkvervanger tesaam met *ad libitum* aanvangspille wat wissel tussen 160 g CP/kg DM en 210 g CP/kg DM gevoer. In die suiwelbedryf word bulkalwers as ongewens beskou en daarom word die bulkalwers normaalweg aan voerkrale verkoop waar hulle as kalfs- of suiwelbeesvleis grootgemaak word. Kalwers kan egter hoër volumes melkvervanger as die konvensionele volume inneem wat tot groter massatoename kan lei. ’n Positiewe korrelasie tussen ruproteïeninname en proteïenneerlegging in die liggaamsweefsel is ook bekend. Dus kan die voeding van groter volumes melkvervanger en hoër ruproteïen-aanvangspille moontlik die grootmaak van melkbulkalwers meer winsgewend maak.

In die praktyk, lei verbeterde voerdoeltreffendheid van kalwers tot hoër winsgewendheid. ’n Tweeledige studie is dus uitgevoer met die eerste fase wat ’n voorspeense melkvervanger en ruproteïenaanvangspille fase behels het en ’n tweede fase wat die effek van voorspeense behandelings op die na-speense prestasie vir voorbereiding van die voerkraal ondersoek het.

In die eerste deel van die studie was drie verskillende melkvervanger volumes (4, 6 & 9 L/dag) en twee verskillende ruproteïenvlakaanvangspille (210 g/kg DM & 260 g/kg DM) aan Holstein-Friesian bulkalwers gevoer om die voorspeense groeiparameters te evalueer. Die behandelings was (1) 4 L melkvervanger, 210 g CP/kg DM aanvangspille (LL); (2) 6 L melkvervanger, 210 g CP/kg DM aanvangspille (LM); (3) 9 L melkvervanger, 210 g CP/kg DM

aanvangspille (LH); (4) 4 L melkvervanger, 260 g CP/kg DM aanvangspille (HL); (5) 6 L melkvervanger, 260 g CP/kg DM aanvangspille (HM); (6) 9 L melkvervanger, 260 g CP/kg DM aanvangspille (HH). Al die kalwers is op die ouderdom van 60 dae gespeen. Die melkvervangervolume van kalwers wat 6 en 9 L/dag gevoer is, is vanaf dag 46 verlaag om effektiewe droë materiaal inname (DMI) voor speen te verseker. Die aanvangspilinname was betekenisvol hoër ($P < 0.05$) vir kalwers wat laer volumes melkvervanger ontvang het. Weeklikse liggaamsmassa en liggaamsmates was geneem om die allometriese groeiverskille tussen die behandelings te evalueer. Die aanvangspille DMI van kalwers wat 4 en 6 L/dag gevoer was, was betekenisvol ($P < 0.05$) beter as die van kalwers wat 9 L/dag gevoer was. Daar was geen verskille in gemiddelde daaglikse toename (GDT) en die totale groei oor die tydperk tussen die melkvervangervolumes waargeneem nie. Die gemiddelde daaglikse toename en die totale groei oor die tydperk was egter betekenisvol ($P < 0.05$) verskillend tussen die twee ruproteïenaanvangspille. Die finale massa van die kalwers het nie betekenisvol verskil tussen die aanvangspille nie, maar die finale massa van kalwers wat 6 L/dag melkvervanger ontvang het, het betekenisvol verskil ($P < 0.05$) van die kalwers wat 4 L/dag ontvang het. Terwyl die finale massa van kalwers wat 9 L/dag melkvervanger ontvang het, het nie betekenisvol verskil van die ander behandelings nie. Geen van die allometriese groei parameters het van mekaar verskil nie. Voeromsetvermoë van die kalwers het geen verskille tussen die ses behandelings getoon nie.

Tydens die na-speen tydperk van die studie was alle kalwers voorberei vir ’n voerkraal vir 80 dae op *ad libitum* weiding terwyl 2 kg per kalf per dag van dieselfde kragvoer daagliks aangevul is. Die doel van die tweede fase was om die oordragingsvermoë van die voor speense behandelings op die na-speense groei en winsgewendheid van Holstein-Friesian osse te evalueer. Na die 80 dae se voorbereiding op die weiding, is die kalwers aan ‘n kommersiële voerkraal verkoop. Op grond van hierdie inkomste, is die winsgewendheind per dier per behandeling bereken. Daar is geen oordragingseffek waargeneem vir kalwers wat hoër volumes melkvervanger met ‘n hoë ruproteïenaanvangspille ontvang het nie, aangesien die totale massatoename tydens die na-speen tydperk nie betekenisvol tussen verskillende behandelingsgroepe verskil het nie. Behandeling LL het gelei tot numeriese stadiger groei gedurende die voor-speen- en na-speentydperk. Die laasgenoemde behandeling het wel betekenisvol verskil ($P < 0.05$) van behandelings LM, HL, HM en HH gedurende die voor speentydperk, maar het slegs betekenisvol verskil ($P < 0.05$) van behandelings LM, LH en HL gedurende die na-speentydperk. Die totale koste om kalwers groot te maak het betekenisvol verskil ($P < 0.05$) vir alle behandelings en hierdie verskil en kon aan voerkoste verskille tydens die voor-speentydperk toegeskryf word. Behandeling HL (4 L/dag melkvervanger en 260 g/kg ruproteïenaanvangspille) was numeries, die mees koste-effektiewe met die hoogste wins, terwyl kalwers wat 9 L/dag melkvervanger ontvang het, die laagste wins tot gevolg gehad het.

Die wins van behandelings LL and HH was betekenisvol laer teenoor behandeling HL, maar het nie betekenisvol verskil van die ander behandelings nie.

Die gebrek aan respons van behandeling LL gedurende die voor-speentydperk was as gevolg van ‘n tekort aan nutrientinname, daarom is die gebrek aan respons in die naspeense tydperk oorgedra. Die voerkoste verskil tussen seisoene, daarom kan die totale koste om kalwers groot te maak verander oor seisoene en verskillende geografiese gebiede. In hierdie studie, het die kalwers wat die konvensionele volume (4 L/dag) melkvervanger ontvang het tesame met ‘n hoë ruproteïen kruipvoer (260 g/kg), tot die mees koste-effektiewe manier gelei om suiwelbulkalwers groot te maak.

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ADG:	Average daily gain
Ad lib:	*Ad libitum*
BW:	Body weight
CP:	Crude protein
DM:	Dry matter
DMI:	Dry matter intake
FCR:	Feed conversion ratio
IGF-1:	Insulin-like growth factor
ME:	Metabolizable energy
MJ:	Megajoules
MR:	Milk replacer
NDF:	Neutral detergent fibre
NPN:	Non-protein nitrogen
NRC:	National Research Council
RDP:	Rumen degradable protein
RUP:	Rumen undegradable protein
VFA:	Volatile fatty acids

Note

This thesis is presented as a compilation of 6 chapters. Each chapter is introduced separately and is written according to the style of the South African Journal of Animal Science.

Chapter 1

General Introduction

Generally, dairy bull calves are unwanted in the dairy industry (Beauchemin *et al.*, 1990). These bull calves are however commonly raised to enter the beef value chain as veal. Veal has been popular around the world because the meat has been considered of a high quality due to its tenderness, juiciness, and low-fat concentration. The latter is also generally considered as healthy (Vieira *et al.*, 2005; Brscic *et al.*, 2014). Previously, producers fed veal calves until slaughter weight solely on milk replacers (MR) and without any access to starter feed to produce white veal. However, without starter feed intake the rumen development is severely hampered while the welfare of the calves is also generally poor. To alleviate these negative implications, the use of starter feed during calf rearing is recommended (Suárez *et al.*, 2006; Khan *et al.*, 2007). This is especially true in the South African market, where veal is a very small niche market, and the predominant market is rather aimed at feedlot production (Cruywagen *et al.*, 2000).

In 1991, the Council of the European Union set a minimum daily ration of fibrous feed, but did not include veal for white meat. Thus, bull calves in Europe were fed a significant level of MR compared to starter feed. This feeding strategy led to pale, white meat due to low dietary iron levels (Webb *et al.*, 2012). Due to welfare concerns the Council of the European Union imposed legislation to make it compulsory to provide a minimum daily ration of fibrous feed (at 50-250 g) from 8 to 20 weeks of age while it is currently compulsory to feed fibrous / starter feed to veal calves (European Council Directive 2008/119/ EC, 2008; European Union, 2009; Webb *et al.*, 2012; Brscic *et al.*, 2014). Dairy bull calf production forms a large part of the North American beef industry and feeding strategies are similar to the European strategies. Normally, calves are fed MR until 16 to 20 weeks of age and are slaughtered at a BW around 205 kg (Terosky *et al.*, 1997). As in Europe, welfare considerations are important in North America (Mench, 2008).

For decades, farmers fed calves restricted volumes of MR to save on labour and feed costs. According to Górka *et al.* (2011) and Diao *et al.* (2019), lower MR intake ensures a higher intake of solid feed, thus stimulating rumen development. However, high MR intake can enhance the growth performance (Soberon *et al.*, 2012; Araujo *et al.*, 2014). According to Hu *et al.* (2019), traditional volumes of MR supplied is approximately 8% to 10% of the birth weight. With an increased volume of MR, it was discovered that pre-weaning average daily gain (ADG) increased (Yunta *et al.*, 2015; Hu *et al.*, 2019). Therefore, researchers have gained more interest in feeding dairy calves more MR (Jasper & Weary, 2002; Yunta *et al.*, 2015). Adequate starter intake pre-weaning is required to support continuous growth post-weaning (Hu *et al.*, 2019). High volumes of MR fed to calves, however, often lead to a decrease in starter feed intake which normally results in slower ruminal development. This, typically leads to poor weaning or high weight loss during the weaning period (Bach *et al.*, 2013; Araujo *et al.*, 2014; Silva *et al.*, 2015). An increase in CP (crude protein) concentrations in the starter feed, results in a lesser slump in ADG and body weight (BW) after weaning of the calves (Stamey *et al.*, 2012).

Several studies reported that calves which received higher volumes of MR, and an increased CP concentration in their starter feed, resulted in greater dry matter intake (DMI), ADG, skeletal measurements and better feed efficiency (Brown *et al.*, 2005; Bartlett *et al.*, 2006; Chapman *et al.*, 2017; Kazemi-Bonchenari *et al.*, 2022; Schäff *et al.*, 2018; Hengst *et al.*, 2012; Guindon *et al.*, 2015). These studies demonstrated that the higher volumes of MR and CP concentrations are mandatory to ensure that the protein requirements of the rapidly growing muscles are met (Morrison *et al.*, 2009). By increasing the CP concentration in the starter feed from 160 g/kg DM to 260 g/kg DM and fed daily to the dairy bull calves at 1.5% of their BW (DM basis), results in an increased ADG and deposition of lean tissue (Appleby *et al.*, 2001; Jasper & Weary, 2002; Bartlett *et al.*, 2006; Sweeney *et al.*, 2010; Chapman *et al.*, 2017). Thus, higher concentrations of CP intake allows for body fat content to decrease, while water and protein content of the meat increase (Bartlett *et al.*, 2006). Bartlett *et al.* (2006) reported that the best efficiency in calves was obtained when the CP concentration of the starter feed was 220 g/kg DM and fed daily at 1.75% of their BW (DM basis).

In heifer calves, the higher lean growth was achieved through feeding higher volumes of MR and also an increased in milk yield was observed during the first lactation (Terré *et al.*, 2007; Hu *et al.*, 2019).

Farmers in Europe experienced increased production costs of calves because of an international increase in the price of skim milk powder (Brscic *et al.*, 2014). Farmers were therefore forced to experiment with and developed alternative strategies to feed the calves. These strategies include starter feed which partially replace the MR (Brscic *et al.*, 2014). Another alternative was to increase the protein in the starter feed to help decrease the MR (Brscic *et al.*, 2014).

According to Guindon *et al.* (2015) however, no post-weaning effects on ADG were observed with this rearing strategy (High MR volume and CP). According to the latter authors this lack of “carry-over” effect was offset by difficulty during weaning as significant starter feed reductions were observed. The authors hypothesized that the latter effect can be avoided with a step wise weaning strategy, decreasing the amount of MR gradually over a few days to increase the starter intake before weaning (Guindon *et al.*, 2015).

A study was therefore conducted at the University of Stellenbosch, Department of Animal Sciences to determine the effect of varying volumes of MR and starter feeds with different levels of CP on the growth performance of dairy bull calves during the pre-weaning and post-weaning period.

The objectives of the study were:

1. To evaluate the growth performance and efficiency of pre-weaned Holstein dairy bull calves that receive different volumes of MR (10%, 15% and 22.5% of BW), as well as different CP levels (210 g/kg DM and 260 g/kg DM) in a starter feed.

2. To compare and evaluate the post-weaning growth performance of Holstein dairy bull calves as influenced by the different pre-weaning treatments.
3. To determine the cost to benefit ratio of feeding higher levels of MR and higher CP starter feed.

1.1 References

Appleby, M.C., Weary, D.M., & Chua, B. 2001. Performance and feeding behaviour of calves on ad libitum milk from artificial teats. Appl. Anim. Behav. Sci., 11. https://doi.org/10.1016/S0168-1591(01)00171-X.

Araujo, G., Terré, M., & Bach, A. 2014. Interaction between milk allowance and fat content of the starter feed on performance of Holstein calves. J. Dairy Sci. 97, 6511–6518. https://doi.org/10.3168/jds.2014-8281.

Bach, A., Terré, M., & Pinto, A. 2013. Performance and health responses of dairy calves offered different milk replacer allowances. J. Dairy Sci. 96, 7790–7797. https://doi.org/10.3168/jds.2013-6909.

Bartlett, K.S., McKeith, F.K., VandeHaar, M.J., Dahl, G.E., & Drackley, J.K. 2006. Growth and body composition of dairy calves fed milk replacers containing different amounts of protein at two feeding rates1. J. Anim. Sci. 84, 1454–1467. https://doi.org/10.2527/2006.8461454x.

Beauchemin, K.A., Lachance, B., & St-Laurent, G. 1990. Effects of concentrate diets on performance and carcass characteristics of veal calves. J. Anim. Sci. 68, 35–4410.

Brown, E.G., VandeHaar, M. J., Daniels, K.M., Liesman, J.S., Chapin, L.T., Keisler, D.H., & Nielsen, M.S.W. 2005. Effect of increasing energy and protein intake on body growth and carcass composition of heifer calves. J. Dairy Sci. 88, 585–594. https://doi.org/10.3168/jds.S0022-0302(05)72722-3.

Brscic, M., Prevedello, P., Stefani, A.L., Cozzi, G., & Gottardo, F. 2014. Effects of the provision of solid feeds enriched with protein or nonprotein nitrogen on veal calf growth, welfare, and slaughter performance. J. Dairy Sci. 97, 4649–4657. https://doi.org/10.3168/jds.2013-7618.

Chapman, C.E., Hill, T.M., Elder, D.R., & Erickson, P.S. 2017. Nitrogen utilization, preweaning nutrient digestibility, and growth effects of Holstein dairy calves fed 2 amounts of a moderately high protein or conventional milk replacer. J. Dairy Sci. 100, 279–292. https://doi.org/10.3168/jds.2016-11886.

Cruywagen, C.W., Lategan, E., & Hoffman, L.C. 2000. The effect of dietary protein degradability and rumen inert fat supplementation on calf performance and veal production. South Afr. J. Anim. Sci. 30, 30–31. https://doi.org/10.4314/sajas.v30i4.3896.

Diao, Q., Zhang, R., & Fu, T. 2019. Review of Strategies to Promote Rumen Development in Calves. Animals 9, 490. https://doi.org/10.3390/ani9080490.

European Union. 2009. European Council Directive 2008/119/EC 2008: Laying down minimum standards for the protection of calves (codified version). Off. J. L 010.

Górka, P., Kowalski, Z.M., Pietrzak, P., Kotunia, A., Jagusiak, W., & Zabielski, R. 2011. Is rumen development in newborn calves affected by different liquid feeds and small intestine development? J. Dairy Sci. 94, 3002–3013. https://doi.org/10.3168/jds.2010-3499.

Guindon, N.E., Antaya, N.T., Cabral, R. G., Whitehouse, N.L., Earleywine, T.J., & Erickson, P.S. 2015. Effects of human visitation on calf growth and performance of calves fed different milk replacer feeding levels. J. Dairy Sci. 98, 8952–8961. https://doi.org/10.3168/jds.2015-9759.

Hengst, B.A., Nemec, L.M., Rastani, R.R., & Gressley, T.F. 2012. Effect of conventional and intensified milk replacer feeding programs on performance, vaccination response, and neutrophil mRNA levels of Holstein calves. J. Dairy Sci. 95, 5182–5193. https://doi.org/10.3168/jds.2011-5261.

Hu, W., Hill, T.M., Dennis, T.S., Suarez-Mena, F.X., Quigley, J.D., & Schlotterbeck, R. L. 2019. Intake, nutrient digestibility, and growth performance of Holstein dairy calves consuming a milk replacer at moderate or high feeding rates. J. Dairy Sci. 102, 7917–7926. https://doi.org/10.3168/jds.2019-16282.

Jasper, J., & Weary, D.M. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85, 3054–3058. https://doi.org/10.3168/jds.S0022-0302(02)74391-9.

Jensen, M.B., Duve, L.R., & Weary, D.M. 2015. Pair housing and enhanced milk allowance increase play behavior and improve performance in dairy calves. J. Dairy Sci. 98, 2568–2575. https://doi.org/10.3168/jds.2014-8272.

Kazemi-Bonchenari, M., Khanaki, H., Jafari, A., Eghbali, M., Poorhamdollah, M., & Ghaffari, M. H. 2022. Milk feeding level and starter protein content: Effects on growth performance, blood metabolites, and urinary purine derivatives of Holstein dairy calves. J. Dairy Sci., S0022030221011097. https://doi.org/10.3168/jds.2021-21208.

Khan, M.A., Lee, H.J., Lee, W.S., Kim, H.S., Kim, S.B., Ki, K.S., Park, S.J., Ha, J.K., & Choi, Y.J. 2007. Starch source evaluation in calf starter: I. Feed consumption, body weight gain, structural growth, and blood metabolites in Holstein Calves. J. Dairy Sci. 90, 5259–5268. https://doi.org/10.3168/jds.2007-0338.

Mench, J.A. 2008. Farm animal welfare in the U.S.A.: Farming practices, research, education, regulation, and assurance programs. Appl. Anim. Behav. Sci. 113, 298–312. https://doi.org/10.1016/j.applanim.2008.01.009.

Morrison, S.J., Wicks, H. C. F., Fallon, R. J., Twigge, J., Dawson, L. E. R., Wylie, A. R. G., & Carson, A. F. 2009. Effects of feeding level and protein content of milk replacer on the performance of dairy herd replacements. animal 3, 1570–1579. https://doi.org/10.1017/S1751731109990437.

Schäff, C.T., Gruse, J., Maciej, J., Pfuhl, R., Zitnan, R., Rajsky, M., & Hammon, H. M. 2018. Effects of feeding unlimited amounts of milk replacer for the first 5 weeks of age on rumen and small intestinal growth and development in dairy calves. J. Dairy Sci. 101, 783–793. https://doi.org/10.3168/jds.2017-13247.

Silva, A.L., Marcondes, M.I., Detmann, E., Machado, F.S., Valadares Filho, S.C., Trece, A.S., & Dijkstra, J. 2015. Effects of raw milk and starter feed on intake and body composition of Holstein × Gyr male calves up to 64 days of age. J. Dairy Sci. 98, 2641–2649. https://doi.org/10.3168/jds.2014-8833.

Soberon, F., Raffrenato, E., Everett, R.W., & Van Amburgh, M.E. 2012. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. J. Dairy Sci. 95, 783–793. https://doi.org/10.3168/jds.2011-4391.

Stamey, J.A., Janovick, N.A., Kertz, A.F., & Drackley, J.K. 2012. Influence of starter protein content on growth of dairy calves in an enhanced early nutrition program. J. Dairy Sci. 95, 3327–3336. https://doi.org/10.3168/jds.2011-5107.

Suárez, B.J., Van Reenen, C.G., Beldman, G., van Delen, J., Dijkstra, J., & Gerrits, W.J.J. 2006. Effects of supplementing concentrates differing in carbohydrate composition in veal calf diets: I. Animal performance and rumen fermentation characteristics. J. Dairy Sci. 89, 4365–4375. https://doi.org/10.3168/jds.S0022-0302(06)72483-3.

Sweeney, B.C., Rushen, J., Weary, D.M., & de Passillé, A.M. 2010. Duration of weaning, starter intake, and weight gain of dairy calves fed large amounts of milk. J. Dairy Sci. 93, 148–152. https://doi.org/10.3168/jds.2009-2427.

Terosky, T.L., Wilson, L.L., Stull, C.L., & Stricklin, W.R. 1997. Effects of individual housing design and size on special-fed Holstein veal calf growth performance, hematology, and carcass characteristics. J. Anim. Sci. 75, 1697. https://doi.org/10.2527/1997.7571697x.

Terré, M., Devant, M., & Bach, A. 2007. Effect of level of milk replacer fed to Holstein calves on performance during the preweaning period and starter digestibility at weaning. Livest. Sci. 110, 82–88. https://doi.org/10.1016/j.livsci.2006.10.001.

Vieira, C., García, M. D., Cerdeño, A., & Mantecón, A.R. 2005. Effect of diet composition and slaughter weight on animal performance, carcass and meat quality, and fatty acid composition in veal calves. Livest. Prod. Sci. 93, 263–275. https://doi.org/10.1016/j.livprodsci.2004.11.020.

Webb, L.E., Bokkers, E.A.M., Engel, B., Gerrits, W.J.J., Berends, H., & van Reenen, C.G. 2012. Behaviour and welfare of veal calves fed different amounts of solid feed supplemented to a milk replacer ration adjusted for similar growth. Appl. Anim. Behav. Sci. 136, 108–116. https://doi.org/10.1016/j.applanim.2011.12.004.

Wilson, L.L., Egan, C.L., & Terosky, T.L. 1997. Body measurements and body weights of special-fed Holstein veal calves. J. Dairy Sci. 80, 3077–3082. https://doi.org/10.3168/jds.S0022-0302(97)76277-5.

Yunta, C., Terré, M., & Bach, A. 2015. Short- and medium-term changes in performance and metabolism of dairy calves offered different amounts of milk replacers. Livest. Sci. 181, 249–255. https://doi.org/10.1016/j.livsci.2015.09.008.

Chapter 2

Literature Review

2.1 Introduction

Globally more than half of the meat and milk consumed by people are supplied by ruminant species including sheep, goats, camels, buffalo and cattle (Genzebu & Tesfay, 2015). This chapter provides an overview of rumen development, protein metabolism and requirements of dairy calves. The influence of milk replacers (MR), as well as growth performance on different crude protein (CP) levels of starter feed are discussed in this chapter.

2.2 Physiological Development

2.2.1 Digestive system of the ruminant

New born calves are born with underdeveloped rumens (Khan *et al.*, 2011). To properly develop, the rumen needs to be stimulated through roughage and starter feed intake (Suárez *et al.*, 2006). Their digestive system therefore function both metabolically and physically as a monogastric animal (Suárez *et al.*, 2006; Mirzaei *et al.*, 2015).

The four compartments of the ruminant stomach consist of the rumen, reticulum, omasum, and abomasum (Van Soest, 1994). The digestion of milk replacer or whole milk in new-born calves mainly takes place in the abomasum and small intestine (Gorka *et al.*, 2009). The abomasum and small intestine is larger than the forestomach in the first few weeks of life (Gorka *et al.*, 2009).

In young ruminants, MR or whole milk is prevented from flowing into the rumen by the closure of the oesophageal groove (Gilbert, 2015). The oesophageal groove is muscular folds in the reticulorumen and the reflex contraction of these muscles results in a groove (Jones & Heinrichs, 2020). The oesophageal groove closes when the reflex is triggered and the MR or whole milk then bypasses the rumen and flows into the abomasum (McDonald *et al.*, 2011; Gilbert, 2015). In the abomasum and duodenum, MR or whole milk is enzymatically hydrolysed and absorbed in the small intestine (Gilbert, 2015). Figure **2.1** is a schematic presentation, indicating how the oesophageal groove closes when the calf consumes MR and how it bypasses the rumen and flows towards the abomasum.

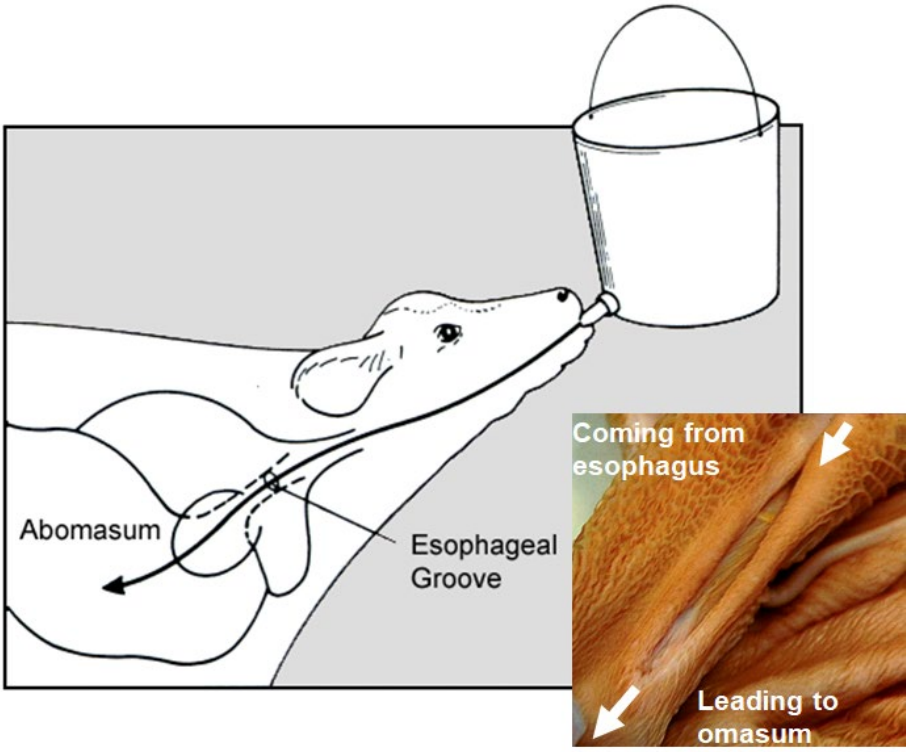

Figure 2.1 Demonstration of how the oesophageal groove functions when the calf consumes milk replacer (Jones & Heinrichs, 2020).

At birth the size of the rumen for a new-born calf is approximately 25% of the total stomach capacity changing to 80-85% at maturity (McDonald *et al.*, 2011; Jones & Heinrichs, 2020). The size of the abomasum is about 60% of the total stomach capacity when the calf is born. When mature, the abomasum is about 7-8% of the total stomach capacity (Jones & Heinrichs, 2020). This indicates how starter feed stimulates rumen development. In Figure **2.2.**, the relative sizes of the four compartments are shown from birth until maturity.

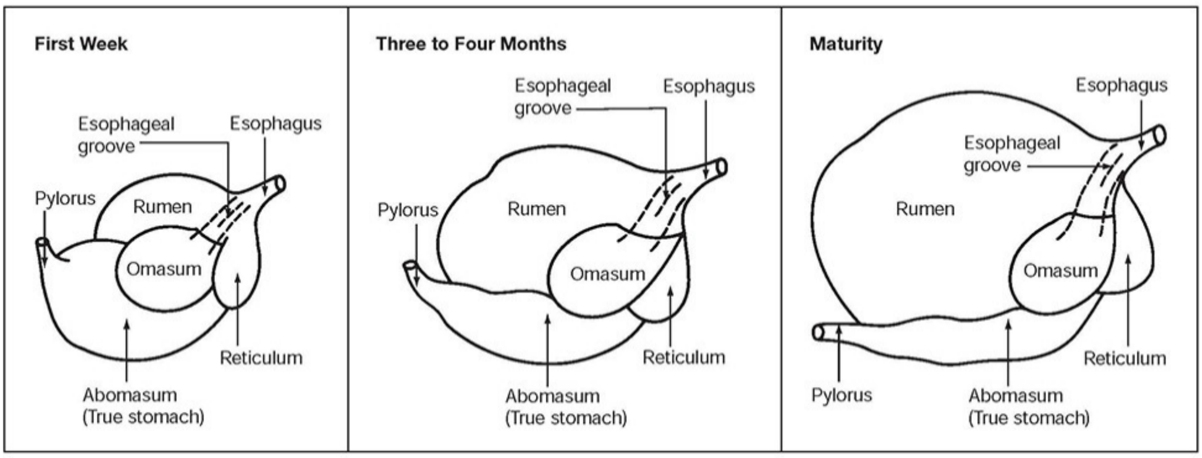

Figure 2.2 The relative sizes of the four compartments in calves from birth to maturity (Jones & Heinrichs, 2020).

2.2.2 Rumen epithelium and papillae development

In the rumen, the epithelium plays an important role in the development of physiological functions including absorption, transportation, short-chain fatty acid metabolism and protection (Baldwin *et al.*, 2004; Diao *et al.*, 2019).

Papillae are small finger-like projections found on the rumen epithelium (McDonald *et al.*, 2011). The main importance of papillae in the rumen is increased surface area, allowing improved absorption of nutrients. According to Tamate *et al.* (1962), development of papillae is linked to a greater extent to energy supply rather than age. It is therefore generally accepted that carbohydrate fermentation in the rumen plays the most important role to facilitate ruminal papillae development (Laarman & Oba, 2011).

High concentrations of volatile fatty acids (VFA) are produced in the rumen when starter feed and forages are fermented (Suárez *et al.*, 2006; Kristensen *et al.*, 2007; Laarman & Oba, 2011). These VFA, especially butyrate, stimulates rumen development, especially the development of papillae (Suárez *et al.*, 2006; Mirzaei *et al.*, 2015). When calves are fed starter feed, the rumen becomes functional within 2-3 weeks (Terré *et al.*, 2007). Papillae length and width are stimulated by the growth of the epithelium cells (Diao *et al.*, 2019). The papillae of new-born calves are normally less than 1mm in height (Huber, 1969). With increased intake of starter feed, the papillae increases in height to a length of between 5 – 7mm (Huber, 1969).

Calves that only receive MR or whole milk exhibit limited ruminal development and is characterized by relative lower rumen weight, capacity, papillary growth, degree of keratinization, pigmentation and musculature development (Baldwin *et al.*, 2004; Diao *et al.*, 2019). In contrast, suckling calves fed a diet of MR or whole milk combined with a starter feed, indicated the ruminal papillae are well developed with a thicker rumen wall. When MR or whole milk and hay are however fed, the papillae are underdeveloped and the rumen wall are thin (Baldwin *et al.*, 2004; Diao *et al.*, 2019; Jones & Heinrichs, 2020). The latter can be explained by higher acetic acid and less butyric acid production (Jones & Heinrichs, 2020). As acetic acid is not utilized as a primary energy source by the rumen wall, it does not stimulate the development of the rumen epithelium and papillae to the same extent as butyrate and propionate (Jones & Heinrichs, 2020). Figure **2.3** indicates how these three different diets influenced the development of the rumen and papillae.

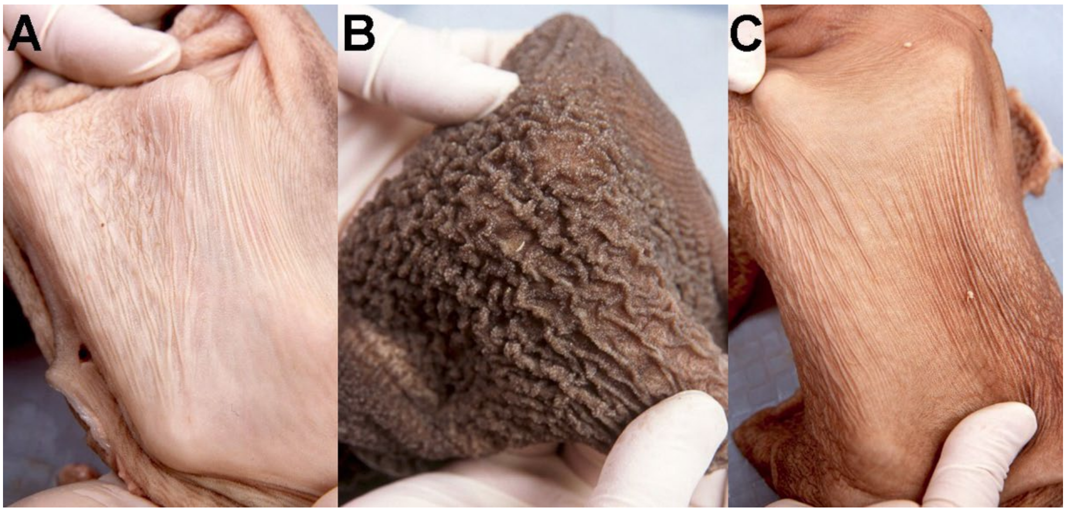

Figure 2.3 Papillae development at 6 weeks (A) when calves only received MR or whole milk, (B) when MR or whole milk and starter feed was fed and (C) when MR or whole milk and hay was fed (Jones & Heinrichs, 2020).

2.3 Metabolic development

2.3.1 Energy

The energy reserves in new-born calves are low and therefore energy has to be provided to the calves through MR or whole milk (Schrama *et al.*, 1995; Jones & Heinrichs, 2020). Metabolic changes take place during the first few weeks of the life of the calf and the secretion and biological activity of enzymes change during this period improving the capacity to digest MR or whole milk (Schrama *et al.*, 1995; Jones & Heinrichs, 2020). In the commercial sector, often calves are transported to separate facilities to be reared. The transportation is often accompanied with periods during which feeding is delayed, adding stress to the calves (Damtew *et al.*, 2018). The stress also causes the calves to consume less MR or whole milk depleting their energy reserves even further (Schrama *et al.*, 1995). Energy in calves is important to maintain and support the body functions as well as to provide the energy needed to utilize proteins to build muscle and body tissue. During the first two weeks of life, the metabolic rate of the calf is extremely high, therefore calves need to consume sufficient amounts of energy (Jones & Heinrichs, 2020).

2.3.2 Strategies promoting rumen development

Specific factors promote the metabolic function of calves to stimulate rumen development. Higher volumes of MR or whole milk (more than 4 L/day) may decrease the plasma concentration of hormones and growth factors, i.e., insulin and insulin-like growth factor 1 (IGF-1). This hormone and growth factor promotes the stimulation of the rumen epithelium (Zitnan *et al.*, 2012; Diao *et al.*, 2019). However, when calves consume starter feed with a lower volume of MR or whole milk, the concentrations of these hormones and growth factors increases (Diao e*t al.,*2019). When MR or whole milk is fed to calves without starter feed, the development of then rumen would be limited. As the calf ages, no rumen function would take place, even if the size of the rumen increase. Thus, starter feed is necessary for the development of the rumen (Govil *et al.*, 2017). The intake of calf starter feed prior weaning is necessary for successfully weaning without experiencing weaning shock (Govil *et al.*, 2017). The rumen microbiome needs water for the microbes to grow, otherwise rumen development slows down. Starter feeds with higher CP concentrations causes greater water intake of calves which can help with rumen development (Govil *et al.*, 2017).

2.4 Protein metabolism and requirements

The protein in ruminant diets can be divided in two classes namely rumen degradable (RDP) and rumen undegradable proteins (RUP) (Van der Merwe & Smith, 1991). Rumen degradable protein is broken down in the rumen by microbes and used as energy source and building blocks by the microbes in the rumen (Van der Merwe & Smith, 1991). Rumen undegradable protein is the protein fraction that is not degraded in the rumen and is digested and absorbed in the abomasum and small intestine (Guliński *et al.*, 2016). A study done by Boorboor *et al.* (2020) indicated that a starter feed with a CP concentration of 160 g/kg DM consisting out of a RDP concentration of 95 g/kg DM and a RUP concentration of 65 g/kg DM does not negatively affect the feed intake and growth performance of calves. The latter study indicated that the lower CP concentration starter feed which contained heat-treated soybean meal (HSBM) and a MR or whole milk volume which is not restricted to calves could increase the performance of calves during the pre- and post-weaning period. When soybean meal was partially replaced by xylose-treated soybean meal, the feed conversion ratio (FCR) of calves improved (Kazemi-Bonchenari *et al.*, 2015). Thus, including RUP in the starter feeds of pre-weaning calves can be beneficial to farmers by increasing the growth performance.

2.4.1 Metabolism

The rumen microbiome forms part of the digestion and hydrolysation of protein to peptides and amino acids. Some amino acids are further digested to organic acids, ammonia and carbon dioxide after hydrolysation occurs (McDonald *et al.*, 2011). Some of the proteolytic micro-organisms that are involved in the digestion of proteins include *Prevotella ruminicola, Peptostreptococci* species, as well as protozoa (McDonald *et al.*, 2011). The results of a study done by Dias et al., (2017) indicated that archaeal, bacterial and fungal communities (in mature rumens) were found in the rumens of calves at an age of 7 days, irrespective if they received MR or whole milk with or without a starter feed.

Figure **2.4** illustrates the digestion and metabolism of proteins in ruminants from consumption until absorbed in the blood. Dietary protein ingested by calves is degraded by the rumen micro-organisms to amino acids. The amino acids are further broken down into ammonia and branched chain fatty acids (Guliński *et al.*, 2016). Thereafter the ammonia produced in the rumen, as well as the other amino acids and peptides are utilised by the micro-organisms to produce microbial protein (McDonald *et al.*, 2011; Guliński *et al.*, 2016). Small amounts of the microbial protein are degraded and nitrogen is recycled in the rumen, however most of the micro-organisms are digested in the abomasum and absorbed in the small intestine (McDonald *et al.*, 2011; Genzebu & Tesfay, 2015). The nutrient availability and efficiency plays a role in the total amount of microbial protein available for digestion in the small intestine of the ruminant (Genzebu & Tesfay, 2015).

The protein and non-protein nitrogen (NPN) degraded in the rumen and excess amino acids catabolized in the liver can lead to an excess ammonia (Munyaneza *et al.*, 2017). Under these conditions, the excess ammonia are absorbed into the portal system, transported to the liver where it is converted to urea (McDonald *et al.*, 2011; Genzebu & Tesfay, 2015; Guliński *et al.*, 2016). The excess urea is then recycled via saliva and/or excreted in the urine (McDonald *et al.*, 2011). Relatively low dietary protein intakes lead to lower levels of ammonia in the rumen fluid. If this happens nitrogen in the form of urea that would otherwise be excreted in the urine is diverted from the portal system and recycled back to the rumen via saliva (McDonald *et al.*, 2011; Guliński *et al.*, 2016). This recycled urea can then be converted back into ammonia by the rumen micro-organisms where it is utilised for microbial protein synthesis, increasing the flow of microbial protein to the abomasum and small intestine (McDonald *et al.*, 2011; Genzebu & Tesfay, 2015).

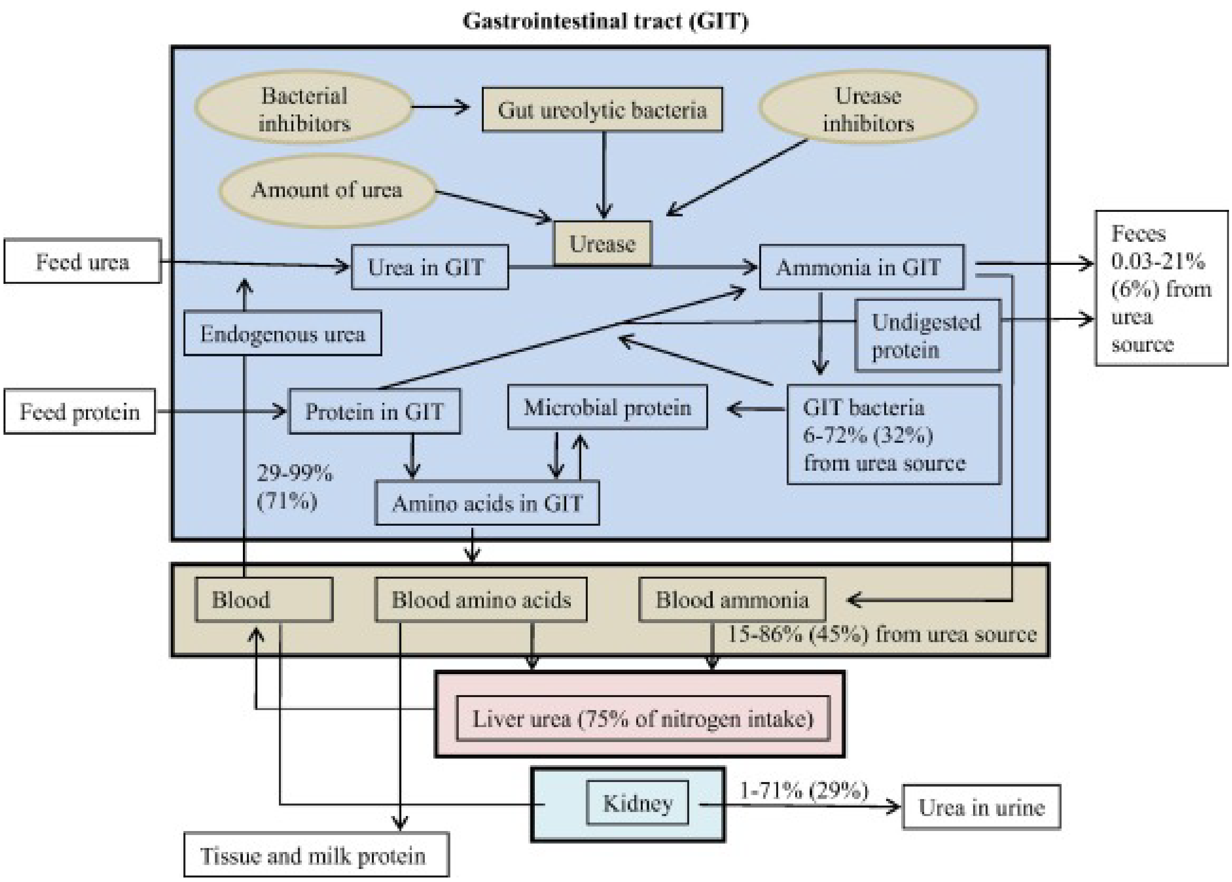

Figure 2.4 Digestion and metabolism of protein in ruminants (Patra & Aschenbach, 2018).

2.4.2 Requirements

Ruminants have different protein requirements as they grow, as well as when they are older (NASEM, 2021). Protein requirements are dependent on physiological changes as the animals grow (Ørskov, 1992). Calves in intensive systems are weaned early from MR or whole milk. According to Ørskov (1992), protein requirements of the calves are highest when weaning takes place. Holtshausen *et al.* (2000) however also highlights that dietary protein requirement is a combination of the rumen microbiome requirements, as well as the calf itself.

2.4.2.1 Protein maintenance requirements

According to Jones & Heinrichs (2020), the protein maintenance requirements depend on the physical size of the animal. According to Van Amburgh *et al.* (2005), the maintenance protein requirements for a pre-weaned calf with a weight of 50 kg and an ADG of 450 g is about 30 g CP per day. This maintenance protein requirement increases when the calf receives a higher amount of dry feed, because the endogenous and metabolic faecal losses also increases (Van Amburgh *et al.*, 2005).

Recent studies examined how management and nutritional improvement has positively affected future productivity of calves, with emphasis on CP concentrations in MR. These studies indicated CP concentrations of 190 to 280 g/kg DM are suitable for optimal growth performance of calves (Hill *et al.*, 2008; Chapman *et al.*, 2017; Jaeger *et al.*, 2020; Schubert *et al.*, 2022).

A study by Hill *et al.* (2013) on pre-weaning calves fed MR and starter feed at 2 different rates, indicated that the metabolizable energy (ME) intakes yielded optimal protein to energy ratios of 218 g of CP/MJ of ME (low ME intake) and 230 g of CP/MJ of ME (high ME intake). The latter study also showed a higher level of CP (more than 220 g CP/kg DM) should be fed with a volume higher than the conventional rate of 450 g of DM of MR daily (Hill *et al.*, 2013).

2.4.2.2 Protein growth requirements

Growth can be defined as an increase in tissue weight (Owens *et al.*, 1993). The growth rate of an animal increases from birth to puberty whereafter the growth rate decreases around 4 years, as an animal starts maturity. The growth curve of calves show, similar to most mammals, a sigmoid curve, having a prepubertal accelerating phase and a post-pubertal decelerating phase (Owens *et al.*, 1993; McDonald *et al.*, 2011). Figure **2.5** show this growth curve of animals that are grown under intensive circumstances. The size and weight of the animal increases over time as development takes place and is referred to as allometric growth. Different organs, tissues and anatomical components however have different growth rates. As an example: when a calf is born, its birthweight is approximately 40 kg. At birth the head of the calf is relatively big and weighs approximately 6.2% of the total body weight (BW). When the calf reaches 100 kg, the head relative to the total BW is approximately 4.2%. These relative ratios further decline as the animal reaches maturity (McDonald *et al.*, 2011).

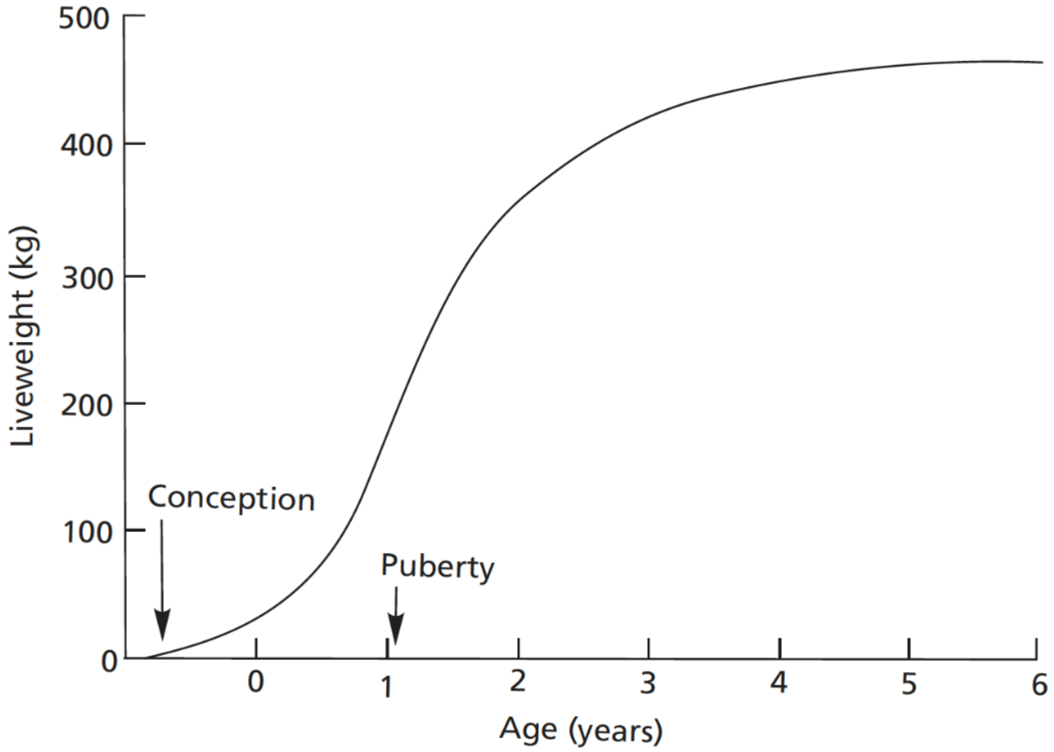

Figure 2.5 The sigmoidal growth curve of animals (McDonald *et al.,* 2011).

When the animal grows, the neural tissue and bone have priority over available nutrients, then the muscles and later the adipose tissue (Owens *et al.*, 1993). Fast-growing animals deposit fat, while muscle growth is still in progress (McDonald *et al.*, 2011). The nutrient requirement of an animal is determined by its growth pattern and any change in nutrient supply therefor affects the pattern of the growth curve (NASEM, 2021). When early maturing calves receive high energy diets, they deposit muscle tissue faster and this can reduce the time to slaughter (Owens *et al.*, 1993). When calves are fed a restricted energy or protein diet, a reduction in mature size is normally expected (Brown *et al.,* 2005). Inadequate nutrient supply can lead to limited protein deposition in animals (NASEM, 2021). If a well-balanced diet is however fed to calves, the maximum rate of protein deposition seems be limited by the growth-stimulating hormones (Owens *et al.*, 1993).

Figure **2.6** depicts the relative body composition of cattle with the weight of each body composition plotted against the empty BW (liveweight of the animals without the gut and bladder). Figure **2.6** also indicate at what stage the protein, fat, and energy increase in the body as the empty BW of the animal increases. It is clear from Figure **2.6** that the rate at which the different components increase differs with protein deposited that occurs at a slower rate in comparison with fat and energy (McDonald *et al.*, 2011).

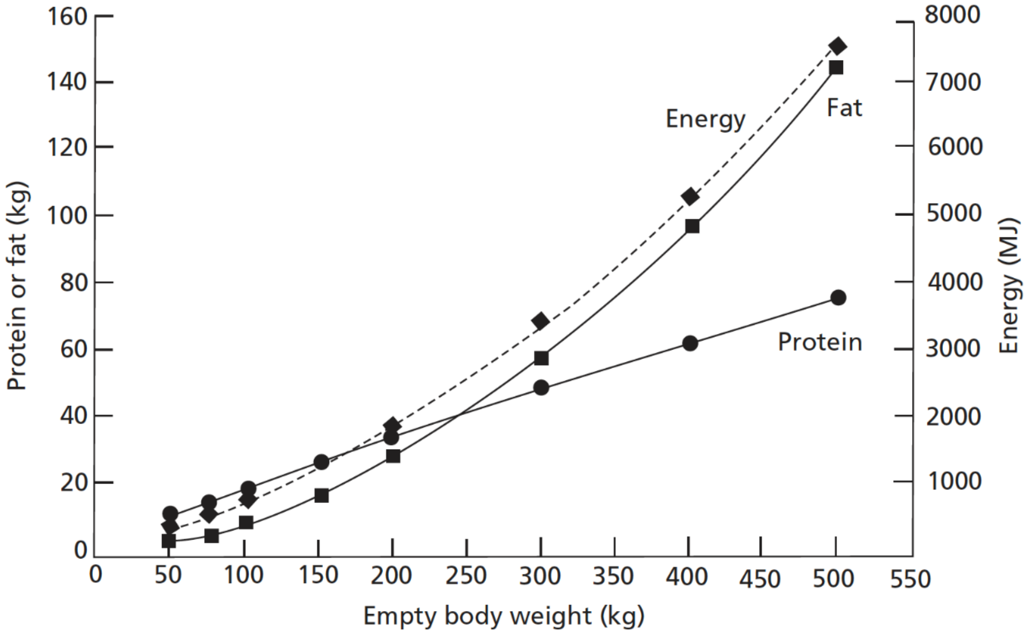

Figure 2.6 The growth of energy, fat and protein in ruminants i.e., cattle (McDonald *et al.,* 2011).

The protein requirements for growth are a function of the energy allowable gain (Van Amburgh & Drackley, 2005). According to Amburgh & Drackley (2005) the composition of protein gain is 30 g N/kg. The protein concentration of the fat free empty bodyweight is relatively stable, with the minimal variation being explained by the dilution of fat gain (Van Amburgh & Drackley, 2005).

Donnelly & Hutton (1976a) reported a protein requirement of 0,166 kg and 0,236 kg digestible protein per day if the ADG was 0,6 kg and 0,8 kg respectively. According to the latter authors the ADG increased when the dietary protein concentration was increased from 200 g/kg to 260 g/kg DM.

Protein requirements for young calves are normally limiting. According to the National Research Council (NRC), the protein requirement for calves is 180 g/kg DM in calf starters (NRC, 2001). In contrast, it was also reported that a high energy starter with a CP concentration of 119 g/kg DM fed to calves, caused the calves to grow equally as well as when starters that contain 147 g CP/kg DM and 169 g CP/kg DM were fed to calves (Morrill & Melton, 1973). Early work of Morrill & Melton (1973), however confirms that calves fed a CP concentration of 210 g/kg DM showed faster growth compared to calves which received only 160 g CP/kg DM. Holstein-Friesian calves which received 149 g CP/kg DM had a faster growth rate compared to when calves received 125 g CP/kg DM and 179 g CP/kg DM (Morrill & Melton, 1973). The latter authors further indicated the best feed efficiency was obtained between week 1 to 12 with a CP concentration of 135 g/kg DM in the starter feed. Bartley (1973) reported better ADG in calves fed a diet containing 220 g CP/kg DM than calves on a diet containing 180 g CP/kg DM. The feed intake of the calves between the groups did not show any significant differences (Bartley, 1973).

According to Jacobson (1969), calves of large dairy breeds should gain weight at a rate of 1 to 1.4 kg per day from birth to 8 weeks of age. It was also seen that calves receiving MR with 250 g CP/kg DM deposited more muscle and less fat tissue in comparison to calves that received a MR with 200 g CP/kg DM (Jacobson, 1969). The protein to energy ratio, as well as the total amount of energy and protein are affected by the rate of gain, age, body size and the composition of the diet. (Jacobson, 1969).

2.5 Protein concentration and growth performance

The aim of veal production is normally to maximize the lean tissue growth (Labussiere *et al.*, 2008). Protein and fat deposition is affected by the CP concentration in the MR or starter feed in the growing phase of calves. In the post-weaning finishing phase in contrast, CP did not have any effect on protein tissue deposition. As the calves grew older, nitrogen utilization results in a low marginal efficiency (Labussiere *et al.*, 2008).

As previously mentioned, the NRC indicate 180 g CP/kg DM as sufficient in calf starter feeds (NRC, 2001), but Bartlett *et al.* (2006) reported more rapid and more efficient growth when a starter feed with a concentration of 220 g CP/kg DM were supplied to calves. Figure **2.7** indicate the relationship between CP intake and CP deposited in the body. Work of Diaz *et al.* (2001) on 3 different levels of MR intake indicate that higher CP intake leads to higher ADG in Holstein calves.

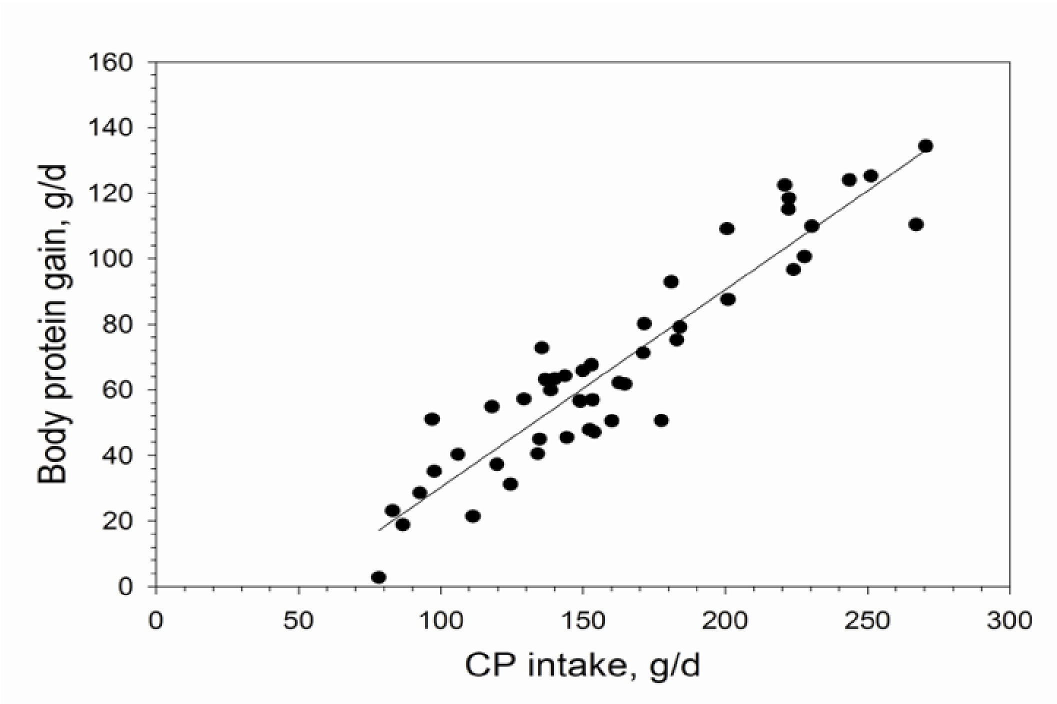

Figure 2.7 Crude protein intake versus protein deposition in the body (Bartlett *et al.,* 2006).

Daneshvar *et al.* (2017) however showed that a CP of 200 g/kg DM and 240 g/kg DM in the starter feed did not have any significant impact on the performance of calves. Several studies indicate a CP concentration higher than 200 g/kg did not lead to better performances and that 190 g/kg CP in starter feed is optimal for maximum performance (Labussiere *et al.*, 2008; Stamey *et al.*, 2012; Daneshvar *et al.*, 2017).

Bartlett *et al*. (2006) reported that the fat concentration of empty body gain decreases and the water and protein concentration increase when the CP concentration of the diet of calves were increased. Calves fed a daily MR diet of 1.75% of BW as DM showed an increase in efficiency of CP utilisation and a better ADG than a MR diet of 1,25% DM of BW (14% and 10% BW as fed) (Bartlett *et al*., 2006). These parameters were not affected by the CP concentration. The study also reports that the ratio of protein gain to apparent digestible protein intake exceeded maintenance requirements, which decreases as CP concentration increases (Bartlett *et al*., 2006). Bartlett *et al*. (2006) suggested that the feeding rate and CP concentration for gains of water and protein for calves, receiving 260 g/kg CP at 1.25% of BW daily indicate that the ME supplied, limited the protein use. The protein to energy ratio in MR can be manipulated to transform the body composition of pre-ruminant calves (Bartlett *et al*., 2006). The energy to protein ration can also be manipulated in the starter feeds rather than in the MR (Rauba *et al*., 2019).

Studies done by Stobo *et al*. (1967) and Drackley (2008) recommended that calves that are fed 4 L of MR/day should receive 200 g CP/kg DM to 220 g CP/kg DM in the starter feed to maximize lean tissue growth. Calves receiving higher than 4 L/day of MR should receive 260 g CP/kg DM to 280 g CP/kg DM in the starter feed to increase the growth rates (Drackley, 2008). According to the latter author, the fat concentration in the starter feed can also be increased. This increased fat concentration can however reduce intake (Drackley, 2008).

More intensified calf feeding programs are however also used where the MR contain an increased CP concentration and lower fat concentration (Hengst *et al*., 2012). Hill *et al.* (2006) used different CP concentrations and fat concentrations in MR supplied to calves. The results indicated that a concentration of 280 g CP/kg DM MR, increased the ADG by 55% when compared with MR containing 200 g/kg CP, but the medical treatments for scouring was higher. The 280 g CP/kg DM MR treatment resulted in lower starter feed intake in comparison to the 200 g CP/kg DM MR. Calves fed the latter diet, resulted in higher ADG and starter intake (Hill *et al*., 2006).

In another study done by Hill *et al.* (2007) fed MR containing 200 g CP/kg DM, 260 g CP/kg DM and 280 g CP/kg DM respectively to calves. The results of the latter study with the 260 g CP/kg DM and 280 g CP/kg DM MR showed an increase in ADG, but a reduced starter intake compared to the 200 g CP/kg DM MR. Calves that received 260 g CP/kg DM at 0.681 kg/day maintained their starter feed intake with an increase in ADG (Hill *et al*., 2007). These results indicate that 260 g CP/kg DM fed at 0.681 kg/day are the maximum amount that calves can receive to reduce the weaning and post-weaning reduction in performance (Hill *et al*., 2007). Jaeger *et al*. (2020) also used an intensive feeding program however, no significant difference for ADG were seen between the MR volumes and the CP concentrations. An interaction between CP and feeding rate for calves receiving a MR with 200 g CP/kg DM at a feeding rate of 0.68 kg/day was observed from day 43 to 56 where the calves showed better feed conversions. This, improved FCR suggests a carry-over effect on the post-weaning performance (Jaeger *et al*., 2020).

2.6 Milk replacers and feeding level

It is well documented that feeding level can play a role in the growth rates of calves (Donnelly & Hutton, 1976b; Gerrits *et al.*, 1996; Labussiere *et al.*, 2009). Conventional calf feeding programs usually limits the volume of MR (Jafari *et al.*, 2021). In a study by Davis & Drackley (1998), the MR volume was limited to a rate of 10% to 15% BW per day throughout weaning. The latter authors suggest MR with a CP concentration between 180 g/kg and 240 g/kg. During the first 2 to 3 weeks after birth, the calf's digestibility of MR of whole milk are high and thereafter increases until weaning (Radostits & Bell, 1970; Schrama *et al.*, 1995; Guilloteau *et al.*, 2009; Quigley *et al.*, 2017). Liang *et al.* (2016) also concluded that calves in the first week of life can digest the MR adequately.

Orellana Rivas *et al.* (2019) used four different MRs to evaluate the performance and metabolism of dairy calves. The control treatment contained 0.55 kg DM per day with a CP of 200 g/kg DM and a fat concentration of 200 g/kg DM. The second MR contained 0.66 kg DM with a CP of 260 g/kg DM and a fat concentration of 170 g/kg DM The third MR contained 0.77 kg DM with a CP of 260 g/kg DM and a fat concentration of 170 g/kg DM while the final MR contained 0.87 kg DM of 260 g CP/kg DM and 170 g/kg DM fat (Orellana Rivas *et al.*, 2019). Milk replacer was fed in equal amounts where actual milk intake was calculated by subtracting the milk refused from the total offered. Calves that were fed the second and third MR consumed the same volume of while both of these groups consumed higher volumes of MR than the calves on the control MR diet (Orellana Rivas *et al.*, 2019). This meant that the BW of the calves reared on the intermediate and high MR were heavier at the end of the trial than the calves reared on the control MR (Orellana Rivas *et al.*, 2019).

It is well documented in literature that calves reared under intensive systems, are offered higher volumes of MR (Jasper & Weary, 2002; Vieira *et al.*, 2008; Borderas *et al.*, 2009). The intensified feeding system make use of higher volumes of MR, as well as a higher CP concentration (De Paula *et al.*, 2017; Jaeger *et al.*, 2020). Bar-Peled *et al.* (1997), Jasper & Weary (2002) and Hill *et al.* (2006) however reported that calves fed high volumes of MR and starter feed experienced a weaning and post-weaning ADG slump. All the latter authors attributed this to a reduced starter feed intake contributing to the weaning shock. It can therefore be concluded that the development and function of the rumen was slower and digestion of starter feed was also slower (Terré *et al.*, 2007). A study by Hill *et al.* (2006) showed that a MR consisting of 270 g CP/kg DM and 170 g/kg DM fat fed at a rate of 0.66 kg of DM/day was effective in improving the ADG and maintained starter feed intake. The latter feeding program did not maximize ADG during the first month of life when compared with the second and third months of the calf's life (Hill *et al.*, 2007). A step-down weaning program strategy can however overcome this post-weaning slump. With this strategy the amount of MR is reduced a couple of days before weaning, forcing the calves to consume higher volumes of starter feed (Khan *et al.*, 2007).

A conventional volume of MR of 10% of BW was compared to *ad lib* MR feeding or 12 L of whole milk by Jasper & Weary (2002) and Borderas *et al.* (2009). The results of these studies indicate calves which receive *ad lib* MR, consumed 89% more MR than the calves which receive the conventional volume. These researchers reported a reduced starter feed intake for the *ad* lib and 12 L whole milk treatment compared to the conventional volume MR. In this study, all calves were gradually weaned, whereafter the starter feed intake rapidly increased resulting in decreased differences between the treatments (Jasper & Weary, 2002). The pre-weaning weight of the calves receiving *ad lib* MR was 63% higher than the weight of the calves receiving the conventional volume of MR (Jasper & Weary, 2002). Borderas *et al*. (2009) indicated the ADG of calves fed 12 L of whole milk was significantly higher than the calves fed 4 L of whole milk for the first 4 weeks however, no treatment differences between the 4 L whole milk and the 12 L whole milk during the last 2 weeks of the trial were observed. However, calves consumed more MR (16 L/day *ad lib*) compared to when 12 L whole milk (10 to 11 L) was offered. This could be due to a lower nutrient concentration of the MR. No treatment differences in the ADG of the calves were observed during the post-weaning period. At the end of the trial, the calves that received the *ad lib* MR maintained a higher BW than the calves that received the conventional volume of MR (Jasper & Weary, 2002). This study indicate that a higher volume of MR benefits the BW and growth of calves and maintains the advantage. No additional weight gain benefit however appears to be present during the post-weaning period.

Appleby *et al.* (2001) reported on a study where two different MR volumes were fed to calves. The first treatment was 5% of BW per feeding (two feedings per bucket) and the second treatment was *ad lib* per teat. The *ad lib* group animals resulted in improved ($P < 0.05$) ADG (Appleby *et al.,* 2001). During the first 3 weeks the starter feed intake was low in both treatments and did not differ significantly. After the 3 weeks, the calves that were fed the conventional volume MR, consumed more starter feed (Appleby *et al.,* 2001). When calves receive high volumes of MR, the volume should be gradually increased. This strategy increases the growth rate at a higher feeding level, as well as limit scouring risk (Jones & Heinrichs, 2020).

2.7 Post-weaning growth and management of calves

The transition from pre-weaning to post-weaning needs to be smooth and gradual to prevent a slump in the ADG of the calves (Drackley, 2008; Drake, 2017). The pre-weaning period is important for the establishment of the rumen microbiome as well as growth (Drackley, 2008). The post-weaning growth is important and the diet should be formulated to maximize nutrient intake (Drackley, 2008; Drake, 2017).

Calves fed the conventional volume (4 L/day) of MR may show compensatory growth during the finishing phase (Silva *et al.*, 2020). The calf's efficiency in converting feed into carcass should however be estimated, because calves that undergo compensatory growth generally have higher non-carcass weight gain (Silva *et al.*, 2020). According to the latter authors, calves fed more than 4 L/day of MR had a greater ADG during post-weaning phase. These calves were also more efficiently in converting feed into carcass (Silva *et al.*, 2020). Silva *et al.* (2020) reported calves that received the conventional volume of MR exhibited compensatory growth and fully compensated for the lost in visceral organ weight after weaning while the loss in BW and carcass weight were only partly compensated. The latter group showed better feed efficiency and higher profitability than the calves who received higher volumes of MR. Despite improved efficiency in the post-weaning phase, the calves that received the conventional volume of MR could not reach the same BW as the calves that received higher volumes MR during the liquid feeding phase (Silva *et al.*, 2020). Silva *et al.* (2020) concluded that the calves that received higher volumes of MR were more profitable as the carry-over effect was better. Cheema *et al.* (2018) reported similar results as to those reported by Silva *et al.* (2020). In the latter study calves that received higher volumes of MR (15% of BW) were weaned using the step-down method at 60 days of age and were found to be more cost effective ($P < 0.05$) than the calves that received a conventional volume of MR (Cheema *et al.*, 2018). Burggraaf *et al.* (2020) reported calves receiving higher volumes of MR grew 8% faster and had a faster growth rate in the post-weaning period when compared with calves receiving the conventional volume of MR. Body dimensions at 6 weeks of age were similar, but calves that were fed the higher volumes of MR had slightly larger dimensions in the latter study. The calves that received the conventional volume of MR had a larger hip width, as well as a larger heart girth circumference (Burggraaf *et al.*, 2020). At slaughtering, the calves that received the higher volumes of MR and high quality pasture were heavier than the conventional MR group of calves (Burggraaf *et al.*, 2020).

When calves are weaned gradually, the feeding of different volumes of MR had no significant carry-over effects. The gradual weaning causes calves to consume higher amounts of starter feed prior to weaning and thus compensate for the lower intake of starter feed during the early milk feeding phases (Drake, 2017; Klopp *et al.*, 2019). If calves did not sufficiently adapt to the starter feed, slower growth after weaning were observed (Terré *et al.*, 2007; Hill *et al.*, 2010). Bach *et al.* (2013) reported better ADG, and higher BW of calves fed 8 L/day of MR compared to calves fed 6 L/day. In contrast to the work of Cheema *et al.* (2018) and Silva *et al.* (2020) the two groups however, showed similar BW after weaning (Bach *et al.*, 2013). In the study of Hu *et al.* (2019), the ADG of the calves decreased while another study (Terré *et al.*, 2007) reported that no short-term effects were observed when post-weaning performance of calves that received different MR levels were evaluated. Conflicting results are therefore reported regarding the postweaning ADG of calves receiving higher volumes of MR.

2.8 Beef production economy

According to Moran *et al.* (1991), on average half of the cost of beef production from dairy bulls is toward feed and the purchase price. Therefore, the main focus was mainly on nutrition to minimize cost (Moran *et al.*, 1991). This approach involved supplying MR or whole milk for the first six weeks of the calf's life supplemented by starter feed high in energy, protein, and small amounts of roughage. This feeding strategy allowed dairy bull calves to grow at least 1 kg/day (Moran *et al.*, 1991). The study also confirmed that the higher the MR intake, the higher the feed costs (Moran *et al.*, 1991). The cost per unit of gain is however important. According to Hawkins *et al.* (2019), a decrease in cost per unit of gain was observed as milk replacer allowance increased, causing an increase in the ADG. Brown *et al.* (2005), fed calves a high protein MR (300 g CP/kg DM) with a high protein starter feed (200 g CP/kg DM) and a low protein MR (210 g CP/kg DM) with a low protein starter feed (170 g CP/kg DM). The results of the study indicated the high protein MR and starter feed was more costly, but the ADG was greater. Therefore, the treatment resulted in a decrease in cost per unit of gain. Thus, the treatment causes greater weight gain through the increased protein intake without causing excess fattening (Brown *et al.*, 2005).

As the prices of beef are relatively high in comparison with pork and poultry (BFAB, 2021) (Figure **2.8**), the quality of the meat should be high for the consumers to repurchase the meat (Llauger *et al.,* 2021). Consumers buying meat expect characteristics such as flavour and nutritional value (Vavrišínová *et al.*, 2019).

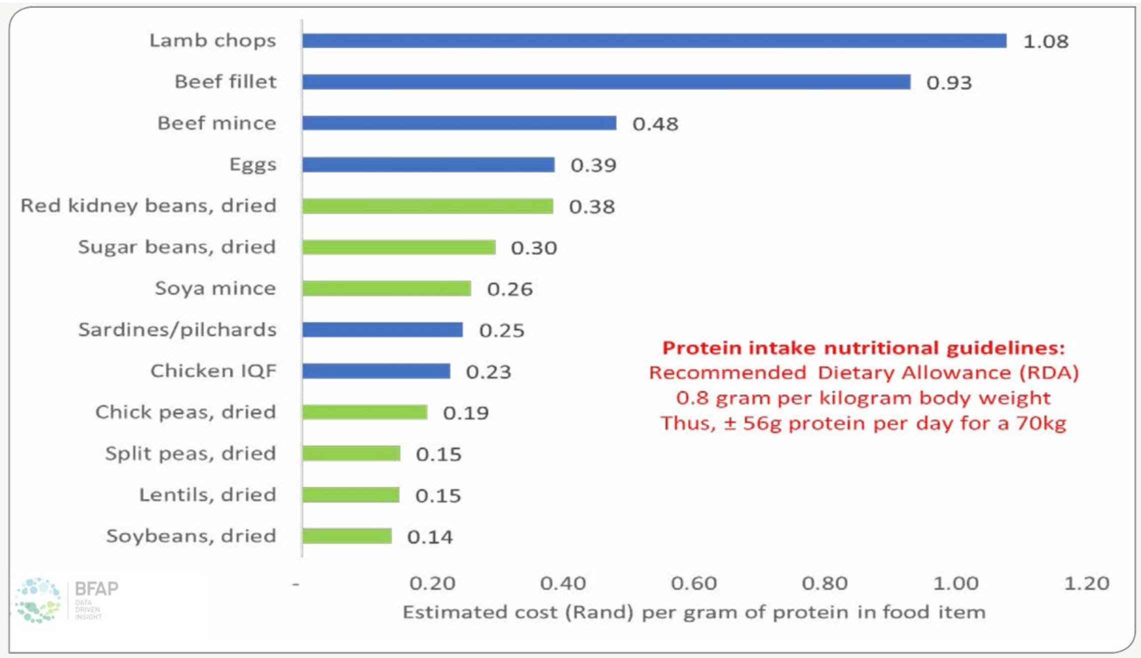

Figure 2.8 Comparing the protein cost of a selection of animal-based and plant-based protein foods (BFAB, 2021).

The profit of beef production is dependent on protein and fat gain, (Bekman & van Arendonk, 1993; Wolfová *et al.*, 2007). However, feed and management costs also have an effect on the profit (Hawkins *et al.*, 2019). Fifteen percent of the gross income for dairy farmers are derived from beef production (Bekman & van Arendonk, 1993). According to Bekman & Van Arendonk (1993) traits relevant for beef producers include BW, ADG, mortality, dressing percentage and carcass quality. The cost of gain per kg decreases as the animal ADG increases, which is more cost effective for the farmer (Peel, 2003; Hawkins *et al.*, 2019).

The daily energy requirements for maintenance for beef production are presented in Table **2.1**. As used by Bekman & van Arendonk, (1993), the beef production model, to fatten bull calves, indicated they need 58.2 MJ ME per day. Economic values for production traits are sensitive to changes in production and meat prices (Peel, 2003). Traits such as final weight, dressing percentage, meat price and mortality were lower for the absolute economic value (Bekman & van Arendonk, 1993). The economic value for daily gain is strongly impacted by the final weight and to a smaller degree the feed price (Peel, 2003). The colour of the meat , fat cover and fleshiness also play a role in the economic value (Bekman & van Arendonk, 1993; Berry, 2021).

Table 2.1 Daily energy requirements for beef (Bekman & Van Arendonk, 1993).

	Energy requirements (MJ Metabolizable energy per day) for beef
Total	58.2
Maintenance	30.1
Protein gain	16.2
Fat gain	12.0

2.9 Conclusion

From literature cited, it is clear that MR intake and the CP concentration therein or MR intake with varying CP concentration starter feeds play a vital role in the growth of a calf. As the veal industry in South Africa is small, dairy bull calves are raised for beef production via the feedlot system. It is therefore important for producers to optimize post-weaning performance.

Previous studies have indicated that when higher volumes of MR are fed to calves, ADG and BW improve, albeit being more expensive. Although higher volumes of MR are more expensive, the latter causes greater ADG which decreases the cost per unit of gain. Therefore, feeding calves higher volumes can increases the profit of the farmer. Several different studies however indicated the opposite and showed that higher volumes of MR did not improve results. It is therefore necessary to further investigate the feeding of different MR volumes to dairy calves.

Several studies indicated that the post-weaning growth rate of calves that received higher volumes of MR were superior to calves receiving a conventional volume of MR of 4 L/day. Weaning calves gradually resulted in less weaning shock. No significant carry-over effects were observed as these calves consume higher volumes of starter feed. Calves that were fed the conventional volume of MR can have compensatory growth post-weaning and can compensate for a lower BW at weaning.

Considerable variation in the effect of CP level in the starter feed of calves have been reported. Some studies indicated that calves that were fed higher CP concentration starter feed perform better than the conventional CP level of 180 g/kg that are prescribed by the NRC. Future research on different CP levels of starter feed can supply valuable information to producers.

2.10 References

Appleby, M.C., Weary, D.M., & Chua, B. 2001. Performance and feeding behaviour of calves on ad libitum milk from artificial teats. Appl. Anim. Behav. Sci., 11. https://doi.org/10.1016/S0168-1591(01)00171-X.

Bach, A., Terré, M., & Pinto, A. 2013. Performance and health responses of dairy calves offered different milk replacer allowances. J. Dairy Sci. 96, 7790–7797. https://doi.org/10.3168/jds.2013-6909.

Baldwin, R.L., McLeod, K.R., Klotz, J.L., & Heitmann, R. N. 2004. Rumen development, intestinal growth and hepatic metabolism in the pre- and postweaning ruminant. J. Dairy Sci. 87, E55–E65. https://doi.org/10.3168/jds.S0022-0302(04)70061-2.

Bar-Peled, U., Robinzon, B., Maltz, E., Tagari, H., Folman, Y., Bruckental, I., Voet, H., Gacitua, H., & Lehrer, A. R. 1997. Increased weight gain and effects on production parameters of Holstein heifer calves that were allowed to suckle from birth to six weeks of age. J. Dairy Sci. 80, 2523–2528. https://doi.org/10.3168/jds.S0022-0302(97)76205-2.

Bartlett, K.S., McKeith, F.K., VandeHaar, M.J., Dahl, G.E., & Drackley, J.K. 2006. Growth and body composition of dairy calves fed milk replacers containing different amounts of protein at two feeding rates1. J. Anim. Sci. 84, 1454–1467. https://doi.org/10.2527/2006.8461454x.

Bartley, E.E. 1973. Effects of a self-fed pelleted mixture of hay and calf starter on the performance of young dairy calves. J. Dairy Sci. 56, 817–820. https://doi.org/10.3168/jds.S0022-0302(73)85255-5.

Bekman, H., & van Arendonk, J.A. M. 1993. Derivation of economic values for veal, beef and milk production traits using profit equations. Livest. Prod. Sci. 34, 35–56. https://doi.org/10.1016/0301-6226(93)90034-F.

Berry, D.P. 2021. Invited review: Beef-on-dairy—The generation of crossbred beef × dairy cattle. Journal of Dairy Science 104, 3789–3819 https://doi.org/10.3168/jds.2020-19519.

BFAB. 2021. Baseline Agricultural outlook, 2021-2030. Accessed 07 July 2022. https://www.bfap.co.za/wp-content/uploads/2021/09/BFAP-Baseline-2021.pdf.

Boorboor, M., Alamouti, A.A., Karimi, N., & Sahraei Belverdy, M. 2020. Effects of reducing crude protein concentration in starter feed containing constant rumen undegradable protein on dairy calves performance. J Anim Physiol Anim Nutr 104, 1287–1293. https://doi.org/10.1111/jpn.13380.

Borderas, T.F., de Passillé, A.M.B., & Rushen, J. 2009. Feeding behavior of calves fed small or large amounts of milk. J. Dairy Sci. 92, 2843–2852. https://doi.org/10.3168/jds.2008-1886.

Brown, E.G., VandeHaar, M.J., Daniels, K.M., Liesman, J.S., Chapin, L.T., Keisler, D.H., & Nielsen, M.S.W. 2005. Effect of increasing energy and protein intake on body growth and carcass Composition of Heifer Calves. J. Dairy Sci. 88, 585–594. https://doi.org/10.3168/jds.S0022-0302(05)72722-3.

Burggraaf, V.T., Craigie, C.R., Muir, P.D., Khan, M.A., Thomson, B.C., Knol, F.W., Lowe, K.A., Taukiri, K.R., Staincliffe, M., McDermott, A., Longhurst, R.D., & McCoard, S.A. 2020. Effect of rearing diet and early post-weaning pasture quality on the life-time growth, meat quality, carcass traits and environmental impact of dairy-beef cattle. Livest. Sci. 239, 104031. https://doi.org/10.1016/j.livsci.2020.104031.

Chapman, C.E., Hill, T.M., Elder, D.R., & Erickson, P.S. 2017. Nitrogen utilization, preweaning nutrient digestibility, and growth effects of Holstein dairy calves fed 2 amounts of a moderately high protein or conventional milk replacer. Journal of Dairy Science 100, 279–292. https://doi.org/10.3168/jds.2016-11886.

Cheema, A.T., Bhatti, S.A., Akbar, G., Wynn, P.C., Muhammad, G., Warriach, H.M., & McGill, D. 2018. Effect of weaning age and milk feeding level on pre- and post-weaning growth performance of Sahiwal calves. Anim. Prod. Sci. 58, 314. https://doi.org/10.1071/AN15719.

Damtew, A., Erega, Y., Ebrahim, H., Tsegaye, S., & Msigie, D. 2018. The effect of long distance transportation stress on cattle: a Review. Biomed. J. Sci. Tech. Res. 3. https://doi.org/10.26717/BJSTR.2018.03.000908.

Daneshvar, D., Khorvash, M., Ghasemi, E., & Mahdavi, A.H. 2017. Combination effects of milk feeding methods and starter crude protein concentration: Evaluation on performance and health of Holstein male calves. Anim. Feed Sci. Technol. 223, 1–12. https://doi.org/10.1016/j.anifeedsci.2016.10.025.

Davis, C.L., & Drackley, J.K. 1998. The development, nutrition, and management of the young calf. 1st ed. Iowa State University Press, Ames.

Diao, Q., Zhang, R., & Fu, T. 2019. Review of strategies to promote rumen development in calves. Animals 9, 490. https://doi.org/10.3390/ani9080490.

Dias J, Marcondes M.I., Noronha M.F., Resende R.T., Machado F.S., Mantovani H.C.,2017.Effect of pre-weaning diet on the ruminal archaeal, bacterial, and fungal communities of dairy calves. Front Microbiol. 8:1553. https://doi: 10.3389/fmicb.2017.01553.

Diaz, M.C., Van Amburgh, M.E., Smith, J.M., Kelsey, J.M., & Hutten, E.L. 2001. Composition of growth of Holstein calves fed milk replacer from birth to 105-kilogram body weight. J. Dairy Sci. 84, 830–842. https://doi.org/10.3168/jds.S0022-0302(01)74541-9.

Donnelly, P.E., & Hutton, J.B. 1976. Effects of dietary protein and energy on the growth of Friesian bull calves: I. Food intake, growth, and protein requirements. N. Z. J. Agric. Res. 19, 289–297. https://doi.org/10.1080/00288233.1976.10429068.

Drackley, J.K. 2008. Calf nutrition from birth to breeding. Vet. Clin. North Am. Food Anim. Pract. 24, 55–86. https://doi.org/10.1016/j.cvfa.2008.01.001.

Drake, N.A. 2017. The performance of veal calves fed concentrate, total mixed ration, or free choice in the post-weaning period.

Ellingsen, K., Mejdell, C.M., Ottesen, N., Larsen, S., & Grøndahl, A.M. 2016. The effect of large milk meals on digestive physiology and behaviour in dairy calves. Physiology & Behavior.154,169-174. https://doi.org/10.1016/j.physbeh.2015.11.025.

Genzebu, D., & Tesfay, G. 2015. The role of bacteria in nitrogen metabolism in the rumen with emphasis of cattle. J. Agric. Environ. Manag. 4(7), 282-290. https://www.researchgate.net/publication/284181905_The_role_of_bacteria_in_nitrogen_metabolism_in_the_rumen_with_emphasis_of_cattle.

Gerrits, W.J., Tolman, G.H., Schrama, J.W., Tamminga, S., Bosch, M.W., & Verstegen, M.W. 1996. Effect of protein and protein-free energy intake on protein and fat deposition rates in preruminant calves of 80 to 240 kg live weight. J. Anim. Sci. 74, 2129. https://doi.org/10.2527/1996.7492129x.

Gilbert, M.S. 2015. Replacing lactose from calf milk replacers: Effects on digestion and post-absorptive metabolism. PhD thesis, University of Wageningen, Netherlands.

Gorka, P., Kowalski, Z.M., Pietrzak, P., Kotunia, A., Kiljanczyk, R., Flaga, J., Holst, J.J., Guilloteau, P., & Zabielski, R. 2009. Effect of sodium butyrate supplementation in milk replacer and starter diet on rumen development in calves. J. Physiol. Pharmacol. 60(suppl. 3), 47-53. https://www.researchgate.net/publication/51440564_Effect_of_sodium_butyrate_supplementation_in_milk_replacer_and_starter_diet_on_rumen_development_in_calves/link/00b4951a65967ba496000000/download.

Govil, K., Yadav, D., Patil, A., Nayak, S., Baghel, R., Yadav, P., & Thakur, D. 2017. Feeding management for early rumen development in calves. Journal of Entomology and Zoology Studies 5, 8.

Guilloteau, P., Zabielski, R., & Blum, J. W. 2009. Gastrointestinal tract and digestion in the young ruminant: Ontogenesis, adaptations, consequences and manipulations. J. Physiol. Pharmacol. 60, 11. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1059.5034&rep=rep1&type=pdf.

Guliński, P., Salamończyk, E., & Mlknek, K. 2016. Improving nitrogen use efficiency of dairy cows in relation to urea in milk – a review. Anim. Sci. Papes Rep. 34(1), 5-24. https://www.igbzpan.pl/uploaded/FSiBundleContentBlockBundleEntityTranslatableBlockTranslatableFilesElement/filePath/15/str5-24.pdf.

Hammon, H.M., Steinhoff-Wagner, J., Flor, J., Schönhusen, U., & Metges, C. C. 2013. Lactation biology symposium: Role of colostrum and colostrum components on glucose metabolism in neonatal calves1,2. J. Anim. Sci. 91, 685–695. https://doi.org/10.2527/jas.2012-5758.

Hawkins, A., Burdine, K., Amaral-Phillips, D., & Costa, J. H. C. 2019. An economic analysis of the costs associated with pre-weaning management strategies for dairy heifers. Animals 9, 47. https://doi.org/10.3390/ani9070471.

Hengst, B.A., Nemec, L.M., Rastani, R.R., & Gressley, T.F. 2012. Effect of conventional and intensified milk replacer feeding programs on performance, vaccination response, and neutrophil mRNA levels of Holstein calves. J. Dairy Sci. 95, 5182–5193. https://doi.org/10.3168/jds.2011-5261.

Hill, T.M., Aldrich, J.M., Schlotterbeck, R.L., & Bateman, H.G. 2006. Effects of feeding calves different rates and protein concentrations of twenty percent fat milk replacers on growth during the neonatal period. Prof. Anim. Sci. 22, 252–260. https://doi.org/10.15232/S1080-7446(15)31101-3.

Hill, T.M., Bateman, H.G., Aldrich, J.M., & Schlotterbeck, R.L. 2007. Effects of the feeding rate of high protein calf milk replacers. Prof. Anim. Sci. 23, 649–655. https://doi.org/10.15232/S1080-7446(15)31036-6.

Hill, S.R., Knowlton, K.F., Daniels, K.M., James, R.E., Pearson, R.E., Capuco, A.V., & Akers, R.M. 2008. Effects of milk replacer composition on growth, body composition, and nutrient excretion in preweaned Holstein heifers. Journal of Dairy Science 91, 3145–3155. https://doi.org/10.3168/jds.2007-0860.

Hill, T.M., Bateman, H.G., Aldrich, J.M., & Schlotterbeck, R.L. 2010. Effect of milk replacer program on digestion of nutrients in dairy calves. J. Dairy Sci. 93, 1105–1115. https://doi.org/10.3168/jds.2009-2458.

Hill, T.M., Bateman, H.G., Quigley, J.D., Aldrich, J.M., Schlotterbeck, R.L., & Heinrichs, A.J. 2013. Review: New information on the protein requirements and diet formulation for dairy calves and heifers since the Dairy NRC 200111. Information presented in invited review at the ADSA, AMPA, ASAS, CSAS, WSASAS joint annual meetings in Phoenix, Arizona, July 15–18, 2012. Prof. Anim. Sci. 29, 199–207. https://doi.org/10.15232/S1080-7446(15)30225-4.

Holtshausen, L., Cruywagen, C.W., & Ferreira, G. 2000. Veal calf performance in response to concentrate diets of different rumen degradable protein content. South Afr. J. Anim. Sci. 30, 58–59. https://doi.org/10.4314/sajas.v30i4.3908.

Hu, W., Hill, T.M., Dennis, T.S., Suarez-Mena, F.X., Quigley, J.D., & Schlotterbeck, R.L. 2019. Intake, nutrient digestibility, and growth performance of Holstein dairy calves consuming a milk replacer at moderate or high feeding rates. J. Dairy Sci. 102, 7917–7926. https://doi.org/10.3168/jds.2019-16282.

Huber, J.T. 1969. Development of the digestive and metabolic apparatus of the calf. J. Dairy Sci. 52, 1303–1315. https://doi.org/10.3168/jds.S0022-0302(69)86744-5.

Jacobson, N.L. 1969. Energy and protein requirements of the calf. J. Dairy Sci. 52, 1316–1321. https://doi.org/10.3168/jds.S0022-0302(69)86745-7.

Jaeger, B.M., Ziegler, D., Schimek, D., Ziegler, B., Raeth, M., Chester-Jones, H., & Casper, D.P. 2020. Growth performance of newborn dairy calves fed a milk replacer with 2 protein concentrations at 2 feeding rates. Appl. Anim. Sci. 36, 48–56. https://doi.org/10.15232/aas.2019-01866.

Jafari, A., Azarfar, A., Alugongo, G.M., Ghorbani, G.R., Mirzaei, M., Fadayifar, A., Omidi-Mirzaei, H., Cao, Z., Drackley, J. K., & Hossieni Ghaffari, M. 2021. Milk feeding quantity and feeding frequency: effects on growth performance, rumen fermentation and blood metabolites of Holstein dairy calves. Ital. J. Anim. Sci. 20, 336–351. https://doi.org/10.1080/1828051X.2021.1884504.

Jasper, J., & Weary, D.M. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85, 3054–3058. https://doi.org/10.3168/jds.S0022-0302(02)74391-9.

Jiang, F.G., Lin, X.Y., Yan, Z.G., Hu, Z.Y., Liu, G.M., Sun, Y.D., Liu, X.W., & Wang, Z.H. 2017.Effect of dietary roughage level on chewing activity, ruminal pH, and saliva secretion in lactating Holstein cows. J. Dairy Sci. 100(4), 2660-2671. https://doi.org/10.3168/jds.2016-11559.

Jones, C.M., & Heinrichs, J. 2020. Feeding the newborn dairy calf. Penn State Ext.

Kazemi-Bonchenari, M., Alizadeh, A.R., Tahriri, A.R., Karkoodi, K., Jalali, S., & Sadri, H. 2015. The Effects of partial replacement of soybean meal by xylose-treated soybean meal in the starter concentrate on performance, health status, and blood metabolites of Holstein calves. Italian Journal of Animal Science 14, 3680. https://doi.org/10.4081/ijas.2015.3680.

Khan, M.A., Lee, H.J., Lee, W.S., Kim, H.S., Kim, S.B., Ki, K.S., Park, S.J., Ha, J.K., & Choi, Y.J. 2007. Starch source evaluation in calf starter: I. Feed consumption, body weight gain, structural growth, and blood metabolites in Holstein calves. J. Dairy Sci. 90, 5259–5268. https://doi.org/10.3168/jds.2007-0338.

Khan, M.A., Weary, D.M., & von Keyserlingk, M.A.G. 2011. Invited review: Effects of milk ration on solid feed intake, weaning, and performance in dairy heifers. J. Dairy Sci. 94, 1071–1081. https://doi.org/10.3168/jds.2010-3733.

Klopp, R.N., Suarez-Mena, F.X., Dennis, T.S., Hill, T.M., Schlotterbeck, R.L., & Lascano, G.J. 2019. Effects of feeding different amounts of milk replacer on growth performance and nutrient digestibility in Holstein calves to 2 months of age using different weaning strategies. J. Dairy Sci. 102, 11040–11050. https://doi.org/10.3168/jds.2019-17153.

Kristensen, N.B., Sehested, J., Jensen, S.K., & Vestergaard, M. 2007. Effect of milk allowance on concentrate intake, ruminal environment, and ruminal development in milk-fed Holstein calves. J. Dairy Sci. 90, 4346–4355. https://doi.org/10.3168/jds.2006-885.

Laarman, A.H., & Oba, M. 2011. Short communication: Effect of calf starter on rumen pH of Holstein dairy calves at weaning. J. Dairy Sci. 94, 5661–5664. https://doi.org/10.3168/jds.2011-4273.

Labussiere, E., Dubois, S., van Milgen, J., Bertrand, G., & Noblet, J. 2008. Effects of dietary crude protein on protein and fat deposition in milk-fed veal calves. J. Dairy Sci. 91, 4741–4754. https://doi.org/10.3168/jds.2008-1203.

Labussiere, E., Maxin, G., Dubois, S., van Milgen, J., Bertrand, G., & Noblet, J. 2009. Effect of feed intake on heat production and protein and fat deposition in milk-fed veal calves. Animal 3, 557–567. https://doi.org/10.1017/S1751731108003777.

Liang, Y., Carroll, J.A., & Ballou, M.A. 2016. The digestive system of 1-week-old Jersey calves is well suited to digest, absorb, and incorporate protein and energy into tissue growth even when calves are fed a high plane of milk replacer. J. Dairy Sci. 99, 1929–1937. https://doi.org/10.3168/jds.2015-9895.

Llauger, M., Claret, A., Bou, R., López-Mas, L., Guerrero, L. 2021. Consumer attitudes toward consumption of meat products containing offal and offal extracts. Foods. 10(7),1454. doi: doi.org/10.3390/foods10071454.

Lowe, G.L., Sutherland, M.A., Stewart, M., Waas, J.R., Cox, N.R., & Schütz, K.E. 2022. Effects of provision of drinking water on the behavior and growth rate of group-housed calves with different milk allowances. Journal of Dairy Science 105, 4449–4460. https://doi.org/10.3168/jds.2021-21304.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A., & Wilkinson, R.G. 2011. Animal Nutrition. Seventh Edition. Pearson.

Mirzaei, M., Khorvash, M., Ghorbani, G.R., Kazemi-Bonchenari, M., Riasi, A., Nabipour, A., & van den Borne, J.J.G.C. 2015. Effects of supplementation level and particle size of alfalfa hay on growth characteristics and rumen development in dairy calves. J. Anim. Physiol. Anim. Nutr. 99, 553–564. https://doi.org/10.1111/jpn.12229.

Moran, J., Hopkins, A., & Warner, R. 1991. The production of pink veal from dairy calves in Australia. Outlook Agric. 20, 183–190. https://doi.org/10.1177/003072709102000309.

Morrill, J.L., & Melton, S.L. 1973. Protein required in starters for calves fed milk once or Twice Daily. J. Dairy Sci. 56, 927–931. https://doi.org/10.3168/jds.S0022-0302(73)85279-8.

Munyaneza, N., Niyukuri, J., & Hachimi, Y.E. 2017. Milk urea nitrogen as an indicator of nitrogen metabolism efficiency in dairy cows: A Review. Theriogenology Insight - Int. J. Reprod. Anim. 7, 145. https://doi.org/10.5958/2277-3371.2017.00032.8.

National Academies of Sciences, Engineering, and Medicine. 2021. Nutrient requirements of dairy cattle: Eighth Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/25806.

NRC. 2001. Ruminant nitrogen usage. National Academies Press, Washington, D.C.

Orellana Rivas, R.M., Komori, G.H., Beihling, V.V., Marins, T.N., Bernard, J.K., & Tao, S. 2019. Effects of milk replacer feeding levels on performance and metabolism of preweaned dairy calves during summer. J. Dairy Sci. 103, 313–324. https://doi.org/10.3168/jds.2019-17360.

Ørskov, E.R. 1992. Protein nutrition in ruminants. 2 ed. Academic Press, Harcourt Brace Jovanovich, London.

Owens, F.N., Dubeski, P., & Hanson, C.F. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71, 3138–3150. https://doi.org/10.2527/1993.71113138x.

Patra, A.K., & Aschenbach, J.R. 2018. Ureases in the gastrointestinal tracts of ruminant and monogastric animals and their implication in urea-N/ammonia metabolism: A review. J. Adv. Res. 13, 39–50. https://doi.org/10.1016/j.jare.2018.02.005.

de Paula, M.R., Oltramari, C.E., Silva, J.T., Gallo, M.P.C., Mourão, G.B., & Bittar, C.M.M. 2017. Intensive liquid feeding of dairy calves with a medium crude protein milk replacer: Effects on performance, rumen, and blood parameters. J. Dairy Sci. 100, 4448–4456. https://doi.org/10.3168/jds.2016-10859.

Peel, D.S. 2003. Beef cattle growing and backgrounding programs. Veterinary Clinics of North America: Food Animal Practice 19, 365–385. https://doi.org/10.1016/S0749-0720(03)00032-X.

Quigley, J.D., Hill, T.M., Deikun, L.L., & Schlotterbeck, R.L. 2017. Effects of amount of colostrum replacer, amount of milk replacer, and housing cleanliness on health, growth, and intake of Holstein calves to 8 weeks of age. J. Dairy Sci. 100, 9177–9185. https://doi.org/10.3168/jds.2017-12784.

Radostits, O.M., & Bell, J.M. 1970. Nutrition of the pre-ruminant dairy calf with special feference to the digestion and absorption of nutrients: A Review. Can. J. Anim. Sci. 50, 405–452. https://doi.org/10.4141/cjas70-063.

Rauba, J., Heins, B.J., Chester-Jones, H., Diaz, H.L., Ziegler, D., Linn, J., & Broadwater, N. 2019. Relationships between protein and energy consumed from milk replacer and starter and calf growth and first-lactation production of Holstein dairy cows. J. Dairy Sci. 102, 301–310. https://doi.org/10.3168/jds.2018-15074.

Schrama, J.W., Van der Hel, W., & Verstegen, M.W.A. 1995. Development of metabolic partitioning of energy in young calves. J. Dairy Sci. 78, 1154–1162. https://doi.org/10.3168/jds.S0022-0302(95)76732-7.

Schubert, D.C., Chuppava, B., Hoffmans, S., Pries, M., Visscher, C., Kamphues, J., & Abd El-Wahab, A. 2022. Impacts of reducing protein content in milk replacer on growth performance and health of young calves. Animals 12, 1756 https://doi.org/10.3390/ani12141756.

Silva, L.H.P., Paulino, P.V.R., Benedeti, P.D.B., Estrada, M.M., Alves, L.C., Assis, D.E.F., Assis, G.J.F., Leonel, F.P., Valadares Filho, S.C., Paulino, M.F., & Chizzotti, M.L. 2020. Post-weaning growth rate effects on body composition of Nellore bulls. Anim. Prod. Sci. 60, 852. https://doi.org/10.1071/AN19032.

Stamey, J.A., Janovick, N.A., Kertz, A.F., & Drackley, J.K. 2012. Influence of starter protein content on growth of dairy calves in an enhanced early nutrition program. J. Dairy Sci. 95, 3327–3336. https://doi.org/10.3168/jds.2011-5107.

Stobo, I.J.F., Roy, J.H.B., & Gaston, H.J. 1967. The protein requirement of the ruminant calf. I. The effect of protein content of the concentrate mixture on the performance of calves weaned at an early age. Anim. Sci. 9, 7–21. https://doi.org/10.1017/S000335610003823X.

Suárez, B.J., Van Reenen, C.G., Beldman, G., van Delen, J., Dijkstra, J., & Gerrits, W.J.J. 2006. Effects of supplementing concentrates differing in carbohydrate composition in veal calf Diets: I. Animal performance and rumen fermentation characteristics. J. Dairy Sci. 89, 4365–4375. https://doi.org/10.3168/jds.S0022-0302(06)72483-3.

Takenaka, A., Tajima, K., Mitsumori, M., & Kajikawa, H. 2004. Fiber digestion by rumen ciliate protozoa. Microbes Environ. 19, 203–210. https://doi.org/10.1264/jsme2.19.203.

Tamate, H., McGilliard, A.D., Jacobson, N.L., & Getty, R. 1962. Effect of various dietaries on the anatomical development of the stomach in the calf. J. Dairy Sci. 45, 408–420. https://doi.org/10.3168/jds.S0022-0302(62)89406-5.

Terré, M., Devant, M., & Bach, A. 2007. Effect of level of milk replacer fed to Holstein calves on performance during the preweaning period and starter digestibility at weaning. Livest. Sci. 110, 82–88. https://doi.org/10.1016/j.livsci.2006.10.001.

Van Amburgh, M., & Drackley, J. 2005. Current perspectives on the energy and protein requirements of the pre-weaned calf. pp 67–82 in calf and heifer rearing: Principles of rearing the modern dairy heifer from calf to calving. Nottingham, Nottingham University Press.

Van Soest, P.J. 1994. Nutritional ecology of the ruminant. Illustrated. Cornell University Press.

Van der Merwe, F.J. & Smith, W. 1991. Dierevoeding. Anim Sci Pty Ltd. Kosmo. Stellenbosch, South Africa.

Vavrišínová, K., Hozáková, K., Bučko, O., Haščík, P., & Juhás, P. 2019. The effect of the slaughter weight on carcass composition, body measurements and veal quality of Holstein calves. Acta Univ. Agric. Silvic. Mendel. Brun. 67, 1235–1243. https://doi.org/10.11118/actaun201967051235.

Vieira, A.D.P., Guesdon, V., de Passillé, A.M., von Keyserlingk, M.A.G., & Weary, D.M. 2008. Behavioural indicators of hunger in dairy calves. Appl. Anim. Behav. Sci. 109, 180–189. https://doi.org/10.1016/j.applanim.2007.03.006.

Wolfová, M., Wolf, J., Kvapilík, J., & Kica, J. 2007. Selection for profit in cattle: II. Economic weights for dairy and beef sires in crossbreeding systems. J. Dairy Sci. 90, 2456–2467. https://doi.org/10.3168/jds.2006-615.

Zitnan, R., Kuhla, S., Sanftleben, P., Bilska, A., Schneider, F., Zupcanova, M., & Voigt, J. 2012. Diet induced ruminal papillae development in neonatal calves not correlating with rumen butyrate. Veterinarni Medicina 50, 472–479. https://doi.org/10.17221/5651-VETMED.

Chapter 3

The effect of milk replacer intake and level of crude protein in starter feed on dairy bull calf pre-weaning growth parameters

3.1 Abstract

The study investigated the effect of different volumes of MR (4, 6 and 9 L) and starter feed containing 210 g CP/kg DM or 260 g CP/kg DM, fed to Holstein bull calves on pre-weaning growth performance. Calves (n = 42; average 2 days of age; 40.986 ± 0.887 kg BW) were randomly assigned to 6 treatment groups. The treatments were (1) 4 L of MR, 210 g CP/kg DM starter feed (LL); (2) 6 L of MR, 210 g CP/kg DM starter feed (LM); (3) 9 L of MR, 210 g CP/kg DM starter feed (LH); (4) 4 L of MR, 260 g CP/kg DM starter feed (HL); (5) 6 L of MR, 260 g CP/kg DM starter (HM) and (6) 9 L of MR, 260 g CP/kg DM starter feed (HH). Milk intake of calves fed 6 and 9 L was stepped down from day 46 to increase the starter feed DMI to 1 kg/day before weaning. Weights and allometric growth measurements were taken weekly to determine difference in growth. Calves had free access to water and were fed ad libitum starter feed and were weaned after a 60-day trial period. Starter feed intake was greater for calves fed lower volumes of MR (P < 0.05). Over the 9 weeks study, the ADG, growth parameters and total weight gain showed no significant difference for the different MR volumes, however calves fed a 260 g CP/kg DM starter feed had a higher ADG and gain over period than calves fed a 210 g CP/kg DM starter feed. The final weight did not differ between the different starter feeds. The final weight of the calves fed 9 L of MR did not differed significantly (P < 0.05) from the calves fed either 4 or 6 L MR.

3.2 Introduction

Due to inadequate feeding and management between birth and weaning, the growth potential of dairy bull calves and the contribution to global food production, has been underestimated (De Carvalho *et al.*, 2021). It is well documented that feeding level can play a role in the growth rates of these calves (Donnelly & Hutton, 1976; Gerrits *et al.*, 1996; Labussiere *et al.*, 2009). One of the common farm practices are feeding 10% of BW (4 L/day) in two portions of 2 L per feeding (De Carvalho *et al.*, 2021). According to Diaz *et al*. (2001), calves offered *ad libitum* milk or milk replacer (MR) can however consume double this volume. It is generally accepted that growth and feed efficiency increases with an increase in milk intake (Bartlett *et al.*, 2006; Khan, 2011). Research further suggests that during the first days of the calf's life, diet quantity and quality play an important role in health, growth performance and development of the calf (Jasper & Weary, 2002; Schäff *et al.*, 2016; Koch *et al.*, 2019).

Currently, intensive MR calf feeding programs, where calves are fed increased volumes of MR containing increased CP concentrations (28.5%) and lower fat concentrations (15%) are becoming more common (Hengst *et al.*, 2012). Thus at weaning, these calves are heavier and have a higher ADG in comparison with calves fed the conventional volume (4 L/day) of MR (Hill *et al.*, 2007; Hengst *et al.*, 2012).

Several studies were done on feeding calves different MR volumes with varying levels of CP (Orellana Rivas *et al.*, 2019; Jaeger *et al.*, 2020b). The results of these studies indicated that calves fed a moderate to high volume of MR had greater BWs compared to calves fed the conventional volume (4 L/day) of MR (Appleby *et al.,* 2001; Orellana Rivas *et al.*, 2019; Stamey Lanier *et al.*, 2021). Calves fed different volumes of MR with varying CP concentrations, had a similar ADG at weaning (Jaeger *et al.*, 2020b). Jaeger *et al* (2020b) reported that the feed conversion ratios (FCR) of calves fed varying CP concentrations did not differ significantly. However, a significant difference was observed for feeding different MR volumes.

Growth can be enhanced by feeding an increased level of CP in the starter feed or a MR with a CP concentration higher than 200 g CP/kg DM as higher CP levels leads to a greater rate of lean tissue deposition (Jacobson, 1969; Blome *et al.*, 2003; Stamey *et al.*, 2012; Kertz & Loften, 2013). Calves fed a 4 L/day MR with starter feed containing CP concentrations that ranges from 200 to 220 g CP/kg DM would increase the growth rates of calves. However, calves fed MR volumes higher than 4 L/day should receive a starter feed with a CP concentration of between 260 g/kg DM to 280 g/kg DM to increase the growth rates (Drackley, 2008).

To ensure faster growth and healthy calves, good quality colostrum must be fed and proper hygiene and feeding management should be a priority (Rauba *et al.*, 2019). The CP concentration of most calf starter feed ranges between 130 g/kg DM to 180 g/kg DM (Akayezu *et al.*, 1994). Akayezu *et al*. (1994) reported that when CP concentrations were increased from 170 g/kg to ≥ 180 g/kg on a DM basis, the BW of calves improved. This was however not the case when the consumption of the starter feed was restricted (Akayezu *et al.*, 1994).

The NRC (2001) indicates that 180 g CP/kg DM is sufficient in starter feeds, but Bartlett *et al*. (2006) reported that starter feed with a concentration of 220 g CP/kg DM was more efficient than the 180 g CP/kg DM. In a study reported by Daneshvar *et al.* (2017), a starter feed with a CP concentration of either 200 g/kg DM or 240 g/kg DM did not have any effect on the performance of dairy calves. Several studies reported that a CP concentration higher than 200 g/kg DM did not lead to better performances and that 190 g CP/kg DM in starter feed is optimal for maximum performance (Labussiere *et al.*, 2008; Stamey *et al.*, 2012; Daneshvar *et al.*, 2017). In contrast, Bartley (1973), Drackley (2008) and Niroumand *et al.* (2020), reported that calves fed a starter feed containing 200 to 220 g CP/kg DM resulted in improved ADG compared to calves fed a diet containing 180 g CP/kg DM, although DMI did not differ.

Calves of large dairy breeds should gain weight at a rate of 1 to 1.4 kg per day from birth to 8 weeks of age (Jacobson, 1969; Akins, 2016). According to Jacobson (1969), the optimal level of protein in starter feeds however depends on different elements including animal age and required rate of gain.

It is clear from literature that some inconsistency is reported when different levels of MR with or without varying CP and fat concentrations or a starter feed with varying CP concentrations were fed to calves. A study was therefore conducted to investigate the effect of increasing volumes of MR and varying levels of CP in calf starter feed on growth parameters, weight gain and feed conversion ratio (FCR) of Holstein dairy bull calves.

3.3 Materials and Methods

3.3.1 Ethical approval details

Ethical approval (ACU-2020-17144) was obtained from the Animal Care and Use Ethics Committee of the University of Stellenbosch.

3.3.2 Experimental location

The trial was conducted at the dairy section of the Welgevallen Experimental Farm of the University of Stellenbosch (Western Cape, South Africa). All the calves were housed in individual pens (3 x 1.2 m) in a shed with solid floors and natural ventilation. Wheat straw was used as bedding. To ensure that the bedding stayed dry, new straw was added daily using a deep litter system. Faeces and wet patches were removed before new straw was added. The trial was executed in 2 blocks of 21 calves, resulting in 7 repetitions per treatment.

3.3.3 Experimental animals and treatments

Forty-two Holstein bull calves between 1 and 3 days of age were purchased from the same producer (Saamstaan, Malmesbury, South Africa). The calves were blocked according to arrival weight and were randomly assigned to one of six treatments. The treatments were as follows: Low CP starter feed (210 g/kg DM) and 4 L/day of MR (LL), Low CP starter feed, 6 L/day of MR (LM), Low protein starter feed, 9 L/day of MR (LH), High protein starter feed (260 g/kg DM), 4 L/day of MR (HL), High protein starter feed, 6 L/day of MR (HM) and High protein starter feed, 9 L/day of MR (HH). The MR concentration was fed at a concentration of 0.142 kg/L from teats. It was mixed in a 50 L bucket at a temperature of 42°C with a drill and fed at a temperature of 40°C The two starter feeds were isocaloric but contained varying CP levels. The calves received starter feed and water *ad lib*. The refusals of the starter feed for all treatments were weighed once a week to determine DMI of the respective calf starter pellets. Starter feeds were formulated to specification and supplied by Epol (RCL FOODS, Worcester, South Africa). The ingredient and chemical composition are presented in Table **3.1** and Table **3.2**. The ingredient composition of the MR is shown in Table **3.3** The milk replacer used during the trial was Sprayfo Blue® which is manufactured by Trouw Nutrition in the Netherlands. The health of the calves was checked every day, and if scours occurred, the calves received electrolytes to prevent dehydration.

Table 3.1 Ingredient composition of the two starter feeds.

Ingredients	Starter feed	
	210 g CP/kg DM	260 g CP/kg DM
White maize	200.00	200.00
Gluten 20	129.20	21.70
Wheat Middlings	190.50	202.60
Soya Oilcake	88.80	96.30
Soya Hulls	52.50	-
Sunflower Oilcake	42.40	94.10
Canola Oilcake	200.00	300.00
Spray Dried Chicken Blood	3.30	26.20
Molasses	46.40	20.00
Limestone Powder	20.40	21.02
Monocalcium Phosphate	1.30	-
Salt	2.70	2.70
Lucerne	15.00	10.00
Premix	3.00	3.00
Toxin Binder	1.00	1.00
Biored	0.20	0.20
Kembind Maxi Dry	1.00	1.00
Rumen Bypass Fat	2.40	-

Table 3.2 Chemical composition of the two starter feeds.

Parameter[1]	Starter feed	
	210 g/kg CP	260 g/kg CP
CP (g CP/kg DM)	212.50	256.90
EE	35.77	38.31
NDF	380.06	368.34
Ash	55.44	68.50
DM	90.34	90.97

[1] CP- Crude protein; EE- Ether extract; NDF- Neutral detergent fibre; DM- Dry matter

Table 3.3 The chemical composition and ingredients of the milk replacer used.

Chemical Composition	g/kg Predicted	g/kg Actual	Nutritional additives per kg
Crude Protein	210.00	198.00	
Crude Fat	170.00	167.26	
Moisture	23.00	29.10	
Crude Ash	87.00	89.90	
Crude Fibre	0.00	0.00	
Lysine	16.00	-	
Calcium	8.00	-	
Phosphorus	6.50	-	
Sodium	8.00	-	
Vitamin A			25 000 IE
Vitamin D3			5000 IE
Vitamin E			300 mg
Selenium			0.3 mg
Copper	4.64	-	10 mg
Iron	0.24	-	90 mg
Iodine, Potassium Iodide			2 mg
Manganese			45 mg
Zinc			84 mg
Propyl gallate			3 mg
Butylated hydroxyanisole			3 mg
Mixture of *Enterococcus faecium* (DSM 7134) & *Lactobacilius rhamnosus* (DSM 7133) (Ratio 7:3)			1 x 10^9 CFU
Ingredients			
Milk products (Whey powder), Oils and Fat (coconut and palm oil), Cereal grains and products derived thereof (hydrolysed wheat protein, wheat starch), minerals and vitamins (calcium carbonate, magnesium sulphate)			

The schedule for the step-up and step-down method is presented in Table **6.1** (Appendix). For the first two days the calves received 2 L of MR per day divided between two feedings. Thereafter it was increased by 0.5 L per day until a total of 4 L per day was reached on day 6 of the trial. From day 6 to 12 of the trial, all the calves received 4 L of MR per day. Starting on day 12, the volume of MR for calves in the 6 and 9 L/day MR group were increased by 0.4 L per day until the target volumes were reached. The number of feedings were also increased to 3 per day for calves on the 6 and 9 L/day treatments. The milk feeding phase of the trial was 60 days when all animals were weaned. A step-down weaning program was used. On day 46 of the trial, the volume of calves fed 6 L of MR per day were reduced to 4 L of MR per day. On the same day the volume for calves fed 9 L of MR per day were reduced to 6 L of MR per day. This was followed by a further reduction to 4 L per day on day 53. The purpose of the phased reduction of MR was to stimulate starter feed intake and to ensure that the calves consumed at least 1 kg of starter feed per day at weaning. The milk bottles were thoroughly cleaned after every feeding.

Body weight (BW) and allometric growth measurements were recorded weekly. The BW was measured with a livestock scale using a Ruddscale KM3-S indicator. The allometric growth measurements included head length and width, hip and wither height, heart girth circumference and body length. Hip height was taken from the base of the rear feet to the hock bones and wither height was taken from the base of the front feet to the wither bones (Gilbert *et al.*, 1993; Wilson *et al.*, 1997; Khan *et al.*, 2011). The heart girth circumference was measured using the circumference of the chest, and body length was measured from the points of the shoulder to the rump (Gilbert *et al.*, 1993; Wilson *et al.*, 1997; Khan *et al.*, 2011). Weekly starter feed intake, MR consumption, calculated DMI, FCR and feed costs were determined.

After the calves arrived on the farm, they received 1 L of MR and 1 L of a commercial electrolyte solution (Diakur® Plus, Boehringer Ingelheim Animal Health South Africa, Randburg, South Africa; Table **3.4**. The electrolyte solution was prepared according to manufacturer instructions.

Table 3.4 Chemical composition of the electrolyte solution fed to the calves.

Chemical Composition	%
Glucose	56.00
Crude Fat and Oils	4.5
Crude Protein	2.7
Crude Ash	14.5
Crude Fibre	2.6
Chloride	3.6
Potassium	1.5
Sodium	4.5
Yeast inactivated	2
Patented hydrophobic citrus fibre (dried citrus pulp and lecithin)	21

3.3.4 Proximate analysis methods of the diet and milk

Proximate analysis was done to determine the moisture, ash, crude protein, crude fat and crude fibre in the respective starter diets and milk replacers. This is presented in Table **3.2** and Table **3.3** respectively.

3.3.4.1 Moisture

Moisture was determined by the AOAC Official Method 934.01 (AOAC, 2002).

3.3.4.2 Ash

Ash was determined by the AOAC Official Method 942.05 (AOAC, 2002).

3.3.4.3 Crude Protein

Crude Protein was determined by the AOAC Official Method 990.03 (AOAC, 2002).

3.3.4.4 Crude Fat

Crude Fat was determined by the AOAC Official Method 920.39 (AOAC, 2002).

3.3.4.5 Neutral Detergent Fibre (NDF)

NDF was determined through the filter bag technique in an ANKOM A2000 fiber analyser according to the ANKOM NDF manual (ANKOM Technology, 2020).

3.3.5 Statistical Analysis

The data was analysed with STATISTICA, version 13 (TIBCO Software Inc., 2017). Confidence levels of 5% was considered significant. A 3 x 2 factorial design was used to analyse the data of the starter feed and MR.

A two-factor ANOVA was subsequently used to determine the effect of the starter feed and MR on the production parameters measured. Data collected over time was subjected to repeated measures analysis of ANOVA. Where the interaction was non-significant, the two main effects were interpreted individually.

3.4 Results and Discussion

3.4.1 Effect of MR

The effect of MR volume on growth parameters, FCR and DMI over the period of 60 days is presented in Table **3.5**. The arrival weight did not differ significantly ($P = 0.316$) for the three MR groups receiving different milk volumes. The final BW differed significantly ($P < 0.05$) between calves fed 4 L and calves fed 6 L MR per day, however, did not differ between calves fed 4 L/day and calves fed 9 L/day and calves fed 6 L/day and calves fed 9 L/day. These findings are in contrast with research reported by Qadeer *et al.* (2021), where final BW of calves was not significantly different for calves that received 4 L or 6 L of MR per day. This difference in findings can be explained by differences in environment and MR with a lower CP concentration used. Stamey *et al.* (2012) reported a nearly linear increase in final BW for calves fed increasing volumes of MR. The current study supports the latter authors when the response from 4 L/day to 6 L/day is considered, however it could not be proven when MR intake was increased to 9 L/day. A reason for the 9 L/day MR group for not performing the best, could be due to rumen development that was impaired by consuming less starter feed. However, the step-down weaning method increased the starter feed DMI over the last 14 days.

The DMI of the starter intake plus the DMI of the MR indicated that the total DMI of the calves did not differ significantly (P = 0.386), which indicated feeding calves higher volumes of MR provide adequate nutrients for growth. The DMI of the starter feed for the calves fed 4 L/day and 6 L/day of MR did not differ significantly, Table **3.5**. This finding was also reported by Qadeer *et al.* (2021) as they also did not observe any difference in DMI for calves fed either 4 or 6 L/day of MR per day. In the current study, calves fed 9 L/day of MR resulted in significantly (P < 0.05) lower starter feed DMI compared to calves fed either 4 or 6 L/day of MR respectively. These results supports that of multiple previous studies who all reported higher starter DMI in calves that received a lower volume of MR (Jasper & Weary, 2002; Brown *et al.*, 2005; Stamey Lanier *et al.*, 2021). It is generally accepted that calves consume greater amounts of starter feed when receiving lower volumes of MR to meet CP and ME requirements, whereas 9 L/day of MR provides adequate nutrients closer to requirements (Hodgson, 1971; De Carvalho *et al.*, 2021; Stamey Lanier *et al.*, 2021). However, when calves consume 9 L/day of MR, they felt satiated and consumes less starter feed (Piao *et al.*, 2021) than calves receiving 4 and 6 L/day of MR respectively. Lowe et al. (2022) observed calves fed higher volumes of MR (10 L/day) spent more time lying which suggested they were more satiated or content in comparison to calves that received 5 L/day of MR. The calves fed lower volumes of MR consume more starter feed and spent more time moving which could lead to unrewarded visits to the milk feeder (Lowe *et al.*, 2022).

No differences in FCR between calves fed 4 L/day, 6 L/day or 9 L/day were found (P-value = 0.518, Table **3.5**). Contrary to the current study, Diaz *et al.* (2001 and Jasper & Weary (2002) reported that higher volumes of MR can improve the FCR. Jafari *et al.* (2021), observed that the FCR did not differ between the MR volumes (total MR intake for 56 d: 3.75 L/day and 5.54 L/day). Chapman *et al.* (2017), indicated calves fed a moderate volume MR (0.66 kg of DM, 270 g CP/kg DM) had a better FCR than feeding a conventional (0.44 kg of DM, 210 g CP/kg DM) or a high volume MR (0.87 kg of DM, 270 g CP/kg DM). Suarez-Mena *et al.* (2021), observed when calves were fed a moderate volume (0.66 kg/day) of MR had a greater FCR than calves fed *ad libitum* volume of MR.

As shown is Table **3.5** in the current study, no significant differences were detected in ADG, total weight gain, body length gain, wither height difference, hip height difference, heart girth circumference gain, as well as head width and length difference between the MR volumes. According to literature, wither height and heart girth circumference also did not differ between lower and higher volumes of MR (Piao *et al.*, 2021). According to Piao *et al.* (2021) however, these parameters tended to be higher in the treatments with higher volumes of MR (1.120 kg/day). When higher MR volumes were fed, the allometric growth measurements of the calves were similar, but the final BW of the calves fed higher volumes were higher than the 4 L/day group.

During growth and development of calves, bone develops earlier than muscle and muscle develops earlier than fat (Berg & Butterfield, 1966). During the pre-weaning period, weight gain consists mostly of water, protein and minerals which are required firstly for bone growth, secondly for muscle growth and lastly for fat deposition (McDonald *et al.*, 2011). Berg & Butterfield, (1966) observed that muscle:bone ratio increased with the BW as the growth curve for bone declines and the growth cure for muscle inclines. This means that the increase in MR volume caused a gain in muscle or fat but had a smaller effect on frame growth. Qadeer *et al.* (2021) also reported no difference in ADG for calves that received 4 L/day and 6 L/day of MR respectively. They reported higher starter intake for calves receiving 4 L/day MR and this provided the required nutrients to meet the growth requirements. Starter feed stimulates rumen development, and therefore promotes the absorption of nutrients which increases the growth performance of calves (Berends *et al.,*2015) Although no significant differences for the ADG was observed among the treatment groups in the current study, DMI of the starter intake for the group that received 9 L/day of MR was significantly lower than for the groups that were fed 4 L/day and 6 L/day of MR respectively (Table **3**.**5**). The reason why no significant differences for ADG, FCR and total DMI was observed when feeding higher volumes of MR could be the higher CP and ME (6 L/day: 21.15 MJ ME/kg DM; (9L/day: 23.35 MJ ME/kg DM) supplied by the solids in the MR. Calves fed 9 L/day were more satiated than calves fed 4 and 6 L/day of MR, therefore consumed less starter feed.

Table 3.5 The effect of milk volume on different growth parameters, feed conversion ratio and dry matter intake.

Item[1]	Milk volume[2]			SEM[3]	P-value
	4 L/day	6 L/day	9 L/day		
Arrival weight (kg)	39.042	42.208	41.708	0.887	0.316
Final weight (kg)	78.042[a]	85.458[b]	82.708[ab]	1.418	0.098
ADG (kg/day)	0.652	0.724	0.683	0.017	0.177
Total weight gain (kg)	39.000	43.250	41.000	1.015	0.191
Body length gain (cm)	12.083	13.333	12.333	0.625	0.717
Wither height gain (cm)	12.917	14.083	13.833	0.514	0.269
Hip height gain (cm)	12.250	14.333	13.500	0.509	0.631
Heart girth circumference gain (cm)	20.000	20.667	21.000	0.532	0.750
Head length increase (cm)	6.167	6.000	6.333	0.941	0.717
Head width increase (cm)	3.083	2.250	2.750	0.273	0.484
FCR	1.954	1.886	1.877	0.030	0.518
DMI for starter feed (kg/day)	43.337[a]	40.662[a]	24.419[b]	2.291	0.0004
DMI for MR (kg/day)	32.501[a]	40.974[b]	51.924[c]	1.346	< 0.001
Total DMI (kg/day)	75.838	81.596	76.343	1.869	0.386

[1] ADG- Average daily gain; FCR- Feed conversion ratio; DMI- Dry matter intake; MR- Milk replacer

[2] 4 L/day- LL & HL; 6 L/day- LM & HM; 9 L/day:-LH & HH

[3] SEM-Standard error of mean

[a,b] Means within rows with different superscripts differ significantly ($P < 0.05$).

3.4.2 Effect of starter feed

The effect of protein level of the calf starter on growth parameters, FCR, DMI for starter feed and MR and total DMI is presented in Table **3.6**. The arrival and final BW did not differ between the different levels of CP in the starter diets that was used (Arrival p- value: 0.679; Final p-value: 0.144). This is in agreement with Kazemi-Bonchenari *et al.* (2022), who also reported higher final BW of calves fed 230 g/kg CP starter compared to the BW of calves that received 180 g/kg CP starter. Akayezu *et al.* (1994), reported differences in ADG between calves fed different levels of CP in the starter feed. The final BW gain was greater for the treatments with CP concentrations of 196 g/kg DM and 224 g/kg DM in comparison with CP concentrations of 150 g/kg DM and 168 g/kg DM in the starter feeds. These authors hypothesized that an improved ADG was observed when feeding starter feed with a higher CP concentration due to the improved utilization of nutrients (Akayezu *et al.*,1994; Kazemi-Bonchenari *et al.*, 2022).

Considering 210 g CP/kg DM and 260 g CP/kg DM starter feeds fed in the current study, no significant differences were observed between the starter feed DMI, the MR DMI, FCR, body length gain, wither height difference, hip height difference, heart girth circumference gain and head width and length difference (Table **3.6**). Kazemi-Bonchenari *et al.* (2022) however reported higher DMI for calves that received 230 g CP/kg DM starter feed compared to those fed a starter feed containing 180 g CP/kg DM. In the current study, calves that received a starter feed containing 260 g CP/kg DM did however tend to have a higher starter feed (P = 0.072) and total DMI (P = 0.074) than calves fed a starter feed containing 210 g CP/kg DM (Table **3.6**). According to Kazemi-Bonchenari *et al*. (2022) higher CP concentration in starter feed fed to calves increases DMI irrespective of the MR volume that is fed. In contrast to the current study and that of Kazemi-Bonchenari *et al*. (2022), Yousefinejad *et al.* (2021), reported no significant differences among growth parameters when the CP concentration in starter feed was increased from 190 g CP/kg DM to 220 g CP/kg DM. The differences between these studies could be explained by the relative lower CP concentrations used by Yousefinejad *et al.* (2021).

Table 3.6 The effect of CP concentration in the starter feed on different growth parameters, feed conversion ratio and dry matter intake.

Item[1]	Protein concentration[2]		SEM[3]	P- value
	210 g/kg	260 g/kg		
Arrival weight (kg)	41.361	40.611	0.887	0.679
Final weight (kg)	80.028	84.111	1.418	0.144
ADG (kg)	0.646[a]	0.727[b]	0.017	0.013
Gain over period (kg)	38.667[a]	43.500[b]	1.015	0.014
Body length gain (cm)	12.389	12.778	0.625	0.770
Wither height gain (cm)	13.056	13.667	0.514	0.559
Hip height gain (cm)	13.444	13.778	0.509	0.750
Heart girth circumference gain (cm)	19.722	21.389	0.532	0.137
Head length increase (cm)	6.167	6.167	0.941	1.000
Head width increase (cm)	2.500	2.889	0.273	0.494
FCR	1.931	1.879	0.030	0.388
DMI for starter (kg)	32.687	39.565	2.291	0.072
DMI for MR (kg)	41.802	41.797	1.346	1.000
Total DMI (kg)	74.489	81.363	1.869	0.074

[1] ADG-Average daily gain; FCR- Feed conversion ratio; DMI- Dry matter intake; MR- Milk replacer

[2] 210 g CP/kg DM- LL & LM & LH; 260 g CP/kg DM- HL & HM & HH

[3] SEM- Standard error of mean

[a,b] Means within rows with different superscripts differ significantly ($P < 0.05$).

3.4.3 Interaction between MR and starter feed

The interaction of the different treatments on growth parameters, FCR and the different DMI's are presented in Table **3.7**. As expected, the arrival weight of the different treatment groups did not differ as they were randomly allocated to treatments (Table 3.8). The final weight of treatments LM and HM were however significantly (P < 0.05) heavier compared to treatments LL and HL. No significant differences in the final weight were observed between treatments LL and HL and treatments LH and HH, as well as between treatments LM and HM and treatments LH and HH. This result was partially unexpected as several previous studies reported linear growth responses as MR volume were increased (Jasper & Weary, 2002; Blome *et al.*, 2003; Bartlett *et al.*, 2006; Ghaffari *et al.*, 2021). Treatment groups LH and HH consumed less starter feed which resulted in similar final weights compared to the other treatment groups which were fed lower MR volumes and consumed more starter feed. Scouring was observed during the first 16 days across all treatment groups, thereafter stabilised and did not impact the gain over period of the calves.

Stamey *et al*. (2012) reported no significant interactions between growth parameters of calves that were fed 4 L/day of MR with a starter feed containing 196 g CP/kg DM and calves that were fed 6 L/day of MR and a starter feed containing 255 g/kg of CP. These results are contradicting the results of the current study as shown in Table **3.7**.

In the current study no significant differences were observed for the growth parameters of body length gain, wither height difference, hip height difference, heart girth circumference gains and head width and length difference. The current results is in agreement to that of Kazemi-Bonchenari *et al.* (2022), who also reported no significant interactions for the growth parameters, except for wither and hip height when calves received a higher volume of MR and 230 g CP/kg DM starter feed. In the current study the wither height difference tended (P < 0.10) to be greater when the calves received 9 L/day of MR and 260 g CP/kg DM starter feed, as well as 6 L/day of MR and 210 g CP/kg DM starter feed. Morrison *et al.* (2009), reported that body size and condition did not differ significantly when feeding a MR with either 210 or 270 g CP/kg DM at a volume of 5 L/day and 10 L/day. It is possible that the energy intake of the calves was limited when feeding higher volumes of MR and this limited the utilization of the increased protein in the starter feed. The metabolizable energy of both feeds in the current trial, were formulated to be 10.4 MJ/kg. The higher volumes of MR and protein causes greater gain of lean muscle but not for growth parameters such as the frame size. The reason that treatment HM (6 L/day, 260 g CP/kg DM starter feed) had a higher final weight can be that the intake volume of MR did not inhibit starter intake and thus energy supply. Under these conditions, this was the optimal volume to achieve the best weight gain. The trial was done during the winter months, therefore more energy was needed by the calves for maintenance and heat production. The protein requirements for maintenance are relatively low, but as the animals were growing rapidly the protein requirement for muscle development is quite high. In terms of energy the opposite is applicable and the available energy and protein can affect the growth performance of calves (Morrison *et al.*, 2009). Brown *et al.* (2005), observed that when energy and protein intake were increased from week 2 to 8 and from week 8 to 14, the BW, rate of growth and frame size were increased.

Treatment LL had a significant lower ($P < 0.05$) ADG and gain over period compared to treatments LM, HL, HM and HH, but did not differ from treatment LH (Table **3.7**). No significant difference for ADG and gain over period was however detected among LM, LH, HL, HM and HH. According to Kazemi-Bonchenari *et al.* (2022) when calves receive high milk volumes, starter feed DMI is reduced, however when starter feed contains higher CP concentrations, it can compensate for the negative effects on the DMI to a degree. This could explain the lack of differences observed in ADG and gain over period on similar diets over the treatment period. When fed the higher volumes of MR, the DMI increased, therefore compensated for the lower starter feed DMI. The total DMI for all the treatments were similar. This therefore explained why the ADG for the different treatments did not differ significantly. Treatment LL had the lowest ADG and gain for the treatment period and interaction with the other treatments was also observed (Table **3.7**). The lowest ADG was expected and can be attributed to the low MR volume fed and lower protein concentration in the starter resulting in lower nutrient supply leading to the slower growth observed in this treatment group.

No significant difference ($P < 0.05$) was detected for starter feed DMI in treatment LL, LM, LH, HL and HH (Table **3.7**). Treatment LL had a significantly lower ($P < 0.05$) starter feed DMI compared to treatment HM. Treatment HM did not differ significantly from treatments LM, LH, HL and HH. The reduced starter feed DMI of treatment groups LH and HH compared to treatment groups LL, LM, HL and HM, could be attributed to the relative high intake volume of MR that caused the calves to be more satiated and agrees to most other published work. According to Koch *et al.* (2019); Stamey Lanier *et al.* (2021) and Ghaffari *et al.* (2021), the higher MR volumes resulted in lower consumption of the starter feed. However, the total DMI of the treatment groups did not differ significantly, except for treatment LL which differed significantly from treatment HM. Treatment LL differed significantly, because the latter group consumed less starter feed and received a lower volume of MR.

Feed conversion ratio determines the amount feed required per kg gain and the lower the ratio the better the efficiency (Arthur *et al.*, 2001). A significant difference ($P < 0.05$) was detected for FCR in between treatments LL, LM and HL, where treatment LL had the worst FCR and treatment LM the lowest FCR (Table **3.7**). The best (lowest) FCR of treatment LM could be explained by the moderate volume of MR (6 L/day) with a lower starter DMI of 36.861. In contrast to the current study, Jaeger *et al.* (2020b), observed a better FCR when calves were fed higher volumes of MR and a higher CP concentration (240 g CP/kg DM). However, in the current study, treatment LM received a higher MR volume, but the CP concentration in the current study was lower. Stamey Lanier *et al.* (2021), indicated calves fed an enhanced MR (291 g CP/kg DM) with a high CP starter feed (260 g CP/kg DM) had a greater FCR than calves fed a low volume of MR (206 g CP/kg DM, 1.25% of BW as DM) with a conventional starter feed (215 g CP/kg DM) and a high volume of MR (291 g CP/kg DM, 1.5% of BW as DM) with the conventional starter.

3.4.4 Repeated measures

Repeated measures of the treatments for BW over the nine weeks are presented in Figure **3.1**.

Considering the current study, for the first 4 weeks of the trial no significance difference in weight was observed for any of the treatments, however from week 5 to 9 treatment LL had a significantly lower ($P < 0.05$) weight than treatment HM. From week 6 to 9, treatment LL weighed significantly ($P < 0.05$) less than LH, HM and HH and during weeks 8 and 9, the BW of LL was significantly ($P < 0.05$) lower than that of the LM group. The reason that treatment LL weighed less than the other treatment groups can be that the nutrient requirements were not met for the calves. A higher protein and energy diet was required because treatment HL had similar weights than the other treatments. Suárez-Mena *et.al.* (2021), reported that calves fed a moderate volume of MR (0.66 kg/day), as opposed to calves fed *ad libitum* during the first 4 weeks tended to have greater growth, however during week 5 and 6 their ADG was lower. During week 8 the calves fed the moderate volume MR, had a greater average ADG than the group fed *ad libitum* (Suarez-Mena *et al.*, 2021). In a study reported by Kazemi-Bonchenari *et al.* (2022), calves fed higher MR volumes with a 230 g CP/kg DM starter feed, resulted in the highest BW over the first few weeks, but when evaluated over the entire growth period, calves fed a moderate volume of MR with a 230 g CP/kg DM starter feed had the highest BW. Figure **3.1**, indicates that, calves in the current trial that were fed treatment HM (moderate) had the greatest BW over the last 3 weeks of the trial. The latter is in agreement of the study done by Kazemi-Bonchenari *et al*. (2022).

Wither height data over the nine weeks are presented in Table **6.2** (Appendix). The wither height of all the calves were not significant different during the trial period, except for week 6 where treatment LL differed significantly lower than treatments LM and HM and during week 9 only from treatment HM. A study done by Brown *et al.* (1958), used six different CP starters in two experiments (122 g CP/kg DM, 166 g CP/kg DM, 202 g CP/kg DM, 243 g CP/kg DM, 200 g CP/kg DM and 237 g CP/kg DM) to observe the growth performance of calves. However, no significant difference in wither height for these different treatments were observed. The lower muscle growth for treatment LL than for treatment HM can be ascribed to the lower volume of MR and CP starter feed. Cowles *et al.* (2006), also observed no significant differences in wither height of calves fed MR's varying in CP concentration (200 g CP/kg DM & 280 g CP/kg DM) and a starter feed of 250 g CP/kg DM. However, the calves fed the intensified MR tended to have greater wither heights.

Table 3.7 The effect of the treatment combinations on different growth parameters, feed conversion ratio and dry matter intake.

Item[1]	Treatments[2]						SEM[3]	P-value
	LL	LM	LH	HL	HM	HH		
Arrival weight (kg)	39.500	41.167	43.417	38.583	43.250	40.000	0.887	0.466
Final weight (kg)	74.750[a]	83.500[ab]	81.833[ab]	81.333[ab]	87.417[b]	83.583[ab]	1.418	0.012
ADG (kg)	0.592[b]	0.706[a]	0.640[ab]	0.713[a]	0.743[a]	0.727[a]	0.017	0.024
Gain over period (kg)	35.250[b]	42.333[a]	38.417[ab]	42.750[a]	44.167[a]	43.583[a]	1.015	0.017
Body length gain (cm)	12.167	13.667	11.333	12.000	13.000	13.333	0.625	0.683
Wither height gain (cm)	11.833	14.833	12.500	12.667	13.833	14.500	0.514	0.498
Hip height gain (cm)	12.667	15.000	12.667	13.167	13.16	15.000	0.509	0.274
Heart girth circumference gain (cm)	18.667	20.167	20.333	21.333	21.167	21.667	0.532	0.805
Head length increase (cm)	6.000	6.167	6.333	6.333	5.833	6.333	0.941	0.717
Head width increase (cm)	2.500	2.333	2.667	3.667	2.167	2.833	0.273	0.484
FCR	2.060[a]	1.835[b]	1.898[ab]	1.847[b]	1.936[ab]	1.855[ab]	0.030	0.041
DMI for starter feed (kg)	40.445[ac]	36.861[ac]	20.754[bc]	46.229[a]	44.384[a]	28.083[cb]	2.291	0.002
DMI for MR (kg)	32.562	40.972	51.871	32.438	40.976	51.977	1.346	0.856
Total DMI (kg)	73.007	77.833	72.626	78.668	85.360	80.060	1.869	0.974

[1] ADG- Average daily gain; FCR- Feed conversion ratio; DMI- Dry matter intake; MR- Milk replacer

[2] LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

[3] SEM- Standard error of mean

[a,b,c,d] Means within rows with different superscripts differ significantly ($P < 0.05$)

Hip height measurements of calves over the nine weeks are presented in Table **6.3** (Appendix). In week 1, the hip height of calves in treatment LL differed significantly lower (P < 0.05) from treatment HM. Week 2, 3 and 7 however showed no significant difference among the treatments. Week 4, 8 and 9 showed a significant difference between treatment LL and HM, where treatment LL is lower. Treatment HL and HM differed significantly (P < 0.05) from each other in week 5. The results of the study reported by (Jaeger *et al.*, 2020a), showed when calves were fed a control MR (0.52 kg/day, an accelerated MR (0.64 kg/day) and a high protein MR (0.64 kg/day, 260 g CP/kg DM), that hip height did not differ between the accelerated MR and the high protein MR. However, the hip height of the calves fed the control MR and high protein MR did differ. When calves were fed 4 L/day and 8 L/day, the hip height of the calves did not differ, but tended to be greater for calves fed 8 L/day (Burggraaf *et al.*, 2020). This suggests that the higher protein concentration and high milk volume do not play a role in the frame size, but in the BW of calves. However, feeding calves a higher MR volume (6 L/day) increased the hip height of the calves compared with feeding 4 and 9 L/day. Thus, a higher volume of MR than the conventional volume can improve the growth performance of calves. Although calves fed 9 L/day did not exhibit the greatest hip height, it was greater than calves fed 4 L/day.

Heart girth circumference of the calves over the nine weeks trial period are presented in Table **6.4** (Appendix). Treatment LL differed significantly (P < 0.05) from treatments HM and HH from weeks 6 to 9. During week 8 treatment HL and HM differed significantly from each other. Kazemi-Bonchenari *et al.* (2022), observed no difference in heart girth circumference when feeding differing volumes of MR (0.53 kg/day & 0.79 kg/day) and different CP starter feed (180 g CP/kg DM & 230 g CP/kg DM). The significant difference between treatment LL, HM and HH, can be attributed to the higher volumes of MR and the 260 g CP/kg DM concentration in the starter feed for calves fed treatment HM and HH.

Calf body length over the nine weeks trial period are presented in Table **6.5** (Appendix). During weeks 4 to 5 and 7 to 8 the LL treatment however differed significantly lower (P < 0.05) from HM treatment, as well as from treatment LM and HH in week 8. In a study by Kazemi-Bonchenari *et al.*, 2022), no difference was observed in the body lengths of calves when fed different volumes of MR (0.53 kg/day & 0.79 kg/day) and different CP starter feeds (180 g/kg & 230 g/kg CP). Makizadeh *et al.* (2020), observed no differences in body length when calves were fed a 180 g/kg CP and a 210 g/kg CP starter feed. The results of the current study indicate that calves fed the conventional volume (4 L/day) of MR with both CP starters had lower body lengths (P > 0.05) than the calves fed higher volumes of MR. Thus, feeding calves higher volumes of MR can improve the body lengths of the calves.

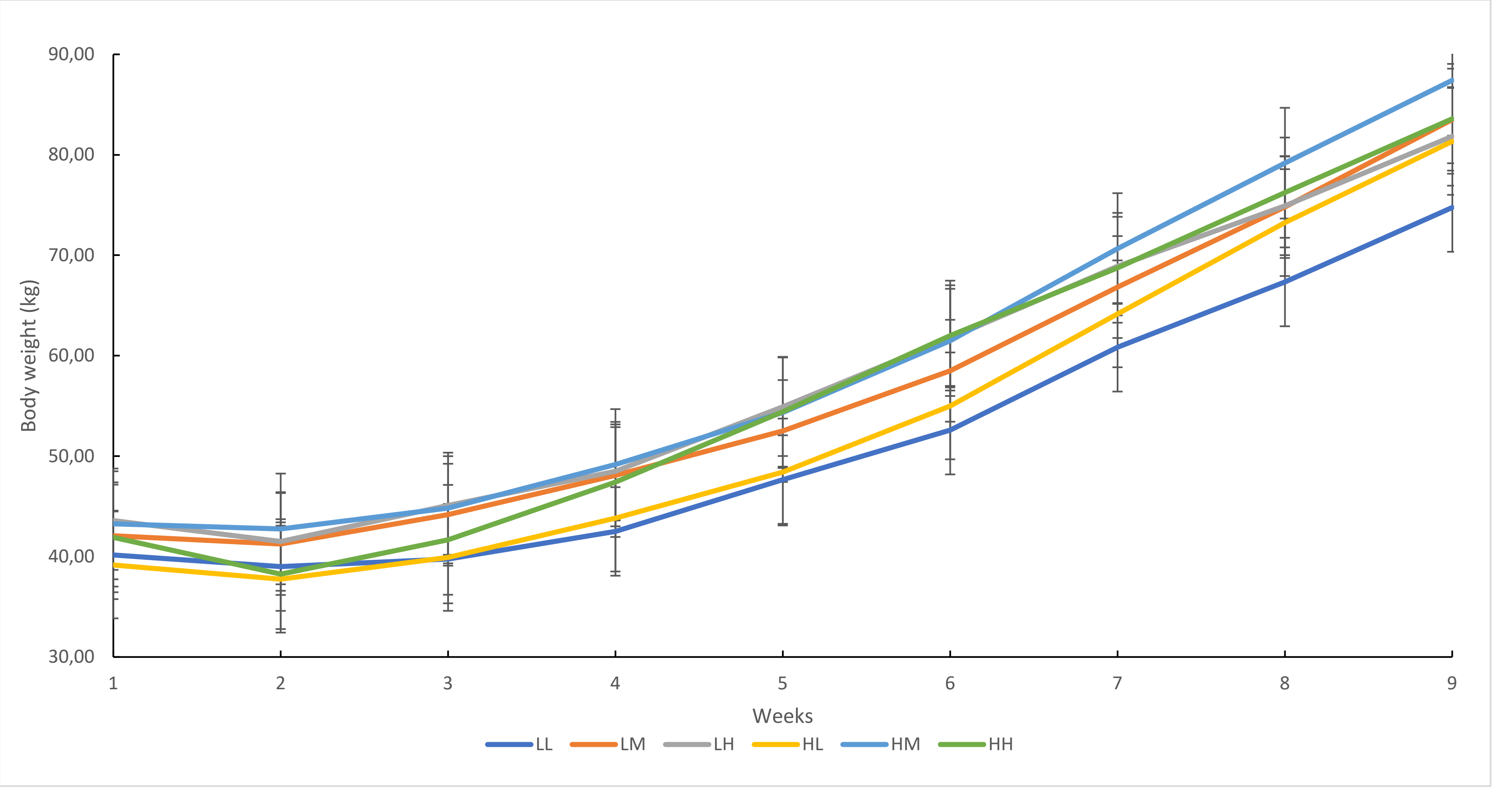

Figure 3.1 Body weight changes of the calves of the different treatments over the 9 weeks milk phase. (LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

3.5 Conclusion

The results of the study describe the response of dairy bull calves to increased MR volumes and increased CP concentrations in the starter feeds. Calves fed 6 L/day of MR had a significantly higher final weight than the calves that were fed 4 L/day of MR, while both did not differ from the groups fed 9 L/day of MR. The fact that the final weight did not increase with increasing MR intake can be attributed to the total DMI. The total DMI did not differ significantly between the different treatment groups. The FCR of treatment LL differed significantly higher from treatments LM and HL with treatment LM to be the most efficient treatment. Calves on a lower MR treatment compensated in terms of their DMI by a higher intake of starter feed leading to similar total DMI over all the groups. For this reason, no difference was observed between the growth parameters for the different MR volumes. The final weight of the calves fed the different CP starters also did not differ, however ADG and gain over period did differ over the entire feeding period. In this study the MR volume of 6 L/day combined with a 210 g CP/kg DM starter feed proved to be the treatment of choice.

3.6 References

Akayezu, J.M., Linn, J.G., Otterby, D.E., Hansen, W.P., & Johnson, D.G. 1994. Evaluation of calf starters containing different amounts of crude protein for growth of Holstein calves. J. Dairy Sci. 77, 1882–1889. https://doi.org/10.3168/jds.S0022-0302(94)77130-7.

Akins, M.S. 2016. Dairy heifer development and nutrition management. Vet. Clin. North Am. Food Anim. Pract. 32, 303–317. https://doi.org/10.1016/j.cvfa.2016.01.004.

ANKOM Technology. 2020. ANKOM200 fibre analyser operator's manual. 2052 O'Neil Rd, Macedon, NY, 145202, NY.

AOAC. 2002. Official methods of analysis of AOAC International. 17th ed. Association of Official Analytical Chemists, Arlington, Virginia, USA.

Appleby, M.C., Weary, D.M., & Chua, B. 2001. Performance and feeding behaviour of calves on ad libitum milk from arti®cial teats. Appl. Anim. Behav. Sci., 11. https://doi.org/10.1016/S0168-1591(01)00171-X.

Arthur, P.F., Archer, J.A., Johnston, D.J., Herd, R.M., Richardson, E.C., & Parnell, P.F. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. J. Anim. Sci. 79, 2805. https://doi.org/10.2527/2001.79112805x.

Bar-Peled, U., Robinzon, B., Maltz, E., Tagari, H., Folman, Y., Bruckental, I., Voet, H., Gacitua, H., & Lehrer, A.R. 1997. Increased weight gain and effects on production parameters of Holstein heifer calves that were allowed to suckle from birth to six weeks of age. J. Dairy Sci. 80, 2523–2528. https://doi.org/10.3168/jds.S0022-0302(97)76205-2.

Bartlett, K.S., McKeith, F.K., VandeHaar, M.J., Dahl, G.E., & Drackley, J.K. 2006. Growth and body composition of dairy calves fed milk replacers containing different amounts of protein at two feeding rates1. J. Anim. Sci. 84, 1454–1467. https://doi.org/10.2527/2006.8461454x.

Bartley, E.E. 1973. Effects of a self-fed pelleted mixture of hay and calf starter on the performance of young dairy calves. J. Dairy Sci. 56, 817–820. https://doi.org/10.3168/jds.S0022-0302(73)85255-5.

Berends, H., van den Borne, J.J.G.C., Stockhofe-Zurwieden, N., Gilbert, M.S., Zandstra, T., Pellikaan, W.F., van Reenen, C.G., Bokkers, E.A.M., & Gerrits, W.J.J. 2015. Effects of solid feed level and roughage-to-concentrate ratio on ruminal drinking and passage kinetics of milk replacer, concentrates, and roughage in veal calves. J. Dairy Sci. 98, 5621–5629. https://doi.org/10.3168/jds.2015-9367.

Berg, R.T., & Butterfield, R.M. 1966. Muscle: bone ratio and fat percentage as measures of beef carcass composition. Anim. Sci. 8, 1–11. https://doi.org/10.1017/S000335610003765X.

Blome, R.M., Drackley, J.K., McKeith, F.K., Hutjens, M.F., & McCoy, G.C. 2003. Growth, nutrient utilization, and body composition of dairy calves fed milk replacers containing different amounts of protein1. J. Anim. Sci. 81, 1641–1655. https://doi.org/10.2527/2003.8161641x.

Brown, L.D., Lassiter, C.A., Jr, J.P.E., Seath, D.M., & Rust, J.W. 1958. Effect of protein level in calf starters on the growth rate and metabolism of young calves. J. Dairy Sci. 41, 1425.

Brown, E.G., VandeHaar, M.J., Daniels, K.M., Liesman, J.S., Chapin, L.T., Keisler, D.H., & Nielsen, M.S.W. 2005. Effect of increasing energy and protein intake on body growth and carcass composition of heifer calves. J. Dairy Sci. 88, 585–594. https://doi.org/10.3168/jds.S0022-0302(05)72722-3.

Burggraaf, V.T., Craigie, C.R., Muir, P.D., Khan, M.A., Thomson, B.C., Knol, F.W., Lowe, K.A., Taukiri, K.R., Staincliffe, M., McDermott, A., Longhurst, R.D., & McCoard, S.A. 2020. Effect of rearing diet and early post-weaning pasture quality on the life-time growth, meat quality, carcass traits and environmental impact of dairy-beef cattle. Livest. Sci. 239, 104031. https://doi.org/10.1016/j.livsci.2020.104031.

De Carvalho, I.P.C., Reis, V.A., Leal, L. N., & Martín-Tereso, J. 2021. Increasing preweaning milk replacer supply affects postweaning energy metabolism of Holstein male calves. Animal 15, 100170. https://doi.org/10.1016/j.animal.2020.100170.

Chapman, C.E., Hill, T.M., Elder, D.R., & Erickson, P.S. 2017. Nitrogen utilization, preweaning nutrient digestibility, and growth effects of Holstein dairy calves fed 2 amounts of a moderately high protein or conventional milk replacer. J. Dairy Sci. 100, 279–292. https://doi.org/10.3168/jds.2016-11886.

Cowles, K.E., White, R.A., Whitehouse, N.L., & Erickson, P.S. 2006. Growth characteristics of calves fed an intensified milk replacer regimen with additional lactoferrin. J. Dairy Sci. 89, 4835–4845. https://doi.org/10.3168/jds.S0022-0302(06)72532-2.

Daneshvar, D., Khorvash, M., Ghasemi, E., & Mahdavi, A.H. 2017. Combination effects of milk feeding methods and starter crude protein concentration: Evaluation on performance and health of Holstein male calves. Anim. Feed Sci. Technol. 223, 1–12. https://doi.org/10.1016/j.anifeedsci.2016.10.025.

Diaz, M.C., Van Amburgh, M.E., Smith, J.M., Kelsey, J.M., & Hutten, E.L. 2001. Composition of growth of Holstein calves fed milk replacer from birth to 105-kilogram body weight. J. Dairy Sci. 84, 830–842. https://doi.org/10.3168/jds.S0022-0302(01)74541-9.

Donnelly, P.E., & Hutton, J. B. 1976. Effects of dietary protein and energy on the growth of Friesian bull calves: II. Effects of level of feed intake and dietary protein content on body composition. N. Z. J. Agric. Res. 19, 409–414. https://doi.org/10.1080/00288233.1976.10420968.

Drackley, J.K. 2008. Calf nutrition from birth to breeding. Vet. Clin. North Am. Food Anim. Pract. 24, 55–86. https://doi.org/10.1016/j.cvfa.2008.01.001.

Gerrits, W.J., Tolman, G.H., Schrama, J.W., Tamminga, S., Bosch, M.W., & Verstegen, M.W. 1996. Effect of protein and protein-free energy intake on protein and fat deposition rates in preruminant calves of 80 to 240 kg live weight. J. Anim. Sci. 74, 2129. https://doi.org/10.2527/1996.7492129x.

Ghaffari, M.H., Hammon, H.M., Frieten, D., Gerbert, C., Dusel, G., & Koch, C. 2021. Effects of milk replacer meal size on feed intake, growth performance, and blood metabolites and hormones of calves fed milk replacer with or without butyrate ad libitum: A cluster-analytic approach. J. Dairy Sci. 104, 4650–4664. https://doi.org/10.3168/jds.2020-18626.

Gilbert, R.P., Bailey, D.R.C., & Shannon, N.H. 1993. Body dimensions and carcass measurements of cattle selected for postweaning gain fed two different diets. J. Anim. Sci. 71, 1688–1698. https://doi.org/10.2527/1993.7171688x.

Hengst, B.A., Nemec, L.M., Rastani, R.R., & Gressley, T.F. 2012. Effect of conventional and intensified milk replacer feeding programs on performance, vaccination response, and neutrophil mRNA levels of Holstein calves. J. Dairy Sci. 95, 5182–5193. https://doi.org/10.3168/jds.2011-5261.

Hill, T.M., Bateman, H.G., Aldrich, J.M., & Schlotterbeck, R.L. 2007. Effects of the feeding rate of high protein calf milk replacers. Prof. Anim. Sci. 23, 649–655. https://doi.org/10.15232/S1080-7446(15)31036-6.

Hill, S.R., Knowlton, K.F., Daniels, K.M., James, R.E., Pearson, R.E., Capuco, A.V., & Akers, R.M. 2008. Effects of milk replacer composition on growth, body composition, and nutrient excretion in preweaned Holstein heifers. J. Dairy Sci. 91, 3145–3155. https://doi.org/10.3168/jds.2007-0860.

Hodgson, J. 1971. The development of solid feed intake in calves. 5. The Relationship between liquid and Solid Feed Intake. Anim. Prod. 13, 593–597. https://doi.org/10.1017/S0003356100000052.

Jacobson, N.L. 1969. Energy and protein requirements of the calf. J. Dairy Sci. 52, 1316–1321. https://doi.org/10.3168/jds.S0022-0302(69)86745-7.

Jaeger, B.M., Ziegler, D., Schimek, D., Ziegler, B., Chester-Jones, H., & Casper, D.P. 2020a. Dairy calf growth performance when fed a modified accelerated milk replacer program. Appl. Anim. Sci. 36, 352–366. https://doi.org/10.15232/aas.2019-01878.

Jaeger, B.M., Ziegler, D., Schimek, D., Ziegler, B., Raeth, M., Chester-Jones, H., & Casper, D.P. 2020b. Growth performance of newborn dairy calves fed a milk replacer with 2 protein concentrations at 2 feeding rates. Appl. Anim. Sci. 36, 48–56. https://doi.org/10.15232/aas.2019-01866.

Jafari, A., Azarfar, A., Alugongo, G.M., Ghorbani, G.R., Mirzaei, M., Fadayifar, A., Omidi-Mirzaei, H., Cao, Z., Drackley, J.K., & Hossieni Ghaffari, M. 2021. Milk feeding quantity and feeding frequency: effects on growth performance, rumen fermentation and blood metabolites of Holstein dairy calves. Ital. J. Anim. Sci. 20, 336–351. https://doi.org/10.1080/1828051X.2021.1884504.

Jasper, J., & Weary, D.M. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85, 3054–3058. https://doi.org/10.3168/jds.S0022-0302(02)74391-9.

Kazemi-Bonchenari, M., Khanaki, H., Jafari, A., Eghbali, M., Poorhamdollah, M., & Ghaffari, M.H. 2022. Milk feeding level and starter protein content: Effects on growth performance, blood metabolites, and urinary purine derivatives of Holstein dairy calves. J. Dairy Sci., S0022030221011097. https://doi.org/10.3168/jds.2021-21208.

Kertz, A.F., & Loften, J.R. 2013. Review: A historical perspective of specific milk-replacer feeding programs in the United States and effects on eventual performance of Holstein dairy calves. Prof. Anim. Sci. 29, 321–332. https://doi.org/10.15232/S1080-7446(15)30245-X.

Kertz, A.F., Hill, T.M., Quigley, J.D. (3rd), Heinrichs, A.J., Linn, J.G., & Drackley, J.K. 2017. A 100-Year Review: Calf nutrition and management. J Dairy Sci.100(12),10151-10172. https://doi: 10.3168/jds.2017-13062.

Khan, M.A. 2011. Invited review: Effects of milk ration on solid feed intake, weaning, and performance in dairy heifers. 94, 11.

Khan, M.A., Weary, D.M., & von Keyserlingk, M.A.G. 2011. Hay intake improves performance and rumen development of calves fed higher quantities of milk. J. Dairy Sci. 94, 3547–3553. https://doi.org/10.3168/jds.2010-3871.

Koch, C., Gerbert, C., Frieten, D., Dusel, G., Eder, K., Zitnan, R., & Hammon, H. M. 2019. Effects of ad libitum milk replacer feeding and butyrate supplementation on the epithelial growth and development of the gastrointestinal tract in Holstein calves. J. Dairy Sci. 102, 8513–8526. https://doi.org/10.3168/jds.2019-16328.

Labussiere, E., Dubois, S., van Milgen, J., Bertrand, G., & Noblet, J. 2008. Effects of dietary crude protein on protein and fat deposition in milk-fed veal calves. J. Dairy Sci. 91, 4741–4754. https://doi.org/10.3168/jds.2008-1203.

Labussiere, E., Maxin, G., Dubois, S., van Milgen, J., Bertrand, G., & Noblet, J. 2009. Effect of feed intake on heat production and protein and fat deposition in milk-fed veal calves. animal 3, 557–567. https://doi.org/10.1017/S1751731108003777.

Makizadeh, H., Kazemi-Bonchenari, M., Mansoori-Yarahmadi, H., Fakhraei, J., Khanaki, H., Drackley, J.K., & Ghaffari, M.H. 2020. Corn processing and crude protein content in calf starter: Effects on growth performance, ruminal fermentation, and blood metabolites. J. Dairy Sci. 103, 9037–9053. https://doi.org/10.3168/jds.2020-18578.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A., & Wilkinson, R.G. 2011. Animal Nutrition. Seventh Edition. Pearson.

Morrison, S.J., Wicks, H.C.F., Fallon, R.J., Twigge, J., Dawson, L.E.R., Wylie, A R.G., & Carson, A.F. 2009. Effects of feeding level and protein content of milk replacer on the performance of dairy herd replacements. animal 3, 1570–1579. https://doi.org/10.1017/S1751731109990437.

Niroumand, M., Rezayazdi, K., & Ganjkhanlou, M. 2020. Supplementation of Holstein dairy calves fed two levels of crude protein with methionine and lysine. South Afr. J. Anim. Sci. 50, 442–451. https://doi.org/10.4314/sajas.v50i3.11.

NRC. 2001. Ruminant nitrogen usage. National Academies Press, Washington, D.C.

Orellana Rivas, R.M., Komori, G.H., Beihling, V.V., Marins, T.N., Bernard, J.K., & Tao, S. 2019. Effects of milk replacer feeding levels on performance and metabolism of preweaned dairy calves during summer. J. Dairy Sci. 103, 313–324. https://doi.org/10.3168/jds.2019-17360.

Piao, M.Y., Ma, J.N., Diao, Q.Y., & Tu, Y. 2021. Effects of diets with different solid-to-liquid feed ratios with the same dry matter intake on the growth performance and gastrointestinal development of male Holstein calves. Anim. Feed Sci. Technol. 274, 114846. https://doi.org/10.1016/j.anifeedsci.2021.114846.

Qadeer, M.K., Bhatti, S.A., Nawaz, H., & Khan, M.S. 2021. Effect of milk or milk replacer offered at varying levels on growth performance of Friesian veal calves. Trop. Anim. Health Prod. 53, 290. https://doi.org/10.1007/s11250-021-02666-7.

Rauba, J., Heins, B.J., Chester-Jones, H., Diaz, H.L., Ziegler, D., Linn, J., & Broadwater, N. 2019. Relationships between protein and energy consumed from milk replacer and starter and calf growth and first-lactation production of Holstein dairy cows. J. Dairy Sci. 102, 301–310. https://doi.org/10.3168/jds.2018-15074.

Schäff, C.T., Gruse, J., Maciej, J., Mielenz, M., Wirthgen, E., Hoeflich, A., Schmicke, M., Pfuhl, R., Jawor, P., Stefaniak, T., & Hammon, H.M. 2016. Effects of feeding milk replacer ad libitum or in restricted amounts for the first five weeks of life on the growth, metabolic adaptation, and immune status of newborn calves (D Weary, Ed.). PLOS ONE 11, e0168974. https://doi.org/10.1371/journal.pone.0168974.

Sjaastad, Ø.V., Hove, K., & Sand, O. 2010. Physiology of domestic animals. (2nd ed.), Scandinavian Veterinary Press, Oslo.

Stamey, J.A., Janovick, N.A., Kertz, A.F., & Drackley, J.K. 2012. Influence of starter protein content on growth of dairy calves in an enhanced early nutrition program. J. Dairy Sci. 95, 3327–3336. https://doi.org/10.3168/jds.2011-5107.

Stamey Lanier, J., McKeith, F.K., Janovick, N.A., Molano, R.A., Van Amburgh, M.E., & Drackley, J.K. 2021. Influence of starter crude protein content on growth and body composition of dairy calves in an enhanced early nutrition program. J. Dairy Sci. 104, 3082–3097. https://doi.org/10.3168/jds.2020-19580.

Suarez-Mena, FX., Dennis, T. S., Aragona, KM., Hill, T.M., Quigley, J.D., & Schlotterbeck, R.L. 2021. Effects of feeding milk replacer at a moderate rate, ad libitum, or with a step-up program on Holstein calf growth performance to 4 months of age. J. Dairy Sci. 104, 7738–7748. https://doi.org/10.3168/jds.2020-19951.

Van Soest, P.J., Robertson, J.B., & Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2.

Wilson, L.L., Egan, C.L., & Terosky, T.L. 1997. Body measurements and body weights of special-fed Holstein veal calves. J. Dairy Sci. 80, 3077–3082. https://doi.org/10.3168/jds.S0022-0302(97)76277-5.

Yousefinejad, S., Fattahnia, F., Kazemi-Bonchenari, M., Khanaki, H., Drackley, J.K., & Ghaffari, M.H. 2021. Soybean oil supplementation and starter protein content: Effects on growth performance, digestibility, ruminal fermentation, and urinary purine derivatives of Holstein dairy calves. J. Dairy Sci. 104, 1630–1644. https://doi.org/10.3168/jds.2020-18823.

Chapter 4

Carry-over effects on post-weaning growth of calves fed varying levels of milk replacer and starter feed containing two different levels pre-weaning and related economics

4.1 Abstract

The aim of this study was to investigate the carry-over effects on the post-weaning growth of Holstein-Friesian steers fed different volumes of milk replacer and 2 different starter feeds during the pre-weaning period, as well as the related economics. Forty-two calves were randomly assigned to 6 treatment groups at the start of the pre-weaning period of 60 days. After weaning the calves were put on grazing for 80 days and their diet was supplemented with average 2 kg of concentrate feed per calf per day. Calves had ad libitum access to water. The treatments during the pre-weaning period were (1) 4 L of milk replacer (MR), 210 g/kg crude protein (CP) DM starter feed (LL); (2) 6 L of MR, 210 g CP/kg DM starter feed (LM); (3) 9 L of MR, 210 g CP/kg DM starter feed (LH); (4) 4 L of MR, 260 g CP/kg DM starter feed (HL); (5) 6 L of MR, 260 g CP/kg DM starter (HM) and (6) 9 L of MR, 260 g CP/kg DM starter feed (HH). The final weight of calves fed 4 L/day of MR, 210 g CP/kg DM *starter feed (LL), during the weaning phase differed significantly lower (P < 0.05) from the other pre-weaning treatments. The average daily gain (ADG) of the calves on all the other treatments did not differ significantly and were all ± 0.900 kg/day except for treatment LL where the ADG was 0.753 kg/day. During the 12 weeks of the trial no carry-over effects was observed for the treatments where high volumes of MR and a higher CP starter was fed, as the gain over the period did not differ significantly between the groups except for treatment LL. Treatment LL resulted in slower growth both during the pre-weaning and post-weaning period. The total cost of raising the calves differed significantly (P < 0.05) for all treatments and this difference was mostly the result of the feed cost during the pre-weaning phase. Treatment HL (4 L/day of MR, 260* g CP/kg DM *starter feed) was the most cost effective with the highest profit, while calves fed 9 L of MR resulted in the lowest profit.*

4.2 Introduction

The main reason for backgrounding post weaned calves is to meet the specifications and weight requirements of feedlots. Calves must reach a specific body weight (BW), body condition and frame size for optimal performance in the feedlot. In South Africa, a slower growth in a demand for animal protein is observed, however the Poultry Masterplan indicated a decline in the share of imported products for domestic consumption, together with export, leads to the growth of the beef industry (BFAB, 2022). According to BFAB (2022), the beef consumption per capita are expected to rise by 2031 by 0.8 kg. Therefore, improved efficiency, nutritional practices during the backgrounding phase has to improve (Dicker *et al.*, 2001). Globally, it is challenging for farmers to control the costs, ie., feed costs, purchase and selling price, to ensure a profitable operation. After weaning, calves are often backgrounded by placing them on grazing for a few months followed by a finishing period in the feedlot until slaughter weight is reached. The use of pasture, ie., Kikuyu and Rhodes grass, reduces feed costs and increases profit (Şentürklü *et al.*, 2018; Manafiazar *et al.*, 2015). A concentrate supplement can be fed to calves during the background period which ensures a more nutritionally balanced intake and is especially important during seasons when the pasture lacks energy or specific nutrients (Dicker *et al.*, 2001; Detmann *et al.*, 2014; McAllister *et al.*, 2020).

Dairy farmers can potentially improve their income by raising the bull calves and finishing them as steers (Bjorklund, 2013). Rutherford *et al.* (2021) reported that during backgrounding Holstein steers, grazing on pasture had an ADG of 0.800 kg. However, for calves to reach the latter ADG, the transitioning from pre- to post-weaning needs to be smooth, otherwise calves will experience a slump in ADG after weaning (Drackley, 2008; Drake, 2017). The rumen microbiome of calves are established during the pre-weaning period, whereas the post-weaning period is important to ensure profitable returns on calves and the diet should be formulated to maximize nutrient intake (Drackley, 2008; Drake, 2017).

Burggraaf *et al.* (2020) reported that during the post-weaning phase, calves that were fed more than 4 L/day of MR during the pre-weaning phase have a better ADG and feed conversion ratio (FCR). However, calves fed conventional MRs (4 L/day, 20 % CP), can show compensatory growth after weaning (Cowles *et al*., 2006). To observe the compensatory growth, the general post-weaning ADG should be less than 0.600 kg/day, otherwise it is difficult to observe (Greenwood & Cafe, 2007).

In contrast of the study done by Burggraaf *et al*. (2020), Kaiser (1976) reported slower growth post-weaning of calves that were fed higher volumes of MR during weaning. According to Kaiser (1976) the significant BW differences of the pre-weaned calves were no longer significant post-weaning as calves fed lower volumes of MR gain weight faster. The reason for the faster growth in calves fed lower MR volumes, could be as a result of better rumen development due to utilising the nutrients of the pasture better. No carry-over effect was therefore observed for calves fed higher volumes of MR during the post-weaning period (Kaiser, 1976).

Growth of calves fed varying CP concentration starters during the pre-weaning period, did not have an influence on the BW, ADG and the FCR of the calves during the post-weaning period (Daneshvar *et al*., 2017). Stamey Lanier, *et al*., (2021) fed calves a conventional starter feed(215 g CP/kg DM) and a high CP starter feed (260 g CP/kg DM) with a low and a high volume of MR. The results of this study was that the calves fed the high MR volume with the high CP starter feed were heavier and maintained their weight advantage post-weaning.

The objective of this study was to compare and evaluate the post-weaning growth performance and cost to benefit ratio of calves fed three different levels of milk replacer and two different starter feeds with different CP concentrations pre-weaning.

4.3 Materials and Methods

4.3.1 Ethical approval details

Ethical approval was obtained from the Animal Care and Use Ethics Committee of the University. The ethical approved reference number is: ACU-2020-17144.

4.3.2 Experimental location

The trial was executed at the Welgevallen Experimental Farm, Stellenbosch University (Western Cape, South Africa) on irrigated kikuyu pasture (*Pennisetum clandestinum*). The trial was executed in 2 blocks of 21 calves resulting in 7 repetitions per treatment. All animals were reared in a group with *ad libitum* access to grazing and the supplement supplied.

4.3.3 Experimental animals and diets

Forty-two Holstein bull calves, weaned at 60 days of age were used. Pre-weaning, groups of calves were individually fed three different volumes of MR and two different starter feeds with varying CP concentration. The treatments during the pre-weaning period were (1) 4 L of milk replacer (MR), 210 g CP/kg DM starter feed (LL); (2) 6 L of MR, 210 g CP/kg DM starter feed (LM); (3) 9 L of MR, 210 g CP/kg DM starter feed (LH); (4) 4 L of MR, 260 g CP/kg DM starter feed (HL); (5) 6 L of MR, 260 g CP/kg DM starter (HM) and (6) 9 L of MR, 260 g CP/kg DM starter feed (HH). During the trial calves received on average 2 kg DM/day of concentrate as supplement to the *ad libitum* pasture. The chemical composition of the concentrate supplied to calves is presented in Table **4.1**. The trial period was 80 days, thereafter calves were moved to a local feedlot for finishing before slaughter. The trial ended when calves were 140 days of age, when they were sold to a commercial feedlot at R30/kg live weight. The concentrate was formulated and supplied by a commercial feed company.

4.3.4 Proximate analysis methods of the finisher diet.

Proximate analysis was performed to determine the percentage moisture, ash, crude protein, crude fat, and crude fibre in the commercial supplement feed. The proximate analysis of the supplement feed is presented in Table **4.1**.

4.3.4.1 Moisture

Moisture was determined by the AOAC Official Method 934.01 (AOAC, 2002).

4.3.4.2 Ash

Ash was determined by the AOAC Official Method 942.05 (AOAC, 2002).

4.3.4.3 Crude Protein

Crude Protein was determined by the AOAC Official Method 990.03 (AOAC, 2002).

4.3.4.4 Crude Fat

Crude Fat was determined by the AOAC Official Method 920.39 (AOAC, 2002).

4.3.4.5 Neutral Detergent Fibre (NDF)

NDF was determined through the filter bag technique in an ANKOM A2000 fiber analyser according to the ANKOM NDF manual (ANKOM Technology, 2020).

Table 4.1 The chemical composition of the commercial concentrate fed during backgrounding phase.

	g/kg	
Item	Predicted	Actual
Crude Protein	140	137.90
Urea	10	
Moisture	120	125.40
Crude Fat	25	24.97
NDF		242.96
Crude Ash		44.50
Calcium (min)	120	
Calcium (max)	8	
Phosphorus	10	
Magnesium	2	
Sulphur	0,7	
Potassium	5,5	
Iron	45 mg/kg	
Copper	10 mg/kg	
Manganese	18 mg/kg	
Zinc	62 mg/kg	
Cobalt	0.2 mg/kg	
Iodine	0.52 mg/kg	
Selenium	0.12 mg/kg	

4.3.5 Statistical Analysis

The data was analysed with STATISTICA, version 13 (TIBCO Software Inc., 2017). Confidence levels of 5% was considered significant. A 3 x 2 factorial design was used to analyse the post-weaning weights of the treatments used in the pre-weaning phase to determine the carry-over effect.

A two-factor ANOVA was used to determine the effect of the starter feed and MR volume on the ADG, gain over period, and BW during the post-weaning period, as well as the margin over feed cost, cost of raising during pre-weaning and the total cost of raising. Data collected over time has been subjected to repeated measures ANOVA. Where the interaction was not significant, the two main effects were interpreted individually.

4.4 Results and Discussion

4.4.1 Effect of MR

The carry-over effect on final weight, ADG and gain over the period of the milk volume fed to calves pre-weaning as well as the profitability associated with the different treatments are presented in Table **4.2**. The initial weight at the start of the post-weaning phase differed significantly ($P < 0.05$) between calves fed 4 L/day and 6 L/day of MR, with 4 L/day lower. However, calves fed 4 L/day and 9 L/day of MR did not differ significantly. The initial weight of the calves fed 9 L/day of MR did not differ significantly from calves fed 6 L/day of MR. The initial weight of the calves fed 4 L/day of MR pre-weaning was the lowest and the highest for calves fed 6 L/day. The initial weights of calves were different as the same calves were used from the pre-weaning trial (Chapter 3). The initial weight of this trial was the final weight of the pre-weaning trial.

The final weight during the post-weaning period of calves fed 4 L/day differed significantly lower ($P < 0.05$) compared to calves fed 6 L /day of MR, but did not differ significantly between calves fed 4 L/day and 9 L/day of MR. The final weight of the calves fed 9 L/day of MR did not differ significantly from calves fed 6 L/day of MR (Table **4.2**). The results of the current study is in agreement with that of Uys *et al.* (2011) who reported that the growth rates of calves fed restricted volumes of MR or *ad libitum* during the weaning phase did not differ significantly during the post-weaning phase. Morrison *et al.* (2009) fed calves two different volumes of MR (5 and 10 L) and two different CP MR (210 g/kg DM and 270 g/kg DM) during the pre-weaning period. During the post-weaning period, no carry over effects were observed in the allometric growth measurements of the calves for the different treatments, which agrees with the current study.

In another study calves were fed MR at a volume of 5 L/day as well as *ad lib* (Miller-Cushon *et al.*, 2013). The results indicated that calves fed *ad lib* MR maintained a greater BW post-weaning, however there were no difference in ADG between the two MR volumes. In the current study, calves fed 6 and 9 L/day maintained their weight advantage during the post-weaning period. This can be due to the step-down weaning technique that was used to increase the starter feed intake of the calves. To observe a greater post-weaning BW when feeding greater volumes of MR, seems to depend on sufficient starter feed intake before weaning (Miller-Cushon *et al.*, 2013). Higher volumes of MR depressed the starter intake of the calves, therefore a weaning strategy, like mentioned above, is needed for calves to consume a sufficient amount of starter feed for rumen development to take place properly (Cowles *et al.* 2006), Otherwise weaning shock take place and calves loses weight directly after weaning.

The ADG and gain over period did not differ significantly between the MR groups (Table **4.2**). In contrast Leche (1971) reported that calves fed a low volume of MR had significantly slower growth during the post-weaning period than calves fed high volumes of MR. A reason for the latter study to observe slower growth after weaning could be due to insufficient starter feed intake which helps with rumen development. Another reason could be that the calves experienced weaning shock which causes more stress in calves fed high volumes of MR that are not gradually weaned (Enríquez *et al.* 2011). If the researcher made use of a step-down weaning program, calves would have consumed more starter feed. Thus, calves can have sufficient nutrient intake post-weaning. In a trial calves fed 4 L/day or *ad libitum* MR, showed that calves fed *ad libitum* were on average 10.5 kg heavier at weaning on day 35 than the calves fed the restricted volume of MR. After weaning the ADG of calves on both treatments slowed down but recovered by day 49. At this stage the ADG for both groups were the same but the calves fed *ad libitum* MR retained their weight advantage (Jasper & Weary, 2002). This result was confirmed by Hill *et al.* (2006), where calves were fed different volumes of MR pre-weaning, however the calves were more efficient during the pre-weaning period, compared to the post-weaning period. Therefore, higher volumes of MR did not influence the growth after weaning. During the current study, it was also observed that higher volumes of MR and higher CP concentrations in the starter feed did not significantly improve post-weaning weight gain, except for calves fed 4 L/day of MR and a 210 g/kg CP starter feed. This result can possibly be explained by pre-weaning nutritional restrictions that could have limited the capacity of the calves to exhibit compensatory growth and therefore achieved equivalent weight for age in later life (Greenwood & Cafe, 2007).

Total pre-weaning and post-weaning cost for the calves on the three levels of MR differed significantly ($P < 0.001$) with the 9 L/day MR group having the highest cost and the 4 L/day MR group the lowest with the weaning cost for the 6 L/day MR group was as expected intermediary. These findings is in agreement to that of Uys *et al.* (2011) who also reported that calves fed *ad libitum* MR had the highest weaning cost.

The profit yielded from 4 L/day and 6 L/day groups did not differ significantly, however the 6L/day group differed significantly ($P < 0.05$) higher than the 9 L/day group. The highest profit was made from the 6 L/day group and the least profit was made from the 9 L/day group respectively (Table **4.2**). The elevated weaning cost of the 9 L/day MR group to all likelihood eroded the profit because no advantage in ADG compared to other groups could be established. When raising calves with higher MR volumes, the economics around it should always be considered. Higher volumes of MR increase the feed costs (Hu *et al.*, 2020). In Chapter 3, it was observed that the starter DMI decrease when high volumes of MR were fed, however the total DMI of calves did not differ significantly, except for treatment LL that differed from treatment HM. Therefore, with the similar total DMI, the cost of raising calves with MR volumes higher than the conventional volume increases the costs significantly. The increased in costs of raising when feeding 9 L/day, decreases the profit margin numerically as seen in Table **4.2**. In a study done by Hu *et al.* (2020), it was observed that it is economically more feasible to feed calves a moderate volume of MR (0.64 to 0.66 kg of DM/day) rather than a higher volume (0.92 to 1.07 kg of DM/day). In this study, calves had a favourable ADG with greater starter intake which was beneficial for rumen development. In another study, it was seen that total feed costs were significantly higher when an intensified MR (306 g CP/kg DM) were fed instead of feeding a conventional MR (215 g CP/kg DM) (Davis Rincker *et al.*, 2011). However, considering other factors like weight gain and milk yield, caused by the two programs, the results did not differ significantly. This study indicated that farmers could consider both programs based on their management. In the current study, it was more profitable feeding 4 L/day and 6 L/day. Raeth-Knight *et al.* (2009), observed feeding calves a conventional MR had the lowest feed cost, as well as the lowest feed cost per kg of BW gain.

4.4.2 Effect of starter feed

The carry-over effect of the different protein concentrations in the starter feed during the post-weaning phase on the weights, ADG, total gain over period and the profitability for the different treatments are presented in Table **4.3**. Initial weight, final weight, ADG, total gain over period, income and profit did not differ significantly between the groups. Obeidat *et al.* (2013), observed that the overall growth performance of the calves was enhanced during the pre-weaning period when a high plane of nutrition (747 and 1.010 g/day DM of a 280 g CP/kg DM MR) were fed. During the immediate post-weaning period no carry-over effects were observed for the calves fed a high plane of nutrition. Akayezu *et al.* (1994), fed calves different CP concentration starter feeds from 4 to 56 days of age. The CP concentrations were 150 g/kg DM, 168 g/kg DM, 196 g/kg DM or 224 g/kg DM. During the pre-weaning period, the ADG increased linearly with increasing CP in the starter feed, however, after weaning the calves fed a 196 g CP/kg DM starter feed had the best growth performance. This study indicates that there was no advantage gained from the 224 g CP/kg DM starter feed. These results agrees to that reported Daneshvar *et al.* (2017) who also did not observed any advantages of feeding higher CP levels during the post-weaning phase in bull calves. Stamey *et al.* (2012), fed calves during the pre-weaning period a conventional MR (4 L/day) with a conventional starter feed (200 g CP/kg DM MR, 196 g CP/kg DM starter feed) and an enhanced MR with a high CP starter feed (285 g CP/kg DM MR, 255 g CP/kg DM starter feed). The post-weaning period BW of calves fed the enhanced MR with a high CP starter feed were greater than that of the other treatment group.

During the current study no significant improvement in BW was observed during the post-weaning period when a starter with 260 g CP/kg DM compared to a 210 g CP/kg DM was fed during the pre-weaning period. This result was not unexpected given the final weight of the pre-weaning phase did not differ between CP levels of starter feed (Table **4.3**). Previous studies, indicate a lack of compensatory growth when calves are reared on restricted diets or low plane diets (Wardrop, 1966; Kaiser, 1976). With calves that experience severe nutritional insults, during the pre-weaning period, the capacity to express compensatory growth is limited and they do not achieve the same weight as other treatment groups that had received a high plane of nutrition (Burggraaf *et al.*, 2020).

However, in the current study the growth restrictions of the calves fed 4 L/day with the 210 g/kg CP starter feed were not severe, but the impact of feeding a lower plane diet were maintained during the post-weaning period. Another reason for no differences, could be that all the treatments received the same supplemented feed and pasture during the post-weaning period which might not have provided enough nutrients for optimal compensatory growth for the calves that had received the 210 g CP/kg DM starter feed during the pre-weaning period. However, the weight advantage of the calves fed the 260 g CP/kg DM starter feed pre-weaning, were maintained during the post-weaning period.

As can be seen in Table **4.3**, the combined cost of the pre-weaning and post-weaning phases differed significantly (P < 0.001 and P = 0.019) between the groups with the group fed the starter feed containing 260 g CP/kg DM having the highest cost. Despite not significant, this group also had the best numeric profit margin at the end of the post-weaning phase. The higher (P < 0.001) cost of the 260 g CP/kg DM starter feed, animals were partially offset by the tendency (P < 0.096) to higher ADG (especially during the liquid phase) to render numerically higher profit values compared to the 210 g CP/kg DM starter feed fed animals (Table **4.3**).

Table 4.2 The carry-over effect on growth during the post-weaning phase of the milk volume fed during pre-weaning and the associated effect on economic parameters.

Item[1]	Milk volume[2]			SEM[3]	P-value
	4 L	6 L	9 L		
Starting weight (kg)	79.500[a]	91.042[b]	86.167[ab]	2.082	0.700
Final weight (kg)	146.167[a]	163.000[b]	156.250[ab]	2.990	0.051
ADG (kg)	0.833	0.900	0.876	0.020	0.381
Gain over post-weaning period (kg)	66.667	71.958	70.083	1.627	0.381
Income (R/head)	4385.00[a]	4890.00[b]	4687.50[ab]	89.70	0.051
Profit (R/head)	1979.46[ab]	2172.97[b]	1699.40[a]	84.13	0.056
Cost of raising (pre-weaning) (R/head)	1555.54[a]	1757.03[b]	2028.10[c]	42.76	< 0.001
Total cost of raising (over 140 days) (R/head)	2405.54[a]	2717.03[b]	2988.10[c]	42.76	< 0.001

[1] ADG- Average daily gain

[2] 4 L/day- LL & HL; 6 L/day- LM & HM; 9 L/day:-LH & HH

[3] SEM-Standard error of mean

[a,b,c] Means within rows with different superscripts differ significantly ($P < 0.05$).

Table 4.3 The carry-over effect of two different protein concentrations fed during weaning on growth parameters during the post-weaning phase and different costs associated with these treatments during the pre-weaning and post-weaning phases

Item[1]	Protein concentration[2]		SEM[3]	P-value
	210 g/kg	260 g/kg		
Starting weight (kg)	82.194	88.944	2.082	0.096
Final weight (kg)	150.722	159.566	2.990	0.112
ADG (kg)	0.857	0.883	0.020	0.510
Gain over period (kg)	68.527	70.611	1.627	0.507
Income (R/head)	4521.67	4786.67	89.70	0.112
Profit (R/head)	1866.42	2034.81	84.13	0.284
Cost of raising (pre-weaning) (R/head)	1695.25[a]	1791.86[b]	42.76	<0.001
Total cost of raising (over 140 days) (R/head)	2655.25[a]	2751.86[b]	42.76	0.019

[1] ADG-Average daily gain

[2] 210 g CP/kg DM- LL & LM & LH; 260 g CP/kg DM- HL & HM & HH

[3] SEM- Standard error of mean

4.4.3 Interaction of starter feed and MR

The carry-over effect of the different pre-weaning treatments during the post-weaning phase alone on the BW, ADG, gain over period and the profitability associated with calf raising are presented in Table **4.4.** The starting weight of LL was significantly (P < 0.05) lower compared to the HM treatment while the LM, LH, HL and HH treatments did not differ significantly (Table **4.4**). These differences could be attributed to the growth differences of the bulls during the pre-weaning phase as described and discussed in Chapter 3.

The LL treatment also led to significantly (P < 0.05) lower final weight than animals from LM, LH, HL, HM and HH treatments. No differences in final weight between LM, LH, HL, HM and HH treatments were observed. At the start of the post-weaning phase, calves fed moderate volumes (6 L/day) of MR had heavier weights than calves fed a low volume of MR as can be seen from the differences in starting weight as shown in Table **4.2**. Considering all treatments, only the LL treatment resulted in significant (P < 0.05) lower final weights post-weaning (Table **4.4**) and could be attributed to the numerically lower starting weight of the animals during the post-weaning period. Investigating the post-weaning growth performance of dairy calves, Dennis *et al.* (2018) and Klopp *et al.* (2020) also reported little effect of pre-weaning treatment on final weight at 4 months of age. Murphy *et al.* (2017) reported that calves fed 1.8 kg DM supplemented feed per head while grazing were heavier (P < 0.05) than calves that only grazed on pasture. It therefore seems that post-weaning production was not influenced by pre-weaning treatment.

The ADG of the LL treatment were during the post-weaning period were significantly (P < 0.05) lower that of the LM, LH and HL treatments but did not differ significantly from HM and HH treatments while the LM, LH, HL, HM and HH treatments did not differ significantly from one another (Table **4.4**). Contrary to results reported by Kaiser (1976) where calves fed high volumes of MR during the pre-weaning period, resulted in slower growth during the first 8 weeks post-weaning. In the current study calves fed higher volumes of MR did not grow slower than calves fed 4 L/day of MR except when the calves received a 210 g CP/kg DM starter feed (Table **4.4**).

The difference in result can be attributed to a more gradual weaning strategy. According to Enríquez *et al.* (2011) a more gradual weaning process reduces weaning shock with associated stress and minimizes any reduction in animal performance post-weaning. In contrast to the current trial and that of Kaiser (1976), Rosenberger *et al.* (2017) reported that calves fed higher volumes of MR during pre-weaning phase had greater weight gain than calves fed lower volumes. In contrast, Ungerfeld *et al.* (2009) reports that weaning stress or shock appears to be greater in calves that consumes more MR or whole milk. This could however not be established in the current study. In the current study the calves did not lose their weight advantage and all groups except the LL group resulted in a similar ADG during the post-weaning period (Table **4.4**). The lower growth rate of the LL group during the pre-weaning period also carried over to a lower (P < 0.05) ADG in the post-weaning period compared to all other treatments. In the current study the calves were weaned using a step-down method ensuring an adequate intake of starter feed before weaning and they consumed on average 2 kg of supplementary feed while grazing. According to Lorenz (2021) a step-down approach allows calves to sustain growth during post-weaning without weaning stress and any adverse effects. In trials where calves were not weaned using a step-down method, and where they were fed high volumes of MR, the calves lost their respective weight advantage during the post-weaning period as they could not consume the same amount of feed as the other group of calves (Huuskonen & Khalili, 2008; Klopp *et al.*, 2020).

Body weight gain over period for the LL treatment were significantly (P < 0.05) lower than that of LM, LH and HL treatments, but did not differ from HM and HH treatments (Table **4.4**). The LM, LH, HL, HM and HH treatments did not differ from one another. The lower weight gain observed with the LL treatment was expected as ADG were also lower. In general, results of the current study agrees to that of Qadeer *et al.* (2021), who reported post-weaning growth that did not differ between calves fed different volumes of MR during the pre-weaning period. Pre-weaning treatment therefore had little effect on post-weaning growth possibly due to the efficient ruminal development during the pre-weaning phase of all treatments (Diao *et al.,* 2019).

The income for LL treatment group were also significantly (P < 0.05) lower than that of the LM, LH, HL, HM and HH treatment groups. The income for the LM, LH, HL, HM and HH treatment groups however did not differ (Table **4.4**). The lower income of the LL group was not surprising given the relative lower final weights. Both the 6 L/day groups MR (LM and HM) resulted in the highest income (Table **4.2** and Table **4.4**).

The profit per animal for the LL and HH treatment groups were significantly lower (P < 0.05) than treatment HL but did not differ significantly from the other treatment groups (Table **4.4**). This result of treatment LL is a direct effect of lower starting weight, ADG, final weight and income.sThe HL group resulted in numerical the highest profit and the HH treatment group the lowest (P < 0.05; Table **4.4**). Despite rendering the lowest (P < 0.05) profit of all treatments, the LL treatment did not result in the lowest profit as the cost of rearing of both the pre-weaning period as well as total rearing cost were significantly lower than all other treatments offsetting poorer growth and income. Rearing calves with a high-quality pasture, improves their growth and reduces the time to slaughter, but according to Burggraaf *et al.* 2020) profitability still depends on the MR volume and starter intake during the pre-weaning period, as well as the beef weaner prices. In the current study pre-weaning treatment directly affected profitability. The reason why the greatest profit was achieved with the HL treatment could be due to feeding a conventional volume of MR (4 /day) with a 260 g CP/kg DM starter feed in the pre-weaning period. These calves had the numeric the greatest starter DMI (46.229 kg- Table **3.7** in Chapter 3) during the pre-weaning period. This could have resulted in better rumen development. After weaning, pasture intake is limited by the rumen capacity therefore the growth rate increases when the rumen is better developed as this improves nutrient intake and utilization (Burggraaf *et al.*, 2020).

Feeding higher MR volumes increases total feed costs. The profitability of rearing calves' changes during the seasons as the feed costs and the meat market price per kg varies. When the

MR volume are increased, the total cost of raising increases, however the higher volumes can result in a lower cost per kg gain (Hawkins *et al.*, 2019). In a simulation model study by Hawkins *et al.* (2019), calves in individual housing were the most expensive to rear as the cost of bedding was included in the calculation. In the current study bedding was not included in the calculations of the profitability. The profitability was only calculated for the different treatments. Brown *et al.* (2005), reported that it was more costly to feed high protein MR with a high protein starter feed (303 g CP/kg DM MR, 250 g CP/kg DM starter feed) than feeding a standard MR with standard starter feed (205 g CP/kg DM). The higher costs of raising calves with the high protein diet was mainly due to the increased level of protein which increased the cost. However, the final BW of the calves on the high protein MR and starter feed were higher and this reduced the cost of gain per kg. Thus, feeding higher protein have the potential to decrease the slaughter age of the calves.

In the current study, it was observed that calves were fed 4 and 6 L/day of MR with a 260 g CP/kg DM starter feed, tended to have greater profitability due to greater final BW during the pre-weaning trial which reduced the cost per kg BW gain. El-Nahrawy (2021) reported that the cost of gain per kg BW were significantly higher when calves received a higher volume of MR and less starter feed (78.34% MR + 11.68% starter feed + 9.98% berseem hay) in comparison to a lower volume of MR and a higher amount of starter feed (72.49% MR + 19.62% starter feed + 7.89% berseem hay). This study indicated that the economic efficiency as a ratio of weight gain and feed cost were 27.21% higher for the lower volume of MR and starter feed than the higher volume of MR (El-Nahrawy, 2021). This finding is in line with that observed by Raeth-Knight *et al.* (2009) who reported that feeding lower volumes of MR were more cost effective than feeding higher volumes of MR.

Total pre-weaning and total weaning cost differed significantly ($P < 0.001$) for all the treatments and mirrored each other. The cost for the HH treatment was the highest and for the LL treatment was it the lowest (Table **4.4**). The high cost of the HH treatment can be attributed to the larger volume of MR fed and conversely the lower cost of the LL treatment can be attributed to the smaller volume of MR fed (Table **4.2**) as the different concentrations of CP in the starter had no effect on the total rearing cost (Table **4.3**). According to Finneran *et al.* (2012) and Ashfield *et al.* (2014) feed cost is minimised when calves are backgrounded on quality grazing exclusively and this generally improves profitability. Several different strategies to wean dairy and dairy cross calves can be adopted. One strategy is to background the calves on pasture without supplementation, another strategy is to background calves on pasture with supplementation, albeit adapting the latter to optimize for the season (Dicker *et al.*, 2001; Poppi *et al.*, 2018). The latter strategy is to make use of a concentrate and using this for both backgrounding and finishing. A feedlot phase, with high levels of concentrate (Mwansa *et al.,* 1992), normally follows a background phase (Şentürklü *et al.,* 2021). According to both Dicker *et al.* (2001) and Poppi *et al.* (2018) the most cost-effective background strategy for dairy cattle and dairy crosses is grazing with supplementation.

As depicted in Table **4.4**, treatment HL was the most cost effective. This treatment was most profitable and had numerical the second lowest total cost. For farmers rearing dairy bull calves under similar conditions, it can be expected that this strategy might be the most profitable.

In this trial no carry-over effect was observed as total weight gain, ADG and final weight did not differ between treatments. Treatment group LL had the lowest initial and final weight, ADG and gain over period. In this group no post-weaning compensatory growth was observed as the average weight gain of this group remained lower than for the other groups. Compensatory growth in calves have been reported during the finishing period for calves previously fed a restricted diet but not to the extent where the calves reached the same final weight than calves that did not suffer a nutritional stress during weaning (Silva *et al.,* 2020). The observed significantly lower ADG during the post-weaning period for the group of calves on the LL treatment can be explained in terms of the nutritional insult caused by the LL treatment during the pre-weaning period. The fact that the post-wean ADG of the HM and HH group did not differ significantly from the LL group was not expected. It can perhaps be an anomaly due to the specific conditions during the post-weaning phase where the average initial weight of these groups was above the average for all the groups.

Treatment group LM had numerical a lower ADG during the pre-weaning period but performed better during the post-weaning period with the greater ADG (Table **4.4**). The greater ADG during the post-weaning can perhaps be attributed to the more advanced rumen development during the pre-weaning period caused by the moderate volume of MR (6 L/day) and greater starter feed intake. Rumen development is better when more starter feed is consumed by calves (Baldwin *et al.*, 2004; Govil *et al.*, 2017). Therefore, the calves could digest the pasture and supplemented feed better than the calves of the other treatments. During the pre-weaning period, treatment LM consumed 36.861 kg of starter feed DMI. Thus, another reason can be that compensatory growth took place during the post-weaning period which compensated for the slower growth during the pre-weaning period.

Calves on treatment LH did not perform well during the pre-weaning period but during the post-weaning period their growth performance improved. Koch *et al.* (2019) and Stamey Lanier *et al.* (2021) in similar trials with dairy bull calves attributed the improved ADG during the post-weaning period to effective step-down weaning as this increases the starter intake (Mirzaei *et al.,* 2020) and improves rumen development (Wickramasinghe *et al.,* 2021).

During the pre-weaning period, the HL treatment group had a better ADG than the treatments groups fed the starter with the lower CP (210 g CP/kg DM). The better growth performance of the HL calves during the pre-weaning period can be attributed to the higher CP intake. These results are in agreement to that of Bartlett *et al.* (2006) also reported improved growth parameters including ADG and BW when higher levels of CP concentration in the starter feed were fed. In contrast, despite improved ADG of calves fed higher levels of MR, Stamey Lanier *et al.* (2021) reported no differences in ADG when calves were fed higher CP levels.

Table 4.4 The carry-over effect of the different treatments fed pre-weaning during the post-weaning phase on growth parameters and the different costs associated with raising calves during the pre-weaning and post-weaning phases.

Item[1]	Treatments[2]						SEM[3]	P-value
	LL	LM	LH	HL	HM	HH		
Starting weight (kg)	74.250[b]	87.667[ab]	84.667[ab]	84.750[ab]	94.417[a]	87.667[ab]	2.082	0.044
Final weight (kg)	134.500[b]	161.167[a]	156.500[a]	157.833[a]	164.833[a]	156.000[a]	2.990	0.046
ADG (kg)	0.753[b]	0.919[a]	0.898[a]	0.913[a]	0.880[ab]	0.854[ab]	0.020	0.028
Gain over period (kg)	60.250[b]	73.500[a]	71.833[a]	73.083[a]	70.417[ab]	68.333[ab]	1.627	0.027
Income (R/head)	4035.00[b]	4835.00[a]	4695.00[a]	4735.00[a]	4945.00[a]	4680.00[a]	89.70	0.046
Profit (R/head)	1677.06[a]	2169.46[ab]	1752.73[ab]	2281.86[b]	2176.49[ab]	1646.07[a]	84.13	0.028
Cost of raising (pre-weaning) (R/head)	1397.94[a]	1705.54[b]	1982.27[c]	1493.14[d]	1808.51[e]	2073.93[f]	42.76	< 0.001
Total cost of raising (over 140 days) (R/head)	2357.94[a]	2665.54[b]	2942.27[c]	2453.14[d]	2768.51[e]	3033.93[f]	42.76	< 0.001

[1] ADG- Average daily gain

[2] LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

[3] SEM- Standard error of mean

[a,b,c,d,e,f] Means within rows with different superscripts differ significantly ($P < 0.05$).

Treatment group HM had numerical the highest final weight at the end of both the pre- and post-weaning periods. As this group received a high intake of MR during the pre-weaning period combined with the starter feed with 260 g CP/kg DM, rumen development could have been impaired resulting in poorer performance during the post-weaning period. During the pre-weaning phase the ADG for the HH group was higher than for the LH treatment group, which was also fed the highest volume of MR. The ADG for the HH group was also numerical higher compared to the groups fed starter feed with the lower CP concentration. The growth during the post-weaning period was numerical the second lowest, indicating that the high volume of MR and high CP concentration starter also impaired growth during the post-weaning period.

The weekly post-weaning average BW of the groups of calves treated during the pre-weaning period is presented in Figure **4.1**. Group HM had a significantly higher ($P < 0.05$) initial weight and although their weekly gain did not differ significantly from the other groups, they retained their weight advantage to a large degree. By week 7 most of other treatment groups except for the LL treatment group changed from being significantly different from the HM group while still not significantly different from LL group. By week 7 group LM changed from not being significantly different from the LL group to not being significantly different from the HM group. By week 11 all the groups except for group LL were not significantly different and this pattern remained constant for the remainder of the trial period.

The weekly post-weaning BW gain of the treatment as described during the pre-weaning period are presented in Table **4.5**. During weeks 2 to 8 and 10 to 12, there were no significant differences observed between any treatments, however during week 9 of the post-weaning period the BW gain the animals who received treatment LL during the pre-weaning period was significantly ($P < 0.05$) lower from that of treatment HM. The step-down weaning method caused those calves fed higher volumes of MR during the pre-weaning period to consumed more starter feed before weaning (Khan *et al.*, 2007). This reduced the ADG slump after weaning, therefore the weekly gain of the calves did not differ during the post-weaning period. The higher starter feed consumption after stepping the MR volume down, causes greater rumen development. Rumen development during the post-weaning period is important as the only nutrients the calves received is from pasture or concentrates which should be degraded by the rumen. A reason for the lower weekly gain of calves on treatment LL could be due to a reduction of pasture intake or that treatment HM had greater pasture intake which increased the weekly gain. As no further significant differences were observed during the remainder of the post-weaning period, it is therefore difficult to explain the latter difference. The general absence of any differences in post-weaning weekly gain over the trial period between pre-weaning treatments highlights the importance of pre-weaning growth. It indicates that calves tended to maintain the advantage in weight achieved in the pre-weaning period during the post-weaning period.

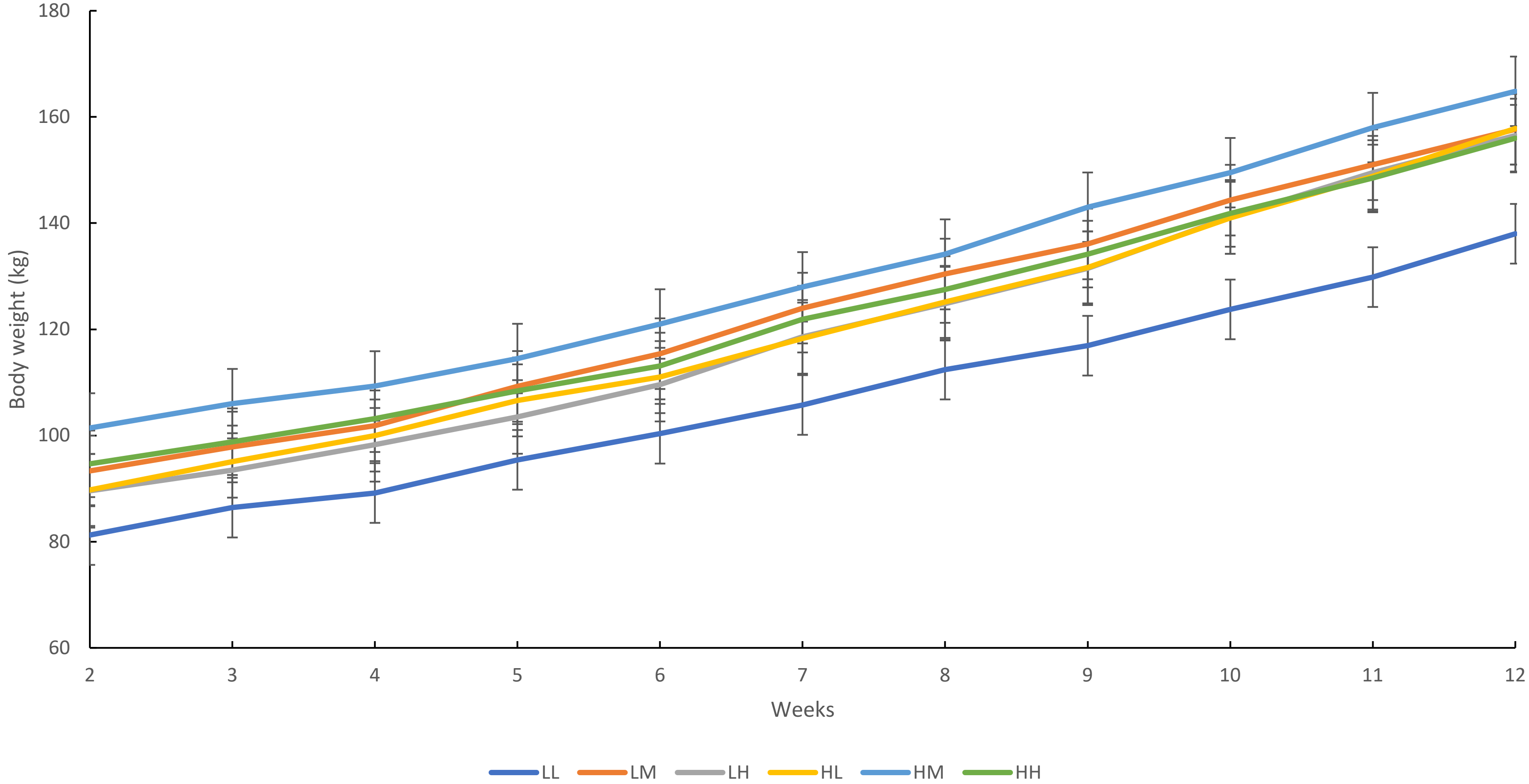

Figure 4.1 Body weight changes during the 12 weeks post-weaning period for the different groups of calves during the pre-weaning period (LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR.

Table 4.5 Post-weaning weekly gain over a 12 week period, for the different groups (pre-weaning treatments) of calves over a 12 weeks period.

		Treatments[1]						SEM[2]	P-value
Item	Week	LL	LM	LH	HL	HM	HH		
Weekly gain (kg)	2	5.750	6.917	4.917	5.000	7.000	7.000	2.833	0.476
	3	5.167	4.500	3.917	5.333	4.583	4.167	3.518	0.991
	4	2.750	4.000	4.750	4.917	3.333	4.333	2.540	0.352
	5	6.250	7.417	5.250	6.417	5.167	5.250	2.349	0.390
	6	4.917	6.167	6.083	4.583	6.500	4.667	2.719	0.746
	7	5.417	8.583	9.000	7.250	7.000	8.833	3.001	0.372
	8	6.667	6.417	6.250	6.917	6.167	5.583	3.278	0.950
	9	4.500[a]	5.667[ab]	6.667[ab]	6.500[ab]	8.833[b]	6.667[ab]	3.351	0.507
	10	6.833	8.250	9.667	9.333	6.500	7.667	3.492	0.233
	11	6.083	6.66	8.333	7.833	8.500	6.667	3.148	0.977
	12	8.167	6.667	7.000	9.000	6.833	7.500	3.574	0.977

[1] LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

[2] SEM- Standard error of mean

[a,b] Means within rows with different superscripts differ significantly ($P < 0.05$).

4.5 Conclusion

The study evaluated growth response in calves during the background phase and possible carry-over effects of three different MR levels, as well as two levels of CP in starter feed fed pre-weaning. During this phase ADG and BW gain for the different treatment groups over the period was similar except for calves fed treatment LL that were fed 4 L/day of MR and a 210 g CP/kg DM starter feed. The final weight of the different treatment groups of calves did not differ significantly except for the LL treatment group. The result confirms that in this trial there was no advantageous carry-over effect for the calves fed either 6 L/day or 9 L/day of MR but that the heavier groups (treatments LM, LH, HL and HM) tended to maintain their weight advantage during the post-weaning period. The additional cost of feeding 9 L/day of MR could not be justified with the profit obtained from the calves as these treatments were lower compared to other treatments. Total raising cost of the calves on the different treatments differed significantly among the treatments. Treatment HL was numerical the most cost-effective with the highest profit due to the lower raising costs. Elevated profit could be ascribed to favourable growth response during the pre-weaning period due to the interaction of feeding 4 L/day of MR and a 260 g CP/kg DM starter feed. The profitability of raising calves is dependent on MR volume and the costs thereof, as well as the starter feed and post-weaning supplementation feed prices. The beef weaner prices also have an effect on the profitability as meat prices changes regularly. Under different economic and environmental conditions profitability might however change.

4.6 References

Akayezu, JM., Linn, J.G., Otterby, D. E., Hansen, WP., & Johnson, D.G. 1994. Evaluation of calf starters containing different amounts of crude protein for growth of Holstein calves. J. Dairy Sci. 77, 1882–1889. https://doi.org/10.3168/jds.S0022-0302(94)77130-7.

AOAC. 2002. Official methods of analysis of AOAC International. 17th ed. Association of Official Analytical Chemists, Arlington, Virginia, USA.

Ashfield, A., Wallace, M., Prendiville, R., & Crosson, P. 2014. Bioeconomic modelling of male Holstein-Friesian dairy calf-to-beef production systems on Irish farms. Ir. J. Agric. Food Dev. Auth. 53, 133–147.

Baldwin, RL., McLeod, K.R., Klotz, J.L., & Heitmann, R.N. 2004. Rumen development, intestinal growth and hepatic metabolism in the pre- and postweaning ruminant. J. Dairy Sci. 87, E55–E65. https://doi.org/10.3168/jds.S0022-0302(04)70061-2.

Bartlett, KS., McKeith, F.K., VandeHaar, M.J., Dahl, G.E., & Drackley, J.K. 2006. Growth and body composition of dairy calves fed milk replacers containing different amounts of protein at two feeding rates1. J. Anim. Sci. 84, 1454–1467. https://doi.org/10.2527/2006.8461454x.

BFAB. 2022. Baseline Agricultural outlook, 2022-2031. Accessed 07 November 2022. ht https://baseline.bfap.co.za/wp-content/uploads/2022/08/BFAP-BASELINE-2022-ONLINE-Final.pdf.

Bjorklund, E.A. 2013. Management and economics of group-fed dairy calves and dairy steers in an organic production system. MSc thesis, University of Minnesota, USA.

Brown, E.G., VandeHaar, M.J., Daniels, K.M., Liesman, J.S., Chapin, L.T., Keisler, D.H., & Nielsen, M.S.W. 2005. Effect of increasing energy and protein intake on body growth and carcass composition of heifer calves. J. Dairy Sci. 88, 585–594. https://doi.org/10.3168/jds.S0022-0302(05)72722-3.

Burggraaf, V.T., Craigie, C.R., Muir, P.D., Khan, M.A., Thomson, B.C., Knol, F.W., Lowe, K.A., Taukiri, K.R., Staincliffe, M., McDermott, A., Longhurst, R.D., & McCoard, S.A. 2020. Effect of rearing diet and early post-weaning pasture quality on the life-time growth, meat quality, carcass traits and environmental impact of dairy-beef cattle. Livest. Sci. 239, 104031. https://doi.org/10.1016/j.livsci.2020.104031.

Daneshvar, D., Khorvash, M., Ghasemi, E., & Mahdavi, A.H. 2017. Combination effects of milk feeding methods and starter crude protein concentration: Evaluation on performance and health of Holstein male calves. Anim. Feed Sci. Technol. 223, 1–12. https://doi.org/10.1016/j.anifeedsci.2016.10.025.

Davis Rincker, L.E., VandeHaar, M.J., Wolf, C.A., Liesman, J.S., Chapin, L.T., & Weber Nielsen, M.S. 2011. Effect of intensified feeding of heifer calves on growth, pubertal age, calving age, milk yield, and economics. J. Dairy Sci. 94, 3554–3567. https://doi.org/10.3168/jds.2010-3923.

Dennis, T.S., Suarez-Mena, F.X., Hill, T.M., Quigley, J.D., Schlotterbeck, R.L., & Hulbert, L. 2018. Effect of milk replacer feeding rate, age at weaning, and method of reducing milk replacer to weaning on digestion, performance, rumination, and activity in dairy calves to 4 months of age. J. Dairy Sci. 101, 268–278. https://doi.org/10.3168/jds.2017-13692.

Detmann, E., Valente, É.E.L., Batista, E.D., & Huhtanen, P. 2014. An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. Livest. Sci. 162, 141–153. https://doi.org/10.1016/j.livsci.2014.01.029.

Diao, Q., Zhang, R., & Fu, T. 2019. Review of strategies to promote rumen development in calves. Animals (Basel). 26;9(8), 490. https://doi:10.3390/ani9080490.

Dicker, R.W., Ayres, J.F., McPhee, M.J., Robinson, D.L., Turner, A.D., Wolcott, M.L., Kamphorst, P. G., Harden, S., & Oddy, V.H. 2001. Post-weaning growth of cattle in northern New South Wales. 2. Growth pathways of steers. Aust. J. Exp. Agric. 41, 971. https://doi.org/10.1071/EA00094.

Drackley, J.K. 2008. Calf nutrition from birth to breeding. Vet. Clin. North Am. Food Anim. Pract. 24, 55–86. https://doi.org/10.1016/j.cvfa.2008.01.001.

Drake, N.A. 2017. The Performance of veal calves fed concentrate, total mixed ration, or free choice in the post-weaning period. MSc thesis, Aarhus University, Denmark.

El-Nahrawy, M.M. 2021. Effect of milk, calf starter and berseem hay feeding regimes on performance of suckling Fiesian and Baladi calves. J. Anim. Poult. Prod. 12, 31–38. https://doi.org/10.21608/jappmu.2021.55029.1007.

Enríquez, D., Hötzel, M.J., & Ungerfeld, R. 2011. Minimising the stress of weaning of beef calves: a review. Acta Vet Scand 53, 28. https://doi.org/10.1186/1751-0147-53-28.

Finneran, E., Crosson, P., O'Kiely, P., Shalloo, L., Forristal, D., & Wallace, M. 2012. Stochastic simulation of the cost of home-produced feeds for ruminant livestock systems. J. Agric. Sci. 150, 123–139. https://doi.org/10.1017/S002185961100061X.

Govil, K., Yadav, D., Patil, A., Nayak, S., Baghel, R., Yadav, P., & Thakur, D. 2017. Feeding management for early rumen development in calves. J. Entomol. Zool. Stud. 5(3), 1132-1139. Available at: https://www.entomoljournal.com/archives/2017/vol5issue3/PartP/5-2-261-486.pdf.

Greenwood, P.L., & I, L.M. 2007. Prenatal and pre-weaning growth and nutrition of cattle: long-term consequences for beef production. Animal 1, 1283–1296. https://doi.org/10.1017/S175173110700050X.

Hawkins, A., Burdine, K., Amaral-Phillips, D., & Costa, J.H.C. 2019. An economic analysis of the costs associated with pre-weaning management strategies for dairy heifers. Animals 9, 471. https://doi.org/10.3390/ani9070471.

Hill, T.M., Aldrich, J.M., Schlotterbeck, R.L., & Bateman, H.G. 2006. Effects of feeding calves different rates and protein concentrations of twenty percent fat milk replacers on growth during the neonatal period. Prof. Anim. Sci. 22, 252–260. https://doi.org/10.15232/S1080-7446(15)31101-3.

Hu, W., Hill, T. M., Dennis, T.S., Suarez-Mena, F.X., Aragona, K.M., Quigley, J.D., & Schlotterbeck, R.L. 2020. Effects of milk replacer feeding rates on growth performance of Holstein dairy calves to 4 months of age, evaluated via a meta-analytical approach. J. Dairy Sci. 103, 2217–2232. https://doi.org/10.3168/jds.2019-17206.

Huuskonen, A., & Khalili, H. 2008. Computer-controlled milk replacer feeding strategies for group-reared dairy calves. Livest. Sci. 113, 302–306. https://doi.org/10.1016/j.livsci.2007.06.017.

Jasper, J., & Weary, D.M. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85, 3054–3058. https://doi.org/10.3168/jds.S0022-0302(02)74391-9.

Kaiser, A.G. 1976. The effects of milk feeding on the pre- and post-weaning growth of calves, and on stomach development at weaning. J. Agric. Sci. 87, 357–363. https://doi.org/10.1017/S0021859600027659.

Khan, M.A., Lee, H.J., Lee, W.S., Kim, H.S., Kim, S. B., Ki, K.S., Park, S.J., Ha, J.K., & Choi, Y.J. 2007. Starch source evaluation in calf starter: I. Feed consumption, body weight gain, structural growth, and blood metabolites in Holstein calves. J. Dairy Sci. 90, 5259–5268. https://doi.org/10.3168/jds.2007-0338.

Klopp, R.N., Suarez-Mena, F.X., Dennis, T.S., Hill, T.M., Schlotterbeck, R.L., & Lascano, G.J. 2020. Postweaning response on growth and nutrient digestion to using different weaning strategies when feeding moderate and high amounts of milk replacer to Holstein calves. J. Dairy Sci. 103, 8143–8150. https://doi.org/10.3168/jds.2019-17704.

Koch, C., Gerbert, C., Frieten, D., Dusel, G., Eder, K., Zitnan, R., & Hammon, H.M. 2019. Effects of ad libitum milk replacer feeding and butyrate supplementation on the epithelial growth and development of the gastrointestinal tract in Holstein calves. J. Dairy Sci. 102, 8513–8526. https://doi.org/10.3168/jds.2019-16328.

Lorenz, I. 2021. Calf health from birth to weaning - an update. Ir. Vet. J. 74, 5. https://doi.org/10.1186/s13620-021-00185-3.

Manafiazar, G., Basarab, J.A., Baron, V.S., McKeown, L., Doce, R.R., Swift, M., Undi, M., Wittenberg, K., & Ominski, K. 2015. Effect of post-weaning residual feed intake classification on grazed grass intake and performance in pregnant beef heifers. Can. J. Anim. Sci. 95, 369–381. https://doi.org/10.4141/cjas-2014-184.

Mirzaei, M., Khanaki, H., Kazemi-Bonchenari, M., Khan, M.A., Khaltabadi-Farahani, A.H., Hossein-Yazdi, M., & Ghaffari, M.H. 2020. Effects of step-down weaning implementation time on growth performance and blood metabolites of dairy calves. J Dairy Sci. 103(11), 10099-10107. https://doi.org/10.3168/jds.2020-18520.

Mwansa, P.B., Makarechian, M., & Berg, R.T. 1992. The effect of levels of concentrate in feedlot diets on the health status of beef calves. Can. Vet. J. 33(10), 665-668. https://europepmc.org/article/med/17424092.

McAllister, T.A., Stanford, K., Chaves, A.V., Evans, P.R., Eustaquio de Souza Figueiredo, E., & Ribeiro, G. 2020. Nutrition, feeding and management of beef cattle in intensive and extensive production systems. Pages 75–98 in Animal Agriculture. Elsevier.

Miller-Cushon, E.K., Bergeron, R., Leslie, K.E., & DeVries, T.J. 2013. Effect of milk feeding level on development of feeding behavior in dairy calves. J. Dairy Sci. 96, 14. http://dx.doi.org/10.3168/jds.2012-5937.

Morrison, S.J., Wicks, H.C.F., Fallon, R.J., Twigge, J., Dawson, L.E.R., Wylie, A.R.G., & Carson, A.F. 2009. Effects of feeding level and protein content of milk replacer on the performance of dairy herd replacements. animal 3, 1570–1579. https://doi.org/10.1017/S1751731109990437.

Obeidat, B.S., Cobb, C.J., Sellers, M.D., Pepper-Yowell, A.R., Earleywine, T.J., & Ballou, M.A. 2013. Plane of nutrition during the preweaning period but not the grower phase influences the neutrophil activity of Holstein calves. J. Dairy Sci. 96, 7155–7166. https://doi.org/10.3168/jds.2013-6699.

Poppi, D.P., Quigley, S.P., da Silva, T.A.CC., & McLennan, S.R. 2018. Challenges of beef cattle production from tropical pastures. Rev. Bras. Zootec. 47. https://doi.org/10.1590/rbz4720160419.

Qadeer, M.K., Bhatti, S.A., Nawaz, H., & Khan, M.S. 2021. Effect of milk or milk replacer offered at varying levels on growth performance of Friesian veal calves. Trop. Anim. Health Prod. 53, 290. https://doi.org/10.1007/s11250-021-02666-7.

Rosenberger, K., Costa, J.H.C., Neave, H.W., von Keyserlingk, M.A.G., & Weary, D.M. 2017. The effect of milk allowance on behavior and weight gains in dairy calves. Journal of Dairy Science 100, 504–512. https://doi.org/10.3168/jds.2016-11195.

Raeth-Knight, M., Chester-Jones, H., Hayes, S., Linn, J., Larson, R., Ziegler, D., Ziegler, B., & Broadwater, N. 2009. Impact of conventional or intensive milk replacer programs on Holstein heifer performance through six months of age and during first lactation. J. Dairy Sci. 92, 799–809. https://doi.org/10.3168/jds.2008-1470.

Şentürklü, S., Landblom, D.G., Maddock, R., Petry, T., Wachenheim, C.J., & Paisley, S.I. 2018. Effect of yearling steer sequence grazing of perennial and annual forages in an integrated crop and livestock system on grazing performance, delayed feedlot entry, finishing performance, carcass measurements, and systems economics1. J. Anim. Sci. 96, 2204–2218. https://doi.org/10.1093/jas/sky150.

Şentürklü, S., Landblom, D., Paisley, S., Wachenheim, C., & Maddock, R. 2021. Frame score, grazing and delayed feedlot entry efffect on performance and economics of beef steers from small- and large-framed cows in an integrated crop-livestock system. Animals (Basel). 11(11), 3270. https://doi: 10.3390/ani11113270.

Silva, L.H.P., Paulino, P.V.R., Benedeti, P.D.B., Estrada, M.M., Alves, L.C., Assis, D.E.F., Assis, G.J.F., Leonel, F.P., Valadares Filho, S.C., Paulino, M.F., & Chizzotti, M.L. 2020. Post-weaning growth rate effects on body composition of Nellore bulls. Anim. Prod. Sci. 60, 852. https://doi.org/10.1071/AN19032.

Stamey, J.A., Janovick, N.A., Kertz, A.F., & Drackley, J.K. 2012. Influence of starter protein content on growth of dairy calves in an enhanced early nutrition program. J. Dairy Sci. 95, 3327–3336. https://doi.org/10.3168/jds.2011-5107.

Stamey Lanier, J., McKeith, F.K., Janovick, N.A., Molano, R.A., Van Amburgh, M.E., & Drackley, J. K. 2021. Influence of starter crude protein content on growth and body composition of dairy calves in an enhanced early nutrition program. J. Dairy Sci. 104, 3082–3097. https://doi.org/10.3168/jds.2020-19580.

Uys, J.L., Lourens, D.C., & Thompson, P.N. 2011. The effect of unrestricted milk feeding on the growth and health of Jersey calves. J. S. Afr. Vet. Assoc. 82, 47–52. https://doi.org/10.4102/jsava.v82i1.33.

Ungerfeld, R., Quintans, G., Enríquez, D.H., & Hötzel, M.J. 2009. Behavioural changes at weaning in 6-month-old beef calves reared by cows of high or low milk yield. Anim. Prod. Sci. 49, 637-642. https://doi.org/10.1071/AN09037.

Vavrišínová, K., Hozáková, K., Bučko, O., Haščík, P., & Juhás, P. 2019. The effect of the slaughter weight on carcass composition, body measurements and veal quality of Holstein calves. Acta Univ. Agric. Silvic. Mendel. Brun. 67, 1235–1243. https://doi.org/10.11118/actaun201967051235.

Wardrop, I. 1966. The effects of the plane of nutrition in early post-natal life on the subsequent growth and development of cattle. Aust. J. Agric. Res. 17, 375. https://doi.org/10.1071/AR9660375.

Wickramasinghe, H.K.J.P., Kaya, C.A., Baumgard, L.H., & Appuhamy, J.A.D.R.N. 2022. Early step-down weaning of dairy calves from a high milk volume with glutamine supplementation. J Dairy Sci.105(2), 1186-1198. https://doi.org/10.3168/jds.2021-21009.

Chapter 5

General conclusion and recommendations

5.1 General conclusion

Consumers in South Africa have a high demand for red meat; therefore farmers raise dairy bull calves as beef. In the commercial environment, dairy bull calves are commonly fed 4 L/day of MR for two months before weaning. After weaning the calves are usually backgrounded on pasture before finishing in a feedlot before slaughter. Feeding calves, a high concentration of CP in the starter feed is necessary for effective protein and growth requirements. Feeding calves higher volumes of MR with a high CP concentration starter feed results in greater and faster weight gain which produces a faster slaughter ready weight and potentially higher profit margin.

In the current study, three different volumes of MR (10%, 15% and 22.5% of BW/calf/day) and two CP concentrations (210 g CP/kg DM and 260 g CP/kg DM) were used.

In the first part of the trial, the growth of the calves was observed through weekly weighing and measuring the hip and wither height, as well as body length and heart girth circumference. The results of the liquid feed phase (60 days) indicated that calves fed treatment HM differed significantly higher from treatment LL. The final BW of treatments LL, HL, LM, LH and HH had no significant difference. The allometric growth measurements of the calves showed no significant differences during the trial. Body weight gain and ADG over the first 60 days of age (liquid feed phase) of the calves fed a conventional volume of MR (4 L/day) and a 210 g CP/kg DM starter feed was significantly poorer compared to other treatments with no differences observed among the other treatments. The total DMI of the treatment groups did not differ significantly.

During the second part of the trial, all the calves were backgrounded in a single group on the same pasture supplemented with a commercial finisher feed for a period of 80 days. The trial was done to observe the carry-over effect of the different treatment combinations during the pre-weaning phase. The final body weight after the backgrounding phase showed calves fed a conventional 4 L/day MR with a 210 g CP/kg DM starter feed was significantly lower than all other treatment groups and ADG and gain over the backgrounding phase were reduced. This carry-over effect could be attributed to a relative lighter weaning weight. The other treatment groups did not differ. Average daily gain over the 80-day period indicates calves fed a conventional MR with a 210 g CP/kg DM starter feed differs significantly lower from calves fed moderate and high volumes (9 L/day) of MR with a 210 g CP/kg DM starter feed, as well as calves fed a conventional volume of MR with a 260 g CP/kg DM starter feed. No carry-over effects were observed as the gain over the period were similar among the treatments.

The total cost of raising calves for the total period of 140 days and the cost of raising during the pre-weaning period showed that all treatment groups differed. The treatment with the conventional volume MR and 210 g CP/kg DM starter feed resulted in the lowest cost while the high-volume MR with the 260 g CP/kg DM starter feed resulted in the highest costs. The treatment that showed the highest profit was the conventional volume of MR with a 260 g CP/kg DM starter feed.

The findings of the trial indicated that during the pre-weaning period, the calves had similar growth on the different treatments. Higher volumes, i.e., 9 L/day of MR leads to a reduction in starter feed consumed, but the nutrient intake of the 9 L/day MR causes similar growth. This option is not ideal as a good MR is expensive. During the post-weaning period, no carry-over effects were observed between the treatments. Therefore, feeding calves a conventional volume of MR with a higher CP starter feed are more ideal. A lower CP starter feed with 6 L/day MR can also be beneficial to raise calves more economically during the pre-weaning and during the post-weaning backgrounding period.

5.2 Recommendations

In future studies, researchers should feed 4 L of MR/calf/day, from the beginning of the trial as the calves in the current study were started on 2 L of MR/calf/day which resulted in a weight loss the first week of the trial. One of the industry standards is feeding a 180 g/kg CP starter feed instead of a 210 g/kg CP starter feed. Therefore, future studies should also consider the lower CP starter feed at the different levels of MR. When dairy bull calves from commercial farms are used, proof of timeous and sufficient colostrum intake should be ensured. When calves have diarrhoea, some roughage should be provided to prevent systemic acidosis and metabolic disorders. All calves should be treated preventative for *Cryptosporidium parvum* if calves are sourced from a commercial farm. After the pre-weaning period, calves from each treatment group should be slaughtered to take some rumen samples and evaluate the rumen development. During the backgrounding phase, elevated supplemented feed levels will increase the growth rate of the calves.

Chapter 6

Appendix

Table 6.1 Schedule used for the different milk replacer volumes by using the step-up and step-down method.

MR treatment group (L/day)	Day(s)	Volume MR fed (L)
4	1-2	2
	3	2.5
	4	3
	5	3.5
	6-60	4
6	1-2	2
	3	2.5
	4	3
	5	3.5
	6-11	4
	12	4.4
	13	4.8
	14	5.2
	15	5.6
	16-45	6
	46-60	4
9	1-2	2
	3	2.5
	4	3
	5	3.5
	6-11	4
	12	4.4
	13	4.8
	14	5.2
	15	5.6
	16	6
	17	6.4
	18	6.8
	19	7.2
	20	7.6
	21	8
	22	8.4
	23-45	9
	46-52	6
	53-60	4

Table 6.2 Repeated measures of wither height for calves fed the differed milk volumes and low (210 g/kg and high (260 g/kg) protein starter feed over the period of 9 weeks.

		Treatment[1]						SEM[2]	P-value
Item	Week	LL	LM	LH	HL	HM	HH		
Wither height (cm)	1	75.333	77.167	78.333	77.000	78.667	76.333	0.543	0.320
	2	78.333	79.500	79.667	77.833	80.000	77.833	0.527	0.685
	3	79.167	81.333	81.000	78.667	81.000	79.500	0.588	0.914
	4	79.833	82.500	81.500	79.833	83.167	80.500	0.579	0.841
	5	81.167	83.833	82.667	81.000	84.167	82.000	0.589	0.943
	6	81.833[a]	86.167[b]	85.333[ab]	83.667[ab]	85.833[b]	84.833[ab]	0.538	0.592
	7	83.833	87.167	87.667	84.667	87.333	86.500	0.522	0.710
	8	86.833	89.500	90.000	86.833	90.167	88.833	0.573	0.800
	9	88.167[a]	92.000[ab]	90.833[ab]	89.167[ab]	92.667[b]	90.833[ab]	0.646	0.949

[1] LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

[2] SEM- Standard error of mean

[a,b] Means within rows with different superscripts differ significantly ($P < 0.05$).

Table 6.3 Hip height for calves fed different milk volumes and low (210 g/kg) and high (260 g/kg) protein starter feed over 9 weeks.

		Treatments[1]							
Item	Week	LL	LM	LH	HL	HM	HH	SEM[2]	P-value
Hip height (cm)	1	78.167[a]	80.833[ab]	80.833[ab]	79.667[ab]	82.333[b]	78.333[ab]	0.575	0.218
	2	80.833	82.500	82.500	81.167	83.833	81.500	0.544	0.697
	3	82.500	84.500	84.333	81.333	84.833	82.000	0.601	0.665
	4	82.667[a]	85.500[ab]	84.500[ab]	82.333[a]	86.667[b]	82.667[a]	0.611	0.588
	5	84.167[ab]	87.333[ab]	86.167[ab]	83.833[a]	87.667[b]	84.333[ab]	0.563	0.704
	6	85.000[a]	89.500[b]	89.667[b]	86.833[ab]	88.500[ab]	87.833[ab]	0.539	0.309
	7	87.333	90.833	91.000	89.500	90.833[a]	89.833[a]	0.539	0.443
	8	89.667[a]	93.333[ab]	92.667[ab]	89.833[ab]	93.500[b]	91.833[ab]	0.572	0.912
	9	91.167[a]	95.333[b]	93.500[ab]	92.833[ab]	95.667[b]	93.333[ab]	0.603	0.807

[1] LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

[2] SEM- Standard error of mean
[a,b]Means within rows with different superscripts differ significantly ($P < 0.05$).

Table 6.4 Heart grith for the different milk volumes and low and high protein concentrations in the starter over the trial period of 9 weeks**.**

		Treatments						SEM	P-value
Item	Week	LL	LM	LH	HL	HM	HH		
Heart girth circumference (cm)	1	77.667	79.667	79.333	78.000	80.833	79.167	0.587	0.902
	2	79.167	80.500	82.333	78.500[a]	82.167	78.833	0.618	0.234
	3	80.500	83.000	82.667	80.667[a]	83.167	81.667	0.629	0.915
	4	81.667[a]	84.333[ab]	85.167[ab]	82.833[ab]	86.000[b]	84.500[ab]	0.602	0.704
	5	83.833	87.000	87.833	85.500	87.883	87.833	0.572	0.829
	6	85.667[a]	89.167[ab]	90.500[b]	88.000[ab]	91.667[b]	91.167[b]	0.612	0.751
	7	89.500[a]	92.000[ab]	94.000[b]	92.667[ab]	96.000[b]	94.833[b]	0.673	0.561
	8	93.833[a]	97.000[abc]	96.667[abc]	94.667[ab]	99.167[c]	98.167[bc]	0.672	0.914
	9	96.667[a]	99.833[ab]	99.667[ab]	99.333[ab]	102.167[b]	100.833[b]	0.685	0.893

[1] LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

[2] SEM- Standard error of mean

[a,b,c]Means within rows with different superscripts differ significantly (P < 0.05)

Table 6.5 Calf body length for the different milk volumes and low and high protein concentrations in the starter fed over the trial period of 9 weeks.

		Treatments[1]						SEM[2]	P-value
Item	Week	LL	LM	LH	HL	HM	HH		
Body length (cm)	1	45.333	45.333	47.000[a]	45.667	46.000	46.333	0.406	0.802
	2	47.333	48.333	48.167[a]	46.667	48.667	46.833	0.333	0.593
	3	48.667	49.833	49.500[a]	49.000	50.500	49.500	0.263	0.875
	4	49.500[a]	50.500[ab]	51.167[ab]	50.333[ab]	52.333[b]	50.833[ab]	0.348	0.440
	5	50.667[a]	51.167[ab]	52.167[ab]	50.833[ab]	53.500[b]	51.833[ab]	0.363	0.270
	6	52.833	53.333	53.500	52.333	54.500	53.000	0.370	0.593
	7	54.000[a]	55.833[ab]	56.500[ab]	55.333[ab]	57.167[b]	55.833[ab]	0.446	0.579
	8	54.833[a]	57.667[b]	57.500[ab]	56.667[ab]	57.833[b]	58.167[b]	0.499	0.784
	9	57.500	59.000	58.333	57.667	59.167	59.667	0.457	0.845

[1] LL: 210 g CP/kg DM, 4 L MR; LM: 210 g CP/kg DM, 6 L MR; LH: 210 g CP/kg DM, 9 L MR; HL: 260 g CP/kg DM, 4 L MR; HM: 260 g CP/kg DM, 6 L MR; HH: 260 g CP/kg DM, 9 L MR

[2] SEM- Standard error of mean

[a,b,]Means within rows with different superscripts differ significantly ($P < 0.05$).