The effect of cow-level factors on colostrum quality, passive immunity and health of neonatal calves in a pasture-based dairy operation

Riaan Mulder[A,B], Geoffrey T. Fosgate[A,C], TakulaTshuma[A], Dirk C. Lourens[A]

[A]Department of Production Animal studies; Faculty of Veterinary Science; University of Pretoria; Private Bag x 04,Onderstepoort,0110, South Africa

[B]Private Veterinarian, 57 Graaff Reinetrd, Uitenhage, South Africa

[C]Corresponding author. Email:geoffrey.fosgate@up.ac.za

Short title: Colostrum quality in pastured-based dairy cows

Summary Text

Pasture-based dairy operations allow for natural grazing behaviour; however, sub-optimal nutrition may be more difficult to prevent due to variable quality of natural forages. The present study aimed to evaluate the effects of pregnant-cow management on colostrum quality, dairy calf health and growth. Cow weight loss during the dry period, an indicator of suboptimal nutrition, had a negative impact on colostrum quality but did not directly affect calf health and growth.

Abstract

A study of 95 cows (19 primiparous and 76 multiparous) and their offspring was performed on a pasture-based dairy in the coastal region of South Africa. Collected data included weight changes during the dry period, colostrum immunoglobulin G (IgG) and calf serum IgG at 24-48 hours after birth. Colostrum and serum IgG concentrations were measured using radial immunodiffusion and colostrum was regarded as having adequate IgG concentration if the amount was ≥50g/L. Calf serum IgG concentration of ≥10g/L was considered adequate transfer of passive immunity. The median (range) colostrum quality for cows with weight loss during the dry period was 23.1 g/L (9.0, 108.1) compared with 61.9 g/L (10.9, 200.0) in cows without weight loss. The median serum IgG of calves from cows with weight loss was 9.9 g/L (0.5, 44.6) compared with 14.0 g/L (0.5, 76.3) in calves from cows that did not lose weight during the dry period. Cows experiencing weight loss were four times more likely to have colostrum with lower levels of IgG (OR = 0.25; 95% CI, 0.07-0.88; P = 0.030). Lactation number was also significantly associated with colostrum IgG concentration ($P < 0.001$) with younger cows tending to have higher IgG levels. Failure of passive transfer did not have a significant effect on any calf health or production variables measured in the study. The effect of dry cow feeding on colostrum IgG concentration is poorly understood and inadequate pasture management could have an impact on colostrum quality in pasture-based dairy herds.

Keywords: Dry period, Dry cow, Nutrition, Passive immunity, Weight loss

Introduction

Sound management of dry cows and pregnant heifers, as well as neonatal calves during the first 24 hours of life, influences the future health of the calf more than any other aspect of calf management (Godden 2008). The importance of feeding adequate quantities of high quality colostrum has been well documented (Kuralkar and Kuralkar 2010). Ingestion and absorption of adequate amounts of colostral immunoglobulins (Ig) are essential for establishing passive immunity, which protects neonates from infectious diseases (Weaver *et al.* 2000).There are many factors that affect colostrum quality and these include breed and age of the dam, pre-partum vaccinations, dry period length and nutrition, and time of colostrum collection.

The results of previous research have suggested that the Ig concentration of colostrum is not commonly affected by maternal nutrition (Blecha *et al.* 1981; Godden 2008; Nowak *et al.* 2012). However, protein restriction during the dry period has been identified as a possible cause of reduced Ig content in the colostrum of beef cows (Blecha *et al.* 1981; Godden 2008; Nowak *et al.* 2012). Also, vitamin E and selenium supplementation increased colostrum production for cows originally fed a selenium and vitamin E deficient ration (Lacetera *et al.* 1996). It has also been reported that cows with excessively short or no dry periods produce less colostrum (Godden 2008) that has lower Ig content (Rastani *et al.* 2005). It is possible that inadequate nutrition is the reason for the documented negative effect of excessively short dry periods on colostrum production.

Consumption of poor quality colostrum can cause failure of passive transfer (FPT), which is an important risk factor for morbidity and mortality in neonatal calves. There is also evidence that adequate passive immunity will positively impact heifer health and production as she grows into an adult (DeNise *et al.* 1989; Weaver *et al.* 2000). Individual and herd-level factors related to health and performance of calves have been investigated (Windeyer *et* *al.*2014) but specific risk factors related to the effects of dry cow management have not been identified.

The primary aim of this research was to determine whether cow-level factors have an effect on colostrum Ig content, passive immunity of the newborn and health of the calf in a pasture-based dairy system in South Africa. Investigated factors included weight loss during the dry period, dry period length, breed, parity, and calving date. We hypothesized that weight loss during the dry period would have a detrimental effect on colostrum quality and calf health.

Materials and methods

Study design

An on-farm prospective cohort study was performed in a closed dairy herd that included Holstein, Jerseys and their crosses in the Eastern Cape Province of South Africa. Primiparous and multiparous cows were selected for study even though only multiparous cows could contribute to the investigation of the effects of weight loss during the dry period. The farm has a year round calving pattern on a predominantly pasture-based system with in-parlour concentrate supplementation. The pasture consists of predominantly kikuyu grass (*Pennisetum clandestinum*) in summer, over sown by a zero-till method in autumn with annual ryegrass (*Lolium multiflorum*). Cows were selected for dry-off when they reached 60 days before their expected calving date or when milk production dropped to less than 8 L average over a 10 day period. Cows were milked only once a day during dry-off in an effort to reduce milk volume. A standard dry-cow mastitis treatment was administered prior to joining the far-off dry group (phase 1). During phase 1, dry cows were kept on natural pasture or as followers of the milking herd on pastures without any supplements. Close-up dry cows were selected on a weekly basis 30 days before their expected calving date. Close-up cows were fed *ad lib* oat or grass hay roughage and received a commercial anionic concentrate feed at 1kg/cow.day. Close-up cows received a standard vaccination protocol including: Rota-virus, Corona-virus, E.coli; Paratyphoid; and a multivalent Clostridial product. Close-up cows were also administered vitamin and mineral supplementation and were dewormed using a doramectin-based product prior to calving. The sample size was calculated as 90 cows based on the assumptions that half of the cows would experience weight loss during the dry period and that 80% of the cows experiencing weight loss would have inadequate colostrum (IgG<50 g/L) versus 50% in the cows that did not experience weight loss (Fosgate 2009). The study was reviewed and approved by the Animal Ethics Committee at the University of Pretoria, Faculty of Veterinary Science (Protocol V015/1).

Cow data collection

Cows were weighed twice a day before dry-off, weekly during the dry period and at the first milking after calving. Weights were measured after leaving the milking parlour at the same time of day both at dry-off and post-freshening. The scale was positioned ensuring that weight was obtained prior to the cow having access to food or water in attempt to minimize the impact of gut fill. Average weight was then calculated for the three days prior to dry-off and the first three days after calving. The weight of the gravid uterus at dry-off was estimated using a published formula (Reynolds *et al.* 1990) and subtracted from the cow weight at dry-off. Weight change during the dry period was calculated as average weight at calving minus the weight at dry-off adjusted for the expected weight of the gravid uterus.

The colostrum of each cow was harvested from healthy udders within 12 hours after parturition. A 10 mL aliquot was collected in plain evacuated serum tubes (Vacutainer, Becton, Dickinson and Company, BD, Beliver Industrial Estate, Plymouth, UK) and frozen at -20°C for subsequent laboratory analysis. Colostrum density was measured with a hydrometer (Calgary, Northfield Laboratories, Oakden, South Australia), which measures the specific gravity of the colostrum. Data for each sample included: individual cow identification, calving date, lactation number, time of colostrum collection after calving, amount at first milking, temperature and physical appearance of the colostrum, specific gravity and whether the calf suckled or not prior to colostrum collection.

Calf data collection

Calves were born on pasture and separated from the dam as soon as observed. Calves that were born overnight were not removed until early morning the following day. Calves were weighed at birth and navels were treated using a 7% iodine product. Colostrum was harvested at separation with a bucket type milking machine and 4 L were fed to the calf using a nipple feeder or stomach tube when the calf was too weak to nurse. Calves were housed in an open area under roof in individual cubicles made of welded metal with a wooden slatted floor. Cubicles were cleaned and disinfected before use. Calf growth pellets (18% crude protein) and fresh drinking water were offered one hour after milk feeding. Feeding buckets were cleaned and disinfected twice a day. Whole blood was collected from the jugular vein of each calf 24 to 48 hours after calving in two 10 mL plain evacuated serum tubes (Vacutainer, Becton, Dickinson and Company, BD, Beliver Industrial Estate, Plymouth, UK). Blood was centrifuged at 2000*g* for 10 minutes on the farm and serum was decanted into two vacutainer tubes. One aliquot of serum was frozen at -20°C and kept for subsequent laboratory analysis. One aliquot of serum was used to measure FPT using a refractometer. A benchmark value of< 5.2 g/dL for total serum protein (TSP) was used as the cut-off for FPT. Collected data for each sample included the individual identification of each calf and its dam. Health of calves was monitored daily by qualitatively assessing mentation and appetite. Physical examinations were performed when abnormalities were identified and administered treatments were recorded on animal records. Calves were defined as having a morbidity event if they required veterinary treatment or diagnostics at any time prior to weaning. Calf survival was measured at 60 days after birth. Calves were weighed and birth and weaning and average daily gain (ADG; kg/day) was calculated. No vaccinations were administered to calves prior to weaning.

Data exclusion

Cow-calf pairs were excluded if cows showed signs of mastitis, cows had a febrile disease (rectal temperature > 39.4°C) at any time during the dry period that required treatment, if the cow had twins, if newborn calves showed any signs of clinical disease, or was too weak to stand, or unable to suckle. Cows were also excluded if the dry period was less than 21 days or greater than 150 days.

Immunoglobulin measurement

Stored samples were batched and sent to a commercial laboratory for testing (Food Chain Laboratories, Port Elizabeth, South Africa). Colostrum and serum samples were thawed at room temperature and the Ig G (IgG) concentration of the samples were evaluated using radial immunodiffusion (RID; Bovine IgG kit, IDBiotech, Rue Marie Curie, 63 500 Issoire, France). Cows were defined as having adequate colostrum quality if the IgG concentration was≥50g/L (Gay *et al.* 1983; Weaver *et al.* 2000; Godden *et al.* 2009). Calf serum values of ≥10g/L were classified as adequate transfer of passive immunity (APT) (Godden 2008).

Statistical analysis

Quantitative data were assessed for normality using descriptive statistics, histograms, and the Anderson-Darling test for normality (MINITAB Statistical Software, Release 13.32, Minitab

Inc, State College, Pennsylvania, USA). Data violated the normality assumption and were descriptively presented as medians and ranges. Univariate logistic regression was used to estimate the effect of cow- and calf-level factors on colostrum IgG concentration (<50 g/L versus ≥50 g/L) and APT (serum IgG ≥10 g/L versus <10 g/L). Logistic regression results were reported as odds ratios (OR), 95% confidence intervals (CI), and Wald P values. Quantitative calf outcomes (eg., ADG, morbidity score) were compared between calves with APT versus FPT using Mann-Whitney U tests. Sensitivity and specificity of tests for FPT and colostrum quality were estimated relative to RID results as the reference standard. Ninety-five percent CI for sensitivity and specificity estimates were calculated using the exact mid-P method. Data were analyzed using software (IBM SPSS Statistics Version 23, International Business Machines Corp., Armonk, New York, USA and Epi Info, version 6.04, CDC, Atlanta, GA, USA) and results interpreted at the 5% level of significance.

Results

One hundred and two cows calved during the three-month study. The first calf was born on 2 March 2012, and the last on 1 June 2012. Forty-three bull calves, 50 heifers and 10 stillborn calves were recorded. Seven cows were excluded from the study: three cows were excluded for excessively long dry periods, two cows had stillbirths, one cow had twins, and another cow had too short a dry period. Therefore, a total of 95 cows were available for analysis. Seventy-six cows were multiparous and available to investigate the effects of weight loss during the dry period. The study population included 57 cows that gained weight during the dry period, 18 cows that experienced weight loss, and one cow died post-partum prior to the collection of weight data. The weight change during the dry period varied from a loss of 35kg to a gain of 103 kg (median = 22 kg gain).

Table 1. Univariate logistic regression analysis to determine factors related to the collection of high quality colostrum (IgG concentration ≥ 50 g/L) in 82 cows calving between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa.

Variable/level	n	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value (Wald)
Weight loss during dry period				
Loss occurring	17	-1.392	0.25 (0.07, 0.88)	0.030
No loss	47	Referent		
Dry period length				
Other length	38	0.118	1.13 (0.42, 3.03)	0.816
42 - 60 days	27	Referent		
Lactation number				
First	17	3.024	20.6 (3.9, 108)	<0.001
Second	24	3.181	24.1 (5.0, 115)	<0.001
Third	19	1.527	4.6 (1.0, 21.1)	0.049
≥ Fourth	22	Referent		
Breed				
Holstein	55	-0.497	0.61 (0.20, 1.88)	0.387
Jersey	10	-1.453	0.23 (0.04, 1.25)	0.090
Crossbreds	17	Referent		
Month of calving				
March	20	-0.057	0.94 (0.32, 2.83)	0.919
April	26	0.097	1.10 (0.40, 3.05)	0.852
May	35	Referent		
Calf sex				
Male	32	0.112	1.12 (0.45, 2.81)	0.812
Female	43	Referent		
Did the calf suckle				
Yes	48	-0.305	0.74 (0.30, 1.80)	0.502
No	33	Referent		

CI = confidence interval.

Eighty-two cows had valid data for colostrum quality and the median (range) IgG concentration was 55.7 g/L (8.6, 200) on RID. Forty-eight percent of cows (39/82) had colostrum IgG< 50 g/L (inadequate quality). The median (range) colostrum quality for cows with weight loss was 23.1 g/L (9.0, 108.1). The median (range) colostrum quality for cows with no weight loss was 61.9 g/L (10.9, 200.0). Seventy-six percent (13/17) of cows with weight loss had colostrum IgG<50 g/L compared with 45% (21/47) in cows that did not experience weight loss. Weight loss during the dry period was significantly associated with lower levels of IgG in the colostrum (Table 1). Cows experiencing weight loss were four times more likely to have colostrum with lower levels of IgG (OR = 0.25; 95% CI, 0.07-0.88; P = 0.030). The amount of weight loss did not appear to be related to the concentration of IgG in the colostrum (Fig. 1). Lactation number was also significantly associated with colostrum IgG concentration (P < 0.001) with younger cows tending to have higher IgG levels (Fig. 2). There appeared to be a slight increasing trend in the colostrum IgG content with increasing dry period length (Fig. 3) but the association was not significant (P = 0.816).

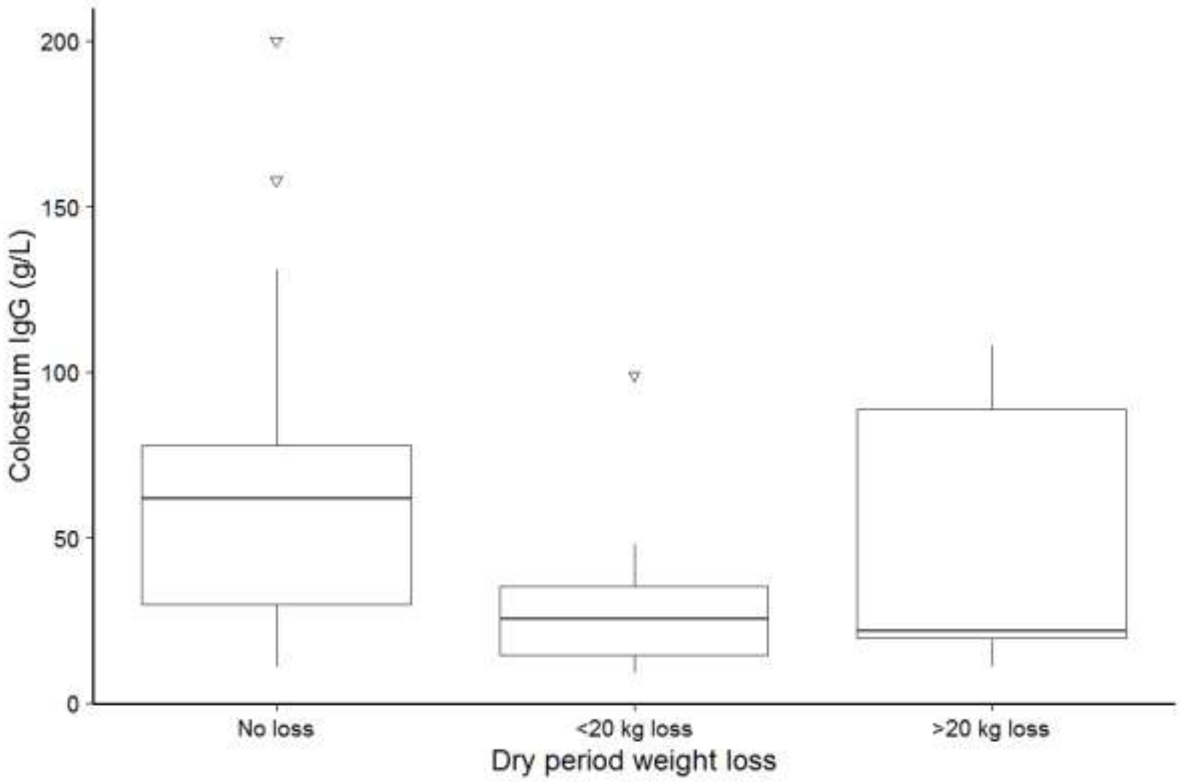

Fig. 1. Descriptive presentation of colostrum IgG concentration by categories of cow weight change during the dry period in 64 cows calving between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa. Triangles represent outlier values.

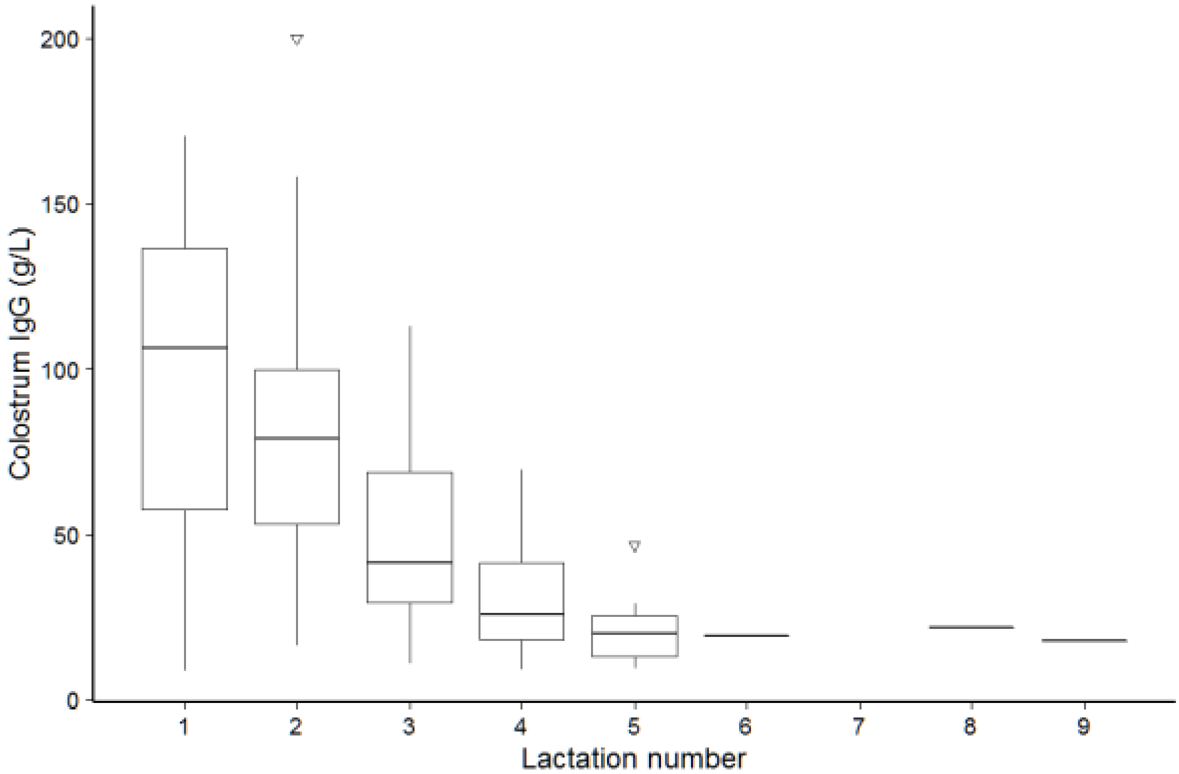

Fig. 2. Descriptive presentation of colostrum IgG concentration by cow parity in 80 cows calving between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa. Triangles represent outlier values.

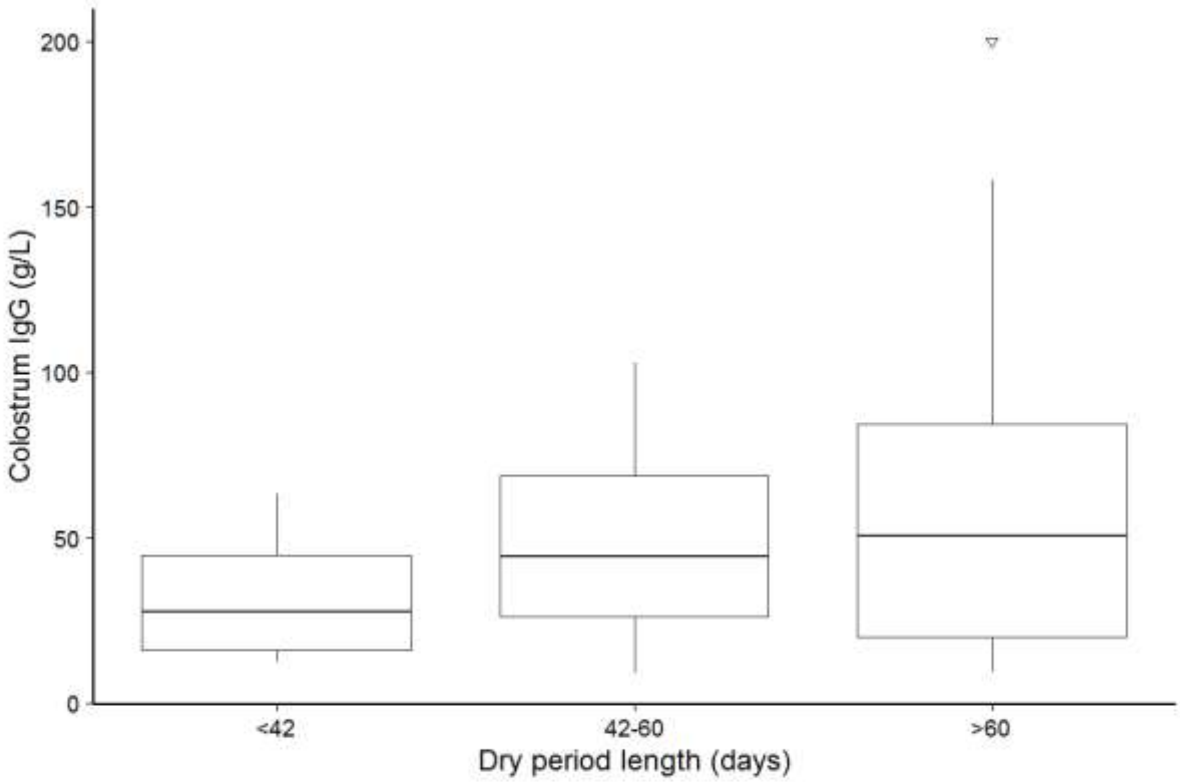

Fig. 3. Descriptive presentation of colostrum IgG concentration by categories of cow dry period length in 65 cows calving between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa. Triangles represent outlier values.

The overall median (range) serum IgG was 15.4 g/L (0.5, 76.3). Of the 80 calves with valid data, 30 calves (38%) had FPT (<10 g/L) based on RID results. The median serum IgG concentration of calves from cows with weight loss was 9.9 g/L (0.5, 44.6). The median serum IgG concentration of calves from cows with no weight loss was 14.0 g/L (0.5, 76.3). Fifty-four percent (7/13) of calves from cows with weight loss had FPT compared with 33% (18/54) in calves from cows that did not experience weight loss. A larger amount of weight loss during the dry period had an apparent effect on the calf serum IgG content (Fig. 4) but the effect was not statistically significant ($P = 0.195$; Table 2). Cows with longer dry period lengths had more variability in the calf serum IgG concentration (Fig. 5) but the effect was not significant ($P = 0.089$). Male calves were 20 times more likely to have FPT compared with heifers (OR = 0.05; 95% CI, 0.01-0.17; $P < 0.001$).

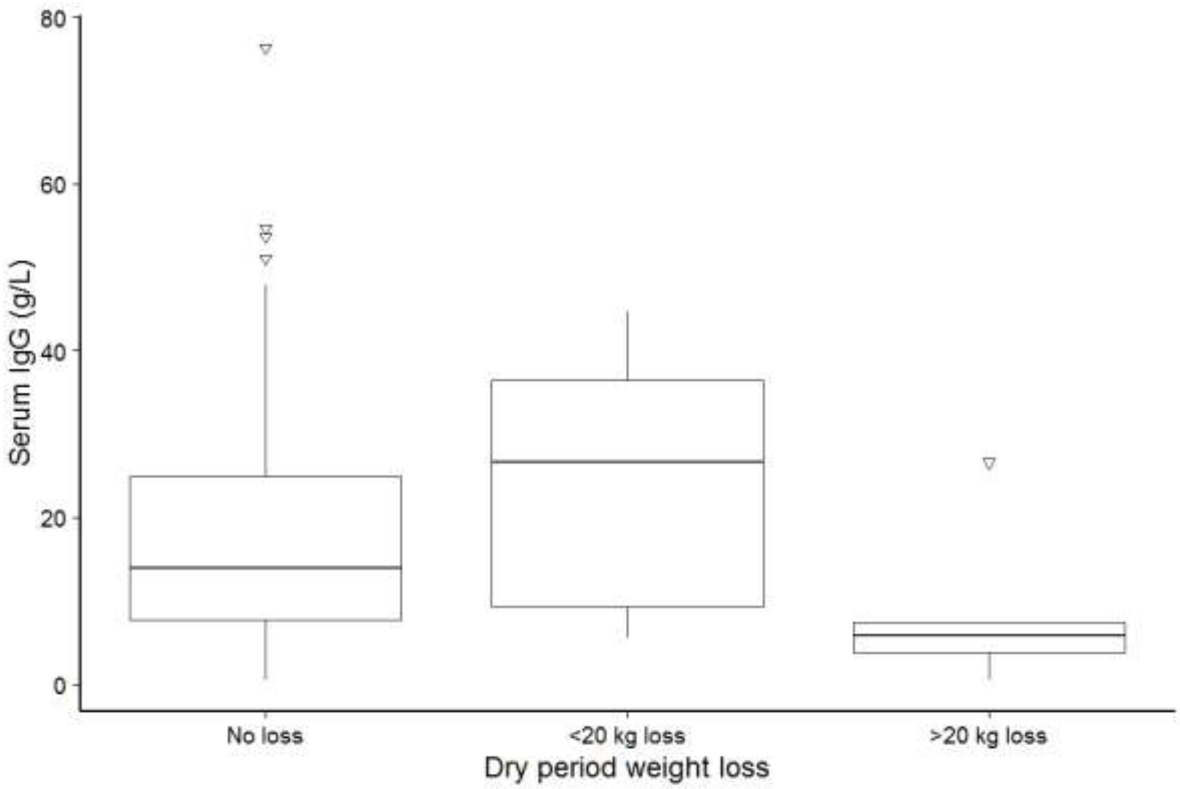

Fig. 4. Descriptive presentation of serum IgG concentration by categories of cow weight change during the dry period in 63 calves between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa. Triangles represent outlier values.

Table 2. Univariate logistic regression analysis to determine factors related to adequate transfer of passive immunity (serum IgG concentration ≥ 10 g/L) in 80 calves born between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa.

Variable/level	**n**	**Parameter estimate ($\hat{\beta}$)**	**Odds ratio (95% CI)**	**P value (Wald)**
Weight loss during dry period				
Loss occurring	13	-0.817	0.44 (0.13, 1.52)	0.195
No loss	50	Referent		
Dry period length				
Other length	36	-0.939	0.39 (0.13, 1.15)	0.089
42 - 60 days	27	Referent		
Lactation number				
First	17	0.501	1.65 (0.43, 6.31)	0.464
Second	24	0.231	1.26 (0.38, 4.24)	0.709
Third	20	0.993	2.70 (0.70, 10.5)	0.151
≥ Fourth	19	Referent		
Breed				
Holstein	49	-0.082	0.92 (0.31, 2.75)	0.883
Jersey	12	0.154	1.17 (0.26, 5.33)	0.842
Crossbreds	19	Referent		
Month of calving				
March	23	0.421	1.52 (0.50, 4.65)	0.460
April	22	-0.038	0.96 (0.33, 2.85)	0.946
May	35	Referent		
Calf sex				
Male	38	-3.024	0.05 (0.01, 0.17)	<0.001
Female	42	Referent		
Did the calf suckle				
Yes	52	0.413	1.51 (0.58, 3.91)	0.394
No	27	Referent		

CI = confidence interval.

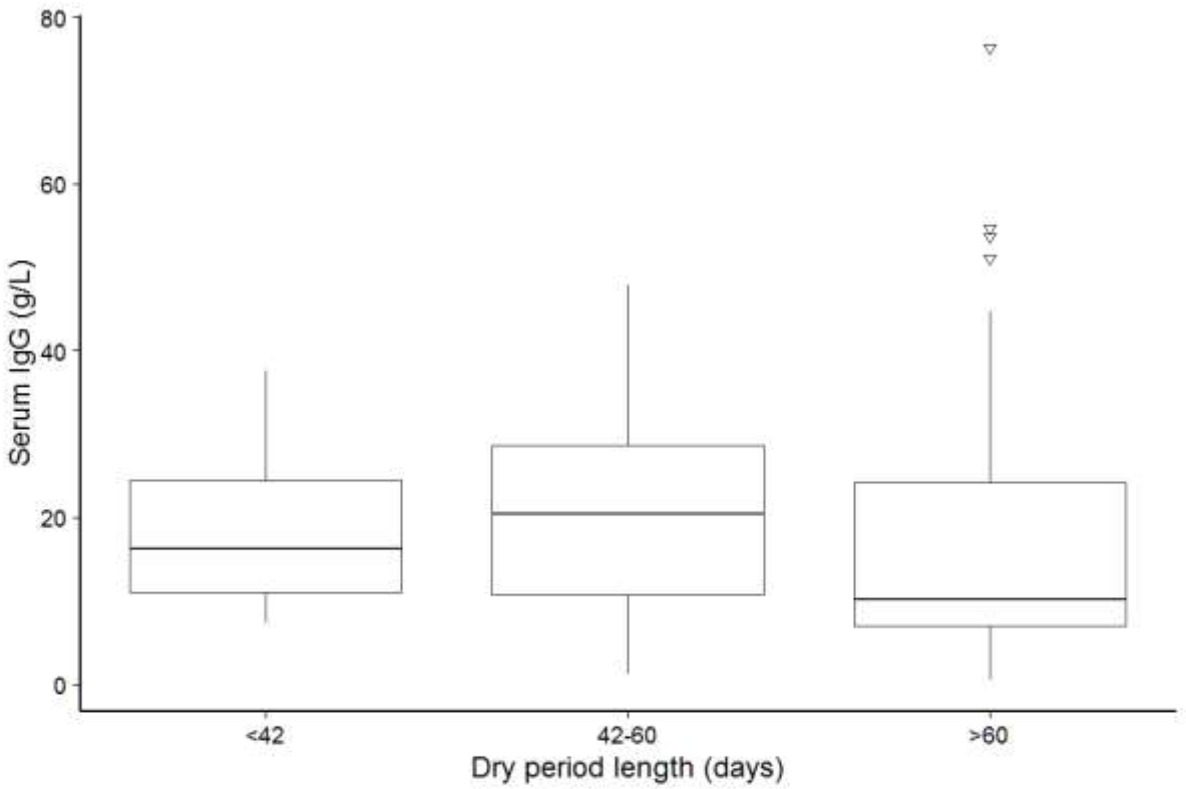

Fig. 5. Descriptive presentation of serum IgG concentration by categories of cow dry period length in 63 calves born between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa. Triangles represent outlier values.

Eighty-seven percent (26/30) of calves with FPT experienced disease prior to weaning compared with 88% (44/50) of those with APT. Eleven calves died during the study (13%). The median day to death was 11, with eight calves dying by day 15. Fifteen percent (5/34) of calves that received inferior colostrum died versus 7% (3/41) of those that received adequate colostrum. Twelve percent (6/50) of calves that had APT died compared with 17% (5/30) in calves with FPT. The median (range) ADG for calves that received inadequate colostrum was 0.40 (0.12, 0.66) and 0.43 (0.11, 0.60) for calves that received adequate colostrum (P=0.449). None of the evaluated calf outcomes were significantly associated with FPT (Table 3).

Table 3. Associations between serum IgG concentration with calf viability and growth in 80 calves born between 2 March and 1 June 2012 in the Eastern Cape Province of South Africa.

	Serum IgG < 10 g/l		Serum IgG ≥ 10 g/l		
Variable	n	Median (IQR)	n	Median (IQR)	P value[1]
Calf birth weight	30	30.3 (25.7, 36.6)	49	32.4 (27.9, 35.2)	0.884
Calf weaning age (days)	25	64 (62, 71)	43	65 (61, 69)	0.744
Calf ADG	25	0.43 (0.36, 0.50)	42	0.38 (0.27, 0.48)	0.099
Diarrhea days	30	4 (2, 8)	50	5 (2, 7)	0.893
Morbidity score[2]	30	1 (1, 1)	50	1 (1, 1)	0.862

IQR = interquartile range. ADG = average daily gain from birth until weaning. TSP = total serum protein.
[1]Based on Mann-Whitney U tests comparing values between the two groups.
[2]Number of morbidity events

Sensitivity and specificity of the colostrometer for detecting low IgG concentration (<50 g/L) were 31% (12/39; 95% CI, 18-46%) and 86% (37/43; 95% CI, 73-94%), respectively. Sensitivity and specificity of the refractometer (<5.2 g/dL) for detecting FPT were 27% (8/30; 95% CI, 13-44%) and 96% (48/50; 95% CI, 87-99%), respectively.

Discussion

The study was designed to evaluate whether weight-loss in pasture-based dairy cows has any effect on colostrum quality, passive transfer of immunity to the offspring and health of the calf. Previous studies have generally focused on the effect of weight loss and negative energy balance after calving, probably because the majority of studies have been performed on well-fed complete mixed ration herds in the Northern Hemisphere. To our knowledge, no previous studies have been conducted on pasture-based systems to correlate colostrum quality and FPT with weight loss during the dry period.

Weight loss during the dry period had a significant effect on colostrum quality and descriptively larger losses of weight (>20 kg) appeared to influence calf serum IgG concentration. Under the conditions of the current study, weight loss is likely an indicator of the cow nutritional status. Previous research results have generally suggested that Ig content of colostrum is not affected by maternal nutrition (Blecha *et al.* 1981; Godden 2008; Nowak *et al.* 2012). An exception was when vitamin E and selenium supplementation was given to cows being fed a selenium and vitamin E deficient ration, which was shown to increase colostrum production (Lacetera *et al.* 1996). The difference in our findings compared to the majority of previous research could be due to our adjustment for the anticipated weight of the gravid uterus or simply be an indication that cows raised in pastured-based dairies in the Southern Hemisphere face different nutritional challenges than is the norm for the previously studied cows.

Jersey cows in the present study had the lowest colostrum IgG concentrations, though this effect was not statistically significant. Breed has been identified as an important predictor of colostrum Ig content (Godden *et al.* 2009). Beef and dairy breeds appear to have differences in colostrum Ig content (Guy *et al.* 1994) and a similar effect has been observed within different dairy breeds (Muller and Ellinger 1981; Pritchett *et al.* 1991). Breed differences have been attributed to genetic differences and dilution effects. Our results are not consistent with the expected breed differences reported in the literature (as reviewed by (Godden 2008).

Colostrum production can be affected by the dry period length and cows with excessively short or no dry periods are expected to produce less colostrum (Godden 2008) that has lower Ig content (Rastani *et al.* 2005). Although not significant, cows with the ideal dry period length in this study were associated with lower calf serum IgG concentrations. This was surprising, but we can argue that the longer dry period could help to add body condition, and that a shorter dry period might reduce the effect of loss in body condition. This effect might have been observed in a subset of the cows in this study and might be the cause of the larger variability observed in the colostrum IgG concentration in cows with longer dry period lengths. Blecha *et al.* (1981) also suggested that nutrition might play a role in colostrum quality. This emphasizes the importance of monitoring body condition scores during the dry period and adapting grazing or feeding strategies to counter losses in condition. This is especially important for the first phase of the dry period during which the majority of weight loss is expected to occur.

Most studies report that older cows produce higher quality colostrum (Godden *et al.* 2009). In one study, older Holstein cows tended to have higher Ig content but this same effect was not observed in the Guernsey cows (Tyler *et al.* 1999). We expected to observe higher colostrum quality in the older cows as reported previously (Moore *et al.* 2005)including a similar study in pasture-based dairy cattle(Angulo *et al.* 2015). However, our results actually indicated a decreasing trend in colostrum IgG concentration in older animals. This decreasing trend was unexpected and also different than previous studies that did not identify different Ig concentrations in older cows (Muller and Ellinger 1981; Gulliksen *et al.* 2008). Third lactation cows had the highest proportion of calves with APT, but this effect was not significant. Primiparous cows yielded good quality colostrum and their calves were not more likely to suffer from FPT. Heifers likely had a more uniform nutritional level prior to calving unlike multiparous cows that experienced a reduced plane of nutrition during phase 1of the dry period. This highlights the need to closely monitor multiparous cows after dry-off and adjust nutrition sooner for individual animals.

In total, 37% (n=72) of calves had FPT, which was lower than the 58% recorded by Gulliksen *et al.* (2008) but higher than the 19% recorded by Beam *et al.* (2009). Surprisingly, the history of suckling did not significantly influence colostrum quality or FPT. Our results identified FPT in 44% of calves that did not suckle and 24% in those that did suckle. In the present study, cows were not observed continuously and the collection of colostrum samples was delayed for calves born during the night. Previous work (Moore et al. 2005, Morin et al. 2010) has suggested that delayed colostrum collection has a profound effect on measured colostrum quality. Delayed colostrum collection could therefore be a confounder in the present analysis and it is also possible that whether or not a calf had suckled might have been misclassified due to non-continuous observations.

Only 32% of the male calves had >10g/L IgG compared with 90% in the females. Serum was collected 24-48 hours after birth and therefore should not have been influenced by feeding or housing practices. This finding is consistent with previous research indicating that bull calves were more likely to have agammaglobulinaemia than heifers (Vogels *et al.* 2013). Bull calves are typically sold soon after birth but they were retained during the study and followed up until weaning. These results therefore suggest that the study protocol implementation might have differed based on calf sex.

Eleven calves died during the study (13%), which was similar to the 12% found by Donovan *et al.* (1998). Two main contributors were identified: *Cryptosporidium parvum* and pneumonia. Cold and wet weather during the study, coupled with the housing method, could have played a major role in these deaths. The high incidence of calf diarrhoea, mainly due to Cryptosporidium, likely affected calf ADG and mortality. As reported by Roche *et al.* (2015), dairy heifer growth and live weight at first calving are regarded as important management variables, but growth rate targets for different farming systems are not well defined. Our findings suggest that ADG is not influenced by either inadequate colostrum or FPT. Contrary to the well-established belief, FPT also was not associated with the increased risk of calf morbidity and mortality. However, the study farm experienced unusually high rainfall during the study and this might have adversely affected the health and growth of all calves in general.

There are a number of tests available to measure the IgG content of colostrum. On-farm evaluations include colostrum osmolality, sodium sulfite turbidity, zinc sulphate turbidity and refractometry (Bartier *et al.* 2015). Available laboratory assays include RID, electrophoresis and ELISA (Chigerwe *et al.* 2008). These assays can also be used to measure

FPT in calf serum (Calloway *et al.* 2002; Dawes *et al.* 2002). The RID and ELISA measure serum IgG concentration directly whereas indirect methods estimate IgG concentration using TSP amount (Weaver *et al.* 2000).

The indirect densimeter measurement of colostrum quality had good specificity for detecting inadequate colostrum (86%) but poor sensitivity (31%). These findings are similar to the sensitivity and specificity of 32% and 97% (respectively) as reported in a recent review (Godden 2008). The indirect assessment of TSP by refractometry also had high specificity (96%) but very low sensitivity (27%) for detection of FPT. It is therefore likely to misclassify a percentage of low IgG concentration serum as adequate. This is in contrast to previous reports that estimated a sensitivity of 94% and specificity of 74% for detecting FTP at the 5.5 g/dL cutoff (Weaver et al. 2000).

The current study was undertaken on a typical medium-sized pasture-based dairy farm in the Eastern Cape Province of South Africa. It follows the typical management of dry cows in the area and therefore provided valuable insight into some of the challenges of this type of system. However, limitations of this study include a small sample size, a single study farm and observations only during a single season. A larger sample size spread over a longer period might have yielded more significant results. Other important limitations were caused by the lack of continuous observations that caused variability in the time of colostrum collection and calf removal from the dam. There was also variability in the amount of colostrum consumed by each individual calf. These are important random errors that likely reduced the chance of identifying significant differences. Another limitation is that the weight of the gravid uterus was estimated based on the stage of gestation and subtracted from the total weight of the cow at dry-off. This approach did not account for individual cow variation and therefore residual error in the classification of cows with and without weight loss during the dry period might have remained.

Conclusion

Even though literature generally suggests that nutrition does not affect colostrum quality significantly, this work indicates that the dry period under pasture conditions has a significant effect on colostrum IgG concentration. Therefore, grazing and feeding strategies need to be adapted to counter loss of body condition during the dry period. The fact that primiparous cows yielded better colostrum, further highlights that dry cow management of multiparous cows might play a bigger role in colostrum quality than previously reported.

Acknowledgements

The research was supported in part by the University of Pretoria and the National Research Foundation (NRF) of South Africa (Grant No. 76734). The funding source had no involvement in the conduct of this research, or in preparation and submission of this article**.**

REFERENCES

Angulo, J, Gomez, LM, Mahecha, L, Mejia, E, Henao, J, Mesa, C (2015) Calf's sex, parity and the hour of harvest after calving affect colostrum quality of dairy cows grazing under high tropical conditions. *Tropical Animal Health and Production***47**, 699-705.

Bartier, AL, Windeyer, MC, Doepel, L (2015) Evaluation of on-farm tools for colostrum quality measurement. *Journal of Dairy Science***98**, 1878-1884.

Beam, AL, Lombard, JE, Kopral, CA, Garber, LP, Winter, AL, Hicks, JA, Schlater, JL (2009) Prevalence of failure of passive transfer of immunity in newborn heifer calves and associated management practices on US dairy operations.*Journal of Dairy Science***92**, 3973-3980.

Blecha, F, Bull, RC, Olson, DP, Ross, RH, Curtis, S (1981) Effects of prepartum protein restriction in the beef cow on immunoglobin content in blood and colostral whey and subsequent immunoglobin absorption by the neonatal calf. *Journalof Animal Science***53**, 1174-1180.

Calloway, CD, Tyler, JW, Tessman, RK, Hostetler, D, Holle, J (2002) Comparison of refractometers and test endpoints in the measurement of serum protein concentration to assess passive transfer status in calves. *Journal of the American Veterinary Medical Association***221**, 1605-1608.

Chigerwe, M, Tyler, JW, Middleton, JR, Spain, JN, Dill, JS, Steevens, BJ (2008) Comparison of four methods to assess colostral IgG concentration in dairy cows.*Journal of the American Veterinary Medical Association***233**, 761-766.
Dawes, ME, Tyler, JW, Hostetler, D, Lakritz, J, Tessman, R (2002) Evaluation of a commercially available immunoassay for assessing adequacy of passive transfer in calves.*Journal of the American Veterinary Medical Association***220**, 791-793.
DeNise, SK, Robison, JD, Stott, GH, Armstrong, DV (1989) Effects of passive immunity on subsequent production in dairy heifers.*Journal of Dairy Science***72**, 552-554.
Donovan, GA, Dohoo, IR, Montgomery, DM, Bennerr, FL (1998) Associations between passive immunity and morbidity and mortality in dairy heifers in Florida, USA. *Preventive Veterinary Medicine***34**, 31-46.
Fosgate, GT (2009) Practical sample size calculations for surveillance and diagnostic investigations. *Journal of Veterinary Diagnostic Investion***21**, 3-14.
Gay, CC, McGuire, TC, Parish, SM (1983) Seasonal variation in passive transfer of immunoglobulin G1 to newborn calves.*Journal of the American Veterinary Medical Association***183**, 566-568.
Godden, S (2008) Colostrum management for dairy calves. *Veterinary Clinics of North America Food Animal Practice***24**, 19-39.
Godden, SM, Haines, DM, Konkol, K, Peterson, J (2009) Improving passive transfer of immunoglobulins in calves. II: interaction between feeding method and volume of colostrum fed.*Journal of Dairy Science***92**, 1758-1764.
Gulliksen, SM, Lie, KI, Solverod, L, Osteras, O (2008) Risk factors associated with colostrum quality in Norwegian dairy cows.*Journal of Dairy Science***91**, 704-712.
Guy, MA, McFadden, TB, Cockrell, DC, Besser, TE (1994) Regulation of colostrum formation in beef and dairy cows.*Journal of Dairy Science***77**, 3002-3007.
Kuralkar, P, Kuralkar, SV (2010) Nutritional and Immunological Importance of Colostrum for the new born. *Veterinary World***3**, 46.
Lacetera, N, Bernabucci, U, Ronchi, B, Nardone, A (1996) Effects of selenium and vitamin E administration during a late stage of pregnancy on colostrum and milk production in dairy cows, and on passive immunity and growth of their offspring. *American Journal of Veterinary Research***57**, 1776-1780.
Moore, M, Tyler, JW, Chigerwe, M, Dawes, ME, Middleton, JR (2005) Effect of delayed colostrum collection on colostral IgG concentration in dairy cows.*Journal of the American Veterinary Medical Association***226**, 1375-1377.
Muller, LD, Ellinger, DK (1981) Colostral immunoglobulin concentrations among breeds of dairy cattle*Journal of Dairy Science***64**, 1727-1730.
Nowak, W, Mikula, R, Zachwieja, A, Paczynska, K, Pecka, E, Drzazga, K, Slosarz, P (2012) The impact of cow nutrition in the dry period on colostrum quality and immune status of calves. *Polish Journal of Veterinary Science***15**, 77-82.
Pritchett, LC, Gay, CC, Besser, TE, Hancock, DD (1991) Management and production factors influencing immunoglobulin G1 concentration in colostrum from Holstein cows.*Journal of Dairy Science***74**, 2336-2341.
Rastani, RR, Grummer, RR, Bertics, SJ, Gumen, A, Wiltbank, MC, Mashek, DG, Schwab, MC (2005) Reducing dry period length to simplify feeding transition cows: milk production, energy balance, and metabolic profiles.*Journal of Dairy Science***88**, 1004-1014.
Reynolds, LP, Millaway, DS, Kirsch, JD, Infeld, JE, Redmer, DA (1990) Growth and Invitro Metabolism of Placental Tissues of Cows from Day 100 to Day 250 of Gestation. *Journal of Reproduction and Fertility***89**, 213-222.

Roche, JR, Dennis, NA, Macdonald, KA, Phyn, CVC, Amer, PR, White, RR, Drackley, JK (2015) Growth targets and rearing strategies for replacement heifers in pasture-based systems: a review, *Animal Production Science***55**, 902-915.
Tyler, JW, Steevens, BJ, Hostetler, DE, Holle, JM, Denbigh, JL, Jr. (1999) Colostral immunoglobulin concentrations in Holstein and Guernsey cows.*American Journal of Veterinary Research***60**, 1136-1139.
Vogels, Z, Chuck, GM, Morton, JM (2013) Failure of transfer of passive immunity and agammaglobulinaemia in calves in south-west Victorian dairy herds: prevalence and risk factors. *Australian Veterinary Journal***91**, 150-158.
Weaver, DM, Tyler, JW, VanMetre, DC, Hostetler, DE, Barrington, GM (2000) Passive transfer of colostral immunoglobulins in calves. *Journal of Veterinary Internal Medicine***14**, 569-577.
Windeyer, MC, Leslie, KE, Godden, SM, Hodgins, DC, Lissemore, KD, LeBlanc, SJ (2014) Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age.*Preventive Veterinary Medicine***113**, 231-240.