Effects of Photoperiod and Glucose-Supplemented Drinking Water on the Performance of Dairy Calves

V. R. Osborne,*¹ N. E. Odongo,* A. M. Edwards,† and B. W. McBride*

*Department of Animal and Poultry Science, and

†Computing and Communications Services, University of Guelph, Guelph, Ontario, Canada N1G 2W1

ABSTRACT

Long-day photoperiods (LDPP) have been shown to increase milk production in lactating dairy cattle. The objective of this study was to determine the effects of supplemental light and glucose-supplemented drinking water on starter dry matter intake (DMI), water intake, serum and rumen metabolites, and growth performance of calves from birth to 8 wk of age. The experiment was conducted as a completely randomized design with a 2 × 2 factorial arrangement of treatments. The calves were assigned at birth to 1 of 4 treatments: 1) 10 h of light, 14 h of dark (short-day photoperiods; SDPP), ad libitum intake of water, and no glucose supplementation; 2) 10 h of light, 14 h of dark, and ad libitum intake of water supplemented with 50 g of glucose/L; 3) 18 h of light, 6 h of dark (LDPP), and ad libitum intake of water, and no glucose supplementation; and 4) 18 h of light, 6 h of dark, and ad libitum intake of water supplemented with 50 g of glucose/L. Fluorescent lights were used to provide lighting at an intensity of approximately 600 lx at the eye level of calves. The calves were bucket-fed 2 L of whole milk offered twice daily at 0700 and 1600 h and had a free access to a textured calf starter. The calves on LDPP were heavier at d 56 than SDPP calves regardless of level of glucose supplementation. The average daily gain of the calves on LDPP from d 29 to 42 and from d 43 to 56 was greater than for SDPP calves regardless of the level of glucose supplementation. The greater average daily gain of LDPP calves from d 29 to 56 coincided with the greater calf starter DMI of these calves. Body widths through hooks were highly ($r = 0.72$) correlated with body weights, which in turn were related to calf starter DMI. Calves on LDPP had greater ruminal osmolality and greater concentrations of acetate, propionate, butyrate, and total volatile fatty acids than SDPP calves regardless of the level of glucose supplementation. Calves on LDPP

had lower Ca:P ratio than the SDPP calves regardless of level of glucose supplementation. The concentrations of serum glucose and sodium for the glucose-supplemented calves were greater than for nonsupplemented calves regardless of lighting regimen. These results suggest that LDPP encouraged greater consumption of calf starter, which stimulated faster rumen development in the LDPP calves as evidenced by greater volatile fatty acid concentrations.

Key words: photoperiod, drinking water, glucose supplementation, dairy calf

INTRODUCTION

Long-day photoperiod (LDPP; 16 to 18 h of light) is galactopoietic in dairy cows (Dahl et al., 2000). Supplemental lighting (16 to 18 h of light) during lactation has been shown to increase milk yield in dairy cattle (Evans and Hacker, 1989; Dahl et al., 1997, 2000) and stimulate BW gain in heifers (Tucker et al., 1984). Heifers (84 ± 15 d of age) exposed to LDPP had greater growth and an earlier onset of puberty compared with heifers exposed to short-day photoperiod (SDPP; 8 h of light, 16 h of dark; Rius et al., 2005). Long-day photoperiod has been shown to promote mammary parenchymal growth before and after puberty (Petitclerc et al., 1985). Rius and Dahl (2006) showed that LDPP exposure during the prepubertal growth phase resulted in greater milk secretion during the first lactation. Photoperiod manipulation therefore offers a management tool that could enhance growth and accelerate the onset of puberty (Hansen et al., 1983; Petitclerc et al., 1983; Schillo et al., 1992) and therefore reduce the age of heifers at first parturition (Peters et al., 1980; Schillo et al., 1983). However, there is little information on the effects of LDPP on growth performance in neonatal calves.

Water is an important nutrient in dairy production (Houpt, 1984; Murphy, 1992). Too often, it is assumed that if a calf is being fed a liquid diet, its needs for water will be satisfied (NRC, 2001). However, fresh water in addition to water consumed as part of the diet, is critical for optimal growth and consumption of dry

Received May 31, 2007.

Accepted July 31, 2007.

¹Corresponding author: vosborne@uoguelph.ca

feed (Leaver and Yarrow, 1972; Kertz et al., 1984). Water constitutes 70 to 75% of the weight of the calf and plays important roles as a solvent for nutrients, a thermoregulator, and an osmoregulator (Davis and Drackley, 1998). Osborne et al. (2002) showed that glucose supplementation in the drinking water of transition cows improved the nitrogen status of the cow by reducing the rumen ammonia levels and blood urea. Additionally, Thomas et al. (2007) showed that flavoring agents need not be added only to the starter feed for calves, but also that flavor can stimulate DMI and BW gain when used in drinking water.

The primary stimulus for the development of ruminal epithelia in calves is controlled by the VFA propionate and butyrate (Flatt et al., 1958; Sander et al., 1959; Quigley et al., 1997). Waldo and Schultz (1960) showed that sucrose moderately increased *in vivo* butyrate production in steers. The role of rumen development and the process of transitioning calves from their neonatal reliance on nutrients supplied by milk to nutrients supplied in solid feed is therefore of substantial economic importance to producers. Additionally, adding sucrose to the diet of dairy cattle in early lactation increased DMI (Nombekela et al., 1994). It was hypothesized that supplementation of "sugar water" in calf's drinking water would stimulate calf starter intake and accentuate the production of propionate and butyrate in the rumen and therefore accelerate rumen development. The objective of this study was to determine the effects of supplemental light and glucose-supplemented drinking water on starter DMI, water intake, serum and rumen metabolites, and growth performance of calves from birth to 8 wk of age.

MATERIALS AND METHODS

Animals and Experimental Design

Twenty-four female Holstein dairy calves (initial BW of 42.2 ± 3.8 kg, mean $\pm$ SD) housed in an insulated nursery (room temperature, 20°C) at the Elora Dairy Research Centre, University of Guelph (Guelph, Ontario, Canada), were used in the study. Animals were cared for and handled in accordance with the Canadian Council on Animal Care regulations, and the University of Guelph Animal Care Committee reviewed and approved the experiment and all procedures carried out in the study. Calves were separated from dams at birth and placed in individual 1.2- $\times$ 1.5-m pens bedded with kiln-dried wood shavings. The calves were fed 2 L of pooled colostrum within 90 min of birth, a second 2 L of colostrum 8 to 12 h after the first colostrum feeding, and whole milk thereafter.

The study was conducted as a completely randomized design with a 2 $\times$ 2 factorial arrangement of treatments

Table 1. Nutrient composition of textured calf starter

Nutrient	%, DM
DM, %	85.4
CP, %	18.0
ADF, %	7.5
NDF, %	22.8
Ca, %	1.13
P, %	0.69
K, %	1.13
Mg, %	0.28
Na, %	0.35
Vitamin A, IU/kg	12,500
Vitamin D, IU/kg	5,000
Vitamin E, IU/kg	45
NE _M , ¹ Mcal/kg	2.45
NE _G , ¹ Mcal/kg	1.72

¹Calculated using NRC (2001).

from June 23 to September 8, 1999. The calves were assigned at birth to 1 of 4 treatments: 1) 10 h of light, 14 h of dark (SDPP), *ad libitum* intake of water, and no glucose supplementation; 2) 10 h of light, 14 h of dark, and *ad libitum* intake of water supplemented with 50 g of glucose/L; 3) 18 h of light, 6 h of dark (LDPP), and *ad libitum* intake of water, and no glucose supplementation; and 4) 18 h of light, 6 h of dark, and *ad libitum* intake of water supplemented with 50 g of glucose/L. Fluorescent lights were used to provide lighting at an intensity of approximately 600 lx at the eye level of calves to simulate the lighting outside. The calves were bucket-fed 2 L of whole milk offered twice daily at 0700 and 1600 h and had free access to a standard textured calf starter (Rumax 20% calf starter, Floradale Feed Mill Limited, Floradale, Ontario, Canada) throughout the study. Starterorts were collected and weighed daily. Milk, water, and starter intakes were recorded daily. The chemical analysis of the calf starter is presented in Table 1. The trial lasted from birth to 8 wk of age.

Calves were weighed and measured for withers height, hip height, hip width, and heart girth at birth, d 28, and d 56. Calves were weighed on a platform scale (Salter Scales, Fairfield, NJ). Withers and hip heights were measured using a sliding-scale height stick with a bubble level. Heart girths were measured using a Nasco Holstein dairy heart girth tape (Nasco, Fort Atkinson, WI) and hip width with a hipometer caliper (Dairy Innovations, Alexander, NY). With the heart girth tape method, the tape was placed around the heart girth of the animal and pulled taut. The measurement was read directly off the tape according to the circumference of the animal. With the hipometer, the forceps-like arms were cupped over the greater trochanters of the left and right femurs of the heifer. The measurement was then recorded according to the width of the

opening of the caliper arms by reading directly from the sliding scale of the hipometer (Skidmore, 2001).

Blood samples were obtained at birth and weekly thereafter on d 7, 14, 28, 35, 42, 49, and 56 by venipuncture of the jugular vein before the morning feeding into evacuated 10-mL sterile serum test tubes (Vacutainer, Becton Dickinson, Rutherford, NJ). Samples were allowed to stand at room temperature for 30 min and then centrifuged at $2,000 \times g$ for 15 min in a refrigerated centrifuge (model TJ-6, Beckman, Palo Alto, CA) at 4°C. Serum was separated and transferred to 7-mL plastic scintillation vials and stored at -70°C until analysis.

Rumen fluid was aspirated 4 h postfeeding on d 28, 35, 42, and 56 using a Geishauser oral probe (Geishauser, 1993). A 200-mL sample of the rumen fluid was extracted and a subsample was filtered and the pH measured immediately using a Fisher Accumeter pH meter (model 610, Fisher Scientific, Hampton, NH) calibrated using pH 4.0 and pH 7.0 buffer solutions (Fisher Scientific). A subsample of the rumen fluid was transferred to a 50-mL disposable sterile centrifuge tube (Fisherbrand, Ottawa, Ontario, Canada) and frozen at -70°C for further analysis.

Chemical Analysis

Samples of the calf starter were obtained from each bag when the bags were opened and composited monthly. Analytical DM content of the starter was determined by oven drying at 135°C for 2 h (method 3.002; AOAC, 1990), and OM was determined by ashing at 500°C for 16 h (method 942.05; AOAC, 1990). The CP contents were determined using a Leco FP 428 nitrogen analyzer (Leco Corporation, St. Joseph, MI; method 4.2.08; AOAC, 1990). The calf starter samples were also analyzed for ADF (method 973.18c; AOAC, 1990) and NDF (Van Soest et al., 1991) using α -amylase (no. A3306, Sigma Chemical Co., St. Louis, MO) and sodium sulfite corrected for ash concentration adapted for an Ankom 200 fiber analyzer (Ankom Technology, Fairport, NY). Calcium, phosphorus, potassium, magnesium, and sodium were analyzed by inductively coupled plasma spectroscopy (method 945.46; AOAC 1990).

The serum was analyzed for electrolytes (Ca, P, Mg, Na, K, and chloride), total protein, urea, glucose, and osmolality. The concentration of BHBA in serum was determined using the Sigma Diagnostics enzymatic method (kit 310-A, Sigma, St. Louis, MO) following the methods of Williamson et al. (1962), and NEFA concentrations were determined using a colorimetric assay (NEFA-C kit, Wako Chemicals, Richmond, VA), following modifications by Johnson and Peters (1993). Blood biochemistry was evaluated using a Boehringer Mann-

heim/Hitachi 911 analyzer at the Laboratory Services Division, University of Guelph, Ontario, Canada.

Rumen fluid samples were thawed and centrifuged at $2,200 \times g$ for 20 min in a refrigerated (4°C) centrifuge as above. Rumen VFA concentrations were determined on a Varian GC3400 gas chromatograph (Varian Canada, Mississauga, Ontario, Canada) using a fused-silica capillary column (1.5 m $\times$ 0.53 mm i.d.; Nukol, Supelco Canada Ltd., Mississauga, Ontario, Canada). The injection and flame-ionization detector temperatures were 200°C, and the carrier gas was helium. The isothermal column temperature was 85°C with a hold time of 10 min. Lactic acid concentration in rumen samples was analyzed using the colorimetric method of Taylor (1996). Rumen ammonia nitrogen (NH_3N) concentration in the rumen fluid was determined using the indophenol-blue colorimetric procedure of Novozamski et al. (1974).

Statistical Analysis

The ANOVA for weight gain, ADG, water intake, calf starter DMI, serum and rumen variables, and structural body measurements was conducted using the MIXED procedure of SAS (v. 9.1, SAS Inst. Inc., Cary, NC), using the model $Y_{ij} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ij}$, where Y_{ij} is the dependent variable, μ is the overall mean, α_i is the effect of light ($i = 1, 2$), β_j is the effect of glucose supplementation ($j = 1, 2$), $\alpha\beta_{ij}$ is the effect of a light $\times$ glucose supplementation interaction ($ij = 1, 2, \dots, 4$), and ε_{ij} is the random residual error. The effects of light and glucose supplementation were considered fixed, and calf within treatment was included as a random effect. To determine time-dependent changes and interactions between time and treatment of effects with repeated measurements, the effects of treatments over time were evaluated using orthogonal contrasts. Birth weight was used as a covariate and effects were considered significant at a probability of $P < 0.05$. Differences among treatment means were tested for significance using Tukey's multiple range test (v. 9.1, SAS Inst. Inc.). Data are expressed as mean $\pm$ SEM, which represents the pooled SE for the model.

RESULTS AND DISCUSSION

Intake and Weight Gain

Initial and final calf weights, average daily and total gain, calf starter DMI, and water intake are presented in Table 2. All calves consumed the entire 2 L of milk offered twice daily. Glucose supplementation had no effect ($P > 0.05$) on starter intake and weight gains. The calves on LDPP were heavier ($P < 0.05$) at d 56 than SDPP calves regardless of level of glucose supple-

Table 2. Effects of photoperiod and glucose supplementation in the drinking water on ADG and repeated measures of BW, ADG, and calf starter, water, and energy intake

Response ¹	No glucose		50 g of glucose/L		SEM	Time, <i>P</i> -value		
	SDPP ²	LDPP ³	SDPP	LDPP		Linear	Quadratic	Cubic
BW, kg	58.0	62.2	57.6	58.5	2.41	<0.01	<0.01	0.21
Initial	43.2	41.3	42.1	40.4	1.63	—	—	—
Final	73.4 ^a	80.5 ^b	72.1 ^a	76.4 ^b	2.91	—	—	—
Gain	30.2 ^a	39.2 ^b	30.0 ^a	36.0 ^b	3.27	—	—	—
ADG, g/d	449.6	575.9	467.3	553.5	66.49	<0.01	0.16	0.73
d 0 to 14	407.2	375.0	452.4	511.9	88.1	—	—	—
d 15 to 28	528.6	726.2	458.3	511.9	73.3	—	—	—
d 0 to 28	467.9	550.6	455.4	511.9	50.35	—	—	—
d 29 to 42	607.2 ^a	940.5 ^b	654.8 ^a	797.6 ^b	107.07	—	—	—
d 43 to 56	700.0 ^a	1,017.9 ^b	535.7 ^c	750.0 ^d	92.82	—	—	—
d 29 to 56	653.6 ^a	979.2 ^b	595.2 ^a	773.8 ^b	71.09	—	—	—
d 0 to 56	560.7 ^a	764.9 ^b	525.3 ^a	642.8 ^b	57.00	—	—	—
Starter intake, kg	3.2 ^a	5.2 ^b	1.7 ^c	2.9 ^a	0.73	<0.01	0.03	0.12
Water intake, L	25.1	34.9	31.3	32.3	7.0	<0.01	<0.01	<0.01
Energy intake, Mcal	23.2	26.2	26.3	28.2	1.39	<0.01	0.79	0.15

^{a-c}Values within rows with different superscript letters are significantly different ($P < 0.05$).

¹Means of 6 calves per treatment.

²SDPP = short-day photoperiod; 10 h of light.

³LDPP = long-day photoperiod; 18 h of light.

mentation (Table 2). Repeated-measures analysis revealed that a quadratic equation adequately described the shape of the curve for weekly calf BW gain from birth to d 56. There were no differences ($P > 0.05$) in ADG from d 0 to 14, ADG from d 15 to 28, or the combined ADG from d 0 to 28 in agreement with Lesmeister and Heinrichs (2004), who also observed no treatment effects in DMI and ADG from d 0 to 28. This was not surprising because calves generally do not gain a significant amount of weight during the first 2 to 3 wk of life due to a variety of challenges including rumen development, health, environmental change, and nutrient intake (Toullec and Guilloteau, 1989; Davis and Drackley, 1998; Diaz et al., 2001).

The ADG of the calves on LDPP from d 29 to 42 and from d 43 to 56 and total gain were greater ($P < 0.05$) than those of calves on SDPP regardless of level of glucose supplementation. Tucker et al. (1984) showed that LDPP stimulated BW gain in heifers. The greater ADG of LDPP calves from d 29 to 56 was directly related to the greater ($P < 0.05$) calf starter DMI of these calves (Table 2). The effects of photoperiod on weight gain, calf starter DMI, and water intake of the calves from birth to 8 wk of age are presented in Figure 1. Calves on the LDPP consumed, on average, 78% more calf starter than SDPP calves. Calves need fermentable carbohydrates and fiber, which are found in calf starter to produce VFA for rumen epithelial development and for establishment of microbial populations (Harrison et al., 1960; Greenwood et al., 1997). In the current study, regression analysis of calf growth suggests that from birth to d 28, calf ADG was driven by milk intake.

However, by d 56, 84% ($P < 0.05$) of the variation in calf BW was explained by the amount of calf starter consumed. The best-fit linear model requiring minimal dietary information relating calf BW to calf starter energy intake was [BW (kg) = 62.7 ($\pm$ 2.22) + 1.33 ($\pm$ 0.186) calf starter energy intake (Mcal); ($n = 24$; residual SD = 1.02; $R^2 = 0.71$; $P < 0.05$)]. There were no differences ($P > 0.05$) in water intake.

Structural Growth

Structural growth measurements of calves are presented in Table 3. Glucose supplementation had no effect ($P < 0.05$) on the structural growth measurements. Body widths through hooks of the calves on LDPP were greater ($P < 0.05$) than those of calves on SDPP regardless of level of glucose supplementation. Body widths through hooks were highly ($r = 0.72$; $P < 0.001$) correlated with BW, which in turn were related to calf starter DMI. The heart girth tape BW estimations were greater ($P < 0.05$) than those recorded on the electronic scale (88 vs. 59 kg, respectively). This was in contrast to Dingwell et al. (2006), who reported that in the heifers aged <3 mo, the heart girth tape measurements were lower than the scale measurements. The heart girth tape method has already been validated for older (>3 mo) heifers and is widely used (Heinrichs and Hargrove, 1987). There is a need to validate the relationship between the hipometer, heart girth, and BW in calves <3 mo of age.

Figure 1. Effects of photoperiod on a) BW, b) calf starter DMI, and c) water intake of dairy calves from d 0 to 56. The treatments were 10 h of light, 14 h of dark (short-day photoperiod, SDPP; —□—) and 18 h of light, 6 h of dark (long-day photoperiod, LDPP; —■—).

Rumen Parameters

Ruminal ammonia, pH, osmolality, acetate, propionate, butyrate, acetate-to-propionate ratio, and total VFA from d 29 to 56 are presented in Table 4. Glucose supplementation had no effects ($P < 0.05$) on rumen parameters. Calves exposed to LDPP had greater ($P < 0.05$) ruminal osmolality and greater concentrations of

acetate, propionate, butyrate, and total VFA compared with SDPP calves at both levels of glucose supplementation, which suggests increased rumen epithelial metabolic activity in the LDPP calves. Ruminal osmolality normally ranges from 240 to 265 mOsm/L with roughage diets and 280 to 300 mOsm/L with concentrate diets (Garza et al., 1989). Consumption of calf starter is critical to the development of an active, functional

Table 3. Effects of photoperiod and glucose supplementation in the drinking water on the repeated measures of structural growth measurements of dairy calves

Response ¹	No glucose		50 g of glucose/L		SEM	Time, <i>P</i> -value	
	SDPP ²	LDPP ³	SDPP	LDPP		Linear	Quadratic
BW based on heart girth measurement, kg	88.5	89.5	88.1	89.1	1.01	<0.01	<0.01
Middle girth circumference, cm	93.9	96.8	93.7	95.1	1.24	<0.01	<0.01
Height at withers, cm	85.3	84.3	84.4	85.8	0.66	<0.01	<0.01
Height at rump, cm	89.0	87.7	84.9	89.2	1.83	<0.01	0.97
BW through hooks, cm	19.8 ^a	20.1 ^b	19.9 ^a	21.0 ^b	0.28	<0.01	0.05

^{a,b}Values within rows with different superscript letters are significantly different ($P < 0.05$).

¹Means of 6 calves per treatment.

²SDPP = short-day photoperiod; 10 h of light.

³LDPP = long-day photoperiod; 18 h of light.

rumen. Butyrate and, to a lesser extent, propionate are used as energy sources by the rumen epithelium and subsequently have the greatest influence on epithelial development (Sander et al., 1959; Tamate et al., 1962). The LDPP calves had lower ($P < 0.05$) ruminal pH and lower ($P < 0.05$) acetate-to-propionate ratios compared with SDPP calves regardless of level of glucose supplementation (Table 4). This is supported by the greater ($P < 0.05$) concentrations of individual and total VFA in LDPP calves compared with SDPP calves (Table 4). This was not surprising because the LDPP calves also consumed 78% more ($P < 0.05$) calf starter DM during this period than SDPP calves. Rumen pH decreased linearly ($P < 0.05$) with time from d 29 to 56 in agreement with Beharka et al. (1998), who showed that ruminal pH was influenced by the age of the calf; that is, the pH declined after wk 2 and then increased at 10 wk of age. Anderson et al. (1987a,b) also reported a quadratic change in the relationship between pH and age of the calf. In the current study, rumen pH was only measured from d 29 to 56. In milk-fed calves, a condition known as “ruminal drinkers” (van Weeren-

Keverling, 1989) occurs when the esophageal (reticular) groove reflex is dysfunctional, allowing milk to spill into the reticulorumen instead of being delivered directly into the abomasum (Bruinessen-Kapsenberg et al., 1982; Dirr and Dirksen, 1989). Lactose and other easily fermentable carbohydrates contained in the milk or nutrient solution are fermented by the ruminal flora to form predominantly lactic acid plus other short-chain fatty acids (Gentile, 1995). As the organic acids accumulate in the rumen, the ruminal pH drops, which leads to acidosis (Gentile, 1995). In the current study, the acidosis was not sufficiently severe to alter health or performance. There were no differences ($P > 0.05$) in ammonia concentrations between treatments (Table 4).

Serum Electrolytes and Metabolites

Serum electrolytes and metabolites of the calves from d 0 to 56 are presented in Table 5. The concentrations of the serum electrolytes and metabolites are consistent with the biochemistry reference values for growing calves published by Lumsden et al. (1980) and Dubreuil

Table 4. Effects of photoperiod and glucose supplementation in the drinking water on the repeated measures of ruminal ammonia, pH, osmolality, acetate, propionate, butyrate, acetate-to-propionate ratio, and total VFA of neonatal dairy calves

Response ¹	No glucose		50 g of glucose/L		SEM	Time, <i>P</i> -value		
	SDPP ²	LDPP ³	SDPP	LDPP		Linear	Quadratic	Cubic
Rumen pH	6.24 ^a	5.78 ^b	6.30 ^a	5.68 ^b	0.160	0.01	0.29	0.70
Ammonia, mmol/L	0.768	0.935	0.760	0.922	0.124	0.89	0.67	0.05
Osmolality, mmol/L	257.0 ^a	326.7 ^b	259.8 ^a	304.3 ^b	18.43	0.72	0.59	0.01
Acetate (A), mmol/L	33.7 ^a	43.1 ^b	31.2 ^a	39.0 ^b	3.53	0.26	0.23	0.17
Propionate (P), mmol/L	15.5 ^a	28.3 ^b	15.3 ^a	23.3 ^b	2.58	0.39	0.89	0.05
A:P	2.55 ^a	1.57 ^b	2.19 ^a	1.76 ^b	0.213	0.68	0.10	0.82
Butyrate, mmol/L	4.7 ^a	7.0 ^b	5.3 ^a	7.7 ^b	0.76	0.19	0.10	0.45
Total VFA, mmol/L	53.8 ^a	78.4 ^b	51.9 ^a	70.0 ^b	6.33	0.25	0.31	0.11

^{a,b}Values within rows with different superscript letters are significantly different ($P < 0.05$).

¹Means of 6 calves per treatment.

²SDPP = short-day photoperiod; 10 h of light.

³LDPP = long-day photoperiod; 18 h of light.

Table 5. Effects of photoperiod and glucose supplementation in the drinking water on the repeated measures of serum parameters of neonatal dairy calves

Response ¹	No glucose		50 g of glucose/L		SEM	Time, <i>P</i> -value		
	SDPP ²	LDPP ³	SDPP	LDPP		Linear	Quadratic	Cubic
Glucose, mmol/L	6.70 ^a	6.46 ^a	7.26 ^b	7.06 ^b	0.252	0.09	0.61	0.21
NEFA, mEq/L	0.135	0.168	0.156	0.135	0.017	<0.01	<0.01	<0.01
Urea N, mmol/L	4.26 ^a	4.22 ^a	3.33 ^b	3.13 ^b	0.262	0.89	0.01	0.08
Total protein, g/L	62.3	60.6	58.0	59.4	3.66	0.09	0.92	0.17
Ca, mmol/L	2.75	2.72	2.71	2.74	0.049	<0.01	<0.01	0.54
P, mmol/L	2.71 ^a	2.77 ^b	2.77 ^b	2.98 ^c	0.064	0.04	<0.01	<0.01
Mg, mmol/L	0.920	0.919	0.918	0.940	0.0341	0.27	0.33	0.87
Na, mmol/L	143.3 ^a	143.6 ^a	144.5 ^a	149.0 ^b	1.40	0.13	0.70	0.85
K, mmol/L	4.96	4.94	4.90	5.09	0.069	<0.01	0.44	0.93
Cl, mmol/L	101.3	101.1	101.5	105.1	1.31	<0.01	0.11	0.89
Cholesterol, mmol/L	2.73	2.67	2.14	2.59	0.180	<0.01	<0.01	<0.01
BHBA, mmol/L	246.2	228.8	222.3	218.0	21.8	<0.01	0.48	0.14
Na:K	29.1	29.2	29.6	29.4	0.38	<0.01	0.21	0.87
Ca:P	1.02 ^a	0.99 ^b	0.99 ^b	0.93 ^c	0.227	<0.01	<0.01	<0.01

^{a-c}Values within rows with different superscript letters are significantly different ($P < 0.05$).

¹Means of 6 calves per treatment.

²SDPP = short-day photoperiod; 10 h of light.

³LDPP = long-day photoperiod; 18 h of light.

and Lapierre (1997). The concentration of serum glucose was greater for the calves supplemented with glucose, regardless of lighting regimen (Table 5). However, the concentrations of urea nitrogen for the calves supplemented with 50 g of glucose/L in the drinking water were lower ($P < 0.05$) than for the control calves regardless of lighting regimen. This finding is consistent with the results of Osborne et al. (2002), who reported that in transition cows, glucose supplementation in the drinking water improved the nitrogen status of the cows by reducing the rumen ammonia levels and blood urea, but did not alter the NE_L balance during the peri-parturient period. In the current study, the glucose treatment also did not ($P > 0.05$) alter total energy intake (Table 2).

The LDPP calves had greater ($P < 0.05$) concentrations of serum P and lower ($P < 0.05$) serum Ca:P ratios compared with the SDPP calves regardless of level of glucose supplementation. Several studies (Forar et al., 1982; Call et al., 1987; Wu et al., 2000) have shown that the concentration of P in serum is a reflection of P intake. During the first 2 to 3 wk of life, the calf is essentially monogastric with a simple stomach, the abomasum, to digest milk components. As the calf consumes dry feed and water, the rumen begins to develop and becomes more important. The bioavailability of P in corn grain for young pigs was estimated to be less than 15% (NRC, 1998). About 70% of the total P is in the form of phytate or myo-inositol hexakisphosphate, a form that is unavailable to pigs (NRC, 1998). The greater concentrations of serum P for LDPP calves were probably due to increased availability of phytate P as a result of a more developed rumen, which encouraged greater intake of calf starter DM. Plasma P concentra-

tion in growing cattle is normally in the range of 1.3 to 2.6 mmol/L (NRC, 2001).

CONCLUSIONS

Long-day photoperiods have been shown to increase milk production in lactating dairy cattle. The results of this study suggest that LDPP encouraged consumption of calf starter, which stimulated faster rumen development as evidenced by greater VFA concentrations and greater ADG in the calves but there was no direct evidence of rumen development per se. Glucose supplementation in the drinking water did not alter water intake. Photoperiod manipulation therefore offers a management tool that could enhance growth and accelerate the onset of puberty and therefore reduce the age of heifers at first parturition. Additional research is required to elucidate the metabolic mechanism.

ACKNOWLEDGMENTS

The authors thank the staff at the Elora Dairy Research Centre, University of Guelph, for their technical assistance, and the Dairy Farmers of Ontario, Ontario Ministry of Agriculture and Food, and the Natural Sciences and Engineering Research Council of Canada (BWM) for financial support.

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