Feeding heat-treated colostrum to neonatal dairy heifers: Effects on growth characteristics and blood parameters¹

J. A. Elizondo-Salazar and A. J. Heinrichs²

Department of Dairy and Animal Science, The Pennsylvania State University, University Park 16802

ABSTRACT

Newborn Holstein heifer calves were studied to compare absorption of immunoglobulin G (IgG₁ and IgG₂), total serum protein concentration, lymphocyte counts, health scores, growth, and starter intake after receiving unheated or heat-treated colostrum. First-milking colostrum was collected from Holstein cows and frozen at -20°C to accumulate a large batch. After thawing and mixing, half of the colostrum was transferred into 1.89-L plastic containers and frozen at -20°C until needed for feeding. The remaining half was heated at 60°C for 30 min, transferred into 1.89-L plastic containers, and then frozen at -20°C until needed for feeding. Forty heifer calves weighing ≥ 32 kg at birth were enrolled into 1 of 2 treatment groups before suckling occurred. For the first feeding, 3.8 L of colostrum was bottle fed by 1.5 to 2 h of age. For the second and third feedings, pasteurized whole milk at 5% of birth body weight (BW) was fed. Subsequently, calves received milk replacer containing 20% crude protein and 20% fat at 10% of birth BW/d until wk 5. Milk replacer was reduced to 1 feeding of 5% birth BW until weaning at 6 wk of age. Blood samples and growth data were collected through wk 8. Batch heat-treatment of colostrum at 60°C for 30 min lowered colostrum bacteria concentration while maintaining colostral IgG concentration and viscosity. Calves fed heat-treated colostrum had significantly greater IgG concentrations at 24 h and greater apparent efficiency of IgG absorption (IgG = 23.4 g/L; apparent efficiency of absorption = 33.2%) compared with calves fed unheated colostrum (IgG = 19.6 g/L; apparent efficiency of absorption = 27.7%). There was no difference between treatment groups in growth measurements, calf starter intake, lymphocyte counts, or health scores.

Key words: colostrum, heat treatment, blood immunoglobulin G, health

INTRODUCTION

Calves are agammaglobulinemic at birth and depend on ingestion and absorption of colostral immunoglobulins, especially IgG, across the intestinal epithelium during the first 24 h of life to establish a protective serum IgG concentration (Bush and Staley, 1980). The literature provides abundant information on factors affecting serum IgG levels in calves. The 2 most important of these are age of the calf when colostrum is first fed and mass of IgG ingested, which is determined by volume of colostrum fed and colostral IgG concentration (Stott et al., 1979; Besser and Gay, 1985).

Colostrum not only provides passive immunity for the newborn calf but can also have profound effects on development of the neonatal intestine, because it contains several bioactive and growth-promoting substances such as peptide hormones, growth factors, cytokines, steroid hormones, thyroxine, nucleotides, polyamines, and enzymes (Koldovsky, 1989). Colostrum is also the first source of nutrients for the calf after birth. It contains proteins, essential and nonessential amino acids, fatty acids, lactose, vitamins, and minerals (Kehoe et al., 2007).

Despite its important nutritional and immune benefits, colostrum feeding may also offer the calf the first opportunity for exposure to infectious pathogens (Swan et al., 2007), because collection, handling, and storage of colostrum introduces risks of microbial contamination (Stewart et al., 2005). Disease-causing pathogens are transferred to newborns via colostral secretions, either by direct shedding from the mammary gland or from postharvest contamination, and may include *Mycobacterium avium* ssp. *paratuberculosis* (Streeter et al., 1995), *Listeria monocytogenes* (Doyle et al., 1987), *Campylobacter jejuni* (Lovett et al., 1983), *Salmonella* spp. (Spier et al., 1991), and *Escherichia coli* (Steele, 1997).

Pasteurization has been suggested as one possible control measure to reduce or eliminate transfer of colostrum-borne pathogens to dairy calves (Godden et al., 2006). However, early studies showed that this process reduced IgG concentrations (Meylan et al., 1996; Godden et al., 2003) and increased viscosity (McMartin et

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²Corresponding author: ajh@psu.edu

al., 2006). Recent studies with colostrum showed that bacterial populations could be drastically reduced without affecting IgG levels and viscosity by heating at a lower temperature than used for pasteurization of milk (Godden et al., 2006; Johnson et al., 2007; Elizondo-Salazar and Heinrichs, 2008). With this in mind, the first objective of this study was to describe the effect of heat treatment of colostrum at 60°C for 30 min on colostrum characteristics including bacterial concentration, IgG₁ and IgG₂ concentrations (g/L), and viscosity (Pa·s). The second objective was to describe the effect of feeding heat-treated (versus unheated) colostrum on passive transfer of colostral immune parameters, health, and growth characteristics to 8 wk of age.

MATERIALS AND METHODS

Colostrum Management

First-milking colostrum with an immunoglobulin concentration >50 g/L (measured by colostrometer; Biogenics, Mapleton, OR) was collected from Holstein cows into new 1.89-L plastic containers and frozen at -20°C until a total of 170 L was gathered. Once collected, colostrum was placed into a cool room at 4°C for 24 h to thaw, pooled, and mixed for 20 min in a commercial batch pasteurizer (Girton Manufacturing Co., Millville, PA) to create a unique batch. Subsamples were taken and stored at -20°C for later analysis. Half of the colostrum was transferred into new, clean 1.89-L plastic containers and frozen at -20°C until needed for feeding (unheated colostrum). The remaining half of the colostrum was placed into 3 stainless steel containers (28 L each). All 3 containers were placed into a steam vat pasteurizer (Girton Manufacturing Co.). The pasteurizer was equipped with agitators to allow even heating of colostrum during pasteurization. Temperature of water and colostrum was monitored every 5 min. Water was heated until colostrum reached the target temperature of 60°C, held for 30 min, and then ice water was used to cool the colostrum. Subsamples were collected from each of the 3 containers and pooled for later analysis. Colostrum was then transferred into 1.89-L plastic containers, and frozen at -20°C until needed for feeding (heat-treated colostrum).

Colostrum Sample Analyses

Unheated and heat-treated colostrum samples were thawed at 4°C and examined for standard plate count (SPC), CNS count, environmental streptococci (ES), coliform count (CC), noncoliform count (NC), *Streptococcus agalactiae* (SAG), and *Staphylococcus aureus* (SA) according to Jayarao et al. (2004). Colostrum

samples were mixed thoroughly by inverting the tube 20 to 25 times, and 50 µL was placed on selective and nonselective media using an inoculating loop. Plate count agar was used for enumeration of SPC. Numbers of ES and SAG in colostrum samples were estimated using modified Edward's agar supplemented with colistin sulfate and oxolinic acid (Sawant et al., 2002). MacConkey's agar no. 3 (Oxoid, Basingstoke, UK) was used to determine CC and NC. Baird Parker's agar (Difco, LePont de Claix, France) was used to determine CNS and SA. Plates for enumeration of SPC were incubated at 32°C for 48 h; plates for enumeration of CNS, ES, CC, SAG, and NC were incubated at 37°C for 48 h. Concentrations of IgG₁ and IgG₂ were determined in all samples by immunoprecipitation using single radial immunodiffusion (RID; VMRD, Pullman, WA). A monocular comparator (VMRD) was used to read the precipitin rings. Viscosity was measured with a digital viscometer (Brookfield Engineering Laboratories Inc., Middleboro, MA) using a parallel plate geometry (plate diameter = 50 mm). The gap between plates was set at 0.50 mm to allow good contact between the sample and the plates. Shear rate was set at 1.0 rpm and temperature was set at 39°C.

Colostrum samples were also analyzed for ash, CP (Leco FP-528 Nitrogen Combustion Analyzer; Leco, St. Joseph, MI), and crude fat (AOAC, 2000) using a Tecator Soxtec System HT 1043 Extraction unit (Tecator, Foss NA, Eden Prairie, MN). One aliquot of colostrum was freeze-dried and analyzed for Ca, P, Mg, Na, K, Zn, Fe, Cu, S, and Mn by Environmental Protection Agency (EPA) method 3051 to microwave digest samples with nitric acid. After digestion, samples were analyzed by EPA method 6010 with inductively coupled plasma spectrometry (US EPA, 1986). Retinol, tocopherol, and vitamin E were extracted according to methods from *Vitamin Analysis for the Health and Food Sciences* (Eitenmiller and Landen, 1999) and analyzed by HPLC techniques as described by Arnaud et al. (1991).

Calf Treatment Allocation and Sample Collection

Protocols for this study were approved by the Pennsylvania State University Institutional Animal Care and Use Committee. Holstein heifer calves from the Pennsylvania State University dairy herd were separated from their dams within 20 to 30 min of birth, before suckling occurred, placed in a 1.0- × 1.0-m holding pen until colostrum was fed, and then housed in 1.2- × 2.4-m individual pens in a naturally and mechanically ventilated barn bedded with wood shavings. Calves remained in individual pens until 8 wk of age, and calf-to-calf contact was eliminated by pen arrangement. Forty heifer calves weighing ≥32 kg at birth were

systematically enrolled into 1 of 2 treatment groups receiving either unheated or heat-treated colostrum for the first feeding. Information for each dam and calf was recorded, including cow identification number, date and time of calving, calving ease, parity, calf identification number, treatment allocation, and age at feeding. Birth weight, heart girth, hip height, and withers height were also recorded for every calf.

Before feeding colostrum, a jugular blood sample was collected from each calf into 8.5-mL serum and 7-mL K₃-EDTA Vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ). For the first feeding, 3.8 L of colostrum was bottle fed between 1.5 and 2 h of life. Colostrum was warmed to approximately 38°C using a hot water bath heated to approximately 52°C. To ensure that all calves received an equal amount of colostrum, an esophageal feeder was used in calves with reduced appetite. For the second and third feedings, pasteurized whole milk at 5% of birth BW was fed. Subsequently, calves were fed milk replacer containing 20% CP (all milk protein) and 20% fat (North American Nutrition Company Inc., Lewisburg, OH) at 10% of birth BW; 5% fed in the morning and 5% fed in the afternoon, until wk 5. Then, milk replacer was reduced to only morning feeding until weaning at 6 wk of age. Blood samples were collected from every calf at 4, 8, 12, 16, 20, 24, and 48 h and at wk 1 to 8 of age. A subsample from each blood sample was collected for measurement of packed cell volume by micro-hematocrit centrifugation. Health scores were assigned daily for each calf to evaluate scours, respiration, and general appearance (Lesmeister and Heinrichs, 2004). Electrolyte therapy was initiated when an animal had a fecal score >3 or was visibly dehydrated and continued until signs abated. Growth measures including heart girth, hip height, BW, and withers height were taken weekly 4 h after the morning feeding for all animals. Fresh calf starter (East Gate Feed & Grain LLC, Reedsville, PA) was offered beginning at 4 d of age, and refusals were recorded once a week. A sample of calf starter was collected twice monthly for the duration of the trial. All collected samples were stored (−20°C) and sent to Cumberland Valley Analytical Services (Hagerstown, MD) for analysis. Clean water was available continuously starting from d 2.

Blood Sample Analyses

Serum total protein (STP) concentrations (g/L) were determined using a commercially available handheld refractometer (VET 360, Reichert Inc., Depew, NY). Sera were then stored at −20°C until analyzed. Serum IgG concentrations (g/L) were determined using a commercially available RID kit (VMRD). Apparent

efficiency of absorption (AEA, %) of IgG, a calculated measure that estimates what proportion of the total IgG mass fed is actually absorbed into the circulation, was calculated using the equation described by Quigley and Drewry (1998), assuming a plasma volume of 9.5% of birth weight.

Blood samples from wk 1 to 4 collected into 7-mL K₃-EDTA Vacutainer tubes were used for lymphocyte and natural killer cell identification using flow cytometric analysis as explained by Pelan-Mattocks et al. (2001) at the Pennsylvania State University Huck Institute for the Life Sciences.

Statistical Analysis

Descriptive statistics were generated to define calf and dam characteristics for the 2 treatment groups. Blood and growth observations were analyzed using repeated measures analysis and the MIXED procedure of SAS 9.1 (SAS Institute, 2006). Calf was used as the random effect. The statistical model used for analysis was

$$Y_{ijk} = \mu + T_i + W_j + (TW)_{ij} + Calf_l + e_{ijk}$$

where Y_{ijk} = dependent variables, μ = overall mean, T_i = fixed effect of treatment i , where i = unheated or heat-treated, W_j = repeated measure of time j , $(TW)_{ij}$ = effect of treatment by time interaction, $Calf_l$ = random effect of calf l , and e_{ijk} = residual.

The AR(1) covariance structure was used in the model. Initial measurements for growth and blood parameters were offered as additional covariates into each model. However, none of these terms was significant, and none interacted with the variable describing colostrum treatment group, so initial measurements were removed from final models. Significance was declared at $P < 0.05$ for all models.

RESULTS AND DISCUSSION

Compositional analysis and characteristics of colostrum samples before and after heat treatment are presented in Table 1. It can be noted that thermal treatment created some changes in colostrum; however, composition was in accordance with values reported by Foley and Otterby (1978) and Kehoe et al. (2007). Composition of calf starter and milk replacer used throughout the study is presented in Table 2. Mean birth weight was 43.3 and 41.4 kg for calves in the untreated and heat-treated colostrum groups, respectively. Age of calves at first feeding ranged from 90 to 120 min for both treatment groups. The median parity

Table 1. Compositional analysis and characteristics of colostrum samples before and after heat treatment

Item	Unheated	Heat-treated
Density, g/mL	1.063	1.063
pH	6.10	6.09
Fat, %	6.27	6.33
Protein, %	14.20	15.75
Lactose, %	3.50	3.10
Total solids, %	28.24	29.54
Ash, %	4.27	4.36
Ca, mg/kg	0.21	0.22
P, mg/kg	0.18	0.19
Mg, mg/kg	0.04	0.04
Na, mg/kg	0.06	0.07
K, mg/kg	0.13	0.13
Zn, mg/kg	20.93	22.25
Fe, mg/kg	<6.00	<6.00
Cu, mg/kg	0.40	0.90
S, mg/kg	0.17	0.18
Mn, mg/kg	<1.00	<1.00
Retinol, µg/g	4.97	3.40
Tocopherol, µg/g	<0.10	<0.10
Vitamin E, µg/g	17.00	9.73

of dams was 3.0 and 2.5 for the unheated and heat-treated colostrum groups, respectively. Calving score for dams in the study never exceeded 3 on a scale from 1 to 5.

Colostrum IgG Concentration, Viscosity, and Bacterial Counts

The effect of treatment on colostral IgG concentration, viscosity, and bacterial load are presented in Table 3. There was no difference ($P > 0.05$) in the least squares means colostral IgG concentration for unheated and heat-treated colostrum. The IgG₁, IgG₂, and total IgG concentrations in untreated colostrum were 73.33, 3.09, and 76.43 g/L, respectively, whereas in the heat-treated colostrum the concentrations were 71.44, 2.98, and 74.42 g/L. Heat-treatment did not affect viscosity of colostrum. Early studies with colostrum pasteurization using the same times and temperatures recommended for milk found that heating denatured 12 to 30% of colostral IgG and increased viscosity (Meylan et al., 1996; Green et al., 2003); however, it has been demonstrated that problems with viscosity and IgG denaturation can be avoided by using a lower pasteurization temperature (Godden et al., 2006; Johnson et al., 2007; Elizondo-Salazar and Heinrichs, 2008).

The results of the present study showed that heat treatment resulted in a significant reduction of SPC, CC, NC, and CNS. Previous laboratory studies have also reported success in reducing or eliminating pathogens when colostrum has been heat-treated (Godden et al., 2006; Johnson et al., 2007).

STP and IgG Concentrations in Calves

The measurement of STP by refractometer as an estimate of serum immunoglobulin concentration is a simple test to assess passive transfer. A value of 50 g/L at 24 h of age has been established as the cutoff point for successful passive transfer (Donovan et al., 1998). Tyler et al. (1996) compared the performance of commonly used tests for passive transfer, demonstrating that an STP concentration of 52 g/L was equivalent to an IgG concentration of 10 g/L.

In the present study, STP concentration increased after first feeding in both treatment groups due to absorption of colostral IgG, as expected. Calves receiving heat-treated colostrum showed greater ($P < 0.05$) STP concentrations at 8, 12, 16, and 20 h than calves fed unheated colostrum.

Serum IgG concentrations at birth were below detectable concentrations of the assay and did not produce rings on RID plates; therefore, they were assumed to be zero (Table 4). However, 4 h after birth, calves fed heat-treated colostrum had higher ($P < 0.05$) serum IgG concentrations than calves fed unheated colostrum. Peak serum IgG₁ concentrations were reached between 24 and 48 h after birth. Calves fed heat-treated colostrum had nearly 20% greater ($P < 0.01$) total IgG concentration at 24 and 48 h than calves fed unheated colostrum (23.4 vs. 19.6 g/L, and 23.9 vs. 20.2 g/L, respectively).

In this experiment, calves were fed a total IgG mass of 283 g, and none of the 40 calves experienced failure of passive transfer, regardless of treatment. Concentrations of IgG and STP at 24 h of age have been shown

Table 2. Compositional analysis of calf starter and milk replacer¹ used in the study

Item	Calf starter	SEM	Milk replacer ²
CP, %	21.26	0.35	20.10
Fat, %	6.35	0.99	20.10
ADF, %	7.30	0.17	0.09
NDF, %	17.90	0.52	0.10
Ash, %	7.84	0.24	6.79
NFC, ³ %	48.21	0.70	37.18
Ca, %	1.12	0.06	0.81
P, %	0.66	0.02	0.60
Mg, %	0.46	0.02	0.09
K, %	1.37	0.04	1.62
Na, %	0.26	0.02	0.58
Mn, mg/kg	176.25	8.94	0.04
Zn, mg/kg	235.12	8.36	0.05
Cu, mg/kg	52.25	2.63	0.01
Vitamin A, ² IU/kg	75,950.00	—	76,550.00
Vitamin D, ² IU/kg	16,275.00	—	16,400.00
Vitamin E, ² IU/kg	325.50	—	328.10

¹All values are expressed on a DM basis.

²Based on manufacturer's analysis.

³Calculated.

Table 3. Colostral IgG levels, viscosity, and bacteriology of unheated or heat-treated colostrums

Variable	Unheated	Heat-treated	SEM
IgG, g/L	76.43	74.42	1.65
IgG ₁ , g/L	73.33	71.44	1.14
IgG ₂ , g/L	3.09	2.98	0.15
Viscosity, Pa·s	0.66	1.09	0.60
Bacterial count, ¹ log ₁₀ cfu/mL			
SPC	5.48 ^b	3.07 ^a	0.71
ES	5.50 ^b	2.92 ^a	1.00
CNS	2.21 ^b	0.00 ^a	0.20
CC	2.93 ^b	0.00 ^a	0.57
NC	3.55 ^b	1.38 ^a	0.69

^{a,b} $P < 0.05$, comparing least squares means for unheated or heat-treated colostrum.

¹SPC = standard plate count; ES = environmental streptococci; CC = coliform count; and NC = noncoliform count.

to be positively correlated (Tyler et al., 1996), meaning that the higher the serum IgG concentration, the higher the value for STP and vice versa. The relationship between circulating total IgG and STP in calves fed unheated or heat-treated colostrum is depicted in Figure 1. Calves in both treatment groups were administered the same mass of protein and IgG from colostrum; however, absorption of IgG varied between treatment groups. Calves fed heat-treated colostrum had greater serum total IgG concentration at 24 h than calves fed the unheated colostrum at the same STP concentration ($P < 0.01$).

The regression equations obtained in this study for the different treatment groups are:

$$\begin{aligned} \text{Unheated: Serum total IgG (g/L)} = \\ 0.734 \times \text{STP (g/L)} - 19.4 \quad (R^2 = 0.462), \end{aligned}$$

$$\begin{aligned} \text{Heat-treated: Serum total IgG (g/L)} = \\ 1.01 \times \text{STP (g/L)} - 32.3 \quad (R^2 = 0.593), \text{ and} \end{aligned}$$

$$\begin{aligned} \text{Both treatments: Serum total IgG (g/L)} = \\ 0.985 \times \text{STP (g/L)} - 32.2 \quad (R^2 = 0.548). \end{aligned}$$

When the cutoff value of 50 g/L of STP proposed by Donovan et al. (1998) is used in this study, determination of passive transfer by measuring STP underestimates the adequacy of passive transfer. In this study, the STP concentration corresponding to 10 g/L of IgG was 40 g/L for calves fed unheated colostrum and 42 g/L for calves fed heat-treated colostrum. This might indicate that refractometry is not an accurate means to estimate serum total IgG concentrations when calves are fed high volumes of raw or heat-treated colostrum.

Because the calves' immune system may take weeks to months to mature and become protective (Erhard et al., 1999) and because the half-life of colostral-derived IgG in the neonatal system is between 11.5 and 26 d (Sasaki et al., 1977), we intended to monitor serum IgG concentrations throughout the experiment. It can be noted in Table 4 that the concentration of maternal immunoglobulins starts to decline as these proteins are gradually distributed and catabolized; however, the differential in serum total IgG concentration between the 2 treatment groups was maintained up to 5 wk of age.

Apparent Efficiency of IgG Absorption

According to Quigley and Drewry (1998), for better understanding of the nature of IgG absorption and the management required to provide adequate passive

Table 4. Serum IgG concentrations (g/L) in heifer calves receiving unheated or heat-treated colostrum

Age	IgG ₁			IgG ₂			Total IgG		
	Unheated	Heated	SEM	Unheated	Heated	SEM	Unheated	Heated	SEM
0 h	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00
4 h	10.8	13.1*	0.80	0.6	0.7	0.05	11.4	13.8*	0.84
8 h	13.1	15.8*	0.79	0.7	0.8*	0.04	13.8	16.6*	0.82
12 h	15.1	18.1*	0.81	0.7	0.9**	0.04	15.8	19.0*	0.84
16 h	16.7	20.0*	0.85	0.8	0.9**	0.04	17.4	20.9*	0.88
20 h	17.9	21.4*	0.87	0.8	1.0**	0.04	18.7	22.4**	0.90
24 h	18.8	22.4**	0.88	0.9	1.1**	0.04	19.6	23.4**	0.92
48 h	19.3	22.9**	0.87	0.9	1.1**	0.04	20.2	23.9**	0.91
1 wk	19.5	22.9**	0.84	1.0	1.1**	0.04	20.4	24.0**	0.87
2 wk	19.3	22.5**	0.79	1.0	1.2*	0.05	20.3	23.7**	0.82
3 wk	18.7	21.7**	0.72	1.1	1.2	0.06	19.8	22.9**	0.75
4 wk	17.8	20.4*	0.65	1.1	1.2	0.07	19.0	21.6*	0.68
5 wk	16.6	18.6*	0.59	1.1	1.2	0.08	17.8	19.8*	0.64
6 wk	15.0	16.5	0.59	1.2	1.2	0.10	16.2	17.7	0.66
7 wk	13.0	13.8	0.69	1.2	1.1	0.15	14.3	15.0	0.78
8 wk	10.7	10.7	0.87	1.3	1.1	0.19	12.0	11.9	0.99

* $P < 0.05$; ** $P < 0.01$: comparing treatment least squares means at each time point.

Table 5. Apparent efficiency of absorption (AEA, %)¹ of IgG in heifer calves receiving unheated or heat-treated colostrums

Age, h	AEA of IgG ₁			AEA of IgG ₂			AEA of total IgG		
	Unheated	Heated	SEM	Unheated	Heated	SEM	Unheated	Heated	SEM
4	16.1	19.2	1.24	21.0	35.0**	2.14	16.3	19.7	1.26
8	19.4	23.2*	1.27	22.9	39.5**	1.92	19.5	23.7*	1.27
12	22.2	26.5*	1.34	24.8	43.5**	1.85	22.3	27.0*	1.33
16	24.5	29.2*	1.41	26.7	47.1**	1.85	24.6	29.7*	1.40
20	26.3	31.3*	1.46	28.5	50.1**	1.87	26.4	31.8*	1.46
24	27.6	32.6*	1.48	30.3	52.7**	1.87	27.7	33.2*	1.48
48	28.4	33.4*	1.47	32.0	54.9**	1.88	28.5	34.0*	1.47

¹AEA = [(birth weight × 0.095 × serum IgG)/total IgG fed] × 100.

* $P < 0.05$; ** $P < 0.01$: comparing treatment least squares means at each time point.

immunity, it is necessary to calculate AEA, which measures the efficiency with which IgG is absorbed. Reports on AEA are remarkably variable and AEA for IgG from maternal colostrum has been reported from 6 to 88%; however, most values are between 20 and 35% (Quigley and Drewry, 1998). In this trial, AEA was greater for calves fed heat-treated colostrum (Table 5). The AEA for total IgG from 4 to 48 h of age ranged from 16.3 to 28.5% for calves fed unheated colostrum and from 19.7 to 34% for calves fed heat-treated colostrum. The AEA for total IgG at 24 h of age was very similar to that reported by Johnson et al. (2007), who used 9.9% of BW to estimate serum volume.

Only one published study has reported that feeding heat-treated colostrum resulted in greater serum IgG concentrations in calves (Johnson et al., 2007). They observed that calves receiving heat-treated colostrum were able to absorb a greater proportion of the total mass of IgG presented to the small intestine and this may be explained by the phenomenon of lactogenic immunity provided by colostrum (Acres, 1985; Saif and Smith, 1985). The authors explained that antibodies in colostrum have been shown to bind pathogens present in the gut before absorption can occur. Then, by reducing the number of pathogens in colostrum, the number of pathogens in the gut is also reduced and more

Figure 1. Regression of serum IgG and serum total protein (STP) concentrations at 24 h of age in heifer calves receiving unheated (□) [IgG (g/L) = 0.734 × STP (g/L) – 19.4; $R^2 = 0.46$] or heat-treated (○) [IgG (g/L) = 1.01 × STP (g/L) – 32.3; $R^2 = 0.59$] colostrum.

Table 6. Starter intake and BW in heifer calves receiving unheated or heat-treated colostrum

Age, wk	Intake, kg/wk			BW, kg		
	Unheated	Heat-treated	SEM	Unheated	Heat-treated	SEM
Birth	—	—	—	43.04	41.82	1.03
1	0.207	0.097	1.350	43.81	42.46	1.04
2	0.446	0.263	1.260	45.39	43.95	1.07
3	0.927	0.657	1.260	47.77	46.30	1.14
4	1.861	1.518	1.260	50.95	49.50	1.22
5	3.607	3.234	1.230	54.93	53.55	1.31
6	6.750	6.356	1.170	59.70	58.46	1.43
7	12.198	11.521	1.100	65.28	64.23	1.57
8	21.286	19.266	1.100	71.65	70.84	1.77

antibodies are potentially free for absorption. Another potential explanation for an increase in AEA of IgG is lack of bacterial interference at the receptors that are responsible for IgG absorption. Bacteria can bind the nonspecific receptors on neonatal enterocytes, thus reducing the number of receptors available for IgG uptake (James and Polan, 1978; Staley and Bush, 1985); even if the receptors are different, exfoliation of the microvillus membrane may eliminate immunoglobulin binding sites (Staley and Bush, 1985). However, it is not clear whether these hypotheses are true or not, and further research is needed. In the present study, dairy heifer calves fed a high volume of heat-treated colostrum with a high IgG concentration were able to absorb more IgG than calves fed the same quantity and quality of unheated colostrum. A possible explanation could be that thermal treatment of colostrum denatures some proteins that otherwise would interfere or compete for receptors on neonatal enterocytes, thus reducing the number of receptors available for IgG uptake; however, this has to be further investigated. It would also be important to investigate if the same effect could be seen by feeding calves similar volumes of heat-treated colostrum with low IgG concentrations or lower volumes with varying IgG concentrations.

BW, Feed Intake, and Growth Measures

Least squares means of BW at birth were similar among treatments (Table 6). Although the effects of heat treatment of colostrum on serum IgG concentrations in neonates have been reported previously, no studies have evaluated longer term effects on BW and feed intake. Therefore, it is not known if thermal treatment of colostrum denatures hormones and growth factors, which in turn may reduce growth or gastrointestinal development, making this practice unsuitable for the dairy industry. In this experiment, overall BW and feed intake were not affected at any time during the experiment (Table 6). Least squares means of weekly BW clearly show that feeding heat-treated colostrum

did not have any negative effect on growth. Calf starter intake was similar across both treatments and increased in a curvilinear fashion until the end of the experiment as expected.

Health and Lymphocyte Counts

There was no difference ($P > 0.05$) among treatment groups in fecal, respiratory, or appearance scores pre- or postweaning. It is important to note that because serum IgG concentrations for both treatment groups were about 20 g/L, all calves had adequate passive immunity. No death or diseases related to treatment were observed during the experiment.

T lymphocytes arise in the bone marrow and migrate to the thymus gland to mature (Kindt et al., 2007). There are 2 well-defined subpopulations of T lymphocytes: helper and cytotoxic cells, which can be distinguished from one another by the presence of cell surface proteins or cluster of differentiation (CD) markers, either CD4 or CD8, for helper and cytotoxic cells, respectively (Ellis et al., 1997). The body also contains a small population of large, granular lymphocytes called natural killer cells that constitute a major component of the innate immune system and display cytotoxic activity against a wide range of tumor cells and against cells infected with some but not all viruses (Kindt et al., 2007). Overall, no differences were found among treatment groups at any time for any of the different lymphocytes. However, in wk 4 there was a tendency ($P = 0.07$) for CD4 to be higher in calves fed unheated colostrum. The reasons for this difference are unknown, and this finding may be an artifact of sample size. Johnson et al. (2007), when evaluating the use of heat-treated colostrum versus raw colostrum in neonatal calves at 24 h of age, found no differences in total peripheral white blood cell count, neutrophil counts or percentages, total lymphocyte counts or percentages, or counts or percentages of CD4, CD8, CD14, and B lymphocytes.

CONCLUSIONS

Based on the current study, batch heat treatment of high-quality colostrum at 60°C for 30 min reduced bacteria concentrations and preserved IgG concentration and viscosity. Apparent efficiency of absorption of IgG was greater for calves fed heat-treated (versus unheated) colostrum. Serum IgG concentrations were higher for calves fed heat-treated colostrum. Calves fed heat-treated colostrum showed no negative effects on health or growth parameters. Further studies are needed to clarify the precise mechanisms behind the increased IgG absorption and to investigate if feeding different volumes of heat-treated colostrum with different IgG concentrations would have a similar increase in IgG absorption if fed to calves.

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