Effect of different heating times of high-, medium-, and low-quality colostrum on immunoglobulin G absorption in dairy calves

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ABSTRACT

The objective of this study was to determine the effect of different durations of heat treatment on passive transfer of IgG from high-, medium- and low-quality colostrum. Colostrum was collected from The Pennsylvania State University dairy herd and divided by quality (high, medium, or low) based on colostrometer measurements. Colostrum was pooled by quality to create 3 unique batches. Each batch was further divided in thirds as follows: frozen to be fed without heat treatment, heated at 60°C for 30 min, or heated at 60°C for 60 min. Colostrum samples from each treatment were collected and analyzed for standard plate count, gram-negative noncoliforms, coliforms, and total IgG concentration. Serum samples were collected from 108 Holstein calves before feeding colostrum and 24 h after birth. Blood samples were analyzed for total protein, total IgG, and hematocrit. Colostrum quality (high, medium, or low), heat treatment (unheated, 60°C for 30 min or, 60°C for 60 min), and their interaction were analyzed as fixed effects, with calf sex included as a random block effect. Colostrum IgG was different between quality groups (92.5, 59.4, and 48.1 mg/mL of IgG). Heating colostrum reduced IgG concentration compared with the control by 9% when heated for 30 min and by 12% when heated for 60 min. Colostrum heated for 60 min had a lower standard plate count than colostrum heated for 30 min or not heated (1.8, 2.0, and 3.6 log cfu/mL, respectively). Serum IgG concentration at 24 h increased as colostrum quality increased (18.0, 22.2, and 24.8 mg/mL) and tended to increase as heat treatment time increased (19.7, 20.3, and 25.0 mg/mL of IgG). Apparent efficiency of IgG absorption was greater in calves that received medium-quality colostrum compared with calves fed high-quality colostrum (38.1 and 25.0%, respectively). These results

suggest an upper limit may exist to the amount of IgG absorption in a given time period and that medium- or high-quality colostrum yields similar blood IgG concentration given the same volume of intake.

Key words: calf, colostrum, immunoglobulin G

INTRODUCTION

Calves are required to ingest and absorb adequate amounts of immunoglobulins present in colostrum during the first 24 h of life because they are immunodeficient at birth (Bush and Staley, 1980). Passive transfer of immunity, which refers to the transfer of immunoglobulins from the dam to the neonate, has been defined as being successfully achieved when serum IgG concentration is 10 mg/mL or greater (Weaver et al., 2000; Quigley, 2004). Serum total protein is used as an indicator of passive transfer of IgG (Tyler et al., 1996), with concentrations equal to or greater than 5.2 g/dL considered successful passive transfer (Calloway et al., 2002).

Colostrum quality, quickness of administration, volume fed, (Weaver et al., 2000), and colostrum bacterial population (Gelsinger et al., 2015) can affect passive transfer. Colostrum provides immunity to newborn calves; however, it also can be one of the first opportunities for infectious pathogen exposure (Swan et al., 2007). Colostrum is a potential source of *Mycobacterium avium* ssp. *paratuberculosis*, *Mycoplasma* spp., *Escherichia coli*, and *Salmonella* spp. (Streeter et al., 1995; González and Wilson, 2003; Houser et al., 2008). These pathogens may come from the mammary gland or contamination during colostrum milking, storage, and feeding (Fecteau et al., 2002; McGuirk and Collins, 2004). Colostrum can be heated to reduce or eliminate pathogens (Godden et al., 2006).

Previous research found that heating colostrum to 60°C for 30 or 60 min reduced bacterial content (Johnson et al., 2007; Elizondo-Salazar et al., 2010; Donahue et al., 2012). Heat treatment at 60°C for 30 or 60 min did not affect colostrum viscosity (Elizondo-Salazar et al., 2010) but increased serum IgG concentration and improved apparent efficiency of IgG absorption (AEA;

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Elizondo-Salazar and Heinrichs, 2009a; Godden et al., 2012; Gelsinger et al., 2014). Whereas heat treatment did not affect colostrum IgG concentration (Johnson et al., 2007; Elizondo-Salazar and Heinrichs, 2009a), some studies reported greater numerical loss in IgG from high- compared with low-quality colostrum (Donahue et al., 2012; Gelsinger et al., 2014).

Colostrum IgG concentration is extremely variable among cows and between dairy farms (Kehoe et al., 2007; Baumrucker et al., 2010). Kehoe et al. (2007) reported a range of 11.8 to 74.2 mg/mL in colostrum IgG from dairy farms in Pennsylvania. Previous studies comparing heat-treated colostrum and unheated colostrum have used colostrum containing 50 g/L of IgG (Elizondo-Salazar and Heinrichs, 2009a), 76.6 g/L of IgG (McMartin et al., 2006), or 60 g/L of IgG (Godden et al., 2006). One study showed the effects of heating high-, medium-, and low-quality colostrum on IgG absorption using pooled colostrum containing 98.8, 71.9, or 56.4 mg/mL of IgG, respectively (Gelsinger et al., 2014). In that study, Gelsinger et al. (2014) heated colostrum for 30 min only, whereas the majority of commercial pasteurizers are preset for a 60-min heat treatment based on the early research by Godden et al. (2006) and Johnson et al. (2007). Studies by Donahue et al. (2012) and Gelsinger et al. (2014) showed that colostrum with a high IgG concentration was affected more than medium- or low-IgG concentration colostrum when it was heated. For that reason, the objective of the current study was to determine the effect of different heating times with 3 levels of colostrum IgG (adequate but low, medium, and very high) content on passive transfer from a single feeding of colostrum. We hypothesized that heating for a longer time would influence high-quality colostrum by reducing IgG levels more than in lower-quality colostrum.

MATERIALS AND METHODS

Colostrum Heat Treatment

This research was approved by The Pennsylvania State University Institutional Animal Care and Use Committee (protocol # 47457). First milking colostrum was collected from primiparous and multiparous Holstein cows at The Pennsylvania State University dairy from August 2016 to December 2016, stored in 1.89-L plastic containers (Uline Inc., Chicago, IL), and frozen at -20°C . In December 2016, colostrum was allowed to thaw at 4°C and divided into 3 quality categories (low, medium, and high) based on a colostrometer (Biogenics, Florence, OR) measurement 48 h before heat treatment. Colostrum within each category

was pooled and mixed to create 3 unique batches. Each batch was further divided into 3 uniform batches. One third was transferred into 1.89-L plastic containers and immediately frozen at -20°C until needed for feeding (unheated colostrum). The remaining 2 batches of each quality were heated to 60°C inside stainless steel buckets in a steam vat pasteurizer (Girton Manufacturing Co., Millville, PA) and maintained at that temperature for 30 or 60 min. After heat treatment, hot water was replaced with ice water to cool the colostrum to room temperature. Then, colostrum was transferred into 1.89-L plastic containers and immediately frozen at -20°C until needed for feeding. Each 1.89-L plastic container contained 1.90 kg of colostrum. Samples from each treatment were collected before freezing for IgG concentration and bacterial analysis. This system is similar to that used previously by our laboratory group (Elizondo-Salazar and Heinrichs, 2009a,b; Gelsinger et al., 2014).

Colostrum Sample Analyses

Colostrum samples were thawed at 20°C and analyzed for SPC, coliform count (**CC**), noncoliform gram-negative (**NC**), environmental streptococci (**ES**), contagious streptococci (**CS**), and CNS on duplicate plates as described by Jayarao et al. (2004). Cultures were incubated at 37°C for 48 h. Colonies were counted after 48 h of incubation. Counts from duplicate plates were averaged and log-transformed. Colostrum IgG concentration was measured using radial immunodiffusion. Colostrum samples were diluted 1:10 in 0.85% saline solution. Manufacturer's instructions (<http://69.195.120.15/jjj/wp-content/uploads/2017/04/Triple-J-Bovine-IgG-728411.pdf>) were followed to determine IgG concentration (#728411; Triple J Farms, Bellingham, WA). Colostrum samples were tested in duplicate and sample values with a coefficient of variation $\leq 10.5\%$ were accepted and averaged for analysis.

Colostrum samples were sent to Dairy One Inc. Check Mark Dairy Laboratory (Ithaca, NY) to be analyzed for fat (ether extraction/Mojonnier method), total protein (Kjeldahl method), and TS (direct forced-air oven method; all methods from AOAC, 1990). Samples were analyzed using AOAC (1990) wet chemistry methods. Additional colostrum samples were sent to the Agricultural Analytical Services Laboratory at The Pennsylvania State University to be analyzed for ash, P, K, Ca, Mg, Fe, Na, S, Cu, Zn, and Mn. Samples were prepared by Environmental Protection Agency (EPA) method 3050B and analyzed using EPA method 6010 for inductively coupled plasma spectrometry (US EPA, 1986).

Calf Treatment Enrollment and Sampling

From January 2017 to June 2017, Holstein calves (54 females and 54 males) from The Pennsylvania State University dairy were separated from their dams within 20 min of birth, weighed, and placed in individual pens. Calves weighing between 33 and 56 kg were randomly assigned and stratified by sex to 1 of the 9 colostrum treatments (3×3 factorial arrangement of heat treatment for 0, 30, or 60 min and high-, medium-, or low-quality colostrum). Colostrum was thawed in a warm water bath (50°C) and provided in a single feeding of 3.8 L using an esophageal feeder within 2 h of birth. Calf identification number, weight, treatment allocation, date and time born, and time at colostrum feeding were recorded for each calf.

Before feeding colostrum and 24 h after birth, a jugular blood sample was collected into 10-mL serum and 10-mL sodium heparin Vacutainer tubes (Becton Dickinson, Franklin Lakes, NJ). The serum Vacutainer tube was refrigerated overnight, centrifuged ($1,500 \times g$ for 15 min at 4°C), and the serum was separated from the clot within 24 h of collection (Johnson et al., 2007). Serum protein was determined using an optical refractometer (SPR-T2, Atago Co. Ltd., Tokyo, Japan). Distilled water was used to calibrate the refractometer before each use. Remaining serum samples were stored at -20°C until analyzed for IgG concentration. The sodium heparin Vacutainer tube was used to collect blood to measure packed cell volume. Each blood sample was transferred to a capillary tube, placed in a centrifuge for 3 min, and read using a micro-hematocrit reader (Adams micro-hematocrit reader, Clay-Adams Inc., New York, NY).

Serum IgG Analysis

Serum IgG concentration was determined by ELISA. A 1:200 dilution of affinity purified bovine IgG (Bethyl Laboratories Inc., Montgomery, TX) was created to coat each well. Bovine reference serum (Bethyl Laboratories Inc.) was diluted in Tris saline buffer containing 0.05% Tween 20 (pH = 8.0) to create a standard curve ranging from 0 to 500 ng/mL. All standards were run in duplicate with each assay. Serum samples were diluted 1:100,000 in saline buffer containing 0.05% Tween 20 (pH = 8.0). Serum samples were tested in triplicate and sample values with a coefficient of variation $\leq 10.5\%$ were accepted and averaged for analysis. Between each step in the ELISA protocol, except for the final enzyme reaction, a 60-min incubation at 20°C was allowed and then the wells were washed 5 times using Tris saline buffer. We added 3,3',5,5'-tetramethylbenzidine ELISA peroxidase substrate (Rockland Immunochemicals Inc.,

Gilbertsville, PA) in the final enzyme reaction and incubated for 15 min; a 0.2 M sulfuric acid stopping solution was then added. Absorbance was read at 450 nm using a plate reader (VICTOR³ Multilabel Counter model 1420; PerkinElmer Life Science, Waltham, MA).

Statistical Analysis

Calf characteristics were analyzed using the mixed procedure in SAS (version 9.4; SAS Institute Inc., Cary, NC). Previous studies indicated that a sample size of 9 calves per treatment was adequate and timing and volume of colostrum administration was done using results of previous studies. Colostrum quality (high, medium, or low), heat treatment (60°C for 0, 30, or 60 min), and their interaction were analyzed as fixed effects, with calf sex included as a random block effect to compare BW, serum IgG concentration, serum total protein, and AEA. The AEA was calculated as $AEA = [(birth\ weight \times 0.095 \times serum\ IgG) / total\ IgG\ fed] \times 100$. Hematocrit was included as a covariate in the model for serum IgG concentration, serum total protein, and AEA. The Tukey adjustment was used to compare least squares means and assign superscripts for individual treatments. Colostrum IgG concentrations and bacterial population were compared using Proc Mixed in SAS. Significance was declared at $P < 0.05$.

RESULTS AND DISCUSSION

The compositional analysis of colostrum treatments is presented in Table 1. The fat content was lower than values reported by Foley and Otterby (1978), Kehoe et al. (2007), and Elizondo-Salazar and Heinrichs (2009a; 6.7, 6.7, and 6.1% respectively). However, total protein and TS were similar to the values reported by Foley and Otterby (1978; 14.0 and 23.9% respectively). Ash and mineral contents were similar to the values presented by Elizondo-Salazar and Heinrichs (2009b). The difference in fat content may be related to fat adhered to the sides of the initial storage container used before making composite batches.

A description of colostrum treatments is shown in Table 2. Colostrum IgG concentration was similar to colostrum treatments used by Gelsinger et al. (2014). Colostrum IgG concentration was different between quality groups ($P < 0.01$), which is consistent with the objective of the study. The initial IgG concentrations were 98.1, 65.7, and 52.3 mg/mL for high-, medium-, and low-quality colostrum. The low-quality colostrum was just above the cutoff value between acceptable and unacceptable colostrum (50 mg/mL; Fleenor and Stott, 1980), and the IgG concentration was lower than a previous study (56.4 mg/mL; Gelsinger et al., 2014) where

Table 1. Compositional analysis of colostrum before and after treatment

Item	Unheated			Heated 30 min			Heated 60 min		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Fat, %	4.64	5.25	3.83	3.48	5.29	3.98	4.32	5.44	4.01
Total protein, %	11.6	13.7	15.9	11.8	13.6	15.9	11.8	13.8	16.0
TS, %	21.3	23.7	24.5	21.2	23.8	24.5	21.4	23.8	25.6
Ash, %	5.29	4.95	4.73	5.30	4.48	4.59	5.38	4.81	4.69
Ca, %	0.19	0.21	0.21	0.18	0.21	0.21	0.19	0.21	0.21
P, %	0.19	0.19	0.20	0.19	0.20	0.20	0.19	0.20	0.20
Mg, %	0.03	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.04
Na, %	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
K, %	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
S, %	0.11	0.13	0.16	0.11	0.13	0.16	0.11	0.13	0.16
Zn, mg/kg	59	82.3	79.6	59.2	81.1	77.4	60.7	82.3	79.2
Fe, mg/kg	<3.7	<4.4	<4.1	<4.0	<4.1	<3.9	<3.8	<4.2	<4.1
Cu, mg/kg	<0.75	<0.61	0.65	<0.72	<0.60	0.65	<0.73	<0.65	0.69
Mn, mg/kg	<0.5	<0.4	<0.4	<0.5	<0.4	<0.4	<0.5	<0.4	<0.4

a low-quality colostrum was used. Colostrum IgG concentration was higher in unheated colostrum compared with heated colostrum, showing that heat treatment caused a decrease in IgG concentration, as has been shown previously (Johnson et al., 2007; Elizondo-Salazar et al., 2010; Godden et al., 2012; Gelsinger et al., 2014); however, IgG concentration was similar between colostrum heated for 30 or 60 min ($P = 0.23$). Elizondo-Salazar et al. (2010) also reported a significant decrease in IgG₁ concentration after heating colostrum to 60°C for 30 and 60 min compared with raw colostrum, but no difference between heated colostrum treatments; however, IgG₂ did not change after heating colostrum at 60°C for either duration.

The decreases in IgG concentration from unheated colostrum were 6.1 (6.2%), 10.5 (10.7%), 8.1 (12.3%), 10.8 (16.4%), and 6.3 (12%) mg/mL for 30- and 60-min heat-treated high-quality colostrum, 30- and 60-min heat-treated medium-quality colostrum, and 30- and 60-min heat-treated low-quality colostrum, respectively. Many studies have reported changes in IgG concentration after heat treatment. Donahue et al. (2012) reported a decrease of 6.7 to 9.8 mg/mL of IgG in

colostrum containing more than 70 mg/mL of IgG using a commercial batch pasteurizer at 60°C for 60 min. Gelsinger et al. (2014) observed a decrease in colostrum IgG concentration of 6.5, 0.9, and 3.8 mg/mL in high-, medium-, and low-quality colostrum, respectively. The decrease in IgG concentration was not significant in either study, however.

Colostrum bacterial counts are presented in Table 2. Heating colostrum for either 30 or 60 min caused reductions of SPC, CC, NC, ES, CS, and CNS. Previous on-farm and laboratory studies have reported a reduction in bacterial count when colostrum is heated for 30 or 60 min (Elizondo-Salazar et al., 2010; Donahue et al., 2012; Gelsinger et al., 2014). The unheated colostrum SPC values were 3.9, 3.4, and 3.4 log cfu/mL for low-, medium-, and high-quality colostrum, respectively; these values are lower than values reported in previous studies (Elizondo-Salazar and Heinrichs, 2009a; Gelsinger et al., 2014). The unheated colostrum CC values were 3.3, 0.9, and 0.7 log cfu/mL for low-, medium-, and high-quality colostrum, respectively. It is recommended that colostrum contain <100,000 cfu/mL total bacterial count and <10,000 cfu/mL total

Table 2. Colostrum IgG concentration and bacterial population¹ before and after heat treatment

Item	Unheated			Heated 30 min			Heated 60 min			<i>P</i> -value ²		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Q	M	SEM
IgG, mg/mL	52.3	65.7	98.1	46.0	57.6	92.0	46.0	54.9	87.6	<0.01	<0.01	0.84
SPC, log cfu/mL	3.9	3.4	3.5	2.5	1.6	2.1	2.0	1.6	2.0	0.03	<0.01	0.09
CC, log cfu/mL	3.3	0.9	0.7	0	0	0	0	0	0	0.4	0.12	0.47
NC, log cfu/mL	1.7	2.1	2.4	0	0	0	0	0	0	0.4	<0.01	0.11
ES, log cfu/mL	6.0	2.3	3.3	0	0	1.5	0	0	0.9	0.5	0.04	0.74
CS, log cfu/mL	2.4	0	0	0	0	0	0	0	0	0.4	0.4	0.46
CNS, log cfu/mL	3.6	2.8	3.4	0	0.7	0	0	0	0	1.0	<0.01	0.22

¹CC = coliform count; NC = noncoliform, gram-negative count; ES = environmental streptococci; CS = contagious streptococci.

²Q = colostrum quality (high, medium, or low); M = heat treatment minutes (0, 30, or 60).

Table 3. Birth weight, age at colostrum feeding, and blood parameters at birth for calves in each treatment (n = 12)

Item	Unheated			Heated 30 min			Heated 60 min			P-value ¹			
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Q	M	Q × M	SEM
BW, kg	40.5	40.6	41.0	42.2	42.0	39.9	41.4	42.6	39.6	0.3	0.8	0.7	2.8
Age at colostrum feeding, min	90	65	91	69	84	77	74	79	72	0.8	0.6	0.2	10.3
Total protein, g/dL	4.2	4.1	4.2	4.0	4.1	4.1	4.0	4.0	4.1	0.9	0.5	0.7	0.1
IgG, mg/mL	0.4	0.3	0.7	0.4	0.3	0.5	0.3	0.6	0.5	0.6	0.9	0.9	0.2
Hematocrit, %	32.3	34.4	34.0	35.5	37.0	31.7	36.3	36.5	34.1	0.1	0.3	0.4	1.6

¹Q = colostrum quality (high, medium, or low); M = heat treatment minutes (0, 30, or 60).

coliform count (McGuirk and Collins, 2004), so the unheated colostrum was considered clean colostrum. After heating colostrum for 30 or 60 min, CC and NC were zero. Another study reported zero values for CC and NC after heating colostrum for 30 min (Gelsinger et al., 2014). Colostrum heated at 60°C for 60 min had lower SPC as well as ES, CS, and CNS compared with other colostrum treatments; this agrees with Elizondo-Salazar et al. (2010), who reported lower values for SPC and ES when colostrum was heated at 60°C for 60 min.

A total of 12 calves (6 heifer and 6 bull calves) were assigned to each colostrum treatment. Least squares means for birth BW, age at colostrum feeding, serum total protein at birth, IgG concentration at birth, and hematocrit at birth are reported in Table 3 and were not different between colostrum treatments ($P > 0.05$). Serum IgG concentration at birth was similar to values reported by Johnson et al. (2007) and Gelsinger et al. (2015), and hematocrit was similar to values reported by Gelsinger et al. (2015).

Serum total protein and IgG concentration at 24 h and AEA are shown in Table 4. The interaction between colostrum quality and heat treatment duration was not significant for any of the parameters measured. Serum total protein increased after colostrum consumption and was highest in calves fed high-quality colostrum (5.3, 5.6, and 6.2 g/dL for low-, medium-, and high-quality colostrum, respectively) within each heating time. However, we found no difference in serum total protein

between calves fed low- or medium-quality colostrum ($P > 0.05$). Johnson et al. (2007) and Elizondo-Salazar and Heinrichs (2009b) reported similar 24-h serum total protein. Both studies also reported higher 24-h serum total protein values in calves fed heat-treated compared with unheated colostrum, despite similar IgG concentration. No effect of heat treatment on serum total protein was observed in the present study.

As expected, 24-h serum IgG concentration increased as colostrum quality increased ($P = 0.02$). We also observed a tendency for increased IgG concentration as the duration of heat treatment increased ($P = 0.06$). Early work by Stott and Fellah (1983) fed calves the same colostrum volume at different IgG concentration and demonstrated a positive relationship between serum IgG concentration and colostrum IgG concentration. Similarly, calves in the present study fed heat-treated high-quality colostrum had higher 24-h serum IgG concentrations than calves fed heat-treated low- and medium-quality colostrum. However, calves fed medium-quality unheated colostrum had lower 24-h serum IgG concentration compared with calves fed low-quality unheated colostrum. Calves fed high-quality unheated colostrum had higher IgG concentration than both, as expected.

Passive transfer is considered successful when the serum IgG concentration is >10 mg/mL of IgG at 24 h after birth, below this point is considered failure of passive transfer (Quigley, 2004). In the current study, 9

Table 4. Blood parameters at 24 h for calves in each treatment (n = 12)

Item	Unheated			Heated 30 min			Heated 60 min			P-value ¹			
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Q	M	Q × M	SEM
Total protein, g/dL	5.3 ^b	5.6 ^b	6.1 ^a	5.3 ^b	5.6 ^b	6.3 ^a	5.2 ^b	5.7 ^b	6.1 ^a	<0.01	0.7	0.8	0.1
IgG, mg/mL	19.4	18.2	21.4	13.3	22.1	25.7	21.6	26.3	27.2	0.02	0.06	0.3	3.1
AEA, %	37.3	26.2	20.8	32.6	39.6	25.4	47.3	48.5	28.9	<0.01	0.01	0.2	5.1
Hematocrit, %	28.5	30.3	32.2	31.5	31.8	27.0	31.4	31.2	30.0	0.52	0.79	0.06	1.4

^{a,b}Values within a heat time with different superscripts are different ($P < 0.05$) after accounting for multiple comparison by Tukey's adjustment factor.

¹Q = colostrum quality (high, medium, or low); M = heat treatment minutes (0, 30, or 60).

²Apparent efficiency of absorption, calculated as $AEA = [(birth\ weight \times 0.091 \times serum\ IgG) / total\ IgG\ fed] \times 100$.

calves had failure of passive transfer and actual serum IgG concentrations ranged from 7.2 to 9.5 mg/mL of IgG. Of these, 7 calves received low-quality colostrum heated for 30 min and 2 calves received low-quality unheated colostrum.

Several studies (Johnson et al., 2007; Elizondo-Salazar and Heinrichs, 2009a; Gelsinger et al., 2014) have shown that feeding heat-treated colostrum increases serum IgG concentration. When calves were fed heat-treated colostrum with an initial concentration of 72.6 mg/mL of IgG, Johnson et al. (2007) reported an increase of 23.6% in serum IgG concentration compared with calves fed unheated colostrum. Elizondo-Salazar and Heinrichs (2009a) reported that calves fed heat-treated colostrum had nearly 20% greater serum IgG concentration compared with calves fed unheated colostrum. Gelsinger et al. (2014) reported an increase of 18.4% in plasma IgG concentration in calves fed heat-treated compared with unheated colostrum, despite a significant reduction in colostrum IgG concentration after heat treatment. In the present study, serum IgG concentration increased 3.4 and 27.2% in calves fed colostrum heated for 30 and 60 min, respectively, compared with calves fed unheated colostrum. The small increase in IgG concentration between calves fed colostrum heated for 30 min and calves fed unheated colostrum is likely due to the small decrease in colostrum bacterial count between these 2 treatments. Other studies have indicated that reducing colostrum bacterial count is the main mechanism by which heat-treatment increases IgG absorption (Godden et al., 2012; Gelsinger et al., 2015). The initial colostrum bacterial count in previous studies [3.95, 5.48, and 4.4 log₁₀ cfu/mL from Johnson et al. (2007), Elizondo-Salazar and Heinrichs (2009a), and Gelsinger et al. (2014), respectively] was higher, and subsequent reductions by heating were greater than those of the present study. Bacterial counts of the unheated colostrum used in our study were within industry recommendations; therefore, inhibition of IgG absorption by bacteria was likely low and the possible increase in absorption by heating was limited. This hypothesis supports the suggestion by Johnson et al. (2007), that bacteria can bind to colostrum antibodies before absorption occurs; thus, by heating colostrum, more IgG molecules are going to be free for absorption in the calf gut.

Mean AEA values are shown in Table 4. Absorption was greater in calves that received medium-quality colostrum compared with calves fed high-quality colostrum (38.1 and 25.0%, respectively; $P < 0.01$) and in calves that received colostrum heated for 60 min compared with calves fed colostrum heated for 0 or 30 min (41.5, 32.5, and 28.0%, respectively; $P = 0.01$). A previous study indicated that a certain number of

receptors likely carry IgG from the intestinal wall to the blood stream; however, when the receptors became saturated, there is no way to transport more IgG molecules (Jaster, 2005). It is possible that receptor saturation occurs when a large volume of colostrum with high IgG concentration is fed. These results suggest an upper limit may exist to the amount of IgG that can be absorbed in a given time period and that medium- or high-quality colostrum yields similar blood IgG concentration given the same volume of intake, especially when it is high-IgG, low-bacteria colostrum.

CONCLUSIONS

Serum IgG concentration increased as the quality increased in colostrum fed to the calves on this study, and we noted a tendency for increased serum IgG levels as heat treatment duration increased. Heat treatment reduced SPC, CC, NC, ES, CS, and CNS bacterial counts in the colostrum. The AEA was greater in calves that received medium-quality colostrum compared with calves fed high-quality colostrum, as well as in calves that received colostrum heated for 60 min compared with calves fed colostrum heated for 0 or 30 min. These results suggest an upper limit may exist to the amount of IgG absorption in a given time period and that medium- or high-quality colostrum yields similar blood IgG concentration given the same volume of intake, especially when colostrum bacteria count is also low. These findings support the hypothesis that IgG absorption is improved as a result of a reduction in colostrum bacterial load and emphasizes the importance of feeding low-bacteria colostrum to calves. However, more research in high- and medium-quality colostrum with different bacterial content is necessary to determine the effects of heating time on IgG absorption.

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