Effect of On-Farm Commercial Batch Pasteurization of Colostrum on Colostrum and Serum Immunoglobulin Concentrations in Dairy Calves

S. M. Godden,* S. Smith,† J. M. Feirtag,‡ L. R. Green,‡ S. J. Wells,* and J. P. Fetrow*

* Department of Clinical and Population Sciences, and

‡ Department of Food Science and Nutrition, University of Minnesota, St. Paul, MN 55108, and

† Animal Health Center, PC, Greeley, CO, 80633

ABSTRACT

The objectives were to describe the effect of on-farm commercial batch pasteurization on immunoglobulin (IgG) concentrations and the fluid and feeding characteristics of colostrum and to compare serum IgG concentrations in calves fed fresh versus pasteurized colostrum. Newborn calves (123) were systematically allocated to dietary treatments of either fresh or pasteurized colostrum at both the first and second colostrum feedings. The IgG concentrations were measured for batches of colostrum fed fresh and in pre and post-pasteurized samples for batches of colostrum fed after being pasteurized and in calf serum. Pasteurization reduced colostrum IgG concentration, with the percentage reduction averaging 58.5 and 23.6% for 95-L and 57-L batches, respectively. Pasteurizing high quality colostrum in 57-L (vs. 95-L) batches resulted in higher IgG concentrations in the end product. Pasteurization of 57-L batches produced colostrum of normal or only mildly thickened consistency that could be fed to calves. Serum IgG concentrations were higher for calves fed fresh colostrum and for calves with a shorter time interval (≤ 6 h) between first and second colostrum feedings. After controlling for the time interval between feedings, serum IgG concentrations were significantly higher for 40 calves fed unpasteurized (19.1 mg/ml) vs. 55 calves fed pasteurized colostrum (9.7 mg/ml) for calves fed 2 L at first feeding. By contrast, there was no difference in serum IgG concentrations between 8 calves fed unpasteurized (16.1 mg/ml) and 20 calves fed pasteurized colostrum (13.5 mg/ml) after calves were fed 4 L at the first feeding. While the latter results suggest that pasteurizing colostrum may work for producers with excellent colostrum management, these results are preliminary and should be interpreted with caution, given the fewer number of calves and batches of colostrum involved with this second comparison.

(Key words: colostrum, calf, pasteurization, immunoglobulins)

Abbreviation key: FPT = failure of passive transfer.

INTRODUCTION

A great deal of interest has developed in implementing biosecurity programs to prevent the transmission of infectious disease to dairy replacement calves. One potential method of transmission of infectious diseases to dairy calves is through feeding infective colostrum and milk. Pathogens that may be transmitted in colostrum and milk, either by direct shedding in the mammary gland or postharvest contamination, include *Mycobacterium avium* subsp. *paratuberculosis* (Streeter et al., 1995), *Salmonella* spp. (McEwen et al., 1988; Giles et al., 1989; Steele et al., 1997), *Mycoplasma* spp., *Listeria monocytogenes* (Farber et al., 1988; Steele et al., 1997), *Campylobacter* spp. (Lovett et al., 1983; Steele et al., 1997), *Mycobacterium bovis* (Grant et al., 1996a; Walz et al., 1997), and *Escherichia coli* (Clarke et al., 1989; Steele et al., 1997).

Strategies to prevent transmission of infectious diseases to calves via milk include feeding either milk replacer or pasteurized waste milk. Pasteurization has effectively destroyed viable bacteria for most of these pathogen species. In particular, Butler et al. (2000) demonstrated that pasteurization was effective in destroying *Mycoplasma bovis*, *Mycoplasma californicum*, and *Mycoplasma canadense* spp. The efficacy of pasteurization in destroying *Mycobacterium avium* subsp. *paratuberculosis* also looks promising but remains unsettled. While a number of researchers have reported that pasteurization is effective in destroying this pathogen (Keswani and Frank, 1998; Grant et al., 1999; Stabel, 2001), others have reported that small numbers of the organism may remain viable if inoculated into milk samples at high concentrations (Grant et al., 1996b; Sung and Collins, 1998).

In contrast to milk, the question of preventing infectious disease transmission through colostrum is more challenging. Although currently available commercial colostrum supplements are constantly improving, most

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Corresponding author: S. Godden; e-mail: godde002@umn.edu.

have been shown to be inferior in achieving acceptable levels of passive immunity when fed alone, as compared to feeding high quality fresh colostrum (Quigley et al., 2001). Thus, it is still a general recommendation that calves be fed at least one feeding of fresh high quality colostrum as soon as possible after birth. An alternate technology that may help to break the transmission of infectious disease through colostrum is pasteurization. With a recent interest in adopting pasteurization systems for feeding waste milk on dairy farms, producers are also interested in whether they can also pasteurize colostrum. This question presents some special challenges, for example, does pasteurization result in moderate-to-markedly thickened (congealed) end product that is difficult to clean from equipment or to feed to calves? An additional concern is whether pasteurization causes a degradation of colostral Ig molecules (e.g. IgG) and other immune factors. If pasteurization results in an unacceptably high degree of loss of colostral antibodies, then pasteurization may create a high risk of failure of passive transfer (**FPT**) in the calf, making this practice impractical to adopt commercially.

Laboratory and field studies investigating the practice of pasteurizing colostrum have been limited and have reported varying results with respect to effect of pasteurization on both colostral Ig molecules and on rates of failure of passive transfer in calves. Meylan et al. (1995) heated 5 ml volumes of a total of 18 colostrum samples to 63°C for 30 min to simulate pasteurization of colostrum under laboratory conditions. Mean ($\pm$ SD) IgG values for fresh and pasteurized samples were 44.4 ± 30.3 g/L (range, 3.3 to 87.7 g/L) and 37.2 ± 23.8 g/L (range, 2.9 to 70.3 g/L), respectively. This study reported a mean loss of Ig after pasteurization of $12.3 \pm 8.7\%$ (range, -3.19 to 24.94%). These authors concluded that this 12.3% loss was manageable, assuming that the quality of colostrum is determined by a colostrometer prior to heat treatment and the amount fed is adjusted to ensure successful passive transfer of immunity. Unfortunately, this study was performed using very small volumes of colostrum and under laboratory conditions simulating pasteurization. Further research is needed to study these outcomes when using commercial pasteurization equipment and larger volumes of colostrum, as would be the situation under field conditions.

One field study, using a HTST pasteurization method (72 °C for 15 s), reported that total colostral IgG mass received by 150 calves fed pasteurized colostrum (mean = 151.4 g) was significantly lower than for 150 calves fed unpasteurized colostrum (mean = 203.1; Jamaluddin, 1995). However there was no difference in the number of calves experiencing FPT (based on less than 10 mg/ml of total serum IgG measured at 48 to 96 h after

colostrum intake) between treatment (16.2%) and control (19.5%) groups. Similarly there was no difference in mean serum IgG concentrations between treatment (1476 mg/dl) and control (1435 mg/dl) groups. While the results of this field trial were promising, there are practical concerns with adopting HTST pasteurization of colostrum as it consistently produces an end product that congeals into a thick pudding as it cools, which cannot be easily fed to calves (unpublished results).

The first objective of this study was to describe the effect of commercial on-farm batch pasteurization on colostrum IgG concentrations and fluid characteristics. The second objective was to compare serum IgG concentrations in calves fed fresh versus pasteurized colostrum.

MATERIALS AND METHODS

Commercial Dairy Site and Routine Calf Management

The study was carried out on the site of a 2,700-cow commercial dairy in Colorado. Cows calved in a group bedded pack area that was supervised 24 h/d. Prior to initiating this study, newborn calves were bottle fed 2 L of colostrum within 1 to 2 h of birth and received an additional 2 L of colostrum via bottle by 8 to 14 h of age. After the second colostrum feeding all calves received pasteurized waste milk until weaning (batch pasteurization at 63°C for 30 min). Calves were moved into individual polydome hutches at approximately 12 to 16 h of age. Most bull calves left the property after 3 d of age. Heifer calves remained on the property and are raised to maturity by the owner.

Colostrum Management

Pooled batches of fresh colostrum were assembled and then allocated, depending on day of mixing the batch, to be fed either unpasteurized or pasteurized. A 20-ml fresh (unpasteurized) sample was collected from each batch of fresh colostrum, identified and frozen for later determination of IgG concentration. A 20-ml post-pasteurized sample was also collected, identified, and frozen for those batches that were pasteurized. Colostrum was pasteurized using a commercial batch type pasteurizer (Dairytech, Inc., Windsor, Colorado) that heats the contents to 63°C, holds it for 30 min, and then automatically cools it to feeding temperature (approximately 37 to 41°C). The contents are constantly agitated throughout the entire process. For each of the pasteurized batches the operators recorded the batch size (volume), time to pasteurize (hours), and estimated consistency of the colostrum after pasteurization (1 = normal consistency, 2 = slightly thickened but still ac-

ceptable to feed; 3 = very thick/pudding consistency). Fresh (unpasteurized) and pasteurized colostrum that was not fed immediately was put into appropriately identified (red or blue) individual feeding bottles and refrigerated for later feedings.

During the first 2 wk of the study (03/20/02 to 04/04/02) the producer pasteurized two large batches (95 L) of colostrum (approximately once per week), and then refrigerated and fed the pasteurized colostrum over the next several days. However early experience and testing showed that such large volumes took a very long time to pasteurize (approximately 2.5 to 3 h) and showed an unacceptably high degree of reduction in IgG according to testing of colostrum. Another difficulty was that one of these two batches congealed, making it very difficult to feed to calves. Following this early experience, the research team and dairy manager agreed to pasteurize smaller batches (57 L). This required only 50 to 60 min to complete the pasteurization process and was very consistent in producing a product with normal-to-only slightly thickened consistency, that was still very manageable to feed to calves when using either bottle or esophageal feeder.

Calf Treatment Allocation, Sample Collection, and Records

All calves born during the 1-mo period between 03/20/02 and 04/20/02, were systematically enrolled, depending on alternating days of birth, into one of the two treatment groups receiving either unpasteurized or pasteurized colostrum for both the first and second colostrum feeding. Calves were individually marked according to their allocated treatment group (red = unpasteurized; blue = pasteurized) and then fed the appropriate colostrum treatment for both the first and second colostrum feeding. Following the second feeding, all calves were fed pasteurized waste milk. Initially the colostrum feeding volumes and times were according to previous standard operating procedures on the dairy: 2 L at both feedings, with approximately 8 to 14 h between feedings. However late into the 2nd wk of the study a decision was made to begin randomly varying the volume of colostrum fed at the first feeding, alternating between 2 L (baseline program) and 4 L. It was also decided to begin varying the time interval between first and second feeding, alternating from between 10 or 12 h (baseline program) to feeding some calves sooner. These two new treatments were applied to calves assigned to both pasteurized colostrum and unpasteurized colostrum groups. Information recorded for each calf included the calf identification number, birth date, gender, whether the calf was a single or twin, treatment allocation (fresh or pasteurized colostrum), age (hours

old) at both first and second colostrum feedings, volume at first (2 or 4 L) and second (always 2 L) colostrum feeding, and name of the person feeding the calf. The herd owner or the herd veterinarian collected blood samples from all study calves between 24 and 72 h of age, using jugular vein venipuncture. Serum from these samples was frozen for later measurement of serum IgG concentration. The herd veterinarian was responsible for oversight of the project and visited the herd two to three times weekly to observe that treatment allocation, calf identification, colostrum pasteurization, identification and feeding, and record keeping protocols were followed. Upon completion of the calf portion of this study, on 04/20/02, the herd owner began feeding pasteurized colostrum to all newborn calves. As such, the colostrum-portion of this study continued to collect pre and postpasteurized samples from batches of pooled colostrum that were fed up to 06/25/02.

Serum and Colostrum Sample IgG Analysis

Frozen serum and colostrum samples were submitted to the Colorado Veterinary Diagnostic Laboratories (Colorado State University, Fort Collins, CO, 80523) for determination of IgG concentrations. Serum IgG concentrations were determined using the Bovine IgG Vet-RID (radial immunodiffusion) kit (Bethyl Laboratories, Inc., Montgomery, TX) according to kit instructions and using 5 μ l of serum. After the samples were placed on the plates they were left at room temperature for a minimum of 18 h, and then the precipitation ring diameters measured and IgG values calculated. Three standards with known values (625, 2500, and 5000 mg/dl) were also tested for each run. The diameters of the known standards were then used to calculate the tested serum samples using a programmable calculator. Colostrum IgG concentrations were determined using the same test kit and using the same general testing process. Due to the very high levels of IgG, colostrum samples were first diluted x10 with distilled water, and then 5 μ l of the diluted sample was tested. This initial 10-fold dilution was taken into account when back-calculating the colostrum IgG concentration for each sample.

Statistical Analysis - Effects of Pasteurization on Colostrum IgG

Analysis of variance (Proc Mixed in SAS, 1999) was used to describe the association between colostrum treatment (fresh vs pasteurized) and colostrum IgG concentration (continuous dependent variable, mg/ml) for paired samples of colostrum (pre vs postpasteurized samples). An additional categorical variable offered to

this model described batch size (medium = 57 L; large = 95 L). Next, ANOVA (Proc Mixed in SAS, 1999) was used to describe the association between prepasteurization IgG concentration (continuous explanatory variable, mg/ml) and both the percent reduction in pre vs. postpasteurization IgG (continuous dependent variable) and the postpasteurization IgG concentration (continuous dependent variable). Proc GENMOD in SAS (Allison, 1999) was also used to describe the association between prepasteurization IgG concentration (continuous explanatory variable) and whether postpasteurization IgG concentrations were above or below a target cut point of 50 mg/ml (categorical dependent variable: < 50.0 mg/ml vs. = 50 mg/ml). Finally, samples were categorized into quartiles based on prepasteurization IgG concentrations (category 1 < 50 mg/ml; category 2 = 50–59.9 mg/ml; category 3 = 60–69.9 mg/ml; category 4 = 70 mg/ml). Contrast analysis was then performed using Proc GENMOD in SAS (Allison, 1999) to describe the relationship between prepasteurization colostrum IgG concentration and the odds of attaining a final postpasteurization IgG concentration greater than 50 mg/ml, relative to category 1.

Statistical Analysis—Effects of Colostrum Treatment on Calf Serum IgG

A total of 202 calves were enrolled into the study (85 = fresh, 117 = pasteurized colostrum) between 03/20/2002 and 04/20/2002. However, there was concern that certain changes made to the study design near the end of the 2nd wk of the study had the potential to confound study inferences (i.e. began to pasteurize smaller batches, began varying volume fed at first feeding, began varying time interval between feedings). Therefore, it was decided to omit the calf serum data from analysis for all calves (treatment and control) enrolled prior to these treatment changes. Descriptive statistics were produced for calves enrolled during the remainder of the study period, describing IgG concentrations for batches of colostrum that were fed fresh to calves and describing IgG concentrations in pre and postpasteurization samples for batches of colostrum that were fed after being pasteurized. Descriptive statistics were also produced describing serum IgG concentrations, age at first feeding (hours), age at second feeding (hours), and interval between the first and second colostrum feeding (hours) for calves fed either fresh colostrum and pasteurized colostrum.

Least squares regression (ANOVA using Proc Mixed in SAS, 1999) was used to develop a model describing the relationship between calf serum IgG concentrations (dependent variable, mg/ml) and colostrum type, the explanatory variable of interest (CT_i : 1 = fresh, 2 =

pasteurized), plus a residual error term. Because multiple calves were fed colostrum from a single pooled batch of colostrum, the model also controlled for clustering within batch by controlling for batch as a random effect. A forward stepwise procedure was used in building this model, first adding and then removing, one at a time, additional individual covariates as main effects into the model. This was done to investigate whether other covariates were significant predictors of serum IgG and/or were potential confounders for the association between colostrum type and serum IgG concentrations. These additional covariates investigated included volume at first feeding (V_j : 1 = 2 L, 2 = 4 L), time interval between first and second feeding (T_k : 1 > 6 h, 2 ≤ 6 h), gender of calf (G_l : 1 = female, 2 = male), number of calves born (N_m : 1 = single, 2 = twins), interaction between colostrum treatment and volume fed ($T \times V_{ij}$), and interaction between colostrum treatment and time interval between feedings ($CT \times T_{ik}$). Any of these additional covariates with significance at $P < 0.25$ were offered together with colostrum treatment (CT_i) into a final multivariate model and then subjected to a stepwise backwards elimination process. The nature of any significant interactions was then investigated through stratification analysis. Final significance was declared at $P < 0.05$.

RESULTS

Effects of Pasteurization on Colostrum IgG and Fluid Characteristics

A total of 27 paired pre and postpasteurized samples from pooled batches of pasteurized colostrum were collected and analyzed over the entire study period from 03/20/2002 and 06/25/2002. Postpasteurized samples had lower ($P < 0.05$) IgG concentrations than did prepasteurized samples. However there was a strong tendency for an interaction ($P = 0.06$) between colostrum type (pre vs. postpasteurized) and batch size (medium = 57 L, large = 95 L). Subsequent ANOVA after stratification of data by batch size showed a greater magnitude of difference between pre and postpasteurized IgG concentrations when batch size was large (95 L) versus when batch size was moderate (57 L). The average pre and postpasteurized IgG concentrations for the two large (95 L) batches pasteurized in the first 2 wk of the study were 61.3 and 25.3 mg/ml (Table 1). The average percentage reduction in IgG for these two large batches was 58.5%. The average pre and postpasteurized IgG concentrations for the 25 moderately (57 L) sized batches were 58.7 and 44.1 mg/ml, respectively. The mean percentage reduction in colostrum IgG concentration for these 25 moderately sized batches was 23.6% (Table 1).

Table 1. Colostrum pasteurization study -- Ig concentrations in paired pre and postpasteurized colostrum samples.

Variable	N	Mean	SE	Min.	Max.
All pasteurized batches					
IgG prepasteurized (mg/ml)	27	58.9	2.3	35.6	80.7
IgG postpasteurized (mg/ml)	27	42.7	2.0	25.1	62.3
IgG percent loss (%)	27	26.2	3.0	-6.2	62.0
Pasteurized batches sorted by batch size					
95 L (25 gallon) batches					
IgG prepasteurized (mg/ml)	2	61.3	4.7	56.6	66.0
IgG postpasteurized (mg/ml)	2	25.3	0.2	25.1	25.5
IgG percent loss (%)	2	58.5	3.5	55.0	62.0
57 L (15 gallon) batches					
IgG prepasteurized (mg/ml)	25	58.7	2.5	35.6	80.7
IgG postpasteurized (mg/ml)	25	44.1	1.8	31.6	62.3
IgG percent loss (%)	25	23.6	2.6	-6.2	54.1

In addition to effect of batch size, a second factor investigated was whether prepasteurization IgG concentration was associated with either the percent reduction in IgG after pasteurization or the postpasteurization IgG concentration. Only the 25 moderately sized (57 L) batches were used for this analysis, to remove the effect of batch size. Preliminary analysis using Proc CORR (SAS, 1999) showed that there was a significant positive correlation between the levels of IgG prior to pasteurization and the percent loss after pasteurization ($r^2 = 0.46$, $P = 0.019$). However, the percent reduction in IgG was highly variable between individual batches and could not be easily predicted by looking solely at the prepasteurization IgG concentration (Figure 1). There was a positive correlation between the IgG concentra-

tion prior to pasteurization and IgG concentration postpasteurization ($r^2 = 0.68$, $P = 0.0002$). Analysis using Proc GENMOD in SAS showed that samples with a higher prepasteurized IgG concentration were more likely to result in a postpasteurized sample with IgG concentration above the target cut-point of 50 mg/ml (estimate = 0.18; SE = 0.073; $P = 0.0005$). Therefore, in spite of the fact that high-quality batches of colostrum sometimes lost a greater percent of IgG after pasteurization, they still had a greater chance of resulting in a higher final IgG (postpasteurization). Contrast analysis of data after categorizing samples into quartiles showed that samples with a prepasteurization IgG concentration = 60 mg/ml had an increased ($P < 0.05$) chance of having a final (postpasteurization) IgG con-

Figure 1. IgG concentration in paired pre- and postpasteurized batches of colostrum (batch size = 57 L; Note: batches sorted down by prepasteurized IgG concentration)

Table 2. Description of colostrum quality, feeding management, and serum IgG concentrations for calves fed fresh or pasteurized colostrums.

Variable name	Fed fresh colostrum	Fed pasteurized colostrum
	Raw mean ± SE (Range)	
Colostrum quality variables		
Number unique batches fed (n)	6	6
Fresh colostrum IgG for batches fed as fresh colostrum (mg/ml)	54.7 ± 3.5 (40.3 to 64.4)	55.3 ± 2.8 (45.5 to 62.7)
Postpasteurized Colostrum IgG for batches fed pasteurized (mg/ml)	NA	43.3 ± 0.9 (40.3 to 46.3)
Feeding management variables		
Number of calves	48	75
Age at first feeding (h)	0.7 ± 0.03 (0.3 to 1.3)	0.7 ± 0.05 (0.3 to 4.0)
Age at second feeding (h)	8.4 ± 0.5 (2.0 to 14.0)	8.0 ± 0.4 (2.0 to 15.0)
Interval between 1st and 2nd feeding (h)	7.7 ± 0.5 (0.9 to 13.3)	7.3 ± 0.4 (1.3 to 14.3)
Calf serum IgG concentrations (mg/ml)		
All calves	17.6 ± 1.3 (2.1 to 41.1) (48 calves/6 batches)	10.2 ± 0.6 (1.3 to 25.8) (75 calves/6 batches)
Calves fed 2 L at birth	17.9 ± 1.4 (2.8 to 41.1) (40 calves/6 batches)	9.2 ± 0.73 (1.3 to 25.8) (55 calves/6 batches)
vs		
Calves fed 4 L at birth	16.1 ± 3.6 (2.1 to 34.7) (8 calves/2 batches)	12.9 ± 1.1 (4.3 to 19.1) (20 calves/5 batches)
Feeding interval ≤ 6 h	21.2 ± 2.6 (2.1 to 39.1) (18 calves/5 batches)	10.7 ± 7.5 (2.0 to 25.8) (22 calves/6 batches)
vs		
Feeding interval > 6 h	15.5 ± 1.3 (2.8 to 41.1) (30 calves/5 batches)	10.0 ± 0.6 (1.3 to 19.1) (53 calves/6 batches)

centration above the target of 50 mg/ml as compared to samples with a prepasteurization IgG concentration $<$ 60 mg/ml. Sixty-two percent (8 of 13) of samples with prepasteurization IgG concentrations $>$ 60 mg/ml resulted in a final (postpasteurized) product with IgG concentrations $>$ 50 mg/ml. However none of the seven samples with prepasteurization IgG concentrations between 50 and 59.9 mg/ml resulted in a final (postpasteurized) product with IgG concentration $>$ 50 mg/ml.

Effects of Feeding Pasteurized Colostrum on Calf Serum IgG Concentrations

A total of 12 pooled batches of colostrum, six fed fresh and six fed after pasteurization, were fed to 123 calves during the calf-feeding portion of the field study (48 = fresh, 75 = pasteurized). The mean colostrum IgG concentrations for fresh samples of colostrum for pooled batches of colostrum that were to be fed either fresh or pasteurized were not statistically different, at 54.7 and 55.0 mg/ml, respectively (Table 2). The mean IgG for the latter six batches after being pasteurized was 43.3 mg/ml. There was no difference ($P > 0.05$) between the two groups of calves with respect to mean age at first feeding, mean age at second feeding, or mean interval between first and second feeding. Descriptive statistics are presented in Table 2 showing mean serum IgG concentrations for all calves fed either fresh or pasteurized

colostrum, and then subdivided further either by feeding interval ($\leq$ or $>$ 6 h) or by volume at first feeding (2 vs 4 L).

Univariate ANOVA with adjustment for batch as a random effect showed that calves fed fresh colostrum had a significantly higher serum IgG concentrations than calves fed pasteurized colostrum (estimate = $\pm$ 8.14 mg/ml; SE (est.) = 2.2, $P = 0.0004$). For univariate regression LS means estimated that serum IgG concentrations for calves fed fresh vs pasteurized colostrum would be 18.3 ± 1.6 and 10.1 ± 1.5 mg/ml, respectively. Of the additional covariates offered, calf gender (1 = female, 2 = male) and number of calves born (1 = single; 2 = twins) were not significant and were removed from the model building process. Calves with longer intervals ($>$ 6 h) between first and second feedings had lower ($P = 0.04$) IgG concentrations (estimate = -2.8 ± 1.4 mg/ml per additional hour), and so the variable describing feeding interval was carried forward into the final multivariate model. Also, there tended to be an interaction ($P = 0.07$) between colostrum type and volume fed at first feeding. Thus, for the final analysis the data was stratified by volume fed at first feeding (2 vs 4 L), and two final multivariate models developed to describe the relationship between serum IgG and colostrum type, while controlling for interval between feedings (fixed effect) and clustering at the batch level (random effect). The final models estimated that, for calves fed 2 L of

Table 3. Final results of multivariate least squares regression analysis, after stratification by volume at first feeding, describing the association between colostrum treatment and calf serum Ig concentration (mg/ml).¹

Variable level	Calves fed 2 L at first feeding	Calves fed 4 L at first feeding
Fresh colostrum		
Calves represented (n)	40	8
Batches represented (n)	6	2
LS means $\pm$ SE (mg/ml)	19.1 $\pm$ 1.8	16.1 $\pm$ 2.4
Pasteurized colostrum		
Calves represented (n)	55	20
Batches represented (n)	6	5
LS means $\pm$ SE (mg/ml)	9.7 $\pm$ 1.8	13.5 $\pm$ 2.2
P Value ²	0.0004	0.38

¹Models in Proc Mixed control for interval between feedings (≤ 6 or > 6 h) as a main effect and control for batch number as a random effect.

²P value: Compares LS means for serum IgG within each column.

colostrum at first feeding, calves fed pasteurized colostrum had lower ($P = 0.0004$) serum IgG concentrations than did calves fed unpasteurized colostrum (estimate = -9.5 ± 2.6 mg/ml; Table 3). The variable describing interval between feedings was also significant within this model, with serum IgG concentrations estimated 3.1 ± 1.5 mg/dl higher for calves with a short interval between feedings (≤ 6 h). However, for calves fed 4 L of colostrum at first feeding, there was no statistical difference ($P = 0.38$) and a much smaller numerical difference in serum IgG concentrations for calves fed pasteurized colostrum (estimate = -2.6 ± 2.9 mg/ml) vs. calves fed unpasteurized colostrum (Table 3). Similarly, there was no effect ($P = 0.35$) of the variable describing interval between feedings in this model.

DISCUSSION

Effects of Pasteurization on Colostrum IgG and Fluid Characteristics

Three issues that need to be addressed and overcome if commercial dairy producers are to successfully adopt the practice of pasteurizing colostrum as part of their biosecurity program are 1) effect on fluid characteristics, 2) effect on functional IgG concentration, and 3) effect on transmission of pathogens. Limited previous research has been published investigating any of these effects under field conditions and when using commercially available batch pasteurization equipment. In this study there was a 26.2% reduction in IgG levels in pasteurized colostrum. However, this loss was affected greatly by batch size. While the reason for this effect is not fully understood, the authors hypothesize that this may be related, in part, to the effect of prolonged exposure of Ig to heat in the larger batches, which took 2.5 to 3 h to complete the pasteurization process, as compared to 50 to 60 min for medium-sized batches.

While batch size would not affect the standard 30-min period that the contents are held at 63°C, larger batches may take longer to attain this target temperature and longer to cool to feeding temperature, resulting in prolonged exposure of Ig molecules to elevated temperatures. It may be possible that reducing batch size even further could result in even quicker pasteurization and further conservation of IgG, but this hypothesis was not included in this study. Despite the effect of batch size, the IgG losses in pasteurized colostrum observed in this study were significantly greater than for one previous study that heated 5-ml volume of 18 colostrum samples to 63°C for 30 min to simulate pasteurization of colostrum under laboratory conditions (Meylan et al., 1995). That study reported a mean loss of colostrum Ig of 12.3%. Differences in findings between these two studies could be attributable to pasteurization design (commercial vs. laboratory simulation), batch sizes, colostrum quality, and possibly time to complete the pasteurization process.

With respect to the possible effect of colostrum quality, the Meylan et al. (1995) study reported that the loss of IgG was greater in five samples of good-quality colostrum (> 48 g of IgG/L) than for seven samples of poorer quality colostrum (< 48 g of IgG/L). The mean IgG loss for good and poor quality colostrum was 20 and 6.63%, respectively. The current study also demonstrated that high quality colostrum tended to show a greater percent reduction in IgG in the postpasteurized product. However this finding was not consistent among all batches, as four high quality batches (prepasteurized level > 50 mg/ml) had less than a 15% reduction in IgG. Also, the percent reduction is not necessarily the most important end-point to consider, but rather the total amount of functional IgG in the final postpasteurized sample. The current study showed that high quality samples ($= 60$ mg/dl IgG in the prepasteurized sam-

ple) are more likely to result in a final product with the postpasteurized IgG concentration above the target cut-point of 50 mg/ml.

One other potential issue related to colostrum quality is its relationship with fluid and feeding characteristics of the pasteurized end product. In the laboratory study, Meylan et al. (1995) reported that the four samples with the highest IgG content coagulated during the pasteurization process, whereas poorer quality samples were only partially coagulated or remained liquid. In the current study only one batch of colostrum, a 95-L batch that took 2.5 to 3 h to process, coagulated. Almost all of the 25 batches (57-L) studied in the current study remained normal in consistency, with only one batch thickening slightly. All were of suitable consistency that they could be easily fed to calves using either bottle or esophageal feeder.

Effects of Feeding Pasteurized Colostrum on Calf Serum IgG Concentrations

One weakness in this study's design that must be acknowledged is that pooled batches of colostrum were not split each day after batch assembly, and then half fed pasteurized and half fed fresh. Instead, pooled batches of colostrum assembled on different days were allocated to be fed entirely either as fresh or as pasteurized colostrum. While the authors understand that the former study design would have been ideal, it was decided that this requirement would have added another level of complexity to the protocol, both for people working on the dairy farm who were processing the colostrum and feeding the newborn calves, as well as for the herd owner and herd veterinarian (study supervisor) who were monitoring adherence to the study protocol. Rather than risk poor compliance and poor data quality, it was decided to select the simpler design of either pasteurizing or not pasteurizing entire batches on alternate days of batch assembly. The potential for this to confound study inferences should have been minimal given that the IgG concentrations for the six batches of colostrum fed fresh were neither statistically nor numerically different from the prepasteurization concentrations of the six batches that were fed after being pasteurized. Future studies conducted under more controlled conditions should seek to avoid this weakness in design.

One previous field study, using a HTST pasteurization method (72°C for 15 s), reported that total colostrum IgG mass received by 150 calves fed pasteurized colostrum was significantly lower than for 150 calves fed unpasteurized colostrum (Jamaluddin, 1995). However they reported no difference in the number of calves experiencing failure of passive transfer (based on ac-

quiring less than 10 mg/ml of total serum IgG measured at 48 to 96 h after colostrum intake) between treatment (16.2%) and control (19.5%) groups. Similarly there was no difference in serum IgG concentrations between treatment and control groups. While the results of this field trial were promising, there are practical concerns with adopting HTST pasteurization of colostrum using commercial equipment and in a field setting. Personal experience (unpublished) in pasteurizing more than a dozen batches of colostrum using a commercial HTST system has resulted in an end product that consistently congealed into a thick pudding as it cooled to feeding temperature, or worse yet, congealed while still inside the machine coils, making it very difficult to clean equipment and producing an end product that could not easily be fed to a calf. Perhaps future research will find ways to avoid this complication. Given this problem, we believe that, for the present, HTST pasteurization of colostrum is not currently a technology that can be practically implemented on farms.

In the current study, serum IgG concentrations were significantly lower in calves that were fed pasteurized colostrum, and in calves that had a longer interval between the first and second colostrum feedings. Of interest is that there appeared to be an interaction between colostrum type (unpasteurized vs. pasteurized) and volume fed at first feeding. Given that these data were derived from a large number of calves and from 12 batches of colostrum which had very similar values of IgG when compared as fresh colostrum, we can be reasonably comfortable with the model inferences. The results of the latter model (for calves fed 4 L at birth) suggest that, in spite of the drop in IgG concentrations in the colostrum itself resulting from pasteurization, higher and more acceptable serum IgG concentrations may be achieved if other colostrum management practices designed to present a greater total mass of Ig to the open gut sooner are already in place, including feeding 4 L at birth and shortening the interval between feedings. However, these results are preliminary and should be interpreted with caution given the fewer number of calves and batches of colostrum involved in this second comparison. Because of this limitation, this should be considered a preliminary study, with further research required to investigate the apparent interaction between feeding pasteurized colostrum and other colostrum management factors on calf serum IgG concentrations.

The question of pasteurizing both waste milk and colostrum is a very topical issue in the dairy industry today, for which there is limited published information. Having acknowledged this study's limitations, it still yields some very valuable information addressing such questions as effect of pasteurization on colostrum IgG

and fluid characteristics, and on calf serum IgG concentrations. The study has the added strength of external validity because it was conducted under field conditions and using commercial on-farm batch pasteurization equipment. While the results of the current study look promising, due to the need for further study on this subject, we want to remain cautious about recommending that producers adopt the practice of pasteurizing colostrum on their own dairies. Further research is required to study the effect of feeding pasteurized colostrum on both calf serum IgG concentrations and calf health. Because bulls left the farm at 3 d of age, there were far too few animals in this study to allow for investigation of differences in calf health and performance (e.g. morbidity, mortality, or growth rates). The dairy producer who participated in this study was pleased with the performance of calves fed pasteurized colostrum and with the technical aspects of pasteurizing and feeding pasteurized colostrum (e.g. feeding consistency, function and cleaning of equipment), and this farm has continued in the poststudy period to feed pasteurized colostrum to all newborn calves. This is no guarantee, however, that this technology can be made to work equally successfully on other farms. The success or failure of a pasteurized-colostrum feeding program could be influenced by a multitude of factors including colostrum quality, timing, frequency, and volume of colostrum feedings to calves, method of pasteurization, collection and handling of fresh and pasteurized colostrum to prevent contamination and preserve quality, and levels of exposure of calves to infectious pathogens in their environment.

It is recommended that producers considering the adoption of commercial batch pasteurization technology to pasteurize colostrum only attempt to do so after ensuring that they can successfully implement the following steps and then carefully monitor the outcome on an ongoing basis.

1. Use only high quality colostrum (goal > 60 mg/ml) measured using a colostrometer.
2. Collect and store colostrum under sanitary conditions, and keep pre and postpasteurized colostrum chilled if there is any delay in pasteurization and/or feeding.
3. Pasteurize only small-to-moderately sized batches (maximum 57 L, or 15 gal).
4. Monitor pasteurizer function by routinely culturing samples of pasteurized colostrum.
5. Pay attention to equipment maintenance and day-to-day cleaning.
6. Feed 4 L of colostrum as soon as possible after birth.
7. Provide a second feeding of 2 L of colostrum within 6 h of the first feeding.
8. Monitor serum IgG concentrations as well as morbidity and mortality rates in calves.
9. Pay strict attention to sanitation and hygiene in the maternity pen, feeding procedures, and the environment, to minimize calf challenge with infectious pathogens.

CONCLUSIONS

This study has demonstrated that on-farm pasteurization of moderately sized (57 L) batches of colostrum using a commercial batch pasteurizer can consistently produce a product of normal or only slightly-thickened consistency that can be fed to calves and cleaned from equipment. Batch pasteurization does result in a statistically significant reduction of IgG in colostrum. However, the percentage of loss of IgG was significantly reduced when pasteurizing moderate (57 L) instead of large (95 L) batches. Also, higher postpasteurized IgG concentrations were achieved when starting with high quality fresh colostrum (> 60 mg/ml). Feeding pasteurized colostrum resulted in significantly lower serum IgG concentrations in calves. However, it appeared that higher and more acceptable serum IgG levels were achieved when feeding pasteurized colostrum was combined with other good colostrum management practices were implemented, specifically feeding 4 L of colostrum at birth and shortening the interval between first and second colostrum feedings. This requires further study. Further research is required on the subject of commercial batch pasteurization of colostrum on dairy farms, including an investigation of effect of batch size on batch time and percent reduction in IgG concentrations, and the effect of feeding pasteurized colostrum on passive transfer in calves and subsequent calf health and performance.

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