CASE STUDY: A Field Survey of On-Farm Milk Pasteurization Efficacy

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Abstract

Thirty-one batch- or continuous-flow milk pasteurizers used on commercial dairy and custom calf-feeding operations were surveyed. One sample of raw waste milk (RWM) immediately prior to on-farm pasteurization and one sample of pasteurized waste milk (PWM) immediately after on-farm pasteurization from daily waste milk pools were evaluated. The RWM and PWM samples were evaluated for nutrient composition, microbiological profile, alkaline phosphatase activity, and antibiotic residues. Percentages of fat (2.79 to 4.70), protein (2.89 to 5.10), and lactose (3.78 to 4.80) in PWM were highly variable between operations, resulting in a wide range of metabolizable energy (4.75 to 6.61 Mcal/kg) contents in PWM. Thirteen percent (n = 4) of on-farm pasteurizers did not denature alkaline phosphatase, indicating incomplete pasteurization. On-farm pasteurization of waste milk reduced (P < 0.001) bacterial plate count and all bacterial species in PWM compared with RWM. On-farm pasteurization of waste milk had no effect (P = 1.0) on β-lactam and non β-lactam antibiotic residues. Waste milk from the same operation tested positive for β-lactam or non-β-lactam residues in both RWM and PWM, indicating on-farm pasteurization had no effect on antibiotic residues. A 50% incidence of antibiotic residues in PWM was observed. Further research is needed to determine the effects of antibiotic residues on calf nutrition. Based on these observation,s PWM should be routinely evaluated to monitor both on-farm pasteurization efficacy and nutrient content of waste milk. On-farm pasteurizers are not always efficacious, and nutrient content of PWM fed to calves can be extremely variable.

Key words: waste milk, calves, pasteurization

Introduction

Feeding raw waste milk (**RWM**) to neonatal dairy calves has been discouraged because of the potential for disease transmission. Stewart et al. (2005) observed that *Mycobacterium paratuberculosis*, *Salmonella* spp., *Mycoplasma* spp., *Listeria monocytogenes*, *Campylobacter* spp., *Mycobacterium bovis*, and *Escherichia coli* are commonly present in raw milk, and feeding neonatal calves raw milk is a potential vector for disease transmission. Stewart et al. (2005) also demonstrated that all aforementioned bacterial species were mitigated by pasteurization. Stabel et al. (2004) confirmed that *Mycobacterium paratuberculosis*, *Salmonella* spp., and *Mycoplasma* spp. are reduced in waste milk by pasteurization. On-farm pasteurized waste milk (**PWM**) is currently being used by dairy producers and custom calf operations to reduce disease transmission risk and the cost of feeding neonatal calves. Interest in on-farm pasteurization has been fueled by the development of reasonably priced milk pasteurization equipment designed specifically for on-farm use. Despite availability and use of on-farm milk pasteurizers, monitoring systems are generally not available for producers and their consultants to evaluate the efficacy of waste milk pasteurization on a routine basis. In addition, there are few data available which examine the efficacy of on-farm waste milk pasteurizers on an industry-wide basis. The objective of this survey was to evaluate the efficacy of on-farm milk pasteurizers and resulting quality of waste milk fed to dairy calves in commercial environments.

Materials and Methods

Field sampling procedures (test kits) were developed by the project investigators that included 2 sterile milk vials, freezer packs, and an insulated mailer box. Dairy producers and custom calf feeders with on-farm milk pasteurizers were asked to provide waste milk samples from a single pool prior to and after on-farm pasteurization. Waste milks were agitated, and a 100-ml sample was placed into a sterile plastic vial. Samples were immediately refrigerated (4 hr), placed in an insulated mailer with an ice pack, and mailed to Ag Source CRI, (Stratford, WI), for laboratory analysis.

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Waste milk samples were evaluated for nutrient content, bacterial contamination, antibiotic residues, and AP activity by Ag Source CRI. Fat and protein were measured by infrared spectroscopy (Combi 30, Foss Electric AS, Hillerod, Denmark). The AP activity was measured using a luminometer (Charm Sciences, Inc., Lawrence, MA). bacterial plate count (**BPC**) (Petrifilm plate, 3M, St. Paul, MN) and somatic cell count (**SCC**) (Fossomatic 300 Cell Counter, Foss Electric AS) were also measured. Waste milks were plated via selective agar method (Marshall, 1992) and colony-forming units per milliliter of *Salmonella* spp., *E. coli*, total coliform species, *Streptococcus agalactiae*, *Streptococcus* spp., *Staphylococcus aureus*, *Staphylococcus* spp., and *Enterococcus* spp. were determined. Waste milk samples were evaluated for β-lactam and non-β-lactam antibiotics using procedures recommended by the company (Charm Sciences, Inc.). Energy content of RWM and PWM were estimated by equations (NRC, 2001).

General descriptive statistics were calculated for survey data using SAS (SAS Institute, Inc., Cary, NC), and statistical inferences between RWM and PWM were evaluated as a completely randomized design. Protein, fat, and energy contents of RWM and PWM were compared using ANOVA procedures of SAS. Relationships between BPC, SCC, and bacterial species present in RWM and PWM were evaluated using correlation (CORR) procedures of SAS. Binomial data (AP, β-lactam and non-β-lactam antibiotic residues) were evaluated using categorical modeling (CATMOD) procedures of SAS.

Results and Discussion

The nutrient composition of PWM from the 31 commercial operations is presented in Table 1. Because nutrient composition of RWM and PWM were similar (data not shown) and because pasteurization is not known to dramatically alter the nutrient composition of milk, discussion comparing

the nutrient composition of RWM as compared to PWM is limited. Mean fat content of PWM was 31.2%, (DM basis), which is 1.3 percentage units greater than the fat content of whole milk (NRC, 2001). A greater fat percentage in waste milk compared with whole milk was expected as waste milk often contains excess colostrum and transitional milk, which have higher fat, protein, and total solids contents compared with whole milk (MWPS, 2003). Likewise, protein content of PWM was 28.1% (DM basis), which is 2.7 percentage units greater than whole milk (NRC, 2001). Similar to fat, the protein content in waste milk compared with whole milk would be elevated by the excess colostrum and transitional milk (MWPS, 2003). Lactose content of PWM was similar to whole milk at 4.42%. Because lactose content in milk is not highly variable (Welper and Freeman, 1992), little variance between whole milk and PWM would be expected.

The greater fat and protein contents in PWM observed in this survey are important in neonatal calf nutri-

tion because they yield a greater metabolizable energy content (5.45 Mcal/kg) than typically defined for whole milk (5.37 Mcal/kg; NRC, 2001). These observations suggest that producers feeding PWM would provide more calories and protein to neonatal calves compared with feeding a similar amount of DM from whole milk or milk replacer (20% fat, 20% protein; NRC, 2001). These observations are supported by Godden et al. (2005) who observed PWM to be more nutrient-dense on a DM basis compared with milk replacer. Godden et al. (2005) also observed increased growth rates when calves were fed equal amounts of DM from PWM compared with calves fed milk replacer. A very wide range of fat and protein and corresponding metabolizable energy contents in PWM was observed between commercial operations surveyed. Between commercial operations, PWM fat content ranged from 22.3 to 37.6% of DM, and protein content ranged from 23.1 to 40.8% of DM (Table 1). Because wide variations in fat and protein content

TABLE 1. Nutrient composition of pasteurized waste milk from 31 commercial dairy or custom calf rearing operations.

Item	Mean	Minimum	Maximum	SD	SE
Nutrient					
Fat, % of DM	31.2	22.3	37.6	4.26	0.77
Fat, %	3.90	2.79	4.70	0.53	0.10
Protein, % of DM	28.1	23.1	40.8	3.49	0.63
Protein, %	3.51	2.89	5.10	0.44	0.08
Lactose, % of DM	35.3	30.2	38.4	1.63	0.29
Lactose, %	4.42	3.78	4.80	0.20	.04
SCC[a] (cells $\times$ 1,000/mL)	1,772	110	3,800	994	179
Energy[b]					
GE[c], Mcal/kg	5.86	5.10	7.11	0.48	0.09
ME[d], Mcal/kg	5.45	4.75	6.61	0.44	0.08
NE_m[e], Mcal/kg	4.69	4.08	5.69	0.38	0.07
NE_g[f], Mcal/kg	3.76	3.27	4.56	0.31	0.05

[a]SCC = somatic cell count. **[Au: are units correct as edited?]**
[b]Calculated values (NRC, 2001).
[c]GE = gross energy.
[d]ME = metabolizable energy.
[e]NE_m = net energy for maintenance.
[f]NE_g = net energy for gain.

TABLE 2. Bacterial composition of raw and pasteurized waste milk from 31 commercial dairy or custom calf rearing operations.

| | | | | | Pasteurized waste milk | | | | | | | |
| | Raw waste milk, n = 31 | | | | Alkaline phosphatase <1, n = 27 | | | | Alkaline phosphatase >1, n = 4 | | | |
Item	Mean	Mini-mum	Maxi-mum	SD	Mean	Mini-mum	Maxi-mum	SD	Mean	Mini-mum	Maxi-mum	SD
					1000 cfu/mL							
BPC[a]	8,822	6	72,000	14,655	9	0	80	23	208	40	420	19
Escherichia coli	10,000	<10	80,000	17,589	21	<10	330	73	901	<10	3,400	1,669
Total coliform species	82,052	600	800,000	148,489	305	<10	5,700	1,116	11,925	900	40,000	18,848
Salmonella species	243	<10	2,000	611	<10	<10	<10	0	<10	<10	<10	0
Streptococcus agalactiae	1,281	<10	34,000	6,089	9	<10	200	38	46	<10	180	90
Streptococcus species	47,281	200	170,000	41,762	1,830	<10	28,000	5,853	27,300	1,200	109,200	28,544
Staphylococcus aureus	549	<10	11,000	2,021	<10	<10	<10	0	<10	<10	<10	0
Staphylococcus species	8,426	<10	88,000	21,992	47	<10	700	144	108	<10	430	195
Enterococcus species	17,274	<10	180,000	36,082	501	<10	9,000	1,801	2,226	<10	8,600	4,252

[a]BPC = bacterial plate count.

of PWM existed between operations, using mean fat and protein values for PWM when developing neonatal calf nutrition programs could misrepresent the nutritional status of calves. Because only one evaluation of waste milk from a given operation was employed in this survey, it is not known whether similar within-operation variations of fat and protein content of waste milk exist. Survey data suggest, however, that sampling and evaluating waste milk for nutrient content would lend important inference to neonatal nutrition programs.

Bacterial population and SCC data for RWM and PWM are presented in Table 2. We observed a large variation in bacterial populations in RWM, which was expected, and has been observed in other investigations (Selim and Cullor, 1997). Compared with other bacterial species present in RWM, the highest observed species was mean total coliforms.

All bacterial populations were substantially reduced by on-farm pasteurization systems (Table 2). The overall efficacy of pasteurization to reduce bacterial populations in milk is well known (Stabel et al., 2004); therefore only a limited discussion is offered. Alkaline phosphatase was active in all

RWM samples, which is logical because AP is an active enzyme in raw milk but is inactivated when milk is heated to pasteurization temperatures (Ludikhuyze et. al, 2000). On-farm pasteurizers denatured AP on 27 of 31 operations, indicating adequate pasteurization of waste milk was achieved on 87.1% of the operations. On-farm pasteurizers on 4 operations (12.9%) did not denature AP, indicating temperature or duration of temperature may not have been sufficient for adequate pasteurization. Denaturing AP is a benchmark criterion to evaluate pasteurization efficacy (Public Health Service: Food and Drug Administration, 2001). On-farm pasteurizers that did not denature AP (n = 4) did, however, reduce BPC, but the net biological effect cannot be completely defined in our survey (Table 2). These data need to be interpreted with caution because the number of on-farm pasteurizers failing to denature AP was small, and initial BPC and specific bacterial species in RWM prior to on-farm pasteurization were widely variable on the survey operations; therefore, inferences are limited.

Regarding mitigation of specific bacteria, *Salmonella* spp., *Strep. agalactiae*

and *Staph. aureus* organisms seemed to be particularly sensitive to on-farm pasteurization; these species were all dramatically reduced by all on-farm pasteurizers whether AP was denatured or not (Table 2). *E. coli*, total coliforms, *Staphylococcus* spp., and *Streptococcus* spp. appeared less likely to be inactivated if the on-farm pasteurizer did not denature AP (Table 2). On operations where pasteurizers denatured AP (Table 2), some viable bacteria was present in PWM, but BPC and coliform species were below human grade A milk standards (Public Health Service: Food and Drug Administration, 2001) indicating an extremely hygienic feed for neonatal calves was achieved by on-farm pasteurization.

A correlation matrix examining possible relationships between RWM quality and PWM quality is presented in Table 3. No correlations were found between BPC of RWM and of PWM. Likewise, no correlations existed between bacterial species observed in RWM and in PWM with the exception of *Streptococcus* spp. and *Staph. aureus*. There were significant correlations ($P < 0.05$) between *Streptococcus* spp. in RWM and BPC, *E. coli* and *Streptococcus* spp. in PWM. These data suggest *Streptococcus* spp.

TABLE 3. Correlation of microbiological activity in raw and pasteurized waste milk from 31 Wisconsin dairy and custom calf rearing operations.[a]

Item	BPC[1]	SCC[2]	*E. coli*[3]	Total coliforms	*Salmonella* spp.	*Strep.* agalactiae[4]	*Strep.* spp.[5]	*Staph.* aureus	*Staph.* spp.[7]	*Enterococcus* spp.[8]
					Pasteurized waste milk					
BPC[b]	—	—	—	—	—	—	—	—	—	—
SCC[c]	—	0.73	—	—	—	—	—	—	—	—
Escherichia coli	—	—	—	—	—	—	—	—	—	—
Total coliform species	—	—	—	—	—	—	—	—	—	—
Salmonella spp.	—	—	—	—	—	—	—	—	—	—
Streptococcus agalactiae	—	—	—	—	—	—	—	—	—	—
Streptococcus spp.	0.62	—	0.62	—	—	—	0.72	—	—	—
Staphylococcus aureus	—	—	—	—	—	—	—	—	0.55	0.65
Staphylococcus species	—	—	—	—	—	—	—	—	—	—
Enterococcus species	—	—	—	—	—	—	—	—	—	—

[a]Only significant correlations (*P* < 0.05) are reported.

[b]BPC = bacterial plate count (cfu/mL).

[c]SCC = somatic cell count (cells/mL). **[Au: are units correct as edited?]**

may be more difficult to inactivate by pasteurization, but data may not be relevant to calf nutrition because *Streptococcus* spp. are bacteria primarily associated with mastitis and not commonly associated with neonatal calf disease (MWPS, 2003). Significant correlations (*P* < 0.05) were likewise observed between Staph. aureus in RWM and *Staphylococcus* spp. and *Enterococcus* spp. in PWM. As previously stated, these relationships may be of little relevance to calf nutrition because *Staph. aureus* and *Enterococcus* spp., like *Streptococcus* spp., are not common vectors for calf diseases (MWPS, 2003). A significant correlation (*P* < 0.05) was observed between SCC in RWM and PWM, which would be expected, as pasteurization has been shown to have only a minor effect on leukocytes present in milk (Santos et al., 2003). Survey data suggests that predicting bacterial contamination of PWM or efficacy of on-farm pasteurizers cannot be easily assessed by enumerating bacterial populations in RWM prior to on-farm pasteurization.

Antibiotic residues (*β*-lactam and non-*β*-lactam) in RWM and PWM are presented in Figure 1. Approximately 65% of RWM and PWM evaluated

were positive for antibiotic residues. Twenty waste milk samples tested positive for *β*-lactam drug residues in both RWM and PWM. In each case, waste milk from the same operation tested positive for *β*-lactam residues in RWM and PWM, indicating on-farm pasteurization had little influence on antibiotic residues in waste milk fed to calves. Similarly, 21 waste milk samples tested positive for non-*β*-lactam drug residues in corresponding RWM and PWM samples. Our data support the observations of Con-
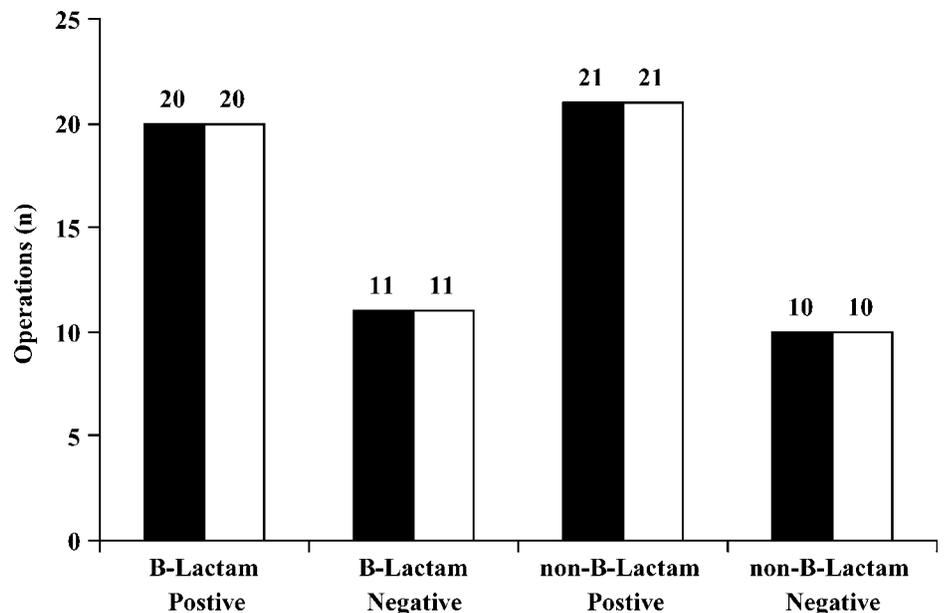
Figure 1. Incidence of antibiotic residues found in raw and pasteurized waste milk from 31 Wisconsin commercial dairy or custom calf rearing operations. Antibiotic residues between raw and pasteurized milk did not differ (*P* = 1.0). ■ *Raw waste milk*; □ *Pasteurized waste milk.*

nor et al. (1992) who also observed that pasteurization had no effect on antibiotic residues in RWM and PWM. Similarly, Simetskii (1973) observed β-lactam and non-β-lactam antibiotics were not inactivated by pasteurization. Because we were unable to quantify the absolute level of antibiotic residues in PWM, specific inferences in regard to neonatal calf nutrition cannot be made. Issues of feeding PWM containing antibiotic residues to dairy calves were beyond the scope of this survey, but warrant further investigation.

Implications

In this survey, the nutrient content of PWM was highly variable between operations utilizing on-farm milk pasteurizers. Because of high nutrient variability, routine testing of PWM for nutrient content should be considered for operations using an on-farm milk pasteurizer. The efficacy of waste milk pasteurizers was questionable on 12.9% of operations. Survey observations suggested producers should adopt a routine testing procedure to evaluate on-farm pasteurizer performance. Maintenance of pasteurizer equipment, management, and routine laboratory evaluation of PWM appear critical to the success of waste milk pasteurization. We found no clear management utility to sample and evaluate waste milk prior to on-farm pasteurization, but excellent milk hygiene prior to on-farm pasteurization seems prudent. Finally, a 50% incidence of antibiotic residues in PWM was observed. Further research is needed to determine the effect of antibiotic residues on calf health and corresponding livestock production systems.

Acknowledgements
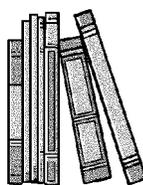
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