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Milking machine and udder health management factors associated with bulk milk somatic cell count in Uruguayan herds

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ABSTRACT

This paper describes the findings of static milking machine tests and milking observations on Uruguayan dairy farms. The aim of this study was to investigate the association between both milking machine performance and udder health management factors and bulk milk somatic cell count (BMSCC) in Uruguayan dairy herds. Data from 907 visits were used for the analysis. The farm visits were made between April 2006 and November 2015 and farms were located in 17 of the 19 departments of Uruguay. Each visit involved a short static machine test and observation of the milking process; the use of blanket dry cow therapy was also recorded. The BMSCC was the variable of interest. Univariable analysis was applied to explore the best set of predictors to be included in the multivariable model. A multivariable linear regression model was fitted. The median BMSCC over the years was 376 thousand cells/mL (interquartile range = 280,000–500,000 cells/mL). The final model showed a lower BMSCC for herds that used post-milking teat disinfection, applied the teat cups to dry teats and maintained the pulsation system in good working order. There was no significant association between BMSCC and blanket dry cow therapy in the final model. The association of these milking machine and udder health management factors with the BMSCC under Uruguayan conditions is relevant information for a dairy industry that needs low BMSCCs to compete on the world market.

1. Introduction

Dairy products are the third most important agricultural export of Uruguay. Seventy percent of the total milk production is exported to a wide range of countries. The milk production system is pasture-based, supplemented by grain; cows are outdoors year round. According to INALE (Uruguayan National Dairy Institute, 2014), the country has approximately 2800 dairy farms that sell milk to a processing plant. The average herd size is 104 milking cows and the daily mean milk production is17.9 L/cow.

Since 1995, dairy processing plants that export milk products are required to test and categorize the milk they receive. The compulsory tests stipulated in decree 359/013 (Normativa y avisos legales del Uruguay) are: milk fat, protein and total solids, cell count, total bacterial count, inhibiting substances and freezing point. Over 70% of dairy producers sell their milk to the main cooperative CONAPROLE, which has a payment system that offers a strong incentive for the production of low cell count milk.

Bulk milk somatic cell count (BMSCC) is an indicator of the prevalence of intra-mammary infection in the herd and is used as a routine test for milk quality at the farm level (Schukken et al., 2003). Periodic BMSCC information is used by farmers and advisers to monitor and correct udder health programs.

There is large body of literature dedicated to the association between BMSCC and farm management. These studies have been mostly carried out in Europe (Barkema et al., 1998; Faye et al., 1997; Kelly et al., 2009; Østeras and Lund, 1988) or North America (Bartlett et al., 1992; Goodger et al., 1993; Hutton et al., 1990; Rodrigues et al., 2005; Schewe et al., 2015; Wenz et al., 2007). In Latin America, studies on the association between management factors and BMSCC are few (Reyes et al., 2017; Tadich et al., 2003; Van Schaik et al., 2005; Vissio et al., 2013). Dufour et al. (2011) reviewed 36 papers and selected factors relating to udder health management and milking machine that show a consistent association with BMSCC: post-dipping, wearing gloves, the presence of automatic cluster removers, milking problem cows last and blanket dry cow therapy. In addition, BMSCC seasonal variations has

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been described by various authors in different countries (Archer et al., 2013; Green et al., 2006; OldeRiekerink et al., 2007; Shock et al., 2015); in general, the BMSCC peak observed in summer could be the results of higher rates of clinical or subclinical infection, and it is probably related to a longer duration of infection (OldeRiekerink et al., 2007).

In Uruguay, Gianneechini et al. (2002, 2014) reported the prevalence of subclinical mastitis (54.2%), incidence of clinical mastitis (11.8%) and the most common causal microorganism of clinical and subclinical mastitis (*Staphylococcus aureus*), and Bouman et al. (2005) reported the strengths and weaknesses of udder health programs as applied in the country. However, to our knowledge, there are no publications on the uptake of different mastitis control measures by farmers or their association with the BMSCC in Uruguay.

Mein et al. (2004) concluded that most new infections are caused by factors other than the milking machine, with few exceptions (Kelly et al., 2009; Østeras and Lund, 1988). Most studies assess either the effect of milking management or the effect of milking machine factors on BMSCC; in this study, both were evaluated at the same time. The aim of this study was to investigate the association between both milking machine performance and udder health management factors and BMSCC in Uruguayan dairy herds.

2. Material and methods

2.1. Study population

Between April 5, 2006 and November 3, 2015 one of the authors (Mette Bouman) visited 1223 farms, some of them more than once; a total of 2115 visits were made. The average number of visits was 1.73; 67.6% of farms were visited once and only 5% of farms were visited more than five times. Farm visits were generally but not exclusively motivated by high cell counts and cases of clinical mastitis (72% of visits). Twenty per cent of the visits were routine milking machine tests and the remaining visits were to investigate hygiene problems or cow behavior changes, for milker training, and to ensure the correct performance of new dairy facilities.

The inclusion criterion was that the farm could provide the following information: farm identification, department, date of visit, number of cows, herd average daily milk yield, BMSCC, milking observations and milking machine characteristics.

Each visit included a short static machine test as described below and observation of the milking routine during a minimum of three parlor turns. All observations were recorded on two forms, one for the milking machine test and another for details about milking routines and dry cow therapy. In addition, information about farm identification, date of visit, the number of lactating cows, herd daily production (L/day) at the time of the visit, BMSCC (cells/mL) over the last month provided by the dairy plant to the producer, and the reason for the visit was recorded.

2.2. Bulk milk somatic cell count

The BMSCC was determined by flow cytometry using Foss, Bentley and Delta instruments of two different laboratories. The samples were taken by the truck driver, either using an automated sampling system (77%) or manually from the top of the bulk tank after agitating for at least 5 min. The data were provided by the dairy plant to the producer (on paper, via laboratory website or by SMS). Cheese makers that were included took their own samples manually from the top of the bulk tank after mixing the milk for 5 min. Seventy-seven per cent of farms were selling milk to a single dairy cooperative (CONAPROLE) which provides cell counts 12–25 times/month. The rest of the farmers sold the milk to 13 different dairy plants with different sampling schemes (a minimum of 3 samples a month) or were cheese makers (6%) that measured bulk milk cell counts minimally once per month.

2.3. Milking machine data collection on farm

Equipment for the static machine test consisted of an Exendis PT-IV and PT-V pulsator tester (ATV- Agri, Holland); teat cup plugs; a SAC flow meter with an Exendis digital vacuum gauge; a spirit level; an electronic rev counter KIMO CT-100; a measuring tape; and calipers. The pulsator testers and vacuum gauge were calibrated annually at the ATV-Agri plant.

Many milking machines in Uruguay are a mix of parts of different origins, assembled by an installer without formal training. The static test is used to pinpoint the causes of, for instance, insufficient effective vacuum reserve, so that the installer receives precise instructions on how to correct the problem. Dynamic testing is used to confirm that the nominal vacuum level is correct and to assess milking technique, in particular when vacuum reserve is at or below its minimum in small milking machines.

Very few milking machines in Uruguay have all the regulatory connecting points: A1, A2, Vm, Vr and Vp as mentioned in ISO 5707:2007:4.22 and 4.2.3. Where present, they were used, but in most cases, the air flow meter (AFM) was connected on or near the receiver vessel and the vacuum gauge was connected to a connection point on the AFM. Comparative tests by the author who carried out the milking machine tests have shown that the difference in vacuum level between connecting the vacuum gauge to point Vm and the connection point on the AFM (at A1) is less than 0.2 kPa.

When there was no suitable connection point A1, the milk line or the connection between receiver vessel and milk pump was used.

The working vacuum was recorded as per ISO6690:2007 (E) 5.2.2.2. The maximum height of the milk line was measured with a tape measure. Less than 1% of the tested milking machines were low-line. Vacuum measurement was recorded as “pass” or “fail” based on milk line height in metres as recommended by DairyNZ (https://www.dairynz.co.nz/milking/the-milking-plant/pulsation-and-vacuum-systems/). This table is a good predictor of a vacuum of 32–42 kPa in the short milk tube (ISO 5707:2007 8.7) during the peak flow period under a wide range of milk tube bores and lengths, claw capacities and pulsation types. The single value is easy to register. The table was used to adjust working vacuum before milking if it was outside the recommended range and a dynamic test was carried out to confirm that the mean liner vacuum during peak flow was 32–42 kPa. Therefore, dynamic test results were not used in this analysis, as they did not reflect the vacuum level at which the milking machine was operating until the moment of the test. The effective vacuum reserve was determined as per ISO 6690:2007 5.2.5. Table A.2 of ISO 5707:2007 was used to assign a “pass” or “fail”. Vacuum stability in the milk line was not measured. Pulsators were tested according to ISO 6690:2007 6.2. Pulsation systems with one or more pulsators with a d-phase of less than 150 ms in one or both channels, a pulsation rate below 45 ppm or a b-phase below 30% were classified as “fail”. Liners were assessed visually and the date of the most recent liner change was recorded. Nitrile liners with more than 2500 milkings and silicone liners with more than 7500 milkings were recorded as “fail”, as were liners with visual damage but prior to their expiry date.

2.4. Milking routine and dry cow therapy data collection on farm

During milking, observations were made on teat preparation, fore-stripping, over-milking, machine stripping and post-milking teat disinfection.

Teat preparation was classified according to whether the teat was wet or dry prior to cluster attachment. Washing with water from a hose and drying (1.3%), no preparation (32.0%) and pre-dipping and drying (0.9%) were combined in the category “milking dry teats”; washing with water from a hose, no drying was classified as “milking wet teats”.

Fore-stripping either to the floor or in a strip cup was recorded as “fore-stripping-yes”. Machine stripping, the practice whereby the milker puts a hand or weight on the cluster at the end of milking to harvest the last milk, was recorded as "machine stripping- yes" when the cows were stripped for more than 5 s. Herds where less than 15% of cows were machine stripped, regardless of the duration, were registered as "machine stripping-no". Herds in which more than 20% of cows were over-milked during more than two minutes were recorded as "over-milking-yes". Herds where the milkers missed more than 20% of teats or covered less than half the teat during teat disinfection, or those herds where milkers disinfected intermittently or not at all, were recorded as "post-milking teat disinfection-no".

Only blanket dry cow therapy was recorded as "dry cow therapy"; herds in which dry cow therapy was used on some cows were classified as "dry cow therapy-no". Selective dry cow therapy with strict selection criteria, as practiced in some dairy countries to reduce antibiotic consumption, was not practiced in the herds included in this study.

2.5. Data analysis

In this study, herd was the unit of analysis. For farms visited several times, the herd predictors considered in this analysis (milking machine and udder health management factors) were those identified and recorded during the last visit. A natural logarithmic transformation of BMSCC was used to approximate the normal distribution (Ali and Shook, 1980), because it was right skewed. The mean of the natural logarithm of BMSCC measures in the month prior to the visit was the dependent variable. The milking machine performance was evaluated considering working vacuum, pulsation, effective reserve and liners as factors. The udder health management factors evaluated were machine stripping, over-milking, milking dry teats, post milking teat disinfection and dry cow therapy. These factors were fit as categorical explanatory variables.

Average milk production (L/cow/day) and number of milking cows were investigated as potential confounders. In the same way, time of visit (season and year), the total number of visits to a farm, the reason for the visit and the dairy plant to which the producer sold the milk were also investigated as potential confounders in the final model. The reason for the visit was categorized as follows: "udder health problem" if the producer reported high milk somatic cell count, high incidence of clinical mastitis or both, and "other" if the visit was for another reason (e.g. routine milking machine test). The dairy plant was classified in binary categories as CONAPROLE and others. All the potential confounders were included in the model from start. A predictor variable was considered a confounding variable when it was associated with both the explanatory variable (udder health management and milking machine factors) and the dependent variable (BMSCC). If the inclusion of this confounding variables induced important change in the parameters estimated it was retained in the final model.

Univariable analysis was performed before fitting the multivariable model; only those factors with a p-value < 0.20 were considered for further analysis. Relationships between BMSCC and factors were investigated using ANOVA for categorical variables and Pearson $\chi 2$ test for continuous variables (milk production and herd size).

The relationship between BMSCC and predictors was initially evaluated by fitting a general linear mixed regression model (Dohoo et al., 2003; Snijders and Bosker, 1999), regarding department as random effect. Department was initially regarded as random effect because it, as unit of aggregation, contains different types of dairy farms, so that between-farm BMSCC variation may depend on the region. The model was as follows: $Y_{ij} = \alpha + \beta^* Z_{ij} + b_j V_j + \varepsilon_{ij}$, where Y_{ij} was the mean of the natural logarithmic BMSCC for herd i in department j; α = regression intercept; β = vector of unknown fixed effects; Z_{ij} = covariate vectors of fixed effects; b_j = vector of random effects for department; V_j = covariate vectors of random effect for department j; ε_{ij} = represent the residual variance. Statistical significance was defined at p-value ≤ 0.05.

Collinearity between the independent variables was assessed pairwise by Spearman rank correlations and if collinearity ($r = 0.80$) existed, the variable with lowest p-value was selected. Manual backward elimination of nonsignificant (p-value > 0.05) fixed effects was used where the initial model included all independent variables as main effects. The variance structure used was variance components.

The Bayesian information criterion (BIC) was used to select the model's variance structures and the best predictor subset (Snijders and Bosker, 1999).

Once the main effects model was fitted, all possible 2-way interactions were examined and retained if the p-value was ≤ 0.05 (Dohoo et al., 2003). Continuous variables (herd size and milk production) were also tested considering nonlinear terms in the model.

Model departures from normality were assessed by mean of residuals analysis using normal probability plots. Residuals were also plotted against the fitted values and tested for outliers. The analyses were performed using PROC MIXED (SAS Institute, 2011).

3. Results

Out of a total of 2115 advisory visits to 1223 farms, we used data from 907 dairy farms that had a full dataset. The study herds were located in 17 of the 19 Uruguayan departments, although most of the visits (54.7%) were made in Colonia and San José (Table 1). The average number of milking cows per herd was 129.7, ranging from 6 to 730. The average production was 17.5 L/cow/day, ranging from 6 to 36 L/cow/day.

The overall geometric mean BMSCC was 375.6 thousand cells/mL, ranging from 70 to 3000 thousand cells/mL (Fig. 1). No statistical difference in BMSCC was found between the herds included in the study compared to those that did not meet the inclusion criteria.

Most milking installations were mid or high line swing-over or walk-through parlors (96%); just under 1% was low line and the remaining 3% milked with churns. Milking machines with at least one fault were observed on 72.7% of the farms; insufficient effective vacuum reserve was the most common fault (50.2%), followed by failures in the pulsation system (35.9%) and inadequate vacuum level (29.0%). The BMSCC was lower on farms that had sufficient effective vacuum reserve and pulsation categorized as "pass". No association was found between BMSCC and vacuum level or liner condition (Table 2).

On approximately one third of the farms (32.3%), teats were dry when the teat cups were applied. Fore-stripping was observed in 57.3% of visits; in 21.7% of herds cows were machine-stripped at the end of milking, and over-milking was observed in 13.5% of herds. Post-milking teat disinfection (75.7%) and dry cow therapy (89.3%) were widely applied as mastitis control practices. No association was found

Table 1
Geographic distribution of 907 dairy farms visited from April 2006 to November 2015 in Uruguay.

Uruguayan departments	N (%)
Colonia	263 (29)
San José	233 (25.7)
Florida	130 (14.3)
Canelones	93 (10.3)
Soriano	72 (7.9)
Flores	27 (3)
Rocha	24 (2.6)
Maldonado	18 (2)
Rio Negro	9 (1)
Tacuarembó	9 (1)
Durazno	8 (0.9)
Lavalleja	6 (0.7)
Rivera	5 (0.6)
Salto	4 (0.4)
Treinta y tres	4 (0.4)
Cerro Largo	1 (0.1)
Paysandú	1 (0.1)

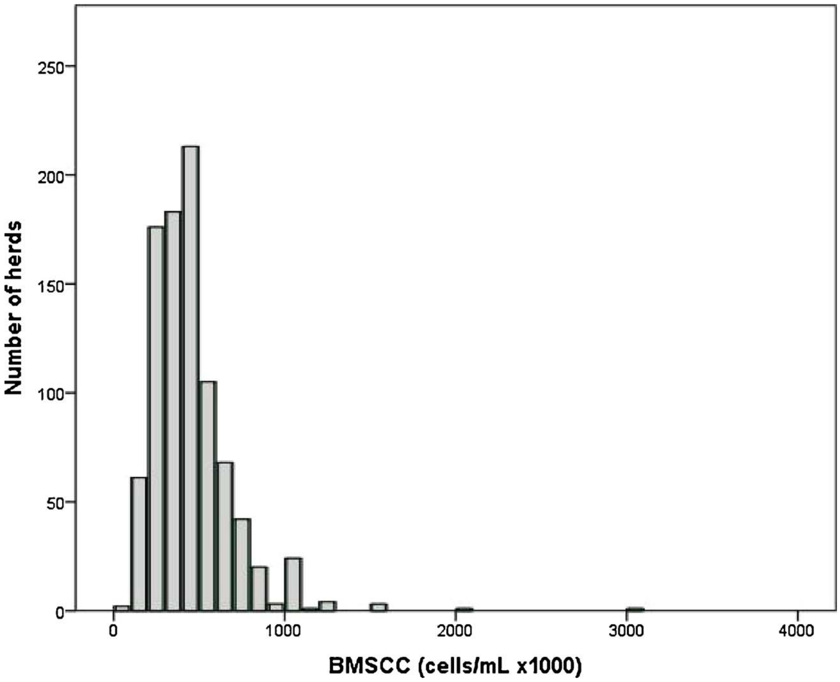

Fig. 1. Monthly geometric mean of bulk milk somatic cells counts (BMSCC) distribution of 907 Uruguayan dairy herds visited from April 2006 to November 2015.

Table 2
Univariate ANOVA between bulk milk somatic cells counts (BMSCC) and milking machine factors in 907 dairy herds visited from April 2006 to November 2015 in Uruguay.

Variables	Level	N (%)	lnBMSCC (CI 95%)	*p*-value
Liners	Fail	363 (40)	5.95 (5.89–6.00)	0.396
	Pass	544 (60)	5.92 (5.88–5.97)	
Correct pulsation	Fail	326 (35.9)	6.02 (5.96–6.07)	< 0.001
	Pass	581 (64.1)	5.89 (5.84–5.93)	
Effective reserve	Fail	455 (50.2)	6.01 (5.96–6.06)	< 0.001
	Pass	452 (49.8)	5.85 (5.80–5.90)	
Vacuum level	Fail	263 (29)	5.97 (5.91–6.04)	0.114
	Pass	644 (71)	5.92 (5.87–5.96)	

Table 3
Univariate ANOVA between bulk milk somatic cells counts (BMSCC) and udder health management factors in 907 dairy herds visited from April 2006 to November 2015 in Uruguay.

Variables	Level	N (%)	lnBMSCC (CI 95%)	*p*-value
Dry cow therapy	No	97 (10.7)	6.15 (6.05–6.26)	< 0.001
	Yes	810 (89.3)	5.91 (5.87–5.94)	
Forestripping	No	387 (42.7)	5.94 (5.89–6.00)	0.647
	Yes	520 (57.3)	5.93 (5.88–5.97)	
Post-dipping	No	220 (24.3)	6.11 (6.04–6.18)	< 0.001
	Yes	687 (75.7)	5.87 (5.83–5.91)	
Milking dry teat	No	614 (67.7)	5.98 (5.94–6.03)	< 0.001
	Yes	293 (32.3)	5.83 (5.77–5.89)	
Machine stripping	Yes	197 (21.7)	6.00 (5.92–6.07)	0.032
	No	710 (78.3)	5.91 (5.87–5.95)	
Overmilking	Yes	122 (13.5)	6.06 (5.97–6.16)	0.001
	No	785 (86.5)	5.91 (5.87–5.95)	

Table 4
Univariate ANOVA between bulk milk somatic cells counts (BMSCC) and dairy plant to which the producer sold the milk and number, reason and time (year and season) of the visit in 907 dairy herds visited from April 2006 to November 2015 in Uruguay.

Variables	Level	N (%)	lnBMSCC (CI 95%)	*p*-value
Dairy plant	CONAPROLE	697 (76.8)	5.89 (5.85–5.93)	< 0.001
	Others	210 (23.2)	6.08 (6.01–6.15)	
Reason for visit	Udder health problems	651 (71.8)	6.10 (6.07–6.14)	< 0.001
	Others*	256 (28.2)	5.50 (5.44–5.55)	
Number of visit	One	587 (64.7)	5.99 (5.94–6.05)	< 0.001
	More than one	320 (35.3)	5.82 (5.76–5.88)	
Year	2006	57 (6.3)	5.95 (5.78–6.13)	< 0.001
	2007	91 (10.0)	6.04 (5.9–6.18)	
	2008	74 (8.2)	5.91 (5.76–6.07)	
	2009	57 (6.3)	6.04 (5.86–6.21)	
	2010	99 (10.9)	6.03 (5.9–6.16)	
	2011	74 (8.2)	5.92 (5.77–6.07)	
	2012	83 (9.2)	5.8 (5.66–5.95)	
	2013	113 (12.5)	5.94 (5.82–6.07)	
	2014	165 (18.2)	5.94 (5.84–6.04)	
	2015	94 (10.4)	5.76 (5.62–5.9)	
Season	Summer	222 (24.5)	6.04 (5.96–6.12)	0.001
	Autumn	235 (25.9)	5.96 (5.88–6.04)	
	Winter	203 (22.4)	5.89 (5.81–5.98)	
	Spring	247 (27.2)	5.85 (5.77–5.92)	

* Routine milking machine tests, hygiene problems, cow behaviour changes, milker training, and to sign off new plants.

for fore-stripping whereas herds in which teats were dry prior to attachment and/or that used post-milking teat disinfection had a lower cell count. Over-milking was associated with herds having a higher BMSCC, while no significant association was seen between machine stripping and BMSCC. Ten percent of the herds were classified as "dry cow therapy-no". Half of these farms did not use dry cow therapy at all and the other half used dry cow therapy on some cows; these herds had a higher BMSCC than herds that used blanket dry cow therapy (Table 3). The BMSCC distribution for variables other than milking machine factors and udder health management is shown in Table 4. A negative association was found between BMSCC and number of milking cows ($\beta = -0.09$; *p*-value < 0.008) and between BMSCC and milk yield per cow ($\beta = -0.25$; *p*-value < 0.001).

As department was not significant as random effect, a multivariable linear regression model was finally fitted. As a result of that and after

Table 5
Final multivariable linear regression model for factors associated with bulk milk somatic cells counts (BMSCC) in 907 dairy herds visited from April 2006 to November 2015 in Uruguay.

Fixed effect variables	Level	Estimate (SE)	p-value	Least squares mean Estimate (CI 95%)	BMSCC (cells/mL) Estimate
Intercept		5.943 (0.060)	< 0.001		
Post-dipping	No	0.117 (0.029)	0.001	5.95 (5.90–6.01)	385
	Yes			5.84 (5.80–5.87)	343
Milking dry teats	Yes	−0.067 (0.027)	0.013	5.86 (5.81–5.91)	351
	No			5.93 (5.89–5.97)	376
Pulsator	Fail	0.067 (0.026)	0.009	5.93 (5.88–5.98)	376
	Pass			5.86 (5.83–5.90)	352
Dairy plant	CONAPROLE	−0.239 (0.029)	< 0.001	5.78 (5.74–5.81)	323
	Others			6.01 (5.96–6.07)	409
Reason for visit	Udder health problems	0.582 (0.027)	< 0.001	6.19 (6.15 − 6.22)	486
	Others[a]			5.60 (5.55–5.66)	272
Milk production[b]		−0.016 (0.003)	< 0.001		

[a] Routine milking machine tests, hygiene problems, cow behaviour changes, milker training, and to sign off new plants.

[b] Liters/cow/day.

the adjustment for several factors (herd production, dairy plant and reason for visit), two udder health management factors and one milking machine factor remained associated with BMSCC.

Herds where post-milking teat disinfection was used and/or teat cups were applied to dry teats had a lower BMSCC than those that did not. Herds that were milked with pulsation that complied with ISO standards had a lower BMSCC (Table 5).

Graphical assessment of the residuals in the final model did not indicate non-normal patterns or lack of uniformity of the residuals across predicted values. Q–Q normal graphs of residuals showed an acceptable normality in the models at all levels. Visual examination of residuals vs. predicted values in the final model did not reveal patterns which would indicate heteroscedasticity.

4. Discussion

Our study encompasses approximately one third of Uruguayan dairy farms that sell the milk to a processing plant. The study population profile showed that average milk yield was similar to national data (17.5 vs. 17.9 L/cow/day) while the average number of milking cows per farm was higher than the average of all Uruguayan farms for these years (131 vs. 104 milking cows) (Uruguayan National Dairy Institute, 2014). The geographic distribution of the study population is a reasonable reflection of the distribution of dairy herds in Uruguay, although the department of Florida is somewhat, and Paysandú severely, underrepresented. In the two departments that did not provide data (Montevideo and Artigas), milk production is marginal (Ministerio de Ganadería, Agricultura y Pesca, DIEA).

Laborde (1979) tested approximately 10% of the milking machines in Uruguay and found only one that did not have a single fault, whereas almost 80% had severe functional or installation defects. Bouman (2003) came to a similar conclusion after testing 217 milking machines where 88% had defects that could affect udder health and only 3% had no defects at all. The present study shows a slight improvement (71.5% of tests with major machine faults) compared to previous ones. In a UK survey 61% of milking machines failed to comply (Berry et al., 2005), although the pass or fail criteria were not the same as ours.

Hutton et al. (1990) did not find any association between milking machine factors and the percentage of low cell count cows in the herd, whereas Østeras and Lund (1988) and Garcés et al. (2006) found certain relations. In our study, the pulsation characteristics were the only milking machine factor associated with BMSCC in the final model. This is consistent with O'Shea et al. (1984), who found a higher new infection rate for *Staphylococcus aureus* with a d-phase of 6.5% (72 ms) as opposed to 17% (188 ms),while Reitsma et al. (1981) found an increased mastitis risk with no pulsation or a d-phase of 170 ms, as compared to a d-phase of 340 or 510 ms. Upton et al. (2016) found that a d-phase of less than 150 ms caused a significant increase in the cross-sectional area of the teat canal, indicating congestion. Although pulsation failure in our study seldom affected all pulsators, Capuco et al.'s study (1994) suggests that a d-phase failure of even a few pulsators rapidly increases the risk of new infection. In our study, 75% of pulsation failures were due to a short d-phase; a quarter of pulsation systems had a short b-phase (10%) or a very slow pulsation rate (15%) (data not shown); both slow down milking (International Dairy Federation, 2000) and increase the probability of hyperkeratosis (Mein et al., 2001).

In our study, milking vacuum was either too high (28%) or too low (3%) on almost one third of farms, but no association was found with BMSCC. However, the results reported by Hamann et al. (1993), Reinemann et al. (2008) and Bade et al. (2009) clearly show that high vacuum causes congestion with open teat ends and poor circulation. On the other hand, Rasmussen and Madsen (2000) found no significant effect of low milking vacuum on either teat condition or udder health, and highlighted the wide possibilities of what a correct milk-line vacuum should be. Furthermore, Gleeson et al. (2004) found that liner bore and cluster weight may have a stronger effect on teat tissue changes than milking vacuum, factors which were not registered in this study.

A group of experts described the machine related mechanisms that could predispose to new udder infection (International Dairy Federation, 1987). Mein et al. (2004), in a review of this document, emphasize the positive role of effective pulsation and the negative impact of liner slips, while questioning the importance of vacuum pump capacity, vacuum regulation, or the capacity of the milk line. In this study, almost half of all milking machines failed to reach the ISO standard for effective vacuum reserve. Although there was an association between effective vacuum reserve and BMSCC in the univariable analysis, it did not remain in the multivariable model. Vacuum reserve is necessary for vacuum stability in all parts of the milking machine (International Dairy Federation, 2000), but Mein et al. (2004) considered that milk-line vacuum stability could only have an effect on new infection rate if the vacuum drop is sufficiently large to cause liner slip. We did not record liner slip in this study.

Liner function is supposed to have a major influence on teat end congestion and mastitis risk (Mein et al., 2004; Reinemann et al., 2008), but no significant association was found between liner age and BMSCC in our study; this is consistent with previous reports (Hutton et al., 1990; Østeras and Lund, 1988). The lack of association between liner condition and somatic cell count may be related to the fact that farmers change the liners when they notice a mastitis problem in the herd, prior to the milking machine test.

Post-dipping and dry teat preparation were associated with BMSCC in the final model. Milking dry teats was associated with lower cell count compared with washing without drying. Teat washing without drying is still common practice in Uruguay (67.7% of visits), as well as in Argentina (Vissio et al., 2013). Recently, Schewe et al. (2015) reported that the use of water during teat preparation was positively associated with BMSCC in herds in the Eastern US, although this association was only found in herds with employees. Chamings (1984) and Sadeghi-Sefidmazgi and Rayatdoost-Baghal (2014) also found lower cell counts in herds that used dry teat preparation, although Kelly et al. (2009) did not find a significant association. One of the benefits of dry teat preparation would be the improvement in teat skin condition (Phillips et al., 1981) and a reduction of *Staphylococcus aureus* colonization of the teat (Myllys et al., 1994). *Staphylococcus aureus* was the most commonly encountered mastitis pathogen in subclinical mastitis in Uruguay (Gianneechini et al., 2002, 2014).

As expected, post-milking teat dipping was highly associated with lower BMSCC, as found by Kelly et al. (2009) and Dufour et al. (2011). This is one of the management variables with strong experimental evidence for its use (Neave et al., 1969) and a recommendation in the National Mastitis Council Recommended Mastitis Control Program (NMC, www.nmconline.org) to prevent new intra-mammary infections, as is the use of dry cow therapy. The association between dry cow therapy and lower BMSCC was not significant; this may have been due to the fact that only a small group of herds did not use DCT (10.7%), limiting the statistical power of the analysis. Kelly et al. (2009), Dufour et al. (2011), and Schewe et al. (2015) have found a strong association between the use of blanket dry cow therapy and lower BMSCC, and there are many experimental studies that validate its use (Halasa et al., 2010, 2009).

No association was found between fore-stripping and BMSCC. Fore-stripping permits the detection of cows with clinical mastitis. As their milk generally has a high cell count (Deluyker et al., 1993), its exclusion from the bulk tank could reduce the BMSCC to an extent, although this depends on the number of cows with clinical mastitis and the total number of cows in the herd. However, our findings agree with those of Reyes et al. (2017), OldeRiekerink et al. (2008) and Kelly et al. (2009) and the results of the meta-analysis of Dufour et al. (2011).

No association was found between over-milking and higher BMSCC in the final model. This was surprising, especially since 96% of milking plants were mid- and high-line installations, which use a higher nominal vacuum than low-line plants, leading to a high end-of-milking vacuum at the teat end. Over-milking leads to increased vacuum at the teat end with edema and delayed teat end closure (Hamann et al., 1993; Hillaerton et al., 2002), which eventually could increase the risk of acquiring new infection. The incorporation of automatic cluster removers (ACRs) to reduce or eliminate over-milking has shown an association with lower BMSCC (Dufour et al., 2011; Hutton et al., 1990; Kelly et al., 2009; Wenz et al., 2007). In Hillerton's study, type of liner was associated with teat firmness after over-milking. Our study did not record liner type and we are unable to suggest an explanation for the lack of association.

The association between milk yield and BMSCC has been reported previously (Rodrigues et al., 2005); our results support the finding that in herds with a higher production per cow the BMSCC tends to be lower. The reason for the visit was, for obvious reasons, highly associated with BMSCC; herds with mastitis problems had almost twice as high a BMSCC as herds that did not report mastitis problems. Herds in which the milk was sold to the main cooperative CONAPROLE had significantly lower cell counts than herds that delivered milk to other dairy plants. CONAPROLE uses a payment system with an important bonus for low cell count milk and has an advisory service for herds with high bulk milk cell counts. During the years of the study, the other dairy plants offered less financial incentive for low cell count milk.

The fact that the random effect (department) was not significant in the mixed regression model may indicate that the most of variation in BMSCC was between farms regardless of the department. This means that efforts to improve the BMSCC, in terms of developing a strategy for mastitis control in Uruguay, should be focusing on farms rather than departments. Association should not be confounded with causality in observational studies (Dufour et al., 2011) and this study is no exception. Nonetheless, most of the factors that showed association in the final model are supported by experimental evidence, so these factors are probably of importance for changing BMSCC levels.

Although the study population included close to one third of Uruguayan dairy herds, it was not a random sample, so that inference to the Uruguayan national herd should not be attempted. However, the study may still be internally valid, taking into consideration that the association between machine performance and udder health management factors and BMSCC was adjusted for several variables such as herd size, the reason of the herd visit and the milk processing plant where the milk was marketed. The number of herds included in this study and their geographical distribution also add to the robustness of the results.

The description of the uptake of common mastitis control and prevention practices may be useful as baseline data for future surveys, and could eventually help to identify weak areas in the national mastitis control program. The Uruguayan dairy industry depends heavily on exports and needs low cell count milk to be competitive.

5. Conclusion

Under Uruguayan farming conditions, this exploratory study has shown that post-milking teat disinfection, milking dry teats and maintaining the pulsation system in good condition were associated with a lower BMSCC. The strength of the association with BMSCC was slightly higher for udder health management factor than for milking machine factors. However, it is clear that Uruguayan dairy farmers need to pay attention to both milking machine maintenance and udder health management to obtain lower BMSCC.

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