IMPACT OF A WIDE RANGE OF TEAT LENGTHS ON UDDER HEALTH AND MILKING TIME IN HOLSTEIN COWS*

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The objective of our experiment was to evaluate the impact of teat length on milk yield, actual milking time (AMT), milk conductivity (MC), somatic cell count (SCC) and mastitis incidence during lactation. The effect of teat length was evaluated as the occurrence of non-ideal teats (NIT; shorter than 40 mm or longer than 60 mm) at udder level and as the average length of teats on udder (ALTU). The experiment was conducted on 59 dairy cows of Holstein breed. SAS 9.3 was used for statistical calculation. There were great variances in teat length (22–96 mm) and in the rear/front teat ratio (0.8). Only 33% of the tested cows had optimal length of all teats. No evidence for a negative impact of NIT on udder health was found. ALTU showed a statistically significant effect on AMT and SCC ($P < 0.05$). Cows in the group of udders with short teats showed the worst results for SCC ($P < 0.05$) and MC. Udders with short teats showed the fastest AMT (6.78 min; $P < 0.05$) compared to udders with medium and long teats (7.36 min; $P < 0.05$ and 7.55 min; $P < 0.05$, respectively). Our results show that while using an udder friendly milking system, the effect of teat length on udder health could be negligible.

dairy cow, teat length, non-ideal teats, mastitis, somatic cell count, milk yield

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INTRODUCTION

Cows with higher udders, deeper central ligaments, tighter attachments and centrally placed teats of middle length are the most desirable (Nemcova et al., 2007). Teat length is one of the basic parameters of the linear evaluation by the World Holstein Friesian Federation (WHFF). The optimum size of teat is considered to be 40–60 mm (Hamoen, 2016). Monardes et al. (1990) highlighted the importance of selection to improve the structural properties of the udder, primarily due to increased susceptibility to mastitis in cows with poor udder morphology formation. These findings were confirmed by the conclusions of several works (Seykora, McDaniel, 1985; Bader et al., 2001), under which they confirmed a lower risk of mastitis in dairy cows with required and good udder formation.

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The selection of teatcup liners is a crucial part of a good milking management. Teat morphology is an important parameter in choosing the most suitable liner for a herd because of the direct interaction between teat and teatcup liner (Zwertvaegher et al., 2011). Dimensions of teat liners are adapted to the ideal teat length, which should be the most frequently occurring in the herd (Zwertvaegher et al., 2012). If the teatcup liner is too short or the teat length is excessively long, the incidence of new cases of mastitis is significantly increased. This is due to the deterioration of blood circulation in teats, formation of edema and cyanosis, and overall reduction in immunity of the tissue (Mein et al., 2004). Forces applied on the teats during milking result in physiological and pathological changes, which may counteract the normal teat defense mechanism. Consequently, the teats may become more sensitive for the entry of pathogens with intramammary infections as a result (Zwertvaegher et al., 2011). Therefore, the condition of the teat plays a considerable role in the incidence of mastitis infections (Gleeson et al., 2004; Bhutto et al., 2010).

Somatic cell counts (SCC) are an important parameter of udder health and generally the threshold of 200 000 cells·ml^{-1} is recommended as the limit to separate uninfected mammary quarters from the infected ones (Schepers et al., 1997; Djabri et al., 2002). Milk conductivity can also be used as a parameter of udder health, because it tends to increase in milk from infected udders (Bansal et al., 2005; Norberg, 2005). The shape of milk flow curves and high milk flow rate can be used to identify cows with increased risk of mastitis incidence. These milk flow traits are mostly affected by genetic traits, milking conditions, and teat morphology (Weiss et al., 2004; Tancin et al., 2006; Sandrucci et al., 2007). High milk flow rate is often associated with shorter teat canals (Naumann, Fahr, 2000); and studies of Rogers, Spencer (1991) and Tilki et al. (2005) also found negative correlation between milk flow rate and teat length. Teat shape and length can also play a role in milk production, and Tilki et al. (2005) recommend breeding cows with cylindrical and funnel teat shape to increase milk production.

Thus the good udder morphology is essential for securing good udder health and high quality of milk. The aim of this work was to evaluate the effect of a wide range of teat lengths on the udder health, milk yield, and milking time, while using a modern teat liner with a three-sided concave barrel designed for a wider teat range.

MATERIAL AND METHODS

The present experiment was conducted on the farm located in the Central Bohemian Region in the time period from July 2016 to June 2017. At the start of the experiment, there were 59 cows of Holstein breed in their first (*n* = 16), second (*n* = 21), and third and subsequent (*n* = 22) lactation. The first measurement for each cow took place within 17 days after calving. Subsequent measurements were carried out four weeks apart until the start of late lactation (149–165 days in milking (DIM)). Teat length measurements were done by the same person each time and were taken before evening milking. The final measurement was done before drying off the tested cows (285–315 DIM). Overall, seven measurements were performed for each dairy cow during the experimental period, with the exception of cows that were culled for various reasons from production herd during the course of the experiment.

Dairy cows were milked twice a day in the fishbone parlor with 24 places, where an automatic detachment system with the critical flow of milk set to 0.5 kg·min^{-1} was used. The milking system was set to 42 kPa of vacuum and 55 pulses per min with the pulsation ratio 60/40. Only manual stimulation by cleaning and forestripping of the first streams of milk was used before the cluster attachment to the udder. Used teatcup liners had three-sided concave barrel (Milkrite IP10) and were designed to work effectively with a wide range of teat lengths.

The length of teats was measured by a caliper. Teats were measured before milking from the teat end to the teat basis. SCC was measured by the 'in-line real time'milk analyzer Afilab (Afimilk, Israel). The results of the SCC are presented in the range given in four brackets: 1: (0–200 thousand cells·ml^{-1}), 2: (200–400 thousand cells·ml^{-1}), 3: (400–800 thousand cells·ml^{-1}), 4: (800 thousand^{+} cells·ml^{-1}). The data in brackets from the 'in-line real time' analyzers were taken from the day of the measurement, two days before and two days after. The values of these 5 records in brackets were averaged and used in statistical evaluation. Thus the values ranged from 1 to 4 and they represented relative SCC, from which the relative somatic cell value (RSCV) was calculated. The daily milk yield (MY), actual milking time (AMT, daily average) and milk conductivity (MC, daily average) data were also taken related to the day of the measurement and evaluated. The cases of mastitis incidence during the lactation of cows involved in the experiment were obtained from the veterinary records.

Cows were divided into 5 groups (0–4) based on the number of non-ideal teats within each udder (NIT), when the ideal teat length is considered to be 40–60 mm (Hamoen, 2016). To evaluate the effect of the average length of teats on udder (ALTU), cows were divided into three groups – udders with short teats (< 45 mm; approximately 20% of tested cows), udders with medium teats (45–55 mm; approximately 60% of tested cows) and udders with long teats (> 55 mm; approximately 20% of tested cows). For

Table 1. Basic statistics for selected parameters

Selected parameters	n	$\bar{x}$	SD	Min.	Max.
Length of rear left teats (mm)	360	43.84	7.49	22	68
Length of rear right teats (mm)	360	46.27	7.73	26	83
Length of front left teats (mm)	360	56.23	9.10	34	84
Length of front right teats (mm)	360	56.41	9.31	31	96
Length of rear teats (mm)	360	45.05	7.14	25	72
Length of front teats (mm)	360	56.32	8.50	35.5	84
Length of teats (mm)	360	50.68	6.97	30.5	77.75
Daily milk yield (kg)	360	33.05	7.42	7.7	57.4
Milk conductivity ($mS \cdot m^{-1}$)	360	8.82	0.63	7.4	11.6
AMT (min)	360	7.39	1.77	3.8	14.4
RSCV	360	1.39	0.68	1	4

AMT = actual milking time, RSCV = relative somatic cell value, n = number of observations, $\bar{x}$= arithmetic means, SD = standard deviation, min. = minimum value, max. = maximum value

Table 2. Correlations between selected parameters

	Length of front teats (mm)	Length of teats (mm)	NIT	MY (kg)	MC ($mS \cdot m^{-1}$)	AMT (minutes)	RSCV
Length of rear teats (mm)	0.587*	0.87*	–0.057	0.229*	0.271*	0.265*	0.161*
Length of front teats (mm)		0.91*	0.347*	0.178*	0.073	0.164*	–0.044
Length of teats (mm)			0.182*	0.225*	0.182*	0.234*	0.055
NIT				–0.024	0.018	0.035	–0.021
MY (kg)					0.086	0.394*	0.122*
MC ($mS \cdot m^{-1}$)						0.193*	0.33*
AMT (min)							0.193*

MY = daily milk yield, MC = milk conductivity, NIT = occurrence of non-ideal teats, AMT = actual milking time, RSCV = relative somatic cell value

*statistical significance at $P < 0.05$

correlations, individual averages of teat lengths within udder were used.

Program SAS 9.3 (SAS/STAT® 9.3, 2011) was used for statistical evaluation. Basic parameters were determined using the UNIVARIATE procedure. The relations between teat length, RSCV, MC, MY, and AMT were calculated using the correlation coefficients – CORR procedure. The comparison between rear and front teats was carried out by paired *t*-test. The effect of NIT on the occurrence of mastitis was evaluated by one-way ANOVA method using the GLM procedure. Subsequently, the selected parameters (RSCV, MC, AMT, MY) were detailedly evaluated using the procedure MIXED. The REG procedure (STEPWISE option) was used to select suitable factors for the model equation set up. The best model for the evaluation was selected in accordance with the values of the Akaike Information Criterion (AIC). For the model equation, the fixed effects of ALTU, lactation number (LN) and lactation stage (LS) were used. The difference was detailedly evaluated using the Tukey-Kramer test.

The model equation is as follows:

$$y_{ijklm} = \mu + a_i + b_j + c_k + D_l + e_{ijklm}$$

where:

y_{ijklm} = dependent variable (relative somatic cell value, milk conductivity, actual milking time, milk yield)

μ = general dependent variable

a_i = fixed effect of average length of teats on udder (ALTU) (i = 1, < 45 mm, n = 70; i = 2, 45–55 mm, n = 203; i = 3, > 55 mm, n = 81)

Table 3. Occurrence of non-ideal teats on udder during the course of the experiment

Lactation stage		Number of non-ideal teats					Average length of teats
		0	1	2	3	4	
1 (DIM 3–17)	*n*	19	22	13	4	1	50.11
	%	32.2	37.3	22	6.8	1.7	
2 (DIM 30–46)	*n*	15	14	22	1	3	53.7
	%	27.3	25.5	40	1.8	5.5	
3 (DIM 63–77)	*n*	10	19	21	5	0	51.15
	%	18.2	34.5	38.2	9.1	0	
4 (DIM 92–113)	*n*	22	16	9	4	2	50.8
	%	41.5	30.2	17	7.5	3.8	
5 (DIM 121–137)	*n*	21	14	10	4	0	49.59
	%	42.9	28.6	20.4	8.2	0	
6 (DIM 149–165)	*n*	23	17	8	3	0	49.3
	%	45.1	33.3	15.7	5.9	0	
7 (DIM 286–314)	*n*	9	12	12	4	1	49.65
	%	23.7	31.6	31.6	10.5	2.6	
Total	*n*	119	114	95	25	7	50.68
	%	33.06	31.67	26.39	6.94	1.94	

DIM = days in milking

b_j = fixed effect of lactation number (LN) (j = 1, n = 101; j = 2, n = 128; j = 3 and more, n = 131)
c_k = fixed effect of lactation stage (LS) (k = 1, 3–17 DIM, n = 59; k = 2, 30–46 DIM, n = 55; k = 3, 63–77 DIM, n = 55; k = 4, 92–113 DIM, n = 53; k = 5, 121–137 DIM, n = 49; k = 6, 149–165 DIM, n = 51; k = 7, 286–314 DIM, n = 38)
D_l = random repeated effect of animals (n = 38–59)
e_{ijklm} = random residual error

The significance level $P < 0.05$ was used to evaluate the differences between groups.

RESULTS

Basic statistics

Basic statistics for teat length, parameters of udder health, MY and AMT are stated in Table 1. The average length of teats in our test group was 50.68 ± 6.97 mm and the length of individual teats ranged from 22 mm to 96 mm. Rear pairs of teats were found to be a lot shorter than the front pairs ($P < 0.05$). The ratio of rear to front pairs of teats was 0.8 in our test group.

Correlations between selected parameters are shown in Table 2. The average length of teats at udder level did not show significant correlation with RSCV, but significant correlations were calculated to AMT ($r = 0.234$; $P < 0.05$), MC ($r = 0.182$; $P < 0.05$) and MY ($r = 0.225$; $P < 0.05$). Significant correlations were also calculated between MC and RSCV ($r = 0.33$; $P < 0.05$); and between AMT and MY ($r = 0.394$; $P < 0.05$).

Non-ideal teats (NIT)

As shown in Table 3, only 33% of cows had ideal teat length for whole udder during the experiment. This effect showed neither statistical significance in the GLM procedure, nor correlations with the monitored parameters. No cases of mastitis were detected in the

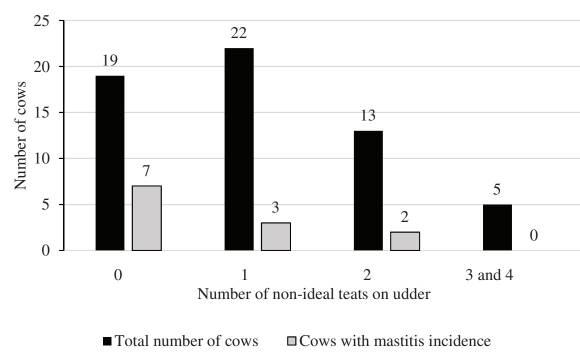

Fig. 1. Mastitis incidence within tested herd during the observed lactation based on the number of non-ideal teats at the beginning of lactation

Table 4. Effect of the average length of teats on udder (ALTU), lactation number (LN) and lactation stage (LS) on selected parameters using MIXED procedure

Effect	Group	*n*	Relative somatic cell value	Milk conductivity (mS·m^{-1})	Milk yield (kg)	Actual milking time (min)
			LSM ± SE	LSM ± SE	LSM ± SE	LSM ± SE
ALTU	udders with short teats < 45 mm	70	1.47 ± 0.100^{A}	8.89 ± 0.089	31.31 ± 0.896	6.78 ± 0.254^{A}
	udders with medium teats 45–55 mm	203	1.42 ± 0.074^{B}	8.76 ± 0.065	32.11 ± 0.652	7.36 ± 0.201^{B}
	udders with long teats > 55 mm	81	1.34 ± 0.095^{B}	8.81 ± 0.084	33.35 ± 0.848	7.55 ± 0.242^{B}
LN	1	101	1.35 ± 0.133	8.55 ± 0.115^{A}	27.12 ± 1.155^{A}	7.03 ± 0.365
	2	128	1.32 ± 0.117	8.86 ± 0.100	34.22 ± 1.014^{B}	7.05 ± 0.320
	3 and more	131	1.56 ± 0.113	9.05 ± 0.098^{B}	35.43 ± 0.988^{B}	7.60 ± 0.312
LS	4 (DIM 3–17)	59	1.80 ± 0.088^{A}	9.02 ± 0.079^{A}	32.24 ± 0.792^{A}	7.12 ± 0.228^{A}
	2 (DIM 30–46)	55	1.50 ± 0.091^{B,C}	8.83 ± 0.081	37.73 ± 0.820^{B,C}	8.15 ± 0.234^{B,C}
	3 (DIM 63–77)	55	1.31 ± 0.089^{B}	8.84 ± 0.079^{C}	34.58 ± 0.798^{D,E}	7.84 ± 0.229^{B,E}
	4 (DIM 92–113)	53	1.15 ± 0.092^{B,D,E}	8.72 ± 0.082^{B,E}	32.56 ± 0.823^{D,G}	7.35 ± 0.235^{D,G}
	5 (DIM 121–137)	49	1.27 ± 0.094^{B}	8.65 ± 0.084^{B,G}	31.55 ± 0.845^{D,F,I}	7.14 ± 0.239^{D,F,I}
	6 (DIM 149–165)	51	1.31 ± 0.093^{B}	8.59 ± 0.083^{B,D,I}	30.40 ± 0.839^{D,F,K}	6.95 ± 0.238^{D,F,K}
	7 (DIM 286–314)	38	1.54 ± 0.101^{F}	9.09 ± 0.090^{F,H,J}	26.77 ± 0.911^{B,D,F,H,J,L}	6.06 ± 0.253^{B,D,F,H,J,L}

DIM = days in milking, *n* = number of observation, LSM = Least Squared means, SE = standard error

Different letters in columns mean statistical significance $^{A–B, C–D, E–F, G–H, I–J, K–L}$($P < 0.05$)

group of dairy cows with three or more non-ideal teats. On the other hand, mastitis incidence was the highest in the group of cows with ideal length of teats within udder (Fig. 1), although these results are not statistically significant.

The MIXED procedure

The effects of ALTU, LN and LS on the monitored parameters were evaluated using the MIXED procedure. The model equation shows 15.4–40.2% variability and was statistically significant for the tested parameters ($P < 0.05$). ALTU was statistically significant for AMT and RSCV ($P < 0.05$), while LN was only significant for MY and MC, but showed tendency for AMT and RSCV. Effect of LS was statistically significant for all tested parameters (Table 4).

The lowest value of MC was observed for the group of udders with medium teats, while udders with short teats showed the highest values, but with no statistical significance. Results for RSCV also show the highest values for udders with short teats ($P < 0.05$). With the increase in ALTU we observed prolonging of AMT ($P < 0.05$; Table 4).

The lowest RSCV was observed for cows on second lactation (Table 4), while cows on third and further lactation had the highest RSCV. MC significantly increased with LN (from 8.59 to 9.08 ms·m^{-1}; $P < 0.05$). AMT values were similar for first and second lactation, with notable increase for the cows on their third and further lactation. There is a significant increase in MY with LN (Table 4).

The effect of LS was statistically significant for all monitored parameters ($P < 0.05$; Table 4). The highest value of RSCV was observed in the beginning of lactation, with a continual decrease until the 4th stage. From this point the RSCV started to continually increase until the end of lactation ($P < 0.05$; Table 4). The RSCV at the end of lactation would be even higher, but a lot of problematic dairy cows with high SCC were culled from herd in the period of the 6th to 7th lactation stage. MC also shows a similar trend with the highest values at the beginning and the end of lactation. The monitoring of MY during lactation shows numerous statistical significances ($P < 0.05$; Table 4). The highest MY was observed at the second stage (37.86 kg; Table 4), and it continually decreased from this point till the end of lactation. MY was strongly linked with AMT.

DISCUSSION

The cows included in our experiment showed a high degree of teat length imbalance within the tested herd and also between front and rear teats. Similar imbalances within the herd were also observed by Stadnik et al. (2010), reporting the average length of teats in the test group 53.7 mm, but the length of the individual teats was 32–94 mm. Rear teats were significantly shorter than front pairs in our test group (rear : front ratio = 0.8). Although shorter rear pairs are a usual standard, according to WHFF the ratio between the front and rear teats should be above 0.90 (Hamoen, 2016). Zwertvaegher et al. (2012) also pointed out the high differences in teat lengths between dairy cows and also between teats of the individual quarters within udder.

Overall, two thirds of tested cows had at least one teat, which could be not considered as optimal – it was either too long or too short. Undesirable lengths of teats are still highly represented in production herds (Zwertvaegher et al., 2012). Even one teat can bring udder health problems and discomfort during milking for the animal. For example, teats that are too short for a given liner do not reach the collapsing point of the liner, whereas teats that are too long penetrate the liner below the collapsing point. In both cases, the liner cannot massage the teat end, which results in the poor teat end condition (Mein et al., 2004; Rasmussen et al., 2004). These imbalances (within herd and rear : front ratio) could be problematic, while trying to select correct teat liner for the herd. If the liner does not fit the teat properly, its main function to cyclically massage the teat, to avoid congestion and edema, will be strongly impaired (Mein et al., 2004). In our study, we used teat liners designed to work effectively with a wide range of teat lengths. Also thanks to their three-sided concave barrel design, the force applied on the teat during milking can be distributed to a larger area of the teat apex. This design greatly reduces the occurrence of hyperkeratosis compared to standard round liner barrel design (Haeussermann et al., 2016), therefore lowering the risk of mastitis incidence (Neijenhuis et al., 2001). Gleeson et al. (2004) highlighted the design of the teatcup liner, because liners had a larger effect on teat tissue changes than other machine settings.

Many authors reported udder health problems if the teats are too short or too long (Seykora, McDaniel, 1985; Strapak et al., 2015; Pisestyani et al., 2016). Asymmetry of udder quarters significantly contributed to the incidence of mastitis (Klaas et al., 2004). But in our study, mastitis incidences were the lowest for cows with 3 and 4 non-ideal teats and surprisingly the highest for the cows with optimal teat length. Those results are in contrary with many other studies (Seykora, McDaniel, 1985; Bader et al., 2001) which showed a negative impact of poor udder morphology on udder health. Besides teat morphology, used milking settings also have a huge impact on udder health, especially vacuum level and critical milk flow for automatic detachment of cluster from udder (Gleeson et al., 2003; Parilova et al., 2011; Edwards et al., 2013). We think that the combination of udder friendly milking settings and correctly picked (designed) teat liner prevents NIT morphology to be reflected into the udder health problems. However, mastitis incidence was observed on a relatively small number of animals and only for a period of one lactation.

Average udder teat length had statistically significant correlations to MY, MC and AMT, while rear teats even showed significant correlations to RSCV. Those relations have been reflected for the effect of ALTU in MIXED procedure only for AMT and RSCV ($P < 0.05$). SCC are considered as a gold standard for mastitis detection, but MC is widely used as an indicator of udder health, too (Viguier et al., 2009). Thus in our experiment, a significant correlation was between RSCV and MC, and the worst results for both parameters were obtained from the group of udders with short teats. The findings of Strapak et al. (2015) also suggest lower SCC and better udder health for cows with longer teats. Rear teats are generally shorter than the front ones (Weiss et al., 2004) and are also more sensitive to mastitis (Tancin et al., 2007). On the other hand, Coban et al. (2009) found positive, yet small and statistically insignificant relationship between SCC and teat length. Lower SCC and better udder health for short teats were also observed in other studies (Klaas et al., 2004; Singh et al., 2014). Ptak et al. (2011) found small genetic correlations between teat length and SCC. However, the increased SCC in cows with longer teats might be attributable to a higher risk of injury to longer teats from milking, handling and housing (Berry et al., 2004). Different conclusions coming from research articles related to the possible relationship between the length of teats and SCC could be probably explained by the depth of the insertion of teat into liner. Thus a longer teat could be at low risk of mastitis occurrence if the insertion of the teat in liner is within the ability of the liner to sufficiently collapse under teat end for effective massage.

AMT prolongs significantly with longer teats, while the difference in MY between ALTU groups is not as big. This suggests that the udders with shorter teats have a higher milk flow during milking, which is in accordance with findings of Rogers, Spencer (1991). But Weiss et al. (2004) did not observe any correlations between milkability traits and externally measurable teat characteristics like teat length and teat diameter, even the teat canal length was the same between front and rear teats. Quarters with higher peak milk flow and/or with short teat canal have higher susceptibility to infections (Grindal et al., 1991; Lacy-Hulbert, Hillerton, 1995). Long teat canals can be positively reflected in udder health (Klein et al., 2005), but also can be connected to milk flow disorders and slower milking (Geishauser et al., 2000; Strapak et al., 2015). In our study, increases in AMT were significantly correlated with those in MC and RSCV. Weiss et al. (2004) and Celik et al. (2008) did not find connection between teat length and teat canal length. Therefore, based on our knowledge of teat canal influence on milk flow and udder health, we can only speculate that in our study short teats had shorter and wider teat canals (thus faster milk flow), which negatively impacted udder health.

The effect of LN and LS had significant effects with numerous statistical significances on the tested parameters in the MIXED procedure. The effect of LS on milk yield development during lactation was in agreement with a typical lactation curve. Our results are in accordance with the study of Tancin et al. (2006), in which milk yield and milking time reached maximum in the second month of lactation and then continuously decreased as lactation proceeded.

In the beginning and at the end of lactation, the mammary gland is at higher risk of acquiring bacterial infections (Green et al., 2007). Our results also confirm the high risk of mastitis occurrence as the MC and RSCV were higher at the beginning and at the end of lactation as compared to stages in between. Most cases of clinical mastitis occur in the first month of lactation (Barkema et al., 1998; Svensson et al., 2006). Therefore, those stages of lactation are considered to be 'high risk' periods for the incidence of intramammary infections. Our increased attention and care to prevent intramammary infections should be focused on older cows and on cows in risky stages of lactation.

Cows on second lactation achieved the best results, either for RSCV or for fast milking of high milk yields, while the lowest MC was measured for cows in first lactation. A visible increase in RSCV was observed for cows on third and further lactation. In general, cows in higher parities have higher SCC (Laevens et al., 1997; De Haas et al., 2002; Tancin et al., 2007).

CONCLUSION

Our results show there is no negative effect of NIT on udder health, milk yield, and milking time. In our opinion, the combination of correct teat liner choice, udder friendly milking setting, continual improvement of milking equipment and their better adaptation to cow's physiology overshadows the effect of non-ideal teat morphology on udder health. On the other hand, the effect of ALTU showed significantly faster milking time and highest SCC for udders with short teats, while the best results for MC were observed for teats of medium length. Our results suggest that breeding should be focused on cows with medium to long teats to improve udder health. Our results will need to be confirmed on a larger test group, with added external and internal teat morphology parameters and milk flow characteristics, to better understand the impact of teat morphology on udder health and milkability.

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