



Electrical conductivity of milk as related to daily milk yield of udder quarters in automatically milked cows

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ABSTRACT

The aim of the study was to determine the frequency of udders with specific levels of milk electrical conductivity and milk yield in primiparous and multiparous cows. Relationships between the health and milk yield of individual udder quarters in the primiparous and multiparous cows were also analysed. The left and right front quarters constituted, respectively, 67.39 and 67.90% of the quarters from which milk with electrical conductivity ≤ 5.50 mS/cm was drawn. In the conductivity class >7.00 mS/cm, the right and left rear quarters showed the highest proportions (9.59 and 7.13%, respectively). Individual udder quarters from the cows most often produced either less than 7.00 kg or more than 10.00 kg milk per day. These differences concerned the front and rear udders. In the first two classes of milk electrical conductivity, the frequency of individual udder quarters in the primiparous and multiparous cows was similar. For milk with the lowest electrical conductivity, the values ranged from 50.38% (front left) to 52.62% (rear left) in primiparous cows, and from 47.38% (rear left) to 49.62% (front left) in multiparous cows. As the health of the mammary gland deteriorated, daily milk production of all its quarters was observed to decrease. A more marked reaction to this condition was observed in the front quarters, the yield of which decreased by 3.40 kg (left) and 3.02 kg (right). The rear left quarters decreased their yield by 2.85 kg/day, and the rear right ones by 2.18 kg/day. Higher production levels in all mammary quarters and in every milk electrical conductivity class were noted in the multiparous cows. The increasing milk electrical conductivity was paralleled by a lower daily milk yield of the udder quarters in both primiparous and multiparous cows. For the front left and right quarters, this decrease was 2.77 and 2.41 kg in the youngest cows, and 4.27 and 4.26 kg in the older cows. The decrease in milk production from the rear left quarters was 2.67 kg/day in primiparous and 3.76 kg/day in multiparous cows; the respective values for the rear right quarters were 2.01 and 3.86 kg milk/day.

Key words: Cow, Electrical conductivity of milk, Milk, Quarter milking, Udder quarter, Yield

The world's milk production has undergone significant changes over the last few decades. Because cow milking is labour-intensive and tedious, robotic milking has been the most rapidly developing technology. The use of modern cow milking techniques on a larger scale makes it now possible to gather more and more data about the animals and the drawn milk on a continuous basis. It is possible to closely monitor the parameters of interest to milk producers, in particular the milk yield of cows and the cytological quality of their milk. The resulting benefits include rapid diagnosis of the early stages of mastitis as well as current information on the chemical composition of milk and daily milk yield of individual udder quarters (Forsbäck *et al.* 2010, Jédruce 2013). This information facilitates making appropriate selection decisions when improving udder structure, including the reduction of mastitis (Nakov and Trajcev 2012, Nakov *et al.* 2014), and also when culling cows with divergent production levels of individual udder quarters (Atasever and Erdem 2009).

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One of the solutions to detect udder inflammation is to test the electrical conductivity of milk. The measurement of conductivity can detect mastitis several milkings before visible symptoms appear (Norberg 2005, Berglund *et al.* 2007). The presence of mastitis increases the electrical conductivity of milk because of increase in sodium and chlorine levels, and decrease in potassium and lactose content, which are paralleled by an increase in pH. Also, somatic cell count and serum albumin content change the passage of an electric current through the milk (Bruckmaier *et al.* 2004). Milk from a healthy udder has an electrical conductivity of 4.00–5.50 mS/cm (Yoshida *et al.* 2005).

From the viewpoint of machine and automatic milking, udders with evenly developed quarters are the most optimal (Berglund 2007). Forsbäck *et al.* (2011) and Haghkhah *et al.* (2011) assert that normal development of the cow's udder quarters is very important in terms of improving milk production efficiency in cows. According to Kuczaj (2010), productivity of the front and rear quarters in cows highly suitable for machine milking should form between 42 and 58% of the overall milk yield.

In view of the continuously increasing milk production

potential of the cows and increasingly advanced milk collection technologies, it is important to continually monitor the physiological adaptation of the cows to new milking conditions by monitoring its parameters, including quarter milking (Sandrucci *et al.* 2007).

The aim of the study was to determine the frequency of udders with specific levels of milk electrical conductivity and milk yield in primiparous and multiparous cows. Analysis was also made of the relationships between the health and milk yield of individual udder quarters in the primiparous and multiparous cows.

MATERIALS AND METHODS

The analyses were performed using a database obtained from the management system for DeLaval voluntary milking system VMS, and concerned the milking results (daily yield of udder quarters, electrical conductivity of quarter milk) of 240 Polish Holstein-Friesian cows of Black-and-White variety with a lactation yield of around 10,000 kg milk. The data were gathered from around 360,000 milkings performed over 18 months (2015–2016).

Cows were kept in a free-stall barn and fed PMR and concentrate diets formulated to meet current requirements. The concentrate, which consisted of maize, soybean meal, rapeseed meal, triticale and a premix, was fed in the milking robots. Cows were milked by 4 automatic milking units.

Using division of the udder into four quarters – left front (LF), right front (RF), left rear (LR) and right rear (RR), calculations were made for the frequency (chi-square test- χ^2) in the primiparous and multiparous cows of the electrical conductivity classes of quarter milk (≤ 5.50 mS/cm – healthy cows; 5.51–7.00 mS/cm – milk with elevated SCC – udder quarter with subclinical mastitis; >7.00 mS/cm – milk with high SCC – udder quarter with clinical mastitis) and the daily milk yield classes of the udder quarters (≤ 7.00 , 7.01–10.00, >10.00 kg milk).

To determine the effect of milk electrical conductivity on daily milk yield of the udder quarters, the following linear model (GLM procedure) was used (SAS 2014):

$$y_{ij} = \mu + a_i + b_j + e_{ij} \text{ (Table 3)}$$

where, y_{ij} , ij-th milking; μ , overall mean; a_i , fixed effect of the i-th class of milk electrical conductivity (≤ 5.50 , 5.51–7.00, >7.00 mS/cm); b_j , fixed effect of the j-th daily milking udder quarter (LF, RF, LR, RR); e_{ij} , random error of observation.

$$y_{ijk} = \mu + a_i + b_j + c_k + e_{ijk} \text{ (Table 4)}$$

where, y_{ijk} , ijk-th milking; μ , overall mean; a_i , fixed effect of the i-th class of milk electrical conductivity (≤ 5.50 , 5.51–7.00, >7.00 mS/cm); b_j , fixed effect of the j-th age of the cows (primiparous, multiparous); c_k , fixed effect of the k-th daily milking udder quarter (LF, RF, LR, RR); e_{ijk} , random error of observation.

Significant differences between the means were analysed with the Scheffe test.

Daily milk yield of the udder quarters was visualized when milk electrical conductivity increased by the unit used in the analyses (0.25 mS/cm). LFP, left front primiparous;

LFM, left front multiparous; RFP, right front primiparous; RFM, right front multiparous; LRP, left rear primiparous; LRM, left rear multiparous; RRP, right rear primiparous; RRM, right rear multiparous; and EC, milk electrical conductivity.

RESULTS AND DISCUSSION

Hamann and Gyodi (2000) reported that milk obtained from healthy cows has an electric conductivity of less than 5.50 mS/cm. In their study, this level was represented by milk from around 51% of the milkings. In the milk of healthy cows, somatic cell count of less than 200,000/ml is often considered as a threshold value between a healthy and a diseased quarter (Schepers *et al.* 1997). In our study (Table 1), based on the adopted classification of milk electrical conductivity, over 67% of the front quarters (right and left) and around 63% of the rear quarters (right and left) were classified as healthy. Smaller differences in the frequency of individual udder quarters occurred in the second class of milk electrical conductivity (5.51–7.00 mS/cm). Their proportion ranged from 28.18% (RR quarters) to 29.10% (LR quarters). In the next class of milk electrical conductivity (>7.00 mS/cm), which is indicative of clinical mastitis, the proportions of the quarters showed greater differences. RR and LR quarters (9.59% and 7.13%, respectively) were more frequent than the front (RF and LF) quarters (3.43 and 3.76%, respectively).

A direct relationship of milk electrical conductivity with the cows' mammary gland health and thus with their productivity was reported by Antanaitis *et al.* (2015). In cows with subclinical mastitis, milk conductivity increased to 6.50 mS/cm and was found to gradually increase with increasing udder disease.

When analysing the proportion of individual udder quarters with specific daily milk yields, considerable differences were found between the front and rear quarters (Table 1). The proportion of front quarters decreased as daily milk yield increased from ≤ 7 kg to >10 kg (from 51.24% to 16.41% for left quarters, and from 53.43% to 15.16% for right quarters). The proportion of rear quarters was more uniform in particular classes of daily milk yield and ranged from around 30% (7.01–10.00 kg) to 36.30–38.84% (>10.00 kg).

Table 1. Frequency of udder quarters in successive classes of milk electrical conductivity and daily milk yield

Factor	Frequency of udder quarters (%)				
	LF	RF	LR	RR	
N	358825	356382	358221	350918	
Electrical conductivity (mS/cm) $\chi^2=197^{**}$	≤ 5.50	67.39	67.90	63.77	62.23
	5.51–7.00	28.85	28.67	29.10	28.18
	>7.00	3.76	3.43	7.13	9.59
Daily milk yield of udder quarters (kg) $\chi^2=452^{**}$	≤ 7.00	51.24	53.43	31.90	33.23
	7.01–10.00	32.35	31.41	29.26	30.47
	>10.00	16.41	15.16	38.84	36.30

** $P \leq 0.01$.

Table 2. Frequency of udder quarters in successive classes of milk electrical conductivity in primiparous and multiparous cows

Electrical conductivity (mS/cm) $\chi^2=196^{**}$	Group of cow	Frequency of udder quarters (%)							
		N	LF	N	RF	N	LR	N	RR
≤5.50	Primiparous	241776	50.38	241591	52.33	228437	52.62	218587	52.55
	Multiparous		49.62		47.67		47.38		47.45
5.51–7.00	Primiparous	103521	32.45	102210	32.83	104543	31.01	98924	33.99
	Multiparous		67.55		67.17		68.99		66.01
>7.00	Primiparous	13528	31.81	12581	33.12	25541	45.04	33407	44.83
	Multiparous		69.19		66.88		54.96		55.17

**P≤0.01.

In the first two classes of milk electrical conductivity, the frequency of different udder quarters in the primiparous and multiparous cows was similar (Table 2). For the lowest class of electrical conductivity, in primiparous cows it ranged from 50.38% (left front quarters) to 52.62% (left rear quarters), and in multiparous cows from 47.38% (left rear quarters) to 49.62% (left front quarters). It is worth noting that all the udder quarters in this class of milk electrical conductivity were represented at a similar level in younger and older cows. The ratio of udder quarters (primiparous to multiparous cows) was as follows: left front 50.38:49.62%, right front 52.33:47.67%, left rear 52.62:47.38%, right rear 52.55:47.45%. In the second group of milk electrical conductivity, the proportion of udder quarters ranged from 31.01% (left rear) to 33.99% (right rear) in primiparous cows, and from 66.01% (right rear) to 68.99% (left rear) in multiparous cows. In this case, however, there were clear differences in the percentage of individual udder quarters between primiparous and multiparous cows. The greatest differences were observed for the left rear quarters (31.01:68.99%) followed by the left front quarters (32.45:67.55%). In the groups of cows with the highest milk electrical conductivity, the proportion of individual udder quarters ranged from 31.81% (left front) to 45.04% (left rear) in primiparous cows, and from 54.96% (left rear) to 69.19% (left front) in multiparous cows. In this group of cows, the differences in the percentage of rear udder quarters between the primiparous and multiparous cows were less marked with the ratios of 45.04:54.96% (left) and 44.83:55.17% (right), respectively.

With deteriorating udder health, daily milk production of the four quarters was observed to gradually decrease (Table 3) (P≤0.01). A more noticeable reaction to this condition was noted for the front quarters, whose yield

decreased by 3.40 kg (left quarters) and 3.02 kg (right quarters). The production level of the rear quarters was slightly more stable despite their deteriorating health (increase in milk electrical conductivity from ≤5.50 to >7.00 mS/cm). In the left rear quarters, the yield decreased by 2.85 kg/day, and in the right rear quarters by 2.18 kg/day.

According to some authors, mastitis-related lower milk production in the automatic milking systems can be partly related to the teat cleaning procedures, because this process takes place without the visual control of the milker (Hovinen and Pyorali 2011).

The production losses due to udder quarter inflammation were analysed by Mungube *et al.* (2005), who considered holdings of different sizes that used different production systems. They estimated the milk yield to decrease by 1.2%, 6.3% and 33% in quarters with CMT (California Mastitis Test) scores of 1+, 2+ and 3+, respectively. In the final analysis, a quarter with subclinical mastitis caused a milk production loss of 17.2%.

Analysis of the results in Table 3 revealed certain analogies concerning the daily milk yield of udder quarters in consecutive classes of milk electrical conductivity. In the first class, left quarters produced more milk than right quarters, whereas in the other two classes, right quarters produced more milk than left quarters. The rear quarters were superior over the front quarters, with the most marked difference in the third class of milk electrical conductivity (left and right): 6.80, 7.27 and 4.08, 4.18 kg/day, respectively.

The literature contains studies reporting that the front quarters are characterized by lower yield and the ratio of their productivity in relation to the rear quarters ranges from around 40 to 60% (Weiss *et al.* 2004, Kuczaj 2010).

Higher production levels in all four quarters, in each

Table 3. Daily milk yield of udder quarters from cows in different classes of milk electrical conductivity

Electrical conductivity (mS/cm)	Daily milk yield of udder quarters (kg)							
	LF		RF		LR		RR	
	LSM	SE	LSM	SE	LSM	SE	LSM	SE
≤5.50	7.48 ^A	3.14	7.20 ^A	3.12	9.65 ^A	4.15	9.45 ^A	4.21
5.51–7.00	6.55 ^B	3.08	6.65 ^B	2.96	8.08 ^B	3.78	8.92 ^B	3.66
>7.00	4.08 ^C	3.18	4.18 ^C	3.21	6.80 ^C	4.74	7.27 ^C	4.17

A, B, C Means in columns with the different letters differ significantly at P≤0.01.

Table 4. Daily milk yield of udder quarters from primiparous and multiparous cows in different classes of milk electrical conductivity

Electrical conductivity (mS/cm)	Group of cow	Daily milk yield of udder quarters (kg)								Total	
		LF		RF		LR		RR		LSM	SE
		LSM	SE	LSM	SE	LSM	SE	LSM	SE		
≤5.50	Primiparous	7.08 ^A	2.48	7.02 ^A	2.55	8.71 ^A	3.29	7.90 ^A	3.22	7.56	3.09
	Multiparous	7.87 ^B	3.64	7.58 ^B	3.55	10.49 ^B	4.63	10.86 ^B	4.50	9.06	4.35
5.51–7.00	Primiparous	6.33 ^A	2.52	6.32 ^A	2.53	7.62 ^A	3.15	7.23 ^A	3.06	6.87	3.02
	Multiparous	7.01 ^B	3.97	7.02 ^B	3.64	9.08 ^B	4.75	9.26 ^B	4.31	8.06	3.99
>7.00	Primiparous	4.31 ^A	2.88	4.61 ^A	2.69	6.04 ^A	3.68	5.89 ^A	3.09	5.05	3.53
	Multiparous	3.60 ^B	3.68	3.32 ^B	3.93	6.73 ^B	5.63	7.00 ^B	4.66	5.91	3.22
Total	Primiparous	6.65 ^A	2.62	6.64 ^A	2.65	8.10 ^A	3.36	7.59 ^A	3.16	–	–
	Multiparous	7.52 ^B	3.82	7.21 ^B	3.66	10.02 ^B	4.79	10.45 ^B	4.50	–	–

^{A, B}Means in columns (with electrical conductivity classes) with the different letters differ significantly at $P \leq 0.01$.

class of milk electrical conductivity, were noted in multiparous cows (Table 4). As the electrical conductivity of milk increased, there was a significant ($P \leq 0.01$) decrease in daily milk yield of the udder quarters in both primiparous and multiparous cows. For the left front and right front quarters, this decrease was 2.77 and 2.41 kg in youngest cows, and 4.27 and 4.26 kg in older cows. The results show that regardless of the cow group, a higher decrease in milk yield along with deteriorating udder health (milk electrical conductivity increasing from ≤ 5.50 to > 7.00 mS/cm) concerned the front quarters. Differences in the daily milk yield of the rear quarters in the consecutive classes of milk electrical conductivity were less pronounced. The decrease in milk production from the rear left quarters was 2.67 kg/day in primiparous and 3.76 kg/day in multiparous cows; the respective values for the rear right quarters were 2.01 and 3.86 kg milk/day.

The results of our analyses concerning the daily milk yield of individual quarters are distinctly more beneficial than those obtained by Slyzius *et al.* (2013) for a population of Black-and-White cows, which produced 3.42 and 3.47 kg milk (left rear and right rear quarters) and 2.63 and 2.71 kg milk per milking (left front and right front quarters), respectively. However, it is to be noted that the herd was milked twice daily.

An age-related increase in milk electrical conductivity was observed in cows by Janzekovic *et al.* (2009), who reported milk conductivity to be 5.2–6.8 mS/cm after the first and second calving, and 5.6–7.2 mS/cm after the third and fourth lactation.

The curves describing the reduction of milk yield from the front and rear udder quarters of primiparous and multiparous cows show that the deteriorating health of the mammary glands (increased electrical conductivity of milk) had a greater effect on their productivity in the case of the front quarters (Figs 1–4).

The curves for the daily milk yield of the front quarters in primiparous cows is comparable to the curves for the daily milk yield of the rear quarters in primiparous and multiparous cows. However, a slightly different situation

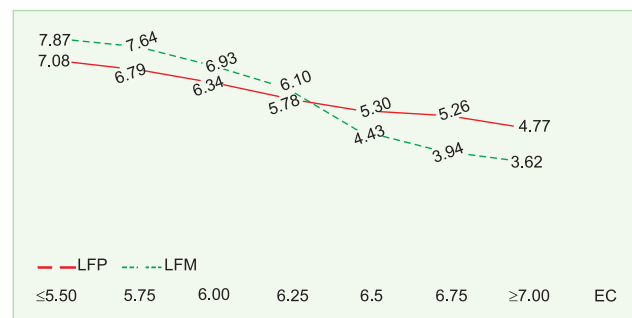


Fig. 1. Increase in milk electrical conductivity (EC mS/cm) as related to daily milk yield (kg) of left front quarters in primiparous and multiparous cows. LFP, Left front primiparous; LFM, Left front multiparous.

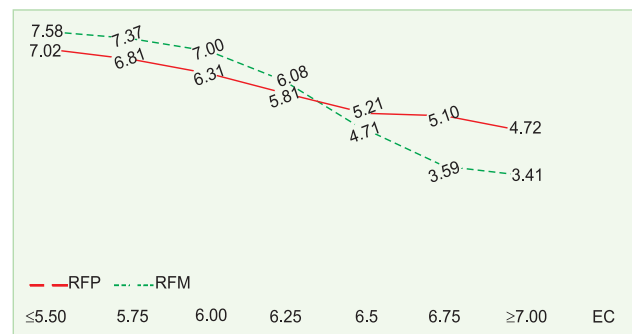


Fig. 2. Increase in milk electrical conductivity (EC mS/cm) as related to daily milk yield (kg) of right front quarters in primiparous and multiparous cows. RFP, Right front primiparous; RFM, Right front multiparous.

occurred in the front quarters of multiparous cows, for which a greater decrease in daily milk yield was observed for both the right and left quarters when milk electrical conductivity increased to 6.25–6.50–6.75 mS/cm. This shows that the front quarters, which are less productive than the rear quarters, may be more sensitive to mastitis-induced changes in older cows. This is partly because the front udder quarters are generally less vulnerable to and less frequently affected by inflammations compared to the rear quarters. Therefore, being anatomically and physiologically independent, the

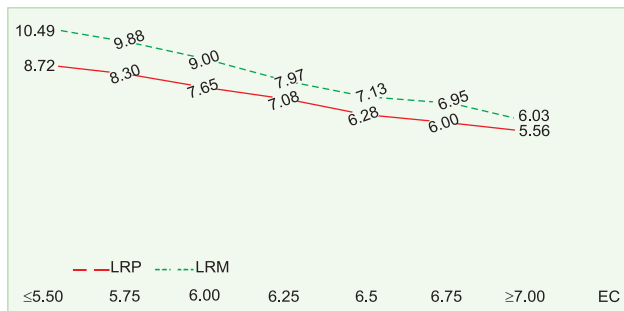


Fig. 3. Increase in milk electrical conductivity (EC mS/cm) as related to daily milk yield (kg) of left rear quarters in primiparous and multiparous cows. LRP, Left rear primiparous; LRM, left rear multiparous.

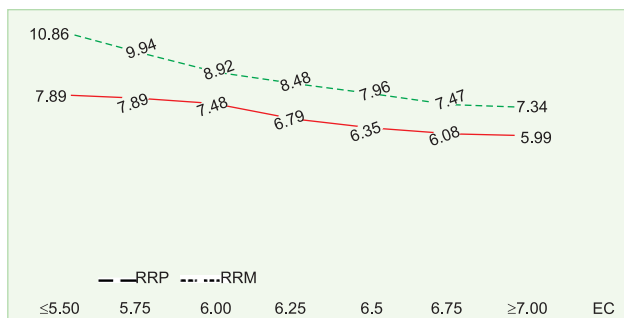


Fig. 4. Increase in milk electrical conductivity (EC mS/cm) as related to daily milk yield (kg) of right rear quarters in primiparous and multiparous cows. RRP, Right rear primiparous; RRM, right rear multiparous

front quarters (right and left), compared to the rear quarters, may be slightly less effective in defending themselves against environmental pathogens.

The results presented above show that the increase in milk electrical conductivity (which reflects deteriorating udder health) in primiparous and multiparous cows adversely affects the production potential of udder quarters in the cows. Thus, it is one of the more important factors generating milk production losses resulting from reduced milk yield of the cows. As a consequence, from the viewpoint of breeders and milk producers, it should be essential to continuously monitor the health of each udder quarter as a separate mammary gland.

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