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Detection of high levels of somatic cells in milk on farms equipped with an automatic milking system by decision trees technique

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Abstract: The purpose of the study was to use decision trees to predict increased levels of somatic cells in cow's milk. The material for the study comprised data collected in 2012–2014 from five farms in Poland equipped with an automatic milking system. Data on 803 Polish Holstein–Friesian cows were collected. In order to predict somatic cell count data mining techniques were used to build a graphical model of a decision tree. This study found that the most important factors to anticipate an elevated somatic cell count in cow's milk are milk conductivity, lactation stage, and lactation (primiparous and multiparous cow groups), as well as milking speed and rumination time. An increase in these parameters was also associated with a higher percentage of samples with an elevated somatic cell count. It has been shown that in order to keep somatic cell count low in automatic milking system herds a farmer should pay particular attention to the milking speed.

Key words: Milk, cattle, automatic milking system, decision trees, somatic cells

1. Introduction

Several milking systems are currently used worldwide, the automatic milking system (AMS) being one of them. This system gives the cow a relatively large freedom of choosing milking time and frequency over the day (1). Many researchers found that an increased frequency of milking influences milk yield as well as the condition of udders and teats. Mastitis is usually diagnosed based on elevated somatic cells (SCs) in milk. It is still one of the most frequent and at the same time most cost-inducing diseases in milk production. Hence prompt detection of udder inflammations in cows is still very important. This is necessary in order to maintain proper quality of milk and overall good health in cows (1,2). An increased somatic cell count (SCC) in milk collected from cows reared in farms, with complete monitoring of all indicators related to milk yield, can be relatively quickly detected. The analysis of change in levels of selected milking parameters, prior to the occurrence of udder inflammation symptoms, provides a means to anticipate the onset of inflammation. In Poland, in barns equipped with an AMS, the farmer has access to regular data from the robot and, if the farm is covered by official milk productivity control, results of monthly sample milking. Both groups of data contain information that can help the farmer to closely monitor the herd for an increased SCC. The AMS provides milking information such as conductivity, color, and temperature of milk per quarter, parameters that are very frequently referred to in the literature as good indicators to monitor udder health (1,3,4). In addition, warnings about problems related to udder health of particular cows are generated. Based on sample milking, the farmer receives precise information on the level of SCs in milk, being the primary indicator of mastitis (5). Unfortunately, in a vast majority of Polish farms, farmers abandon recording the level of SCs at each robot visit. Early detection of elevated SCs in milk is a key to efficient herd management. Many researches point to the need for constant herd monitoring and indicate that milk parameters begin to change several days prior to the diagnosis of mastitis (5,6).

Worldwide studies on the anticipation of an increased SCC carried out until recently were based not only on analyses of the indicators recorded by a milking robot, but also on observation carried out in the herd (7), analysis of hygienic quality (8,9), and microbiological quality of milk on each milking or during monthly milk sampling. Such a huge quantity of factors recorded during milking requires state-of-the-art computation techniques and mathematical

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and statistical tools that make it possible to not only predict udder inflammation (9). To precisely detect udder inflammation, using various parameters recorded by the AMS, tools offered by mathematics and statistics have been increasingly applied in research studies. These include decision trees (4,7,10), artificial neural networks (2,11), and fuzzy logic models (8,9). The first technique is of particular interest as it presents results in the form of a diagram that explains, in a relatively simple way, the very complex conditioning of the analyzed traits. The number of factors and how they are analyzed and interpreted suggest that in-depth research should be conducted in this regard to provide farmers with more consistent messages (12–17).

The purpose of the present study was to use decision trees to anticipate increased levels of SCs in cow's milk.

2. Materials and methods

2.1. Material studied and area descriptions

The material for the study comprised data collected between 2012 and 2014 from five farms located in Poland equipped with an AMS. In all herds Polish Holstein–Friesian (HF) cattle, the robots were installed in 2011, the animals were kept in similar conditions, in new barns, fed with partly mixed rations (PMRs). Data on 803 cows were collected. On the initial stage of analyses 609,975 AMS milkings were included in the analysis. After final verification, 7247 milkings were used for final analysis. Such a huge reduction of the dataset was due to the fact that the study used only the results of AMS milkings from the days when, for each cow, official monthly productivity tests were performed. All features that are normally recorded during a sample milking were taken into account, as well as selected features obtained from milking robots that were related to milk yield. Lely Astronaut L4 robots provided detailed information on animal milk yield.

2.2. Methods

Changes in the level of SCs were analyzed depending on lactation, productivity class per milking, season, conductivity, and rumination time. The database obtained in this way was divided based on the SCs in test milking. Two groups were set up: one consisted of samples with a low SCC (<80,000 SCs/mL - this group being preferable from the point of view of milking cow breeding), and the other consisted of samples with an increased SCC (>80,000 SCs/mL).

Each node or leaf included the following information: node ID (1), the percentage of samples with lower SCC (<80,000 SCs/mL) (2), percentage of samples with higher SCC (>80,000 SCs/mL) (3), the number of observations in the node or leaf (4).

2.2.1. Statistical analysis

Data mining techniques were used to build a graphical model of the decision tree used for SCC predictions. In establishing the decision tree, two partition criteria were taken into account: one used the Gini index, and the other the entropy function. The ranking of variables depending on their significance (weight), which was decisive for the partition of the dataset, was established based on the "importance" measure (10,18,19).

The matching qualities of models were compared using the average square error, misclassification rate, cumulative lift, Kolmogorov–Smirnov statistics, and area under the ROC curve (ROC index) (18). Diminishing values of the first two statistics signify improve the quality of the model. For the remaining model quality criteria, this relationship is inverse, i.e. a better model is associated with higher values of these statistics.

The following criteria were taken into account to compare the quality of information presented in tree models (two models of decision trees): average square error, cumulative lift, Kolmogorov–Smirnov statistics, misclassification rate, and the area under the receiver operating characteristic curve (ROC) (18,19). Decreasing values of the average square error, misclassification rate, and increasing values of Kolmogorov–Smirnov statistics and areas under ROC indicate better quality of the applied model. Statistical analysis was conducted using Enterprise Miner 7.1 software available as part of the SAS package (18).

3. Results

Table 1 provides the metrics indicating the quality of models used to identify the factors responsible for the increased level of SCs in cow's milk. From among the models considered here, the most favorable values of all metrics were found for a model built by the decision tree methods based on the Gini index.

In the analysis group, for 7247 analyzed samples, about 18% of milkings contained less than 80,000 SCs per mL (Table 2). More than 70% of per-day milkings, yielding less than 20 kg, were found to have a higher SCC. At the same time, sample milking yielding more than 30 kg of milk had a lower SCC (over 52%).

It was also found that until the 100th day in lactation, more than 54% of milking samples were characterized by a lower SCC, with this percentage systematically decreasing to 32% in milk samples collected after the 305th day in lactation (Table 2). In the summer and autumn seasons, there were more than 53% milkings with a higher SCC, whereas in the spring and winter season it was approximately 51%. Lactation also influenced changes in the quality of milk: about 52% of samples from the first lactation were characterized by a lower SCC, with this

Table 1. Model comparisons.

Statistics label	Logistic regression	Gini	Entropy
Level of somatic cell count			
Kolmogorov–Smirnov statistics	0.314	0.288	0.208
Akaike information criterion	5476.058	-	-
Average squared error	0.215	0.220	0.227
ROC index	0.711	0.691	0.649
Cumulative lift	1.643	1.568	1.558
Misclassification rate	0.347	0.359	0.409

Table 2. The level of somatic cell count in relation to tested factors.

Factors	Level	Somatic cell count per milking – count (%)		Count
		≤80,000	>80,000	
Milk yield per day (kg)	<20	278 (28.90)	684 (71.10)	962
	20–25	399 (41.61)	560 (58.39)	959
	>25–30	640 (49.08)	664 (50.92)	1304
	>30	2118 (52.66)	1904 (47.34)	4022
Lactation stage (days)	<100	1323 (54.04)	1125 (45.96)	2448
	100–199	1130 (51.15)	1079 (48.85)	2209
	200–305	740 (40.88)	1070 (59.12)	1810
	>305	242 (31.03)	538 (68.97)	780
Season	Spring	890 (49.01)	926 (50.99)	1816
	Summer	633 (45.87)	747 (54.13)	1380
	Autumn	1142 (46.20)	1330 (53.80)	2472
	Winter	770 (48.77)	809 (51.23)	1579
Lactation	1	2115 (52.07)	1947 (47.93)	4062
	2	725 (44.98)	887 (55.02)	1612
	>2	595 (37.83)	978 (62.17)	1573
Number of milkings per day	1	71 (33.97)	138 (66.03)	209
	2	814 (37.90)	1334 (62.10)	2148
	3	1573 (50.18)	1562 (49.82)	3135
	4	848 (55.32)	685 (44.68)	1533
	5	126 (59.15)	87 (40.85)	213
	6	3 (33.33)	6 (66.67)	9
Year of calving	2012	925 (43.61)	1196 (56.39)	2121
	2013	1755 (49.21)	1811 (50.79)	3566
	2014	755 (48.40)	805 (51.60)	1560
Herd	A	290 (46.40)	335 (53.60)	625
	B	807 (57.60)	594 (42.40)	1401
	C	1442 (41.12)	2065 (58.88)	3507
	D	432 (57.68)	317 (42.32)	749
	E	464 (48.08)	501 (51.92)	965
Total		1133	6114	7247

percentage decreasing in subsequent lactations (to less than 38% in the 3rd and subsequent lactations). It should be stressed that a majority of animals included in the tests were primiparous cows. The number of milkings per day shows that their lower frequency resulted in a poorer hygienic quality of milk. More than 62% of test milkings with a higher SCC were derived from cows milked only 1 or 2 times per day (Table 2). The analyzed herds were also characterized by differences in the number of milkings with a lower and higher SCC. Herd C, from which the most samples were analyzed (3500), had the lowest proportion of sample milkings with a low SCC (41.12%), whereas Herds B and D had more than 57% of such sample milkings.

Milk samples with a higher SCC were accompanied by higher conductivity, speed of milking, and temperature of milk, as well as higher content of fat, proteins, and dry matter (Table 3). At the same time, better hygienic quality was observed in milk from cows characterized by a higher yield, longer total duration of milking per day, higher content of lactose and urea in samples, and a longer rumination time (Table 3). The impact of all these factors on SCC in cow's milk proved to be highly significant (results not published).

Table 4 contains the values of the "importance" metrics measuring the importance of particular variables in the decision tree model. The ranking of the importance of variables demonstrates that conductivity, average milking speed, lactation stage, herd, lactation, and rumination time were the most important factors responsible for SCC in cow's milk. Other model factors included in the decision tree were the number of milkings per day and milk yield per day. The season and the year of calving were not included in the construction of the decision tree.

The graphical model of the decision tree, presented in Figures 1 and 2, contained 21 leaves and was 6 levels deep. Most divisions in the tree occurred based on milking speed (MilkSpeed, 5 partitions), rumination time (RuminationMinutes, 4 partitions), and barn membership (FarmName, 3 partitions). The stage of lactation (CodeDIM) and conductivity were taken into account twice by the tree algorithm. Lactation (CodeLact), number of milkings (nMilking) per day, milking yield (CodeMilk), and average daily milk temperature (TemperDay) were applied to the model once. The training dataset contained 4346 observations and the validation set only 2901.

In order to interpret the results obtained by applying the decision tree technique one needs to learn how the graph should be deciphered. An example of how to do that is presented below and describes the split of the Nodes 1 and 2. Node 1 contained data on 4346 test milkings, which comprised the training dataset. In the dataset the

Table 3. Analysis of selected milking parameters in relation to SCC.

Analysis		SCC level		Mean
		≤80,000	>80,000	
Milk conductivity (μS/cm)	N	3435	3812	7247
	Mean	66.73	67.57	67.17
Milk yield per day (kg)	Mean	33.26	30.07	31.58
Average milk yield per milking (kg)	Mean	11.30	10.97	11.13
Daily average milk yield (kg)	Mean	33.26	29.81	31.45
Fat content (%)	Mean	3.74	3.95	3.85
Protein content (%)	Mean	3.31	3.42	3.37
Dry matter content (%)	Mean	12.59	12.84	12.72
Lactose content (%)	Mean	4.96	4.86	4.90
Urea content in milk	Mean	288.71	282.61	285.51
Total milking time (s)	Mean	885.86	730.10	803.93
Average milking time (s)	Mean	299.40	267.77	282.76
Milking speed (kg min^{-1})	Mean	2.49	2.75	2.62
Average milk temperature (°C)	Mean	38.67	38.77	38.72
Average rumination time (s)	Mean	468.13	457.29	462.42

Table 4. Importance variables (SCC).

Variable	Number of dividing rules	Importance
Conductivity	2	1.0000
Milking speed	5	0.9814
Lactation stage	2	0.9769
Herd	3	0.7965
Lactation	1	0.6356
Rumination time	4	0.5098
Number of milkings	1	0.3537
Milking yield	1	0.2438
The average daily milk temperature	1	0.2057
Season	0	0.0000
Year of calving	0	0.0000

share of milk samples with low SCC was 47.7% (Figure 1). The first partition of the dataset, conducted based on the conductivity factor, established two subsets (Nodes 2 and 3) significantly differing by the number of samples with a higher and lower SCC. Node 2 was established by samples with average milk conductivity lower than 73.5 µS/cm. In this group, 50.09% of the samples featured higher hygienic quality of milk. Node 3 contained samples for which only 23.7% corresponded to the samples with lower SCC. While Node 3 became a leaf, which could not be divided any further, Node 2 branched (according to the stage of lactation, CodeDIM) into Nodes 4 and 5. Figure 1 presents subsequent splits of Node 4, while branching of Node 5 is depicted in Figure 2. Further splits were based on different factors creating new nodes that should be interpreted in the same way as the example described above. Branching of the tree resulted in the creation of final leaves among which two groups were characterized by the highest and the lowest milk quality. Based on the model of the decision tree it can be noted that the milk samples of the best quality (89.33% of all samples had less than 80,000 SCs per mL) were assigned to Node 52, which was created by the following splits: conductivity (< 73.5 µS/cm), CodeDIM (<200), MilkSpeed (<4.19), FarmName (B,D), MilkSpeed (<2.1), RuminationMinutes (<419) (Figure 1). The leaf that was found to represent the samples with the poorest milk quality was Node 41 (only 3.7% of samples with lower SSC) (Figure 2).

4. Discussion

Lower SCC is generally known to be conducive to better hygienic quality of milk and cow health (12). In this study, all milkings under analysis were divided by SCC into two groups with less and more than 80,000 SCs per mL. Milk with somatic cell content less than 80,000 SCs per mL was found to be of very high quality, and, based on such division, patterns associated with an increased or decreased SCC were sought. The basic parameter measured by the AMS during all milkings is milk yield per milking. This is undoubtedly the single most important parameter for milk production profitability that the daily farmer has influence on. Other authors (2,12) suggest that milk yield is an important factor associated with an increased SCC in cow milk. According to Mollenhorst et al. (15), Green et al. (17), and Schepers et al. (16), higher milk production is inversely related to the SCC, which may be explained by the dilution effect. It may be that a similar effect was observed in this study, because milk samples with an average yield of more than 30 kg per day constituted more than 52% of milkings in the group with a decreased SCC. Researchers have emphasized that the estimated SCC in milk from higher-yielding cows is lower than for milk from lower-yield cows (17). Antanaitis et al. (12) found that the following statistical alerts can be useful for the detection of early udder infection status: decreased productivity, longer milking duration, and increased electrical conductivity (EC) of milk. Such observation was also confirmed in our study. Furthermore, Hammer et al. (14), Mollenhorst et al. (15), Schepers et al. (16), and Green et al. (17) found that a low milk yield and higher parity lactations increase the risk of mastitis in cows. This is clearly visible in the present study, where samples were divided by milk yield and lactation stage. The share of milkings with an increased SCC is significantly larger in the samples collected during late lactation stages and those with a lower milk yield, whereas in the research

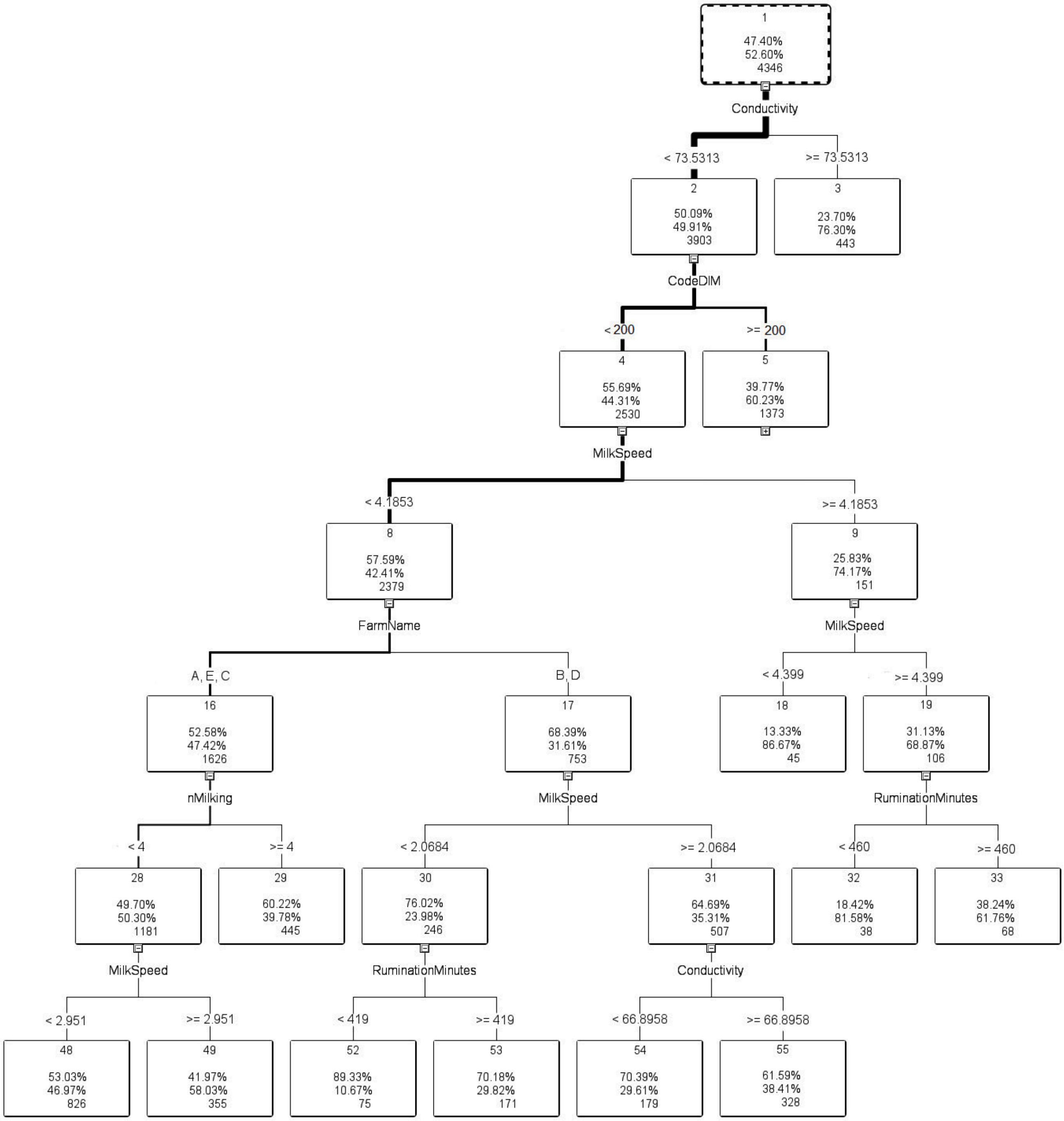

Figure 1. The graphical model of the decision tree – part 1.

by Nogalski et al. (20) SCC decreased with the lactation period.

In previous contributions by the authors of the present study (21), an increased number of milkings and milking duration per day were found to be associated with a higher milk yield in cows. Österman et al. (22) consider that cows milked three times a day have a higher hygienic quality of milk than those milked twice a day. In this study, the highest hygienic quality was found in the samples from cows milked 3 or 4 times a day. Only a small number of animals had a higher frequency of milking per day (Table 1). Friggens and Rasmussen (23) found that, in AMS barns, milk yield per milking was strongly related to the milking interval. At the same time, cows with a higher

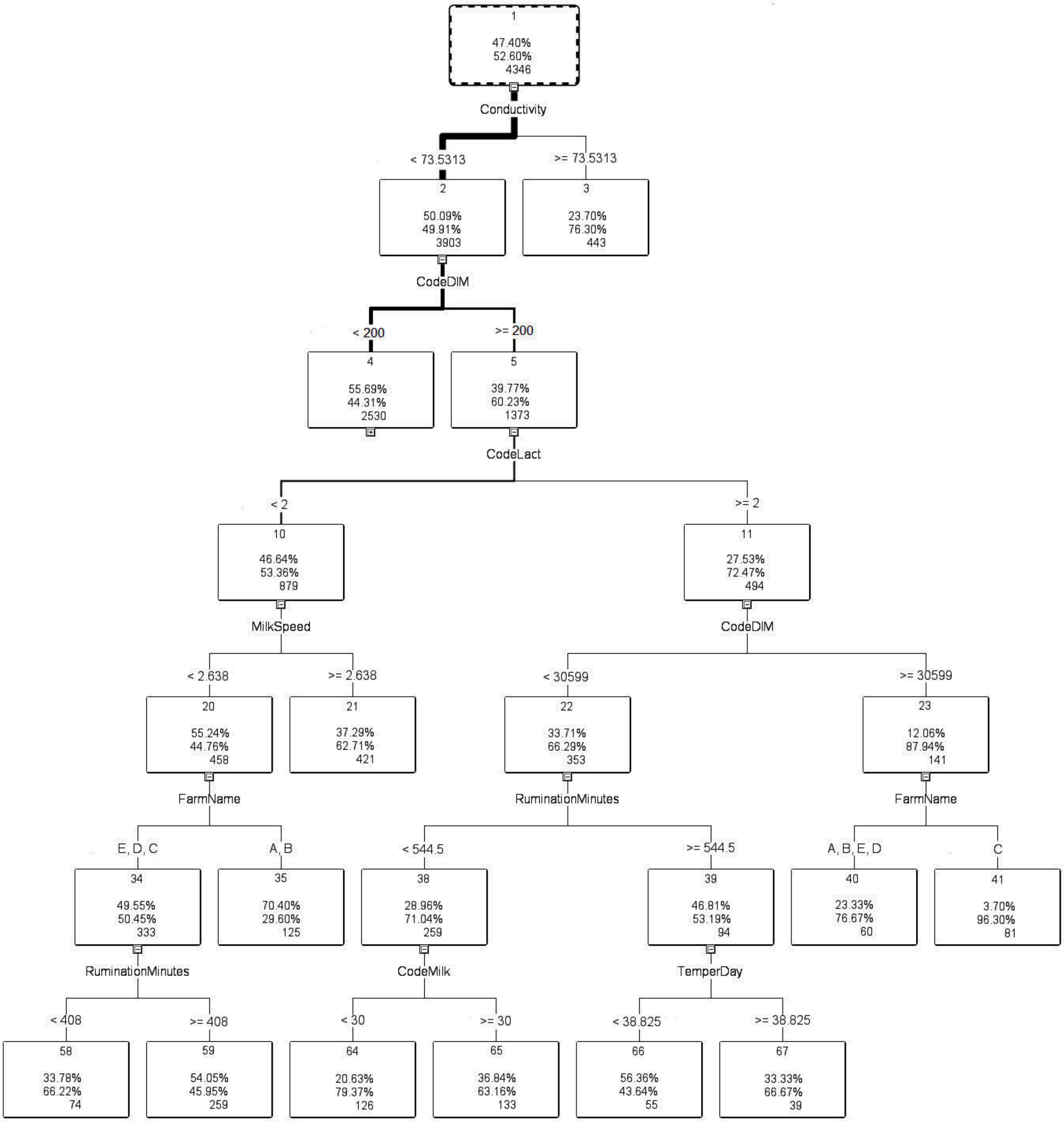

Figure 2. The graphical model of the decision tree – part 2.

number of milkings per day were found to yield about 20% more milk in Red Dane and Holsteins as compared to cows with the lowest number of milkings per day (24). In the study by Mollenhorst et al. (15), there was a weak, albeit significant, effect of milking interval. According to the authors, this suggests that this effect on the SCC value is weak if other variables are controlled and kept at a safe level. In the present study, the number of milkings per day was not included in the decision tree despite clear differences between the comparison groups.

As underscored by Jacobs and Siegford (1), sometimes the herd in which animals live has a higher impact on milk parameters, including on the SCC level, of that milking system. Moreover, in the present study, despite the fact that all animals were milked with an AMS, the herd factor became an important criterion allowing one to establish a graphical decision tree model.

The lactation group proved to be a highly important factor based on which the tree partitions were implemented. In Österman et al. (22), as well as in the present study, the multiparous group had higher values for LSCC (SCC logarithm) than primiparous cows. As noted by Jacobs and Siegford (1), the difference in productivity between primiparous and multiparous cows results primarily from the animals' adaptation abilities, and in barns equipped with AMS the effect of social relationships and interactions between animals should be always taken into account.

Milking durations were significantly different, in statistical terms, between the group of healthy cows and the group with clinical mastitis ($P < 0.001$). This factor was not included in the model in our study. Mollenhorst et al. (15) observed an increase in SCC along with the days in milk (DIM) (especially for DIM > 100). In the present study, cows at an early lactation stage were more frequently characterized by a lower SCC. The effect of DIM on SCC may be explained by a (nonlinear) relation between DIM and milk yield (16).

EC has long been considered a good indicator of udder infection status (3). In our study, the level of this factor varied significantly in milkings with a lower and higher SCC, and was chosen as the first factor in partitioning the decision tree. Nevertheless, as found in different studies, changes in this level are affected by multiple factors, such as feed and water intake, breed, lactation stage, milking frequency, and milk content. EC changes can indicate not only clinical but also subclinical udder infection (3,25). Norberg (25) suggests, however, that EC can be a good indicator for breeding programs geared towards reducing mastitis in cow populations. If EC exceeds 6.0 mS/cm, this indicates onset of the udder inflammatory process (8). Mrode and Swanson (13) note that cows with udder inflammation yielded less milk with a higher EC value that was increasing already in the early phase of the condition; therefore, these parameters need to be included in the prediction models. However, Sun et al. (2), in their study of EC changes in milk, indicated that not all infected quarters were accompanied by a higher EC and lower milk yield per quarter, which should draw attention to the reliability of simulations and may point to the need to apply additional criteria, which the present study attempted to do. In examining each udder quarter separately, Sun et al. (2) emphasized that EC changes depending on the inflammation status. According to Kamphuis et al. (7), when decision trees are applied to the development of models to detect udder inflammation based on milk color and EC, reliable results can be obtained, but the sensitivity of such models in detecting mastitis remains low (less than 70%). In addition to EC, de Mol and Ouweltjes (4) used milk yield to anticipate udder inflammation. Furthermore, Sun (11) proposed in his study two types of artificial neural networks, both targeted at mastitis detection in herds milked by milking robots. For this, he used processed EC data and milk yield per milking.

Milking speed (MS) is a parameter closely related to SCC. With increased speed, the risk of teat damage and higher susceptibility to infections increases as well (26). In the present study, a significantly higher speed was found in milkings from cows with an increased SCC in their milk samples. The level of that factor proved to be particularly important in the group of cows with a lower SCC; it was used four times to build the decision tree. It was clearly demonstrated that the lower MS is, the lower SCC in cow milk is.

Currently, various factors and characteristics are proposed as potential tools to detect SCC, especially in herds where the milking system is fully automated (6). As noted by Hovinen and Pyörälä (3), Pyörälä (5), and Hogeveen et al. (6), careful observation of animals and knowledge on how to use the measurements performed by the robot provide opportunities for the improvement of the hygienic quality of milk. Kamphuis et al. (27) add that a debate and international discussion on how to evaluate and verify the effectiveness of different methods of detecting an elevated SCC in milk are necessary. Presentation of different methods and models to anticipate udder inflammations will allow farmers to decide which herd monitoring method will be best suited to their circumstances and which solution or device to choose. According to Steeneveld et al. (28), however, more economic benefits from the introduction of sensors to record milking parameters can be associated with the reduction in labor than a marked improvement in milk yield or cow health.

In conclusion, studies to indicate which parameters should be taken into account in particular when anticipating a higher SCC are particularly valuable, because they allow one to improve, with precision, the health status of animals and milk quality and to reduce production costs. Our study found that the most important factors to anticipate an elevated SCC in cow's milk are milk conductivity, lactation stage, and lactation (differences between the primiparous and multiparous cow groups), as well as milking speed and rumination time. An increase in these parameters was also associated with a higher percentage of samples with an elevated SCC. Based on the analyses conducted in this study, in order to keep SCC low in AMS herds, farmers should pay particular attention to MS. This parameter is very strongly associated with changes in SCC in milk.

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