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PAPER

Signal spectral analysis to characterize gland milk electrical conductivity in dairy goats

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Abstract

Intramammary infection affects quality and quantity of milk. Having as final target the improving of animal health' monitoring, this research studied the gland milk electrical conductivity (EC) signal in order to identify a possible parameter more representative of the EC variations that can be observed, during a milking, when not healthy (NH) glands are considered. Two foremilk gland samples, from 40 Saanen goats, were acquired for three weeks and lactation stages (LS: 0-60 Days In Milking; 61-120 DIM; =>120 DIM), for a total amount of 1440 samples. Bacteriological analyses and somatic cells counts (SCC) were used to define glands health status. In case of negative bacteriological analyses and SCC <1,000,000 cells/mL, glands were classified as healthy; alternatively, when bacteriological analyses were positive or SCC higher than 1,000,000 cells/mL, for two or more consecutive days, glands were classified as NH. A spectral analysis, to calculate the frequency spectrum and the bandwidth length of the milk EC signal, was performed. To validate data acquired, A MIXED procedure was used considering the HS, LS and the LS x HS as explanatory variables of the statistical model. Results showed that spectral analysis allows characterizing the milk EC variations thorough the bandwidth length parameter. This parameter has a significant relationship with the gland health status and it provides more accurate information than other traits, like the statistical variance of the signal. Therefore, it could be useful to improve the performances of multivariate models/algorithms that detect dairy goat health status.

Introduction

In lactating dairy goats, the inflammation of the mammary gland is one of the most common infectious diseases. It is responsible for important economic losses and it can reduce yield and quality of the milk. Somatic cells are a normal milk constituent that can be considered as indicator for the immune defence of glandular tissue. Interrelationships between variations in goat milk somatic cell count (SCC) and the presence of different causative agents, as well as other influencing factors, were already discussed (Stuhr and Aulrich, 2010). Diagnostic tools, complementary or alternative to SCC, in the evaluation of milk with a high quality standard are needed (Rossi *et al*., 2009). In particular, rapid detection of intramammary infection (IMI) could help to achieve high bacteriological cure rates due to early treatment, with positive economic effects of shorter treatments, less milk loss, and better milk quality.

Udder inflammation can modify the concentration of anions and cations of the milk (Zaninelli and Tangorra, 2007) and consequently the value of its electrical conductivity (EC). According to this hypothesis, measurements of milk EC have been studied and used in dairy cattle as a tool for detecting subclinical and early clinical mastitis before clinical signs appear. On the contrary, in dairy goats research, published studies on the EC of milk from glands as a parameter to detect health status are recent (Diaz *et al*., 2011, 2012; Petzer *et al*., 2008; Romero *et al*., 2012; Tangorra *et al*., 2006; Ying *et al*., 2004). They are mainly focused on the general base knowledge of dairy goat health status (HS) and they report low detection performances, if compared with those reached in dairy cows (Diaz *et al*., 2011; Romero *et al*., 2012). The use of more informative parameters achieved by an increased base knowledge of dairy goat HS, an improvement of sensory technology, and the implementation of more explanatory traits is suggested as a possible way to reach better results in detecting HS also in dairy goats (Zaninelli *et al*., 2014, 2015).

A cow suffering from mastitis may show, during a milking, a variation in milk EC from an infected quarter larger than variations in milk EC from healthy quarters. Nielen *et al*. (1995), investigating the ability of three different models to detect mastitis based on the EC of milk from udder quarters, reported an higher variation of the EC signal in milk from infected quarters. Norberg *et al*. (2004), investigating the association with udder health status of various EC traits, showed that the variance of all valid EC measures (σ^2_{EC}) increases between healthy quarters and infected quarters, with a greater difference in case of clinical infected quarters. Tangorra *et al*. (2010), about a group of Saanen Goats, reported that σ^2_{EC} was grater in infected glands. However, in all these studies, the variations of milk EC were evaluated with general statistical parameters, such as the σ^2_{EC}. Specific indexes, able to characterize the milk EC signal pattern, were not identified. With this goal, the spectral analysis of the milk EC signal could be a valid approach that, up to day, has never been investigated.

For these reasons, the aim of this study was to apply a spectral analysis to the gland milk EC signal in order to identify a new parameter able to better characterize its pattern under a qualitative and quantitative point of view, evaluating also the relationship of this parameter with the gland HS of dairy goats.

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Materials and methods

Animals and farm management

The experiment was carried out at the Experimental Farm of the University of Milan, Italy. In total, 40 Saanen goats, at their second lactation, were randomly selected from a herd of 400 dairy goats. The animals were fed twice

a day with a commercial feed and housed in a pre-fabricated building. Goats were milked at the milking parlour of the farm that was a low-line with self-locking gates, designed with 2 platforms consisting of 16 milking units and 16 places per platform. Set-up parameters of the milking parlour were: a rate of 90 pulsations per minute, a vacuum level of 40 kPa and had a pulsation ratio of 60%. Each animal of the experimental group was milked twice a day: at 7:00 a.m. and again at 5:00 p.m.

Collection and analyses of milk samples

In order to classify the health status of goats, bacteriological evaluations and somatic cell counts were performed on gland milk samples collected during morning milkings. The milk sample procedure involved teat disinfection with chlorhexidine-moistened towels after the discarding of the first milk streams. For each lactation stage (LS) evaluated (LS: 0-60 Days In Milking; 61-120 DIM; => 120 DIM), three consecutive weekly samples were collected from each gland. A total amount of 1440 milk samples were collected: 720 samples were used for bacteriological analysis according to the International Dairy Federation standard method (FIL-IDF, 1981), while the other milk samples (n = 720) were analysed for somatic cell counts (SCC) using a Bentley SomacountTM 500 analyser (an instrument that uses the principle of the laser based flow cytometry; Bentley Instruments Inc., MN, USA) and following the FIL-IDF recommendations (FIL-IDF, 1995). In particular, the milk samples were taken automatically and mixed with a fluorescent dye solution that allows the DNA staining of the somatic cells. Aliquots of the stained suspensions were injected into a laminar stream of carrier fluid and exposed to a laser beam. The obtained fluorescent pulses, converted into electrical pulses, were counted and translated into a somatic cell count by pulse height analyses software according to the AOAC approved methodology. Samples analysed were classified into three experimental cases according to the results of microbiological tests and SCC. Case 1 (C1) included gland milk samples with an absence of pathogenic microorganisms and SCC <1,000,000 cells/mL. Case 2 (C2) included gland milk samples with bacteriological analyses positive for IMI. Case 3 (C3) included milk samples with an absence of pathogenic microorganisms and SCC >1,000,000 cells/mL on two or more consecutive sampling days for non-physiological causes (Diaz *et al*., 2011).

Finally, samples classified in C1 were considered as milk samples collected from healthy glands. Samples classified in C2 were considered as milk samples collected from not healthy (NH) mammary glands. Samples classified in C3 were also considered as milk samples collected from NH mammary glands because in some recent studies on dairy goats (Diaz *et al*., 2011, 2012; Romero *et al*., 2012), it is reported that the persistent overcoming of 1,000,000 somatic cells/mL, not due to physiological causes, is significant for NH glands even if bacteriological analysis are negative for IMI.

Data acquisition system and electrical conductivity measurements

A customized software application, developed using LabVIEW 8.02 (National Instrument, TX, USA), was used to acquire the gland EC signals. They were measured, within milkings, by four experimental milking clusters and stored in .txt files using the goat ID farm number, date and time to name each file. The sampling rate, used to acquire the EC signals, was 1 Hz. A calibration procedure of the whole acquisition system was carried out at the start of the experiment and ebefore each acquisition of EC datausing a solution of water and chlorine-based detergent for the milking machine. A further description of the data acquisition system is provided in Zaninelli *et al*. (2014).

Spectrum analysis

Each time-domain signal can be represented in the frequency domain by its spectrum. It can be obtained by the application of specific mathematical operators to the signal, such as the Fourier Transform (FT). The spectrum allows to describe a signal from a different point of view and in some cases, it allows to highlight some characteristics of the signal pattern in a simple way.

In order to describe the relationship between the time and frequency domains, two different kinds of signals can be taken as examples: a constant function C, and a trigonometric function, such as A sin (t) or A cos (t), of period P. The first one, will have a spectrum made by a singular impulse of amplitude C at the frequency of zero. The second one, will have a spectrum made by a singular impulse of amplitude A at the frequency $f=1/p$. These simple relationships are the basis to understand the general relationship between a signal and its spectrum. A specific pattern in the frequency domain means that the corresponding signal in the time domain can be considered as a sum of trigonometric functions of different amplitudes and frequencies according to its spectrum.

When a signal is discrete in the time domain and made by a sequence of a defined number of samples (N), a different kind of transformation has to be used, called the Discrete Fourier Transform (DFT). This mathematical operator always gives a representation of the signal in the frequency domain. The difference with the FT is that the resulting spectrum is discrete and periodical of period $=1/N$. Furthermore, it can be easily calculated by optimizing algorithms suitable for computer elaboration. In this latter case, the name of the transformation used to calculate the spectrum of the signal changes in Fast Fourier Transform (FFT).

Often a signal has a spectrum that shows some characteristic peaks. These peaks (in some cases called harmonics) characterize in a unique way the signal in the frequency domain, and having bigger amplitudes than the other components of the spectrum, they also give a good description of the main characteristics of the signal pattern in the time domain. However, these peaks are only a part of the spectrum and they do not express all of its informative content. Another way to reach this goal is to evaluate the bandwidth of the signal. This parameter includes in a unique value, all the most important information conveyed by the spectrum and it gives also a representation of the most significant characteristics of the signal in the time domain.

In order to calculate the bandwidth of a signal, its energy can be considered. The total energy owned by the signal can be evaluated as the area below the curve of its spectrum in the frequency domain. As the following step, taking a reasonable threshold (*i.e*. the 95% of the total energy value), the first frequency of the spectrum that overcomes this level can be taken as the end of the signal bandwidth. This parameter, also called bandwidth length, expresses all the most important information of the signal for both the frequency and the time domains.

Spectral analysis performed

The EC signals stored in the .txt files were evaluated by a dedicated Matlab routine (The Mathworks, MA, USA) in order to calculate their spectrums. The main steps performed by the routine on each EC signal evaluated were the following: first, some samples of the signal, related to the start and the end of milking, were deleted from the sequence. Second, the mean value of the resulting signal was calculated, and subtracted to each sample of the sequence. This step was performed in order to have in the spectrum a null peak at the frequency of zero, and consequently, a graph in the frequency domain more readable because not affected by scaling effects. Finally, on the

resulting sequence, the FFT was calculated.

Once the spectrum of the EC signal was obtained, other steps were performed by the Matlab routine. The total energy of the signal was evaluated thorough the following formula:

$$E_{Tot} = \frac{Fs}{K-1}\sum_{i=1}^{K}|X_i|^2$$

in which, Fs was the signal sampling rate, K was the number of frequencies of the discrete spectrum and X_i was the amplitude of the *i*-th frequency of the spectrum. Furthermore, taking a threshold equal to 95% of the total signal energy, the first frequency that overcame that level was identified, and considered as the last frequency of the signal bandwidth. The threshold of 95% of the total signal energy was chosen because considered as a reasonable value able to highlight the most important information conveyed by each spectrum, after to have evaluated the average signal/noise ratio provided by the experimental spectrums obtained. An example of all these steps is provided in Figure 1. In the upper graph are reported the measured EC signals of milk, acquired during a milking from each gland. In the following graphs: on the left side are showed the elaborations performed by the Matlab routine on the EC signal of milk from the left gland; in the right side are reported the elaborations performed on the EC signal from the right gland. In the both sides of the figure, the first graph shows the sequence of signal samples without the start and the end of milking. The middle graph shows the sequence of single samples to which the mean value was subtracted. The last graph shows the spectrum obtained using the FFT transform to the previous sequence of signal samples. Finally, in this latter graph, the value of the first frequency that overcame the threshold selected is reported, in term of frequency and amplitude. This value defines the bandwidth of the signal, also coloured to be easily highlighted.

Statistical analysis

In order to validate data acquired during the experiment, relationships between SCC, EC and glands HS were studied. Values of SCC (×1000 cells/mL) and EC (mS/cm) were log transformed in order to normalize their distributions. The association between SCC, EC and the explanatory variables were evaluated by a MIXED procedure (IBM SPSS Statistics, version 21). Explanatory variables, and the first-order interaction term that were investigated with SCC and EC were: the HS (0, healthy; 1 not healthy), lactation stage (LS - 1=0-60 Days In Milking; 2=61-120 DIM; 3=>120 DIM) and the LS x HS. In the MIXED model, goats were considered as a random effect to account for the clustering of mammary glands within animals (Barkema *et al*., 1997). Furthermore, an unstructured covariance structure was used to account for the repeated measurements, over the time, on the same mammary glands (Diaz *et al*., 2011).

Results

Six samples resulted to be contaminated and therefore were not considered. The prevalence of positive samples corresponded to 53.6% (n=383; Table 1). The most prevalent mastitis agent was coagulase-negative

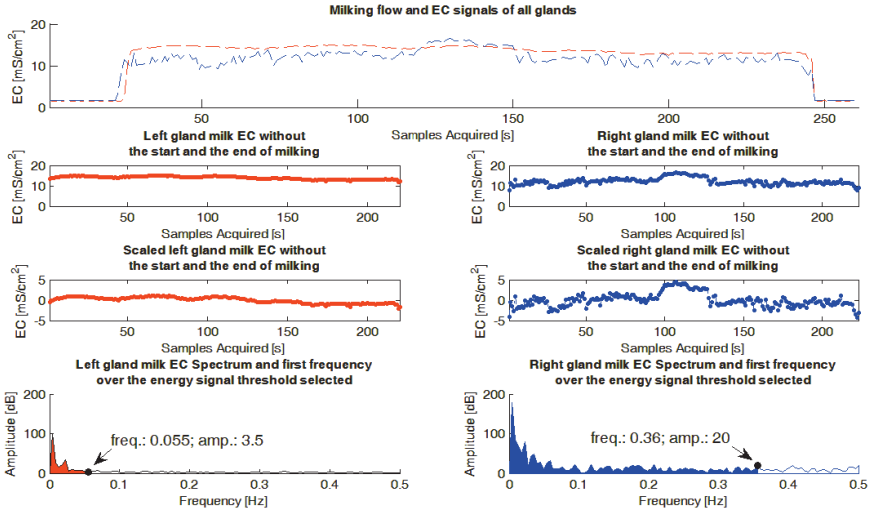

Figure 1. Example of spectrums obtained from the EC signals acquired within a milking. In red, is reported data about the left gland, classified as healthy; in blue, is shown data about a not healthy right gland. The upper graph reports the measured EC signals of milk acquired during a milking from each gland. In the following graphs, for each gland, are shown: i) the sequence of signal samples without the start and the end of milking; ii) the sequence of single samples to which the mean value is subtracted; iii) the spectrum obtained using the FFT transform to the previous sequence of signal samples. In this latter graph, the value of the first frequency that overcame the threshold selected is reported in terms of frequency and amplitude. This value defines the bandwidth length of the signal, also coloured to be easily highlighted.

Table 1. Distribution of mammary glands by health status.

Health status of glands	N	%	Samples classified in C2 (Bact. Pos.)		Samples classified in C3 (Bact. Neg. SCC >1000 x 10^3)	
			N.	%	N.	%
Healthy	308	43.1	-	-	-	-
Not healthy (from goats unilaterally)	170	23.8	149	20.9	21	2.9
Not healthy (from goats bilaterally)	236	33.1	234	32.8	2	0.3
Total	714	100.0	383	53.6	23	3.2

Staphylococcus (CNS-89.8% of the bacteriological positive results; Table 2). The prevalence of glands with SCC>1,000,000 and without pathogenic microorganisms was 3.2% (n=23; Table 1). The overall prevalence of NH samples was about 56.8% for glands and 80.7% for goats. However, no cases of clinical mastitis were observed during the entire experimental period. A higher significant mean value (P<0.001) of SCC was observed in NH glands [5.13±0.08 (logSCC) *vs* 5.84±0.06; Table 3]. Furthermore, the first lactation stage showed a significant lower mean value of SCC if compared with the second and third lactation stages [5.14±0.09 (logSCC) *vs* 5.62±0.11 and 6.02±0.06; Table 3] and the interaction between the HS and LS was not significant. Similar results were observed for the EC and σ^2_{EC}. The mean value of EC showed to be significantly higher (P<0.001) in NH glands [12.70±0.13 (mS/cm) *vs* 13.69±0.67; Table 4], and significantly lower in the first lactation if compared with the other lactation stages [10.86 ± 0.07 (mS/cm) *vs* 14.72±0.09 and 14.80±0.12]. The mean value of σ^2_{EC} showed to be significantly higher (P<0.05) in NH glands [0.098±0.006 (mS/cm) *vs* 0.169±0.012; Table 5], and during the progress of lactation significantly higher values were observed (0.085±0.005 (mS/cm), 0.128±0.012 and 0.223±0.021). For both parameters, the interaction between the HS and LS was not significant.

The bandwidth length showed a significantly higher mean value (P<0.05) in NH glands [0.24±0.01 (Hz) *vs* 0.29±0.01; Table 6] and significantly lower levels between different lactation stages [0.28±0.02 (Hz), 0.27±0.02 *vs* 0.23±0.01]. The interaction between the HS and LS showed to be not significant.

Discussion

Experimental data evaluation

In order to evaluate data acquired during the experiment, the prevalence of bacteriological results and the relationships between

Table 2. Distribution of pathogenic microorganisms found in infected mammary.

Isolated bacterial strains	Number	Percentage
Staphylococcus aureus	4	1.1
Coagulase-negative *Staphylococcus* (CNS)	344	89.8
Escherichia coli	2	0.5
Streptococcus spp.	27	7.0
Lactose-negative bacteria	2	0.5
Pseudomonas	4	1.1
Total	383	100.0

Table 3. Table 3. Overall means and standard errors of somatic cells count (log) of gland milk samples according to health status and lactation stages.

Days in milking	Mean ± SE, logSCC	Healthy Mean ± SE, logSCC	Not healthy Mean ± SE, logSCC
All	5.54±0.05	$5.13±0.08^{A}$	$5.84±0.06^{B}$
0-60	$5.14±0.09^{a,\alpha}$	$4.84±0.11^{\alpha,A}$	$5.55±0.14^{B}$
61-120	$5.62±0.11^{\beta}$	$5.47±0.14^{\beta}$	5.77±0.16
>120	$6.02±0.06^{b}$	$5.68±0.19^{\beta}$	6.07 ±0.07

^{A,B}Means in the same row with different uppercase superscripts differ significantly (P<0.001); ^{a,b}means in the same column with different lowercase superscripts differ significantly (P<0.001); $^{\alpha,\beta}$means in the same column with different lowercase superscripts differ significantly (P<0.01).

Table 4. Overall means and standard errors of electrical conductivity (mS/cm) of gland milk samples according to health status and lactation stages.

Days in milking	Mean ± SE, mS/cm	Healthy Mean ± SE, mS/cm	Not healthy Mean ± SE, mS/cm
All	13.13±0.09	$12.70±0.13^{A}$	$13.69±0.11^{B}$
0-60	$10.86 ±0.07^{a,\alpha}$	$10.66±0.09^{\alpha,A}$	$11.1 ±0.10^{\alpha,B}$
61-120	$14.72±0.09^{b}$	$14.64±0.13^{\beta}$	$14.80±0.14^{\beta}$
>120	$14.80±0.12^{\beta}$	$14.67±0.24^{\beta}$	$14.82±0.13^{\beta}$

^{A,B}Means in the same row with different uppercase superscripts differ significantly (P<0.005); ^{a,b}means in the same column with different lowercase superscripts differ significantly (P<0.001); $^{\alpha,\beta}$means in the same column with different lowercase superscripts differ significantly (P<0.01).

Table 5. Overall means and standard errors of σ^2_{EC} of gland electrical conductivity signals according to health status and lactation stages.

Days in milking	Mean ± SE	Healthy Mean ± SE	Not healthy Mean ± SE
All	0.139±0.008	$0.098±0.006^{A}$	$0.169±0.012^{B}$
0-60	$0.085±0.005^{a,A}$	0.079±0.005	$0.092±0.008^{A}$
61-120	$0.128±0.012^{\alpha,B}$	0.105±0.011	$0.152±0.021^{\alpha,B}$
>120	$0.223±0.021^{b,\beta}$	$0.180±0.048^{A}$	$0.230±0.023^{\beta,B}$

^{A,B}Means in the same row and column with different uppercase superscripts differ significantly (P<0.05); ^{a,b}means in the same column, with different lowercase superscripts differ significantly (P<0.001); $^{\alpha,\beta}$means in the same column, with different lowercase superscripts differ significantly (P<0.01).

Table 6. Overall means and standard errors of the bandwidth lengths related to the spectrums of the gland electrical conductivity signals, according to health status and lactation stages.

Days in milking	Mean ± SE, Hz	Healthy Mean ± SE, Hz	Not healthy Mean ± SE, Hz
All	0.26±0.01	0.24 ± 0.01^{A}	0.29 ± 0.01^{B}
0-60	0.28 ± 0.02^{a}	0.26±0.02	0.30±0.02
61-120	$0.27\pm0.02^{\alpha}$	0.25±0.02	0.29±0.02
>120	$0.23\pm0.01^{b,\beta}$	0.22±0.02	0.26±0.02

^{A,B}Means in the same row and column with different uppercase superscripts differ significantly (P<0.05); ^{a,b}means in the same column, with different lowercase superscripts differ significantly (P<0.001); $^{\alpha,\beta}$means in the same column, with different lowercase superscripts differ significantly (P<0.01).

SCC, EC and HS were investigated.

Microbiological evaluation of NH milk samples offered a panel of pathogens commonly isolated in dairy goats. In particular bacteriological positive samples (53.6%) showed that the most prevalent mastitis agents were represented by CNS (n. 344). While CNS is a minor pathogen in dairy cattle, these organisms are frequently associated with subclinical mastitis in small ruminants and are the most prevalent pathogens of the mammary gland among sheep and goats. In addition, CNS has the potential to become a chronic infection (McDougall *et al*., 2002). The remaining samples classified as NH glands had a low prevalence (3.2%). They were characterized by negative bacteriological culture and as having high levels of SCC in the milk. These results may have been due to agents not diagnosed, such as viral infections, mycoplasmas, stressors, traumas or chemical agents.

SCC was significantly higher in milk samples from NH glands and showed to increase significantly between the first to the second and third lactation stage. These results are in accordance with other studies reported in literature. Romero *et al*. (2012) found highest values of SCC for infected glands [from 5.03-5.31 (logSCC) in healthy glands to 5.47-5.66 in cases of infection]. Díaz *et al*. (2012) found in infected glands a significant increase of SCC after the infection, and in another study conducted in 2011, they reported a significant increase of the average value of SCC during lactation [from 5.83±0.06 (logSCC) for the first month of lactation to 6.03±0.05 for the seventh month of lactation]. Tangorra *et al*. (2010), in a study on 8 Saanen goats followed for the whole lactation, reported mean levels of SCC significantly different in milk from healthy and infected glands [6.18±0.03 (logSCC) *vs* 6.86±0.01] and an increase of SCC during the progress of lactation [from 5.77±0.08 (logSCC) to 6.39±0.03]. Paape *et al*. (2007), analysing data from goats of different breeds, concluded that IMI is the major cause of an increase of milk SCC and reported that a progressive increase in SCC was observed in advanced lactations.

Mean value of gland milk EC showed to be significantly higher in NH glands and to increase significantly during the progress of lactation. Similar results are reported in Díaz *et al*. (2012) and in Díaz *et al*. (2011). They found a significant increase of EC when bilateral infection occurred and an increase of EC with the progress of lactation in cases of multiparous goats. Also Tangorra *et al*. (2010), about the effects of lactation and HS on the measurement of the milk EC, reported results that are in accordance with the present study. They found significant higher values in infected glands [13.03 (mS/cm) *vs* 13.45] and increased values at incremental lactation stages [11.23 (mS/cm), 13.87 and 14.61].

Mean values of milk EC, found in the present study, were higher than those generally reported by other authors (Diaz *et al*. 2011; Stuhr and Aulrich, 2010; Das and Singh, 2000). This result could be explained considering the characteristics of the data acquisition system used. It included an experimental milking cluster developed in order to measure the gland milk EC signal without affect the flow of milk, the vacuum of the milking system and to have the maximum number of lectures during the milking, useful to acquire a good sampling of the EC signal for the spectral analysis performed. Having these targets, a low number of components were added to the commercial milking cluster used and no temperature sensors were included. Therefore, no temperature adjustments were performed, during the recording of the EC data, by the algorithm implemented by the acquisition system. However, this did not affect the spectral analysis performed because, during the elaboration of the data acquired, the mean value of each EC signal was calculated and subtracted to each sample of the corresponding sequence recorded.

In order to evaluate the spectral analysis performed, data acquired during the experiment, in terms of variations of gland milk EC recorded during milkings, were investigated.

The milk EC signals showed mean value of σ^2_{EC} significantly higher in NH glands and with the progress of lactation. Results obtained are in accordance with those reported in literature. Nielen *et al*. (1995a) found higher values of milk EC standard deviation in case of mastitis (0.58 to 0.71 *vs* 0.16 to 0.34, depending on the specific minute of milking evaluated). Norberg *et al*. (2004), in another study on cows, confirmed that σ^2_{EC} increases between healthy quarters and infected quarters. Tangorra *et al*. (2010), in a study that involved a group of Saanen goats, found that σ^2_{EC} was grater in infected glands (0.14 *vs* 0.16 and 0.21 *vs* 0.22 for the second and third stage of lactation, respectively) and higher during the progress of lactation (0.12, 0.15 and 0.22).

However, an increase of variance in the time domain may be due to different reasons: a random effect or a faster and/or bigger oscillation of the signal. These different cases can be well represented in the frequency domain through a spectral analysis. A spectrum constant in all the frequencies corresponds to the first case, also called a *white noise*. Spectrums characterized by main peaks of higher frequencies and/or bigger amplitudes are related to the other cases. The mean length of bandwidth, when these cases occur, is affected. In the first case, it increases to almost the whole frequency domain. In the other cases, it is changed on the basis of the spectrum peaks changes, in terms of frequencies and/or amplitudes.

Results obtained, about the EC signals recorded, showed that mean values of the bandwidth length increased in case of NH glands (from 0.24 Hz to 0.29 Hz) and decreased with the progress of lactation stages (from 0.28 Hz to 0.23 Hz). These results show that the increment of signal variance was not due to random effects (*i.e.* to a white noise), since the means bandwidth length found never increased to almost all the frequency domain. Furthermore, they gave a description on how the EC signal pattern changed in the time

domain. In case of NH glands, since the bandwidth length increased, the signal pattern was generally characterized by faster oscillations, probably of bigger amplitudes. With the progress of lactation, since the bandwidth length decreased, the signal pattern was generally characterized by more slow oscillations, probably of bigger amplitudes. The bandwidth lengths found, therefore, described better the pattern changes of the EC signal than the statistical variance σ^2_{EC}. This suggests that the EC signal bandwidth length parameter, providing more accurate information, should be useful to improve the detection performances of multivariate models that evaluate health status of dairy goats by the use of traits based on the EC.

The results reached have also a practical application that has never been validated in other similar studies. They show that the EC signals acquired by the recording system during the experiment were over sampled. Means value of the bandwidth length had a range between 0.22 Hz and 0.30 Hz. This proves that a sampling rate of 1.7 Hz should be enough to acquire the milk EC signal without losing any important information about its characteristics. This technical set-up is important because by reducing the amount of data that has to be stored and evaluated, the building of the recording sensor/system could be simplified.

Conclusions

The present study showed that spectral analysis achieved similar results to characterize the milk EC signal patterns through their bandwidth lengths in the frequency domain if compared with other traits that describe the variations of milk EC acquired during milkings. In addition, mean value of the obtained EC signal bandwidth lengths showed a significant relationship with the health status of dairy goat glands. Therefore, this new parameter could be useful to improve performances of multivariate models/algorithms that detect the health status of dairy goats. Furthermore, this study provides a technical set-up that could simplify the building of EC recording and elaboration systems.

References

Díaz, J.R., Romero, G., Muelas, R., Alejandro, M., Peris, C., 2012. Effect of intramammary infection on milk electrical conductivity in Murciano-Granadina goats. J. Dairy Sci. 95:718-726.

Díaz, J.R., Romero, G., Muelas, R., Sendra, E., Pantoja, J.C.F., Paredes, C., 2011. Analysis of the influence of variation factors on electrical conductivity of milk in Murciano-Granadina goats. J. Dairy Sci. 94:3885-3894.

Das, M., Singh, M., 2000. Variation in blood leucocytes, somatic cell count, yield and composition of milk of crossbred goats. Small Rumin. Res. 35:169-174.

FIL-IDF, 1981. Laboratory methods for use in mastitis work. Federation Internationale de Laiterie - International Dairy Federation, Brussels, Belgium.

FIL-IDF, 1995. Enumeration of somatic cells. Federation Internationale de Laiterie - International Dairy Federation, Brussels, Belgium.

McDougall, S., Pankey, W., Delaney, C., Barlow, J., Murdough, P.A., Scruton, D., 2002. Prevalence and incidence of subclinical mastitis in goats and dairy ewes in Vermont, USA. Small Ruminant Res. 46:115-121.

Nielen, M., Schukken, Y.H., Brand, A., Haring, S., Ferwerda-Van Zonneveld, R.T., 1995. Comparison of analysis techniques for on-line detection of clinical mastitis. J. Dairy Sci. 78:1050-1061.

Norberg, E., Hogeveen, H., Korsgaard, I.R., Friggens, N.C., Sloth, K.H.M.N., Løvendahl, P., 2004. Electrical conductivity of milk: ability to predict mastitis status. J. Dairy Sci. 87:1099-1107.

Petzer, I.M., Donkin, E.F., Du Preez, E., Karzis, J., Van Der Schans, T.J., Watermeyer, J.C., Van Reenen, R., 2008. Value of tests for evaluating udder health in dairy goats: Somatic cell counts, California Milk Cell Test and electrical conductivity. Onderstepoort J. Vet. Res. 75:279-287.

Romero, G., Pantoja, J.C.F., Sendra, E., Peris, C., Díaz, J.R., 2012. Analysis of the electrical conductivity in milking fractions as a mean for detecting and characterizing mastitis in goats. Small Ruminant Res. 107:157-163.

Rossi, L., Galante, F., Fusi, E., Luini, M., Dell'Orto, V., Baldi, A., 2009. Evaluation the of PL-PG-PA system in relation to quality of bovine milk. Vet. Res. Commun. 33(Suppl.1):293-295.

Stuhr, T., Aulrich, K., 2010. Intramammary infections in dairy goats: recent knowledge and indicators for detection of subclinical mastitis. Forestry 2010:267-279.

Tangorra, F.M., Zaninelli, M., Costa, A., Agazzi, A., Savoini, G., 2010. Milk electrical conductivity and mastitis status in dairy goats: Results from a pilot study. Small Ruminant Res. 90:109-113.

Tangorra, F.M., Zaninelli, M., De Santis, C., 2006. Development of HW and SW solutions for milk traceability. In: F. Zazueta (ed.) Computers in agriculture and natural resources. American Society of Agricultural and Biological Engineers, Orlando, FL, USA, pp. 475-480.

Ying, C., Yang, C., Hsu, J., 2004. Relationship of somatic cell count, physical, chemical and enzymatic properties to the bacterial standard plate count in different breeds of dairy goats. Asian Austrsl. J. Anim. 17:554-559.

Zaninelli, M., Rossi, L., Costa, A., Tangorra, F.M., Agazzi, A., Savoini, G., 2015. Monitoraggio dello stato di salute delle capre attraverso l'analisi on-line della conducibilità elettrica del latte. Large Anim. Rev. 21:81-86

Zaninelli, M., Rossi, L., Tangorra, F.M., Costa, A., Agazzi, A., Savoini, G., 2014. On-line monitoring of milk electrical conductivity by fuzzy logic technology to characterise health status in dairy goats. Ital. J. Anim. Sci. 13:3170.

Zaninelli, M., Tangorra, F., 2007. Development and testing of a "free-flow" conductimetric milk meter. Comput. Electr. Agric. 57:166-176.