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Spatial Dependence of Udder Surface Temperature Variation in Dairy Cows with Healthy Status and Mastitis

Dependência espacial da variação da temperatura de superfície do úbere de vacas de leite saudáveis e com mastite

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ABSTRACT

The objective of this research was to assess the spatial variability pattern concerning udder surface temperature in dairy cows that were healthy and in those with mastitis. A total of 24 animals were selected – eight healthy, eight with subclinical mastitis, and eight with clinical mastitis. Images were taken with a Flir i60 thermographic camera – resolution of 0.01°C, focal length of 1.0 m, and emissivity adjusted to 0.98 – between 05:00 and 07:00, totaling 96 images, three per animal, of the front and rear, right and left mammary quarters. Analyses were run through geostatistics, with semivariogram adjustment to validate the theoretical model and build kriging maps. The average surface temperature of the mammary quarters with positive classification for subclinical mastitis stood between 33.2 ± 0.67ºC and 34.64± 1.07ºC; for negative quarters, values ranged from 29.3 ± 1.78ºC to 32.24 ± 0.62ºC. The udder surface temperatures of healthy animals were lower than those of animals with subclinical mastitis (29.3ºC ± 1.78 and 31.58ºC ± 0.62). The udder surface temperature of animals with clinical mastitis was higher, between 34.0 and 37.5°C, compared to the other clinical statuses. The scale adopted for image pattern analysis successfully identified the spatial dependence of udder surface temperature, which helped standardize diagnostic procedures for healthy animals, and for those with subclinical and clinical mastitis, by means of geostatistics.

Keywords: geostatistics, subclinical mastitis, thermography.

RESUMO

Objetivou-se com essa pesquisa avaliar o padrão de variabilidade espacial da temperatura de superfície do úbere de vacas leiteiras saudáveis e com mastite. Foram selecionados 24 animais, oito saudáveis, oito com mastite subclínica e oito com mastite clínica. As imagens foram obtidas a partir de uma câmera termográfica Flir i60, resolução de 0,01 °C, 1,0 m de distância focal e emissividade ajustada para 0,98. O horário de realização das imagens foi entre às 05 e 07h00, que totalizaram 96 imagens, três por animal, nos enquadramentos anterolateral direito, anterolateral esquerdo, posterior e inferior. As análises foram realizadas pela geoestatística, com ajuste do semivariograma para validação do modelo teórico e construção dos mapas de krigagem. A temperatura média de superfície dos quartos mamários com classificação positiva para mastite subclínica apresentou valores entre 33,2 ± 0,67ºC e 34,64± 1,07ºC; para os quartos negativos entre 29,3 ± 1,78ºC e 32,24 ± 0,62ºC. Os animais saudáveis apresentaram temperatura de superfície de úbere inferior àqueles com mastite subclínica (29,3ºC ± 1,78 e 31,58ºC ± 0,62). A temperatura da superfície do úbere dos animais com mastite clínica foi mais elevada, entre 34,0 e 37,5°C, comparativamente aos demais quadros clínicos. A escala adotada para análise do padrão das imagens identificou com sucesso a dependência espacial da temperatura de superfície do úbere, o que contribuiu para padronização dos procedimentos de diagnóstico para animais saudáveis, com mastite subclínica e clínica, por meio da geoestatística.

Palavras-chave: geoestatística, mastite subclínica, termografia

INTRODUCTION

Mastitis or bovine mastitis is an inflammatory process of the mammary glands resulting from a bacterial infection and can basically present itself in two forms: clinical and subclinical.

The California Mastitis Test (CMT) is a practical, low-cost means largely used for determining mastitis status in lactating animals. The test results are analyzed according to viscosity grade, with five scores, namely: negative, trace, +, ++ and +++.

Infrared thermography can be defined as a non-invasive technique for perceiving the surface temperature of a body, since all bodies with temperature above the absolute zero (0 K) emit thermal radiation (Roberto & Souza, 2014).

Among some studies that have assessed udder temperature variation in lactating cows, the one by Digiovani et al. (2016) stands out for using thermal images as a diagnosis tool to detect subclinical mastitis, finding differences between the temperature of healthy udders and of those with subclinical mastitis. Pezeshki et al. (2011) studied variations in the inflammatory dynamic of Escherichia Coli using infrared thermography and found that the technique was capable of detecting temperature changes on the udder skin surface.

Geostatistics for studying the spatial variability of attributes of zootechnical interest has been used for characterizing animal thermal comfort (Silva et al. 2012; Curi et al. 2014; Queiroz et al.,2017), gas concentration (Medeiros et al., 2014), noise (Oliveira et al., 2016), and for diagnosing diseases in humans (Resmini et al., 2012).

Thus, the objective of this research was to assess the spatial variability pattern of udder surface temperature in dairy cows with healthy status and with mastitis.

MATERIAL AND METHODS

The research was conducted in a milk production unit, at Roçadinho Farm.

The average rainfall in the region is 588 mm per year, with average annual temperature of 22.1°C. According to the Köppen climate classification, the climate of the region is characterized as Bsh, semiarid (Vianello; Alves, 1991).

The selected animals were Girolando cows with the same birth order, lactation stage, age, weight, body score, production and blood group; they were monitored for the udder thermal images to be taken. Number of samples was determined according to selection criteria and totaled 24 animals.

The clinical condition of the animals was established by the California Mastitis Test (CMT), before milking (after the first milk gushes were discarded), because that is when milk fat content is low and does not interfere with the CMT score visual results (Table 1).

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Table 1: Correlation between the California Mastitis Test (CMT) score and somatic cell count.

Score	Viscosity	Somaticcellcount
0	Absent	100,000
Traces	Light	300,000
(1) +	Light/Moderate	900,000
(2) ++	Moderate	2,700,000
(3) +++	Intense	8,100,000

Source: Philpot & Nickerson 1991

To detect clinical mastitis cases, the 'dark-bottomed mug' test was applied. It allowed noticing visible changes in the milk (lower secreted volume, lumps, pus, or aqueous aspect). In addition, the animals were checked for sensitivity to touch on the udder and teats due to an inflammatory case.

Thermal images were taken with an infrared thermographic camera – resolution of 0.01ºC, focal length of 1.0, and emissivity adjusted to 0.98, according to the FlirQuickReport application. The images were taken in the morning, before the first milking, between 05:00 and 07:00, of the front and rear, right and left quarters – four images per animal, totaling 96 thermal images for mammary quarter analysis (Figure 1).

The thermal images were analyzed by means of program FlirQuickReport®, with adjustments to emissivity, room temperature and relative air humidity values, obtained when the images were captured. Meteorological variables were sourced from a datalogger, HOBO U12-12 model, placed at the geometric center in the milking parlor, 1.5 m from the ground. Data were recorded at every second while the thermal images of the animals' udders were being taken.

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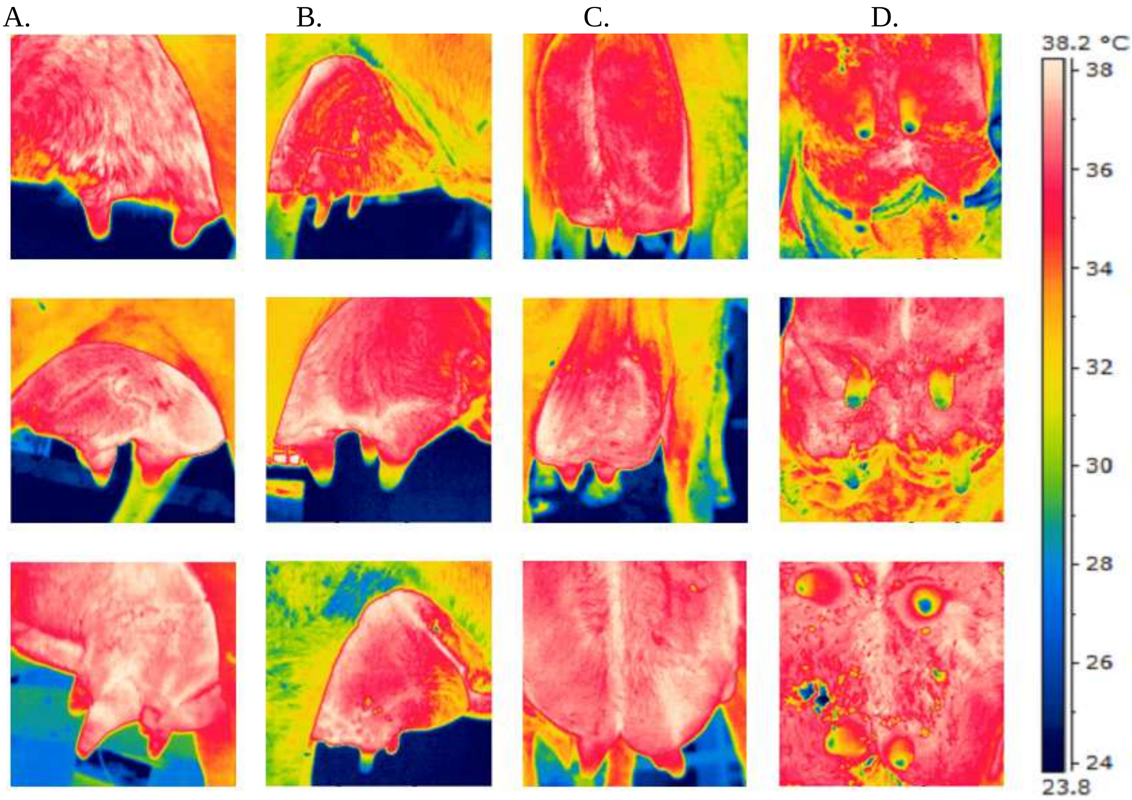

Figure 1. Thermal images of the front left side (A), front right side (B), rear right side (C) and rear left side (D).

The criterion adopted to determine the coverage area of each mammary quarter was developed from a Cartesian plane measuring 2.4 x 0.75 mm^2, adopting a 5 mm spacing for each pixel, referring to surface temperature values for the composition in the selected area, disregarding the edges; thus, a 25 x 80 mm matrix with 102 sampled points was generated (Figure 2).

A representative number of mammary quarters was chosen for analysis – four quarters per animal, with their respective frames, to compose the images, and 12 quarters for each clinical case (healthy animals, animals with subclinical mastitis and clinical mastitis), totaling 36 analyzed mammary quarters.

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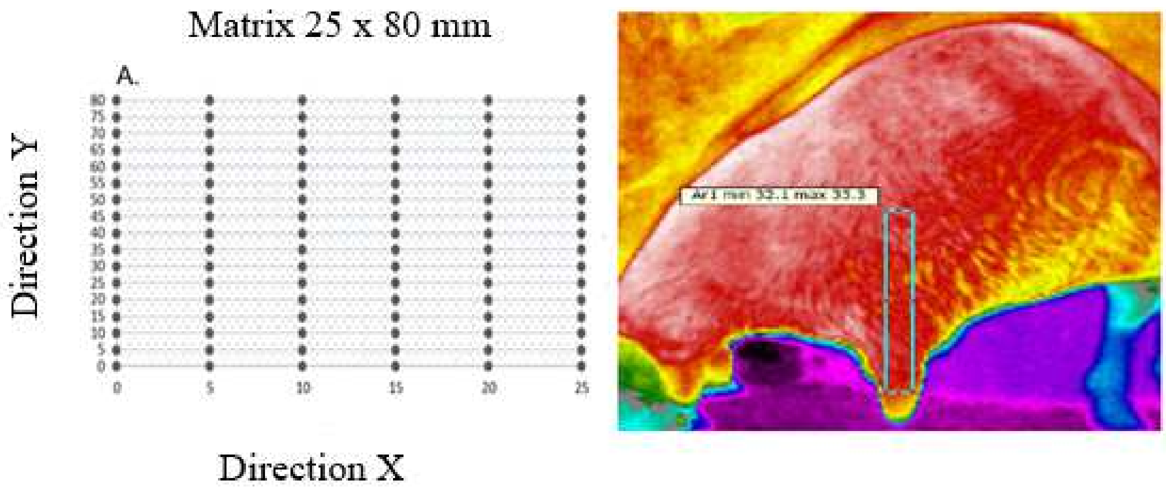

Figure 2. Sampling grid with X and Y coordinates with 102 points (A) referring to the surface temperature of the selected area (B) on the mammary quarter

Data on udder surface temperature for each mammary quarter of the healthy animals and of those with subclinical and clinical mastitis were subjected to descriptive statistical analysis, which determined central tendency measures (mean and median) and dispersion measures (standard deviation and coefficient of variation); moreover, normal distribution was verified through the Kolmogorov-Smirnov test, at a 5% significance level, by means of software STATISTICA®, version 13.2. The spatial dependence analysis was run through semivariogram goodness of fit, based on the stationarity assumption of theintrinsic hypothesis (Vieira, 2000).
From the goodness of fit of a mathematical model, it was possible to estimate the coefficients of the theoretical model for the semivariogram (nugget effect, C0; sill, C0+C1, and range, a). The tool used for geostatistical analysis was GS+ 7.0 (Gamma Design Software, 2004), which allowed obtaining experimental semivariograms; then, the Gaussian, spherical, exponential and linear models were tested. The best models were chosen using the Jack-Knifing criterion (Vauclin et al., 1983), in which standardized errors with mean close to zero and standard deviation close to one presented the best goodness of fit.
To determine the degree of spatial dependence of surface temperature, the classification suggested by Cambardella et al. (1994) was used, considering the 'nugget effect per sill' ratio, and classifying said ratio as strong when < 25%, moderate when from 25 to 75%, and weak when > 75%. The variability degree was characterized with coefficient of variation (CV) values, in accordance with Warrick & Nielsen (1998), who consider as low variability a CV < 15%, medium for values between 15 and 50%, and high variability for CV values > 50%.
Once spatial dependence was confirmed, the ordinary kriging method was used for building the maps on software Surfer®, version 13.6 (Golden Software 2016).

RESULTS AND DISCUSSION

The CMT was performed for each mammary quarter, with the attribution

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of scores ranging from 0 to 5; at score 0, no precipitate formed (healthy); at score 1, there was a light precipitate (infection trace); at score 2, there was moderate precipitate (subclinical mastitis); at score 3, there was a clear precipitate, but without gel formation (subclinical mastitis); at score 4, there was a clear gel formation (subclinical mastitis); and at score 5, there was a pronounced gel formation (subclinical mastitis). To limit subjectivity in the interpretation of results, only scores 2 to 5 were considered for selection of animals with subclinical mastitis.

The average temperatures on the surface of the mammary quarters with subclinical mastitis (score 5) were: 34.64ºC ± 0.67 (front left side), 33.85ºC ± 0.68 (rear left side) and 33.36ºC ± 0.32 (rear right side), respectively (Table 2). Negative mammary quarters presented temperatures ranging from 29.3ºC ± 1.78 to 31.58ºC ± 0.62 (Table 3). According to Polat et al. (2010), quarters with subclinical mastitis presented a surface temperature 2.35 °C higher than that of healthy quarters. However, the values found were 35.80°C for quarters with mastitis, and 33.45°C for healthy quarters, diverging from the values found in this study – 5.3 to 4.55°C above the surface temperature of healthy udders. Bortolami et al. (2015) reported temperatures lower than those found by Polat (2010) for subclinical mastitis. Udder temperature variation magnitude is associated with infection stage and room temperature during thermal image capturing.

Table 2. Descriptive statistics for udder surface temperature in cows with subclinical mastitis

Udder surface temperature (°C)												
	Subclinicalmastitis											
Descriptiveparameters	1				2				3			
	Mammaryquarters				Mammaryquarters				Mammaryquarters			
	RL	RR	FR	FL	RL	RR	FR	FL	RL	RR	FR	FL
Mean (°C)	30.95	31.40	29.30	33.2	32.24	31.58	29.80	34.64	33.85	33.36	30.23	29.63
Median (°C)	31.32	31.97	29.16	33.43	32.25	32.12	29.82	34.95	33.83	33.83	29.95	29.95
SD	1.2	1.78	1.78	0.67	0.62	1.44	0.95	1.07	0.68	0.32	0.92	0.76
Variance	1.45	3.19	7.51	0.45	0.38	2.08	0.9	1.14	0.46	0.1	0.86	0.58
CV (%)	3.89	5.68	9.35	2.02	1.91	4.57	3.19	3.09	2	0.95	3.06	2.57
Curtosis	-0.48	-0.25	-1.07	0.25	-0.61	-0.99	-0.21	-0.58	-0.07	-0.5	-1.32	-1.02
Normality	**	**	**	**	**	**	**	**	**	**	**	**

RL - Rear left quarter; RR - Rear right quarter; FR - Front right quarter; FL - Front left quarter; SD - Standard deviation; CV - Coefficient of variation; **normality at 5% significance.

With respect to the analyzed images, there was a higher occurrence of animals with mastitis on the front left quarter (FL); the temperature of these quarters presented a higher mean, smaller variation, with the coefficient of variation (CV, %) indicating low variability and smaller standard deviation values, followed by the rear left quarter (RL), the front right quarter (FR), and the rear right quarter (RR). According to Warrick and Nielsen (1998), a CV < 15% indicates low variability.

According to Little & Hills (1978), when the mean, median and mode values are similar, data have or are close to normal distribution. This may be indicative that the central tendency measures are not dominated by atypical values in the distribution (Cambardella et al., 1994), which allowed for the geostatistical analyses of the dataset. When data were subjected to the Kolmogorov-Smirnov test, the data normality hypothesis was confirmed for all clinical statuses.

For the animals with subclinical mastitis, kurtosis values were negative, with a less steep normal distribution curve, except for the front left quarter, which was close to zero (0.25). For the healthy animals, values were negative, except for the front left quarter, whose normal curve value stood at 0.04. For the animals with clinical mastitis, values were negative.

Table 3. Descriptive analysis for udder surface temperature in healthy cows.

Descriptiveparameters	Udder surface temperature (°C)											
	Healthy											
	1				2				3			
	Mammaryquarters				Mammaryquarters				Mammaryquarters			
	RL	RR	FR	FL	RL	RR	FR	FL	RL	RR	FR	FL
Mean (°C)	30.16	30.65	30.83	32.65	31.15	30.48	30.48	28.29	33.38	28.04	29.26	29.66
Median (°C)	30.34	30.90	30.86	32.80	30.85	30.18	27.79	27.83	33.51	28.43	29.2	29.67
SD	1.4	2.21	1.70	0.77	1.94	1.74	1.02	2.53	0.81	1.3	1.13	0.18
Variance	1.95	4.9	2.91	0.59	3.75	3.03	1.04	6.39	0.66	1.69	1.29	0.03
CV (%)	4.63	7.23	5.53	2.36	6.22	5.71	3.65	8.93	2.44	4.63	3.88	0.61
Curtosis	-0.61	-0.96	-1.23	-0.28	-1	-0.79	-1.28	-1.29	-0.69	-0.85	-0.9	0.04
Normality	**	**	**	**	**	**	**	**	**	**	**	**

RL - Rear left quarter; RR - Rear right quarter; FR - Front right quarter; FL - Front left quarter; SD - Standard deviation; CV - Coefficient of variation; **normality at 5% significance.

The animals classified with clinical mastitis had an average udder surface temperature of 37.58±0.33oC to 37.11± 0.61°C (Table 4). Mammary quarters with clinical mastitis presented higher temperatures when compared to those quarters with subclinical mastitis and healthy ones (Tables 2 and 3). Values for coefficients of variation indicated low variability (Warrick & Nielsen, 1998), and so did the standard deviations. Kurtosis values were negative, indicating a less steep normal distribution curve. This allows inferring that the evolution of the infectious case raises the udder surface temperature with a reduction in data spatial variability.

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Table 4. Descriptive analysis for udder surface temperature in cows classified with clinical mastitis

Descriptive-parameters	Udder surface temperature (°C)											
	Clinical											
	1				2				3			
	Mammaryquarters				Mammaryquarters				Mammaryquarters			
	RL	RR	FR	FL	RL	RR	FR	FL	RL	RR	FR	FL
Mean (°C)	37.11	37.20	37.27	37.30	37.45	37.48	37.47	37.47	37.52	37.58	37.55	37.56
Median (°C)	37.25	37.27	37.32	37.30	37.50	37.51	37.49	37.52	37.57	37.62	37.57	37.61
SD	0.61	0.56	0.46	0.38	0.37	0.35	0.38	0.35	0.33	0.33	0.36	0.36
Variance	0.37	0.31	0.21	0.15	0.14	0.13	0.15	0.12	0.11	0.11	0.13	0.13
CV (%)	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Curtosis	2.35	3.70	3.36	1.06	-0.60	-0.61	-0.40	-0.99	-1.04	-0.86	-0.73	-0.59
Normality	**	**	**	**	**	**	**	**	**	**	**	**

RL - Rear left quarter; RR - Rear right quarter; FR - Front right quarter; FL - Front left quarter; SD - Standard deviation; CV - Coefficient of variation; **normality at 5% significance.

Table 4 displays the analysis on spatial variability of udder surface temperature for infected quarters, with results for the variability parameters as to the 102 points. The models with the best goodness of fit were the spherical and the Gaussian, following the Jack-Knifing criterion for theoretical semivariogram validation. As per classification by Cambardella et al. (1994), the spatial dependence degree was strong for all mammary quarters. The temperatures presented different ranges of spatial dependence, with the highest values being found for the rear right quarter (1), the rear left quarter (2), and the front right quarter (3). The role of range is to establish the limit between the dependence of variables, serving as an indicative to determine how close or far they are in relation to each other. Points collected at distances greater than the range limit were considered as independent (Vieira, 2000).

The geostatistical analyses indicated that the analyzed attribute did not show spatial dependence on the rear right quarter (1). This lack of spatial dependence may be related to the distance between the points considered, that is, the data showed no variability on the sampling grid (Table 5).

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Table 5. Models and parameters of the semivariograms for udder surface temperature in cows with subclinical mastitis.

Udder surface temperature (°C)												
Subclinicalmastitis												
Parameters Geostatistical	Mastitisonthe FL				Mastitisonthe RL				Mastitisonthe RR			
	Mammaryquarters				Mammaryquarters				Mammaryquarters			
	RL	RR	FR	FL	RL	RR	FR	FL	RL	RR	FR	FL
Nugget effect (C0)	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Sill (C0+C1)	1.77	4.15	9.3	0.44	1.13	0.52	2.53	1.41	0.24	0.87	1.03	0.72
Range (cm)	8.45	9.05	7.58	8.18	8.73	8.66	8.57	7.55	8.21	8.68	8.7	8.55
C0/C0+C1	S	S	S	S	S	S	S	S	S	S	S	S
Model	Gau.	Gau	Gau	Sph	Sph.	Sph	Sph	Gau.	Exp.	Sph.	Sph.	Sph.
R^2	0.8	0.78	0.85	0.79	0.9	0.75	0.84	0.75	0.9	0.77	0.81	0.74
Crossedvalidation												
Meanoftheer-rors	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00
SD	1.00	1.06	1.02	1.11	0.95	1.25	1.05	1.02	1.07	1.23	1.06	1.25

RL - Rear left quarter; RR - Rear right quarter; FR - Front right quarter; FL - Front left quarter; S - Strong; Gau - Gaussian; Sph - Spherical; Exp - Exponential; SD - Standard deviation; C0/C0+C1 - Degree of dependence

According to Souza et al. (2014), when a set of data presents pure nugget effect, spatial dependence cannot be quantified. In this case, the information that best represents these data is the mean. The nugget effect reflects the unexplained variability due to the distance of the sample used, such as local variations, analysis errors, sampling errors, and others (Silva et al.) 2012).

The analysis of semivariograms for the surface temperatures of the mammary quarters indicated no preferential direction, neither for animals with subclinical mastitis nor for healthy ones (Tables 5 and 6); in this case, data have no anisotropy, and data spatial variability occurs in the same way in all directions (Vieira, 2000). The C0/(C0+C1) ratio was considered strong for all quarters, except for the rear left side (cow 3), with dependence deemed as medium (Table 6).

Range values were lower for healthy animals compared to the animals with subclinical mastitis, except for the front right quarter (cow 1), which, comparatively, presented a higher value (Table 6).

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Table 6. Models and parameters of the semivariograms for udder surface temperature in healthy cows

Parameters Geostatistical	Udder surface temperature (°C)											
	Healthy											
	1				2				3			
	Mammaryquarters				Mammaryquarters				Mammaryquarters			
	RL	RR	FR	FL	RL	RR	FR	FL	RL	RR	FR	FL
Nuggeteffect (C0)	0.00	-	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.05
Sill (C0+C1)	2.45	-	0.61	3.43	3.87	4.57	7.76	1.29	0.81	1.9	1.58	0.51
Range (cm)	7.55	-	7.71	7.5	7.74	7.74	8.72	7.6	7.67	7.53	7.59	8.69
C0/C0+C1	S	-	S	S	S	S	S	S	M	S	S	S
Model	Gau	Nef	Gau	Gau	Gau	Gau	Sph	Gau	Gau	Gau	Gau	Sph
R^2	0.87	-	0.86	0.8	0.86	0.78	0.83	0.79	0.85	0.86	0.86	0.95
Crossedvalidation												
Meanoftheerors	0.01	-	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SD	0.84	-	2.56	1.13	0.89	0.99	1.05	1.05	0.98	1.04	0.87	0.98

RL - Rear left quarter; RR- Rear right quarter; FR - Front right quarter; FL - Front left quarter; S - Strong; Gau - Gaussian; Sph - Spherical; Exp - Exponential; SD - Standard deviation; C0/C0+C1 - degree of dependence

In the semivariogram analysis for animals with clinical mastitis, the models with adequate goodness of fit were the spherical, the Gaussian and the exponential, with strong degree of spatial dependence, except for the front right quarter (1, 2 and 3) and the rear right quarter (3). Both presented moderate dependence (Table 7). The surface temperatures of the mammary quarters indicated no preferential direction; in this case, data have no anisotropy (Vieira, 2000).

The ranges presented values higher than the ranges of healthy animals and of those with subclinical mastitis.

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Table 7. Models and parameters of semivariograms for udder surface temperature in cows with clinical mastitis

Geostatistical parameters	Udder surface temperature (°C)											
	Clinical											
	1				2				3			
	Mammary quarters				Mammary quarters				Mammary quarters			
	RL	RR	FR	FL	RL	RR	FR	FL	RL	RR	FR	FL
Nugget efect (C0)	0.04	0.03	0.12	0.00	0.02	0.01	0.1	0.00	0.05	0.07	0.03	0.00
Sill (C0+C1)	0.33	0.35	0.29	0.19	0.17	0.24	0.21	0.16	0.14	0.14	0.09	0.09
Range (cm)	21.4	11.8	12.15	7.9	8.13	9.31	27.2	13.4	13.2	25.5	17.6	7.1
C0/C0+C1	S	S	M	S	S	S	M	S	S	M	M	S
Model	Sph.	Sph.	Gau.	Sph.	Sph.	Sph.	Sph.	Exp.	Sph.	Sph.	Sph.	Exp.
R^2	1	0.99	0.99	0.99	0.84	0.96	0.99	0.83	0.99	0.99	0.99	0.94
Crossed validation												
Mean of the errors	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
SD	0.78	0.8	2.56	1.11	0.6	0.99	1	1.05	0.98	1.04	0.85	0.8

RL - Rear left quarter; RR- Rear right quarter; FR - Front right quarter; FL - Front left quarter; S - Strong; Gau - Gaussian; Sph - Spherical; Exp - Exponential; SD - Standard deviation; C0/C0+C1 - degree of dependence

Figure 3 represents the surface temperature maps, which allow observing the spatial variability of the front left quarters of an animal with subclinical mastitis (Figure 3A), a healthy animal (Figure 3B), and an animal with clinical mastitis (Figure 3C). There is an evident distinction between the maps, with higher occurrence of red areas, meaning higher temperature, associated with the animal with subclinical mastitis, with low concentration of closed outlines, which indicates lower surface temperature variation in the infected quarter (Figure 3A).

The surface temperature within the 33.2-34.0°C range (red hues), as well as the values between 31.3 and 33.1°C (yellow hues), present variation in the sampling space interval and are found at more isolated points (Figure 3A).

The temperature interval for healthy animals was 28.29-33.38°C. For animals with subclinical mastitis, the interval was from 33.2 to 34.64°C. For animals with clinical mastitis, values stood between 37.11 and 37.58°C.

The healthy quarter had a predominance of yellow hues, resulting from the temperature interval between 28.4 and 30.4 °C, and a more homogeneous structure among temperatures, and higher occurrence of concentrations of closed outlines, which suggests greater variations in temperature values. The reddish area on the map corresponds to temperatures from 30.6 to 32.0°C, which occurred less frequently.

Figure 3C presents higher temperatures, ranging from 34.0 to 37.5°C, and predominance of open outlines, suggesting lower variation in temperature, comparatively to the other clinical conditions.

The magnitude and variability of the animals' udder surface temperature are associated with clinical condition and infection stage (Santos et al., 2007), which is evidenced by the spatial varia-

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bility analysis through geostatistics, with a different variation profile, for the udder temperature of healthy animals and of those with subclinical and clinical mastitis.

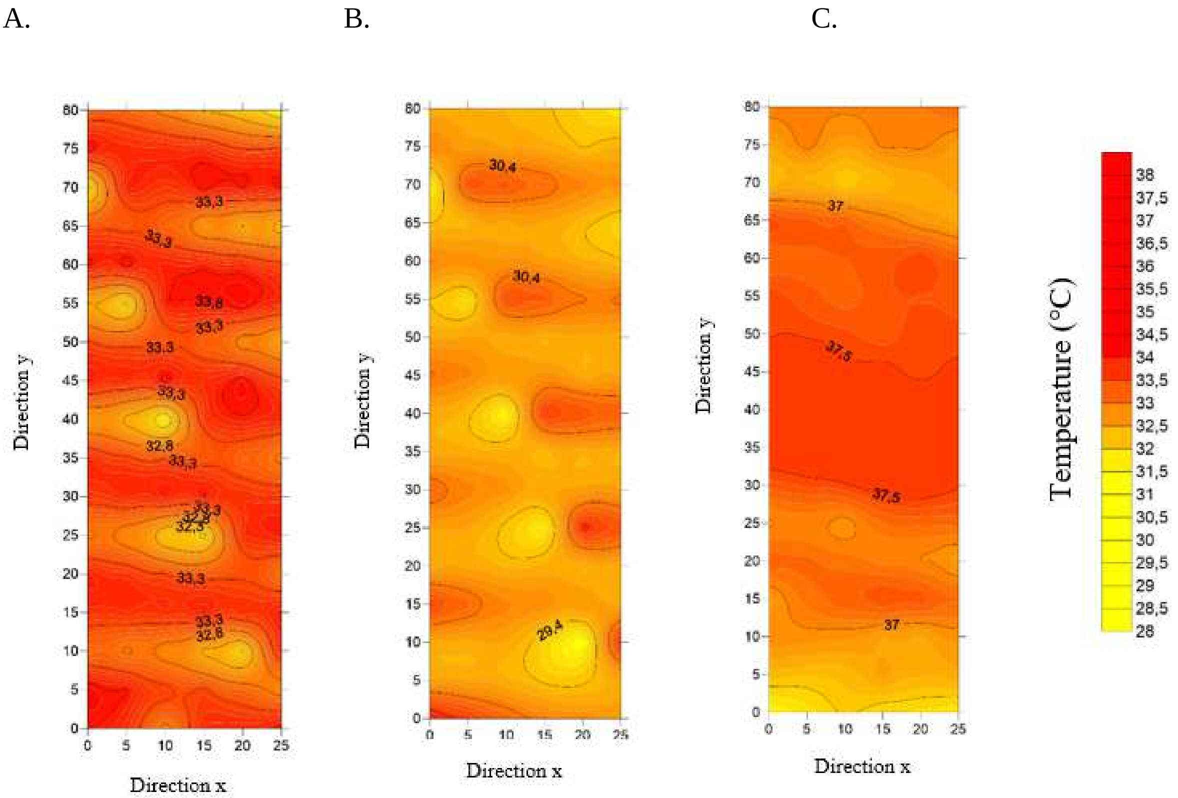

Figure 3. Kriging maps for surface temperature referring to the front left quarters of an animal classified with subclinical mastitis (A), a healthy animal (B), and one with clinical mastitis (C)

CONCLUSIONS

The udder surface temperature of healthy animals was lower than that of those with subclinical and clinical mastitis.

The scale adopted for image pattern analysis successfully identified the spatial dependence of udder surface temperature, which helped standardize diagnostic procedures for healthy animals, and for those with subclinical and clinical mastitis, by means of geostatistics.

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