



Early Detection of Mastitis by Using Infrared Thermography in Holstein-Friesian Dairy Cows Via Classification and Regression Tree (CART) Analysis

Gizem COŞKUN¹, İbrahim AYTEKİN^{1,*}

¹Selçuk University, Faculty of Agriculture, Department of Animal Sciences, Konya, Turkey

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ABSTRACT

Subclinical mastitis is an important udder disease that negatively affects both the animal health and reduces profitability in dairy farms. The increasing performance of thermal cameras over time and their usability in different areas increase their use in livestock. Infrared thermography (IRT) technology is a noninvasive method that can estimate the surface temperature of objects. The objective of this study was to evaluate early detection of mastitis in Holstein-Friesian dairy cattle by using both udder surface temperatures (Tmax) from images obtained with the help of a FLIR One Pro thermal camera and some parameters such as Lab (CIE L*, a*, b*), HSB (Hue, Saturation, Brightness), RGB (Red, Green, Blue) by processing thermal images with the help of ImageJ program via classification and regression tree (CART) analysis. According to CMT by using CART analysis in this study, 64.9% of cows with udder surface temperature lower than 38.85 were healthy, and 73.3% of cows higher than 38.85 were determined as unhealthy. As for SCC, 77.6% of cows with udder surface temperature lower than 38.65 were healthy and 58.6% of cows with higher than 38.65 were determined as unhealthy. The areas under ROC (AUC) were found to be statistically significant in the diagnosis of subclinical mastitis. (P<0.01) The sensitivity and specificity of the CART algorithm for CMT and SHS diagnostic tests were 85.42%, 81.48% and 90.20%, 80.39%, respectively. There was no significant difference between SHS and CMT tests in the area under the ROC curve (P>0.05). As a result, IRT technology can be used as a useful diagnostic tool in the early detection of mastitis.

1. Introduction

Inadequate and unbalanced nutrition is one of the major problems for humanity. With an essential role in healthy and balanced nutrition, milk is a unique nutrient at every stage of human life. The quality of milk required for food safety is linked to udder health in cows. For this reason, the first production step plays a key role for healthy milk (Aytekin et al 2018). Mastitis is considered as an economically important udder disease, especially in its subclinical form (Kaşıkçı et al 2012). In dairy cattle it results in severe economic losses from reduced milk production, treatment cost, increased labor, milk withheld following treatment and premature culling (Sharif et al 2009). Wide variation in the mastitis in a herd is attributable to genetic (herd, breed etc.) and non-genetic factors (parity, season, age, calving month, calving year, lactation stage etc.). Also, udder and teat morphology can also affect the mastitis level of the dairy cows (Uzmay et al 2003). Moreover, cow cleanliness is important for providing hygienic

milk production and the welfare of dairy cows (Aytekin et al 2021).

Monitoring of mastitis program is important for the udder health status of the herd and the quality of the raw milk in the herd. Monitoring udder health and milk quality can be routinely determined by evaluating the somatic cell count (SCC). The somatic cell count of uninfected mammary glands should be less than 200,000 cells/mL (Schukken et al 2003). In addition, the California mastitis test (CMT), which subjectively estimates the somatic cell number indirectly, is widely used in enterprises. CMT solution forms a gel by breaking down the cell membrane of leukocytes or epithelial cells in the milk sample and allowing the DNA to react with the test reagent. The higher the number of nucleated cells in the milk, the higher the gelation rate (Koçyiğit et al 2016). In addition to these methods, several different analytical methods such as White Side Test (WST), Catalase Test, Wisconsin Mastitis Test (WMT), breed method, coultercounter, DNA filter method and integrated fluorescent microscope methods have been used, as well as electrical conductivity, milk color sensor devices and biochemical analysis (Baştan et al 1997; Yağcı 2008; Kaşıkçı et al 2012; Aytekin & Boztepe 2013; Aytekin et al.

* Corresponding author email: aytekin@selcuk.edu.tr

2018).. In short, early diagnosis of mastitis is very important in terms of minimizing economic losses in enterprises, protecting the welfare of animals and producing quality milk. Infrared thermography (IRT) is an important and noninvasive method that can estimate the skin surface temperature of examining physiological changes and responses (Hovinen et al 2008; Jones & Plassmann, 2002; Byrne et al. 2018).

Thermal cameras first started to be used in military areas and later became widespread in industrial areas (Polat et al. 2010). Recently, IRT has been used frequently for early diagnosis of some diseases such as mastitis (Bitman et al 1984; Porcionata et al 2009; Polat et al 2010; Sathiyabarayhi et al. 2016 and Golzarrian et al. 2017), lameness (Eddy et al 2001; Alsaad et al. 2012; Stokes et al. 2012; Giansella et al 2018; Fabbri et al. 2020), oestrus detection (Hurnik et al 1985; Talukder et al 2014; Marquez et al. 2019), sperm quality (Menegassi et al. 2015), pregnancy (Jones et al. 2005; Bowers et al 2009; Radigonda et al 2017), heat stress (Daltro et al 2017; Unruh et al 2017), prediction of live weight (Stajnko et al 2008; Stajnko et al 2010; Kuzuhara et al 2015), measurement of body temperature (Cangar et al 2008; Nascimento et al 2011), milking machine performance (Castro-Costa et al 2014; Tangorra et al 2019), animal welfare (Stewart et al 2005; Abudabos et al 2013), in the livestock. Furthermore, its small size provides portability and ease of use, while being able to use the image remotely without physical contact with the animal provides great convenience as a safe evaluation method and detecting diseases in the livestock (Fabbri et al 2020). First of all, the main advantages of the thermal camera are that it is a remote, non-contact and non-invasive method, absolutely painless, fast and reliable, a real time technique, enable monitoring of dynamical variations of temperature and also has no harmful radiation effects (Lahiri et al 2012). Moreover, in thermal imaging, the hottest areas appear red or white color, while the coldest areas appear blue or black color (Colak et al 2008; Polat et al 2010; Sathiyabarathi et al 2016).

CART is a non-parametric method that analysis complex relations between dependent and independent variables with group effects by classifying the sample into homogenous sub-groups and entering the model (Kayri & Boysan 2008). Classification and regression tree (CART) practiced for nominal, ordinal, and continuous variables is one of the data-mining algorithm used for constructing the decision tree (Çelik et al 2016). Furthermore, CART has an advantage is that the analysis technique is free from the presumptions of multiple regression analysis such as normality, homogeneity, and interdependency of observations for parametric methods are ignored (Kayri & Boysan 2008).

The objective of the present study is to evaluate the potential benefit of the thermal camera as a noninvasive

tool by CART analysis in the early detection of mastitis in Holstein-Friesian dairy cattle.

2. Materials and Methods

Animals and Milking managements

The animal material of this study consisted of Holstein-Friesian dairy cows reared in a private dairy cattle farm in Karapınar district of Konya province. Data collection and animal breeding practices were performed according to the animal welfare rules stated in Article 9 in government law in Turkey (No. 5996). Dairy cows were fed ad libitum with TMR containing a mixture of concentrated feed and forage such as straw, alfalfa, fescue grass, corn silage and alfalfa silage. Milking was carried out 3 times a day by two milkers in the enterprise. Milking management and hygiene rules were implemented in the enterprise. Dairy cows milked three times daily in a 2 x 15 parallel milking parlour with EcoHerd management program. Milk sampling, udder photography and animal breeding practices were performed according to the animal welfare rules stated in Article 9 in government law in Turkey (No. 5996).

Milk sampling

Milk samples of 102 head primiparous Holstein-Friesian dairy cows were taken by using sampling equipment during milking time in order to represent homogeneous of all milk. The milk samples were cooled immediately and transported in cooler boxes to the Animal Biotechnology laboratory of the Department of Animal Science within 2 h. California Mastitis Test (CMT) and Somatic Cell Count (SCC) were determined from milk samples taken into falcon tubes (50 mL) in the morning milking.

Somatic Cell Count (SCC) and Electrical Conductivity (EC)

Somatic Cell Counts SCC (cell/ml) from milk samples were measured using NucleoCounter SCC-100 (Chemometec, Denmark). The numbers of cells/ml in the SCC counter are above limit of 10,000 cells/ml and below limit of 2,000,000 cells/mL. Milk's electrical conductivity was obtained from the milking system sensor (ENGS, EcoHerd, Version 1.01).

California mastitis test (CMT) analysis

CMT scores of all samples were determined by using a same solution, equipment and expert. Milk samples were homogeneously taken from each cow at the milking by using milk sampler. Then, milk samples were placed in a plastic test paddle, divided into 4 separate wells, in order to determine mastitis status. CMT solution was added on the milk samples taken and after mixing same direction in an oval shape for about 20 seconds, it was diagnosed by the expert (Shitandi & Kihumbu 2004).

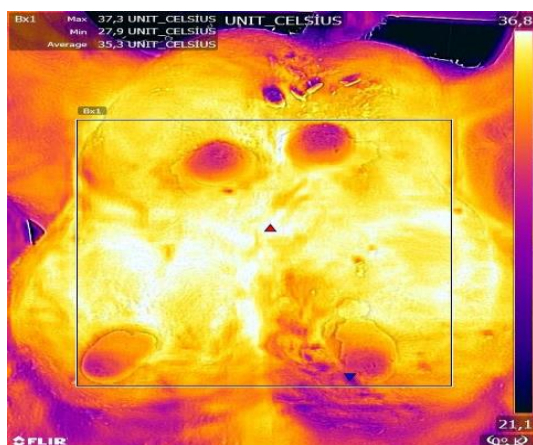


Figure 1
Thermal and normal udder images

Infrared Thermography and digital images processing

Thermal images were taken under the udder using FLIR One Pro before milking in the enterprise with parallel milking parlour. FLIR One Pro operates at 0°C – 35°C (32°F – 95°F) and can detect temperatures from -20°C – 400°C (-4°F – 752°F). Udder skin surface temperatures were determined using the FLIR tools program after taking the infrared thermal images. Lab (CIE L*, a*, b*), HSB (Hue, Saturation, Brightness) and RGB (Red, Green, Blue) values were determined by processing digital images with the Image-j program (Rasband, 1997). It represents the color change of L* between 0 (black) and 100 (white), green (-a) to red (+a) and blue (-b) to yellow (+b) in the digital image processing (CIE 1978). H, S and B color spaces are defined as Hue (H), saturation (S) and brightness (B), respectively. The use of the HSB color model is closer to the human eye's potential to see than the RGB model. The HSB color model is generally used for the separation of colored objects. Hue (H) is the portion of color that varies between 0 and 1 (or 0 to 360°) that corresponds in the position of the colorcylinder. Saturation (S) represents the amount of gray from 0 (gray) to 100% (main color) in the color. The brightness (V) indicates the brightness or intensity of the color ranging from 0 (Black) to 100% (brightest) (Joblove & Greenberg 1978). A thermal image taken under the udder using FLIR One Pro before milking are given in Figure 1.

Statistical analysis

CMT and CSCC such as subclinical mastitis diagnosis tests were binary dependent variables such as healthy and unhealthy. Also, udder skin surface temperatures, electrical conductivity and image processing parameters (L, a, b, Hue, Saturation, Brightness, Red, Green and Blue) were independent variables. In order to create the decision tree structure, threshold value for healthy or unhealthy of animals assumed to be a 200,000 cells/mL for CSCC and negative for CMT. That is, others were coded as unhealthy. There are many algorithms in decision trees in literature. CART (Classification and Regression Tree) data mining algorithm (Breiman et al 1984) was used in this study. CART is a



tree-based algorithm that is not in a mathematical form. It creates a binary classification tree by dividing a subset into smaller subsets. CART algorithm for decision tree-based diagnosis of mastitis has been preferred due to binary node splitting rule and visual results much easier to interpret recently. In the 10-fold cross-validation, the whole data set (102 records) was randomly divided into 10 approx. equal parts of 10 records, from which nine were used to train a given type of a prediction model and one served as an independent test set. This procedure was repeated 10 times (Eyduran et al 2017; Aytekin et al 2018). The Gini index was used as the division criterion. Accuracy, sensitivity and specificity formulas were calculated according to Mikail & Keskin (2015) and Aytekin et al (2018). Confusion table for the classifier algorithms was given in Table 1.

Table 1
Confusion table for the classifier algorithms

		Predicted as	
		Unhealthy	Healthy
Observed	Unhealthy	X	Y
	Healthy	W	Z

$$\text{Accuracy} = (X+Z)/(X+Y+W+Z)$$

$$\text{Sensitivity} = X / (X+Y)$$

$$\text{Specificity} = Z / (W+Z)$$

$$\text{Error proportion} = 1 - \text{Accuracy}$$

$$se_{AUC} = \sqrt{\frac{AUC(1 - AUC) + (n_A - 1)(q1 - AUC^2) + (n_B - 1)(q2 - AUC^2)}{n_A n_B}}$$

$$n_A = X + W \quad \text{and} \quad n_B = Y + Z$$

$$q1 = \frac{AUC}{2 - AUC} \quad \text{and} \quad q2 = \frac{2AUC^2}{1 + AUC}$$

In the above equation represent, X, Z, Y and W represent the numbers of true positive, true negative, false positive and false negative, respectively and formula was used from developed by Hanley and McNei (1982) to determine AUC (AUCse). Pairs of algorithms in area under ROC curve were compared on the basis of z test. IBM SPSS 23 (IBM Corporation, Armonk, New York, USA) statistical package program was used for CART algorithm for decision tree-based diagnosis of mastitis.

MedCalc trial version 19.5.1 was used to calculate the area under the ROC curve and its comparison (AUC) and compare the algorithm pairs in the field.

3. Results and Discussion

An infrared camera detects the thermal radiation emitted by a surface and the intensity of the emitted radiation is converted to temperature. Also, IRT can be static or dynamic. Infrared radiation emitted by a surface depends on the experimental conditions such as moisture, airflow and surrounding temperature. Hence, it is an absolute necessity for thermography experiments, especially in medical applications where temperature changes are within a few degrees, to be performed in controlled environments (Lahiri et al 2012). Since the lactating cows were milked in the same environmental conditions in the milking parlor, the factors affecting the thermal image such as moisture, airflow and surrounding temperature had the same effect on all animals in this study.

Classification table of the CART algorithm was given in Table 2. Classification performances for each

Table 2

Classification table of the CART algorithm

Dependent Variable	Observed	Predicted		Correct (%)
		Unhealthy	Healthy	
CSCC	Unhealthy	41	10	80.4
	Healthy	5	46	90.2
	Overall (%)	45.1	54.9	85.3
CMT	Unhealthy	44	10	81.5
	Healthy	7	41	85.4
	Overall (%)	50.0	50.0	83.3

Table 3

Classification performances for each diagnosis test of CART algorithm

Methods	Sensitivity	Specificity	AUC	Accuracy	P	Pairwise comparison of AUC P-value
CSCC	0.9020	0.8039	0.8530±0.0351 ^A	0.8530	0.000	0.8279
CMT	0.8542	0.8148	0.8340±0.0371 ^A	0.8330	0.000	

^A The difference between the algorithms with letter in CMT or CSCC column is not significant (comparison of the subclinical mastitis diagnostic tests)

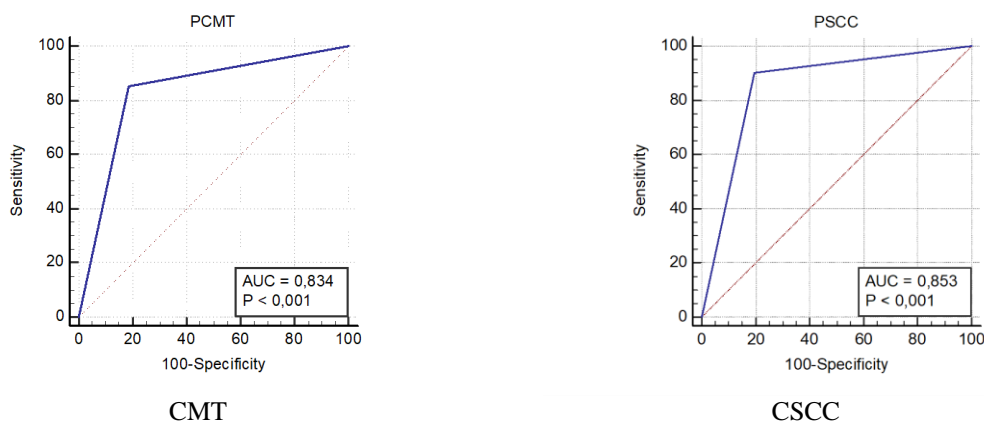


Figure 2
ROC curve for each diagnosis test of CART algorithm

diagnosis test of the CART algorithm and comparison of algorithms in area under ROC curve were given in Table 3. ROC curves were used to determine the usefulness of tests used to diagnose diseases. ROC curves for each diagnosis test of CART algorithm were depicted in Figure 2.

The areas under ROC (AUC) were found to be statistically significant in the diagnosis of subclinical mastitis ($P < 0.01$). The sensitivity, specificity and accuracy of the CART algorithm for CSCC diagnosis test were 0.9020, 0.8039 and 0.8530, respectively. CSCC test of CART algorithm correctly classified 90.20% of unhealthy cows, 80.39% of healthy cows and 85.30% of all cows ($P < 0.000$). The sensitivity, specificity and accuracy of the CART algorithm for CMT diagnosis test were 0.8542, 0.8148 and 0.8330, respectively. CMT test of CART algorithm correctly classified 85.42% of unhealthy cows (with mastitis), 81.48% of healthy cows and 83.30% of all cows ($P < 0.000$). According to CART algorithm, there was no significant difference between SHS and CMT tests in the area under the ROC curve ($P > 0.05$).

Classification tree diagram constructed by CART for CSCC test was given Figure 3. According to Figure 3, half of the 102 head Holstein-Friesian dairy cattle were classified as healthy and the other half as unhealthy in node 0. Node 0 was split into two smaller subgroups (Nodes 1 and 2) by electrical conductivity. In the first depth of the classification tree structure, cows whose electrical conductivity had 8.60 or lower in their milks were healthy at a percentage of 64.1 (Node1), but cows whose electrical conductivity had greater than 8.60 in their milks were characterized as unhealthy at the percentage of 95.8 (Node 2). Since the homogeneity is achieved at node 2 (split complete), the terminal node had been reached.

Cows in node 1 were classified into two smaller subgroups (Nodes 3 and 4) according to thermal temperature predictor. Cows whose electrical conductivity had greater than 8.60 in their milks and whose skin surface temperature had greater than 38.65 in their udders were unhealthy at the percentage of 56.8 (Node 4).

As for node 4, cows were classified into two smaller subgroups (Nodes 7 and 8) according to saturation predictor. While 69.2% of cows were healthy (Node 7) based on electrical conductivity (≤ 8.60), thermal temperature (> 38.65) and saturation (≤ 181856.5) predictors, 81.2% of cows were unhealthy (Node 8) based on electrical conductivity (≤ 8.60), thermal temperature (> 38.65) and saturation (> 181856.5) predictors.

Considering node 3, cows were classified into two smaller subgroups (Nodes 5 and 6) according to ther-

mal temperature predictor. Indeed, 65.5% of the cows (Node 5) were found to be healthy if the electrical conductivity value had ≤ 8.60 (Node 1) and the thermal temperature value had > 38.65 (Node 3) in addition to the udder skin surface temperatures being ≤ 37.95 . In addition to the previous nodes (1 and 3), similarly, 95% of cows (Node 6) with udder skin surface temperatures greater than 37.95 were found to be healthy. In other words, 95% of cows were understood to be healthy when udder skin surface temperature range was between > 37.95 and ≤ 38.65 . This results also showed similarities with the udder skin surface temperature values 38.8 ± 1 °C in study made of Bitman *et al.* (1984) and 37.61 °C in study made of Sathiyabarathi *et al.* (2018).

Node 5 was divided into two subgroups as Node 9 and 10 according to the Hue value. In addition to node 5, while 100% of cows having hue ≤ 64783.0 were found healthy (Node 9), 47.6% of cows having hue > 64783.0 were classified as unhealthy (Node 10).

Node 10 via CART algorithm was divided into two subgroups as node 11 and node 12 according to the L value. In addition to predictors down to node 10, while 100% of cows with L value ≤ 59788.0 were healthy (Node 11), 62.5% of cows with $L > 59788.0$ were classified as mastitis (Node 12). Classification tree diagram constructed by CART for CMT test was presented Figure 4. According to Figure 4, 102 head Holstein-Friesian dairy cattle as healthy and unhealthy were classified 52.9% and 47.1%, respectively in node 0.

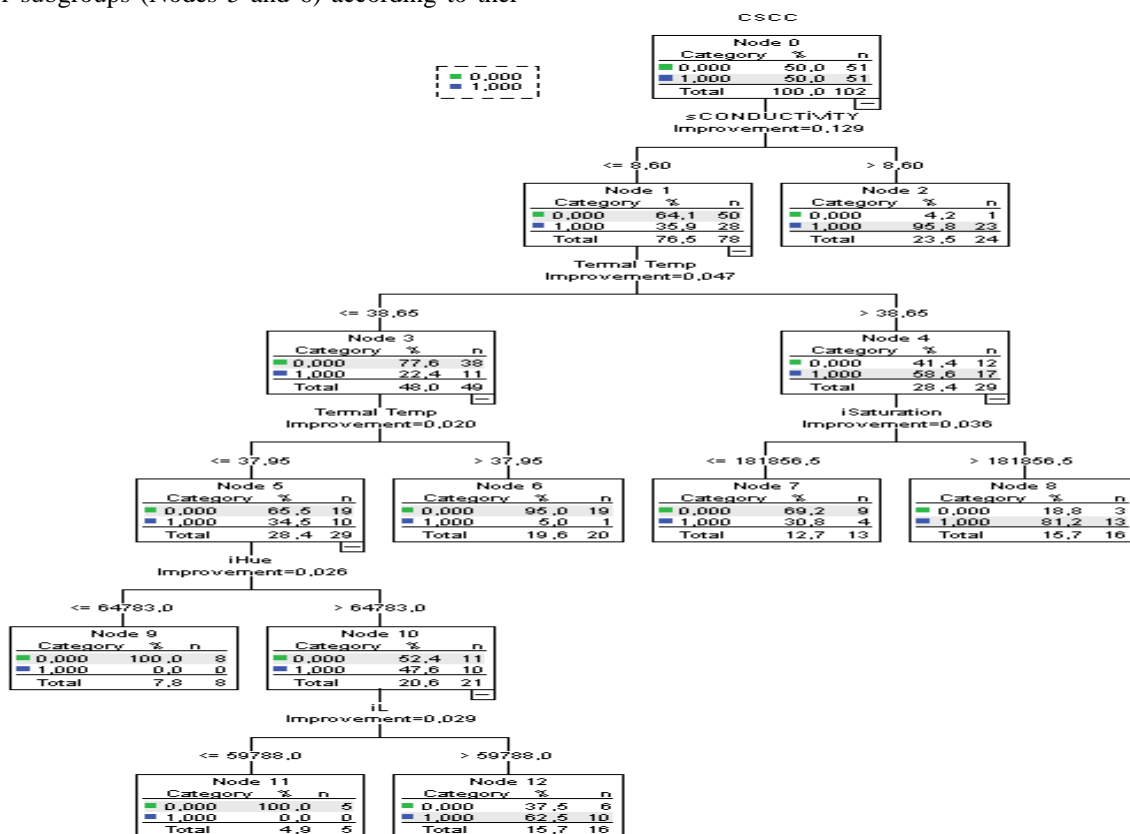


Figure 3
Classification tree diagram constructed by CART for CSCC test

Again as in CSCC, cows in node 0 were classified into two smaller subgroups (Nodes 1 and 2) according to electrical conductivity predictor in classification tree diagram constructed by CART for CMT test. In the first depth of the classification tree structure, cows whose electrical conductivity had 8.80 or lower in their milks were healthy at a percentage of 63.9 (Node1), but cows whose electrical conductivity had greater than 8.80 in their milks were characterized as unhealthy at the percentage of 94.7 (Node 2). Since the homogeneity

is achieved at node 2 (split complete), the terminal node had been reached.

Cows in node 1 were classified into two smaller subgroups (Nodes 3 and 4) according to red predictor, one of the parameters obtained by processing thermal image. 53.8% of the cows (Node 3) were found to be healthy if the electrical conductivity value had ≤ 8.80 (Node 1) and the redness value of thermal temperature value had ≤ 226603.5 (Node 3). As seen on Note 4, 80.6% of cows with red value > 226603.3 were found to be unhealthy.

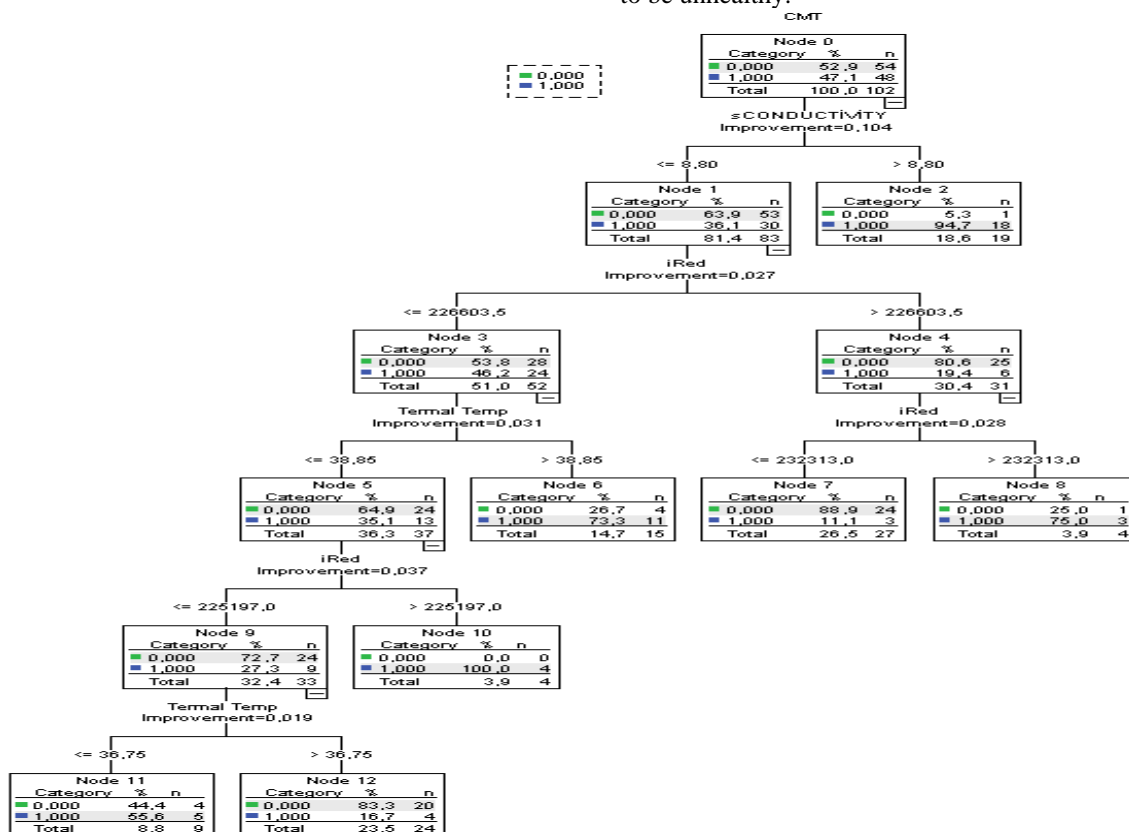


Figure 4
Classification tree diagram constructed by CART for CMT test

In node 4, while 88.9% of cows with electrical conductivity both with a value of ≤ 8.80 and with a range of $226603.5 < \text{red} \leq 232310.0$ in the node 7 were found to be healthy, 75% of cows with values of electrical conductivity (≤ 8.80) and red (> 226603.3 and > 232313.0) in the node 8 were classified as unhealthy. As for node 3, two subgroups as node 9 and 10 according to the udder skin surface temperature were classified. In node 5, 64.9% of cows with electrical conductivity with a value of ≤ 8.80 , red with a value of ≤ 226603.5 and thermal temperature with a value of ≤ 38.85 were found to be healthy. Unlike node 5, 73.3% of cows with values thermal temperature with a value of > 38.85 were classified as unhealthy in node 6.

Cows in node 5 were classified into two smaller subgroups (Nodes 9 and 10) according to red predictor. 72.7% of the cows (Node 9) having electrical conductivity ≤ 8.80 , red ≤ 226603.5 , thermal temperature ≤ 38.85 and red ≤ 225197.0 were found to be healthy, As

seen on Note 10, 80.6% of cows having red > 225197 was found to be unhealthy.

As for node 9, node 10 and 11 subgroups according to the udder skin surface temperature were classified. In addition to the classified predictors down to these subgroups, 55.6% of cows having udder skin surface temperature ≤ 36.75 and 83.3% of cows having udder skin surface temperature > 36.75 were found to be unhealthy and healthy, respectively.

There is a great deal of literature on both individual and combined use of diagnostic tests such as somatic cell count, California mastitis test and electrical conductivity value in the diagnosis of subclinical mastitis in dairy cattle until today (Baştan et al 1997; Aytekin & Boztepe 2013; Aytekin & Boztepe, 2014; Aytekin et al 2018; Aytekin et al 2021). It has been proven in recent studies that the thermal camera is a useful tool in both diagnostic and physiological evaluations (Lahiri et al 2012). The increasing performance of thermal cam-

eras over time and their usability in different areas makes their use in livestock very popular. IFT has been used in many areas in livestock until today, and some studies such as Bitman et al (1984), Berry et al (2003), Hovinen et al (2008), Porcionata et al (2009), Polat et al (2010), Metzner et al (2014), Sathiyabarayhi et al (2016), Pampariene et al (2016), Golzarian et al (2017), Byrne et al (2018), Juozaitienė et al (2018) have been conducted for the diagnosis of mastitis in dairy cattle.

Bitman et al (1984) reported that body and udder temperature in dairy cattle was 38.8 ± 1 °C. In a study investigating the use of thermal camera for early detection of mastitis and its relation with other mastitis tests, udder surface temperatures of healthy, subclinical and clinical mastitis groups were 37.22, 38.08 and 38.25, respectively (Sathiyabarayhi et al 2016). Researchers stated that thermal camera is a rapid and non-invasive technique for early detection of mastitis in dairy cattle. According to CMT by using CART analysis in this study, 64.9% of cows with udder surface temperature lower than 38.85 were healthy, and 73.3% of cows higher than 38.85 were determined as unhealthy. According to SCC, 77.6% of cows with udder surface temperature lower than 38.65 were healthy, and 58.6% of cows with higher than 38.65 were determined as unhealthy. The accuracy of these two systems is as high as 83.3% and 85.3%, respectively. Results obtained in the current study Bitman et al (1984) and Sathiyabarayhi et al (2016) is compatible with the results reported.

Polat et al (2010) compared the ability of thermal camera to detect mastitis with somatic cell count and california mastitis test results. The study showed that the sensitivity and specificity of the thermal camera (95.6% and 93.6%, respectively) did not differ from those of CMT (88.9% and 98.9%), there was a positive correlation between udder surface temperature and SCC ($r = 0.73$) and CMT ($r = 0.86$). The surface temperatures of udder lobes with negative +1, +2 and +3 CMT scores were determined as 33.23, 34.64, 35.75 and 36.27, respectively. The researchers reported that the thermal camera was successful in diagnosing sub-clinical mastitis. In the current research, the reason of udder surface temperature higher than study conducted by Polat et al (2010) can be due to limiting factors use of thermal camera.

On the contrary, in the study was carried for detect subclinical mastitis at early stage, Porcionata et al (2009) stated that the diversity was important between different udder regions, also somatic cell count did not affect udder surface temperature ($P > 0.05$). For this reason, the researchers stated that the thermal camera cannot be used in the diagnosis of subclinical mastitis. Golzarian et al (2017) investigated the use of thermal camera in determining mastitis. Thermal image results were compared with SHS and CMT test results. They reported that the accuracy of this system is as low as 57.3%. Consequently, Porcionata et al (2009) and Golzarian et al (2017) literature results and current study

results do not compatible. This can be due to the lack of attention to factors that limit the use of the thermal imager.. Environmental factors such as humidity, temperature, ventilation, wind, and sunlight significantly affect the imaging results. In addition to environmental factors, it is possible to minimize the errors in imaging when important issues such as the distance between the animal and the thermal camera, the angle of the thermal camera, the cleaning of the udder to be image and the physical activity of the animals before imaging (Cilulko et al 2013; Coşkun & Aytekin, 2020).

4. Conclusion

The most important step in the sustainability of quality milk production and animal welfare in herd management is to know the factors that cause mastitis and to take the necessary precautions. Otherwise, severe economic losses from reduced milk production, treatment cost, increased labor, milk withheld following treatment and culling may happen in herd. In the present study, the results showed that there was a statistically significant relationship between udder skin surface temperature obtained via IRT technology and diagnostic tests such as SCC and CMT in the early detection of mastitis by CART algorithm ($P < 0.00$). Accuracies of the CART algorithm for CSCC and CMT diagnostic test had high rate such a 85.30% and 83.30%, respectively.

In addition to being a fast, effective and non-invasive tool, IRT technology is sensitive enough to detect minor temperature changes on the breast surface caused by subclinical mastitis. Consequently, according to the classification tree diagram constructed by CART for CSCC and CMT diagnostic tests, the current study results showed that the use of thermal cameras in the early diagnosis of subclinical mastitis is a successful detection method. In addition, it can be stated that their reliability will increase even more when used in combination with other mastitis diagnostic methods by paying attention to the factors limiting the use of thermal cameras. Also, since IRT technology is likely to be used more in the livestock sector in the near future with the technological developments over time, more comprehensive studies should be needed.

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