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Prediction of Meat Quality Using Infrared Orbital Temperature as a Non-Invasive Tool in Karacabey Merino, Hungarian Merino and Kivircik Lambs

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Abstract

The study was conducted to predict meat quality using infrared orbital temperature (IROT) as a non-invasive tool in lambs. The study was carried out on a commercial sheep farm. IROT images were collected from 70 male lambs before slaughter. IROT images of lambs were collected with an infrared camera (FLIR, T540). Meat colour parameters, drip loss, expressed juice and meat pH were evaluated as predictors of meat quality. Linear and quadratic regression analysis was used to investigate the relationship of IROT with numerous meat quality variables. IROT value showed a significant correlation with expressed juice (r=-0.416 P<0.05) in Karacabey Merino, and meat redness (r=0.407, P<0.05) and lightness (r=0.411, P<0.001) values in Kivircik lambs. Prediction equations for expressed juice by using IROT were significant in Karacabey (R^2=0.173, RMSE=1.20, P<0.05) and, Hungarian Merino (R2=0.303, RMSE=1.67, P<0.05) lambs. In Kivircik lambs, meat redness (R^2=0.165, RMSE=1.39, P<0.05) and Chroma (R^2=0.169, RMSE=1.37, P<0.05) values measured after 1h blooming were predicted using IROT as well. In conclusion, IROT value might be used to predict the expressed juice, redness, and Chroma of lamb, but it is noteworthy that all equations exhibited low coefficient of determination values.

Keywords: Lamb, drip loss, expressed juice, meat colour, meat pH

Introduction

The importance given by consumers to product quality has increased in parallel with the increase in education and income levels in societies. Therefore, over the years, the expectation of quality as well as quantity in animal products has increased in line with this trend. In meat, one of the most important animal products, quality can be listed as sensory factors (colour, odour, juiciness, aroma etc.), nutritional factors (protein, minerals, dry matter content etc.), hygienic factors (pH, putrefaction, residue) and technical factors (1). On the other hand for consumers, the most important meat quality criteria are colour and fatness, which can be visually evaluated at the purchasing stage, and water losses that may occur during storage and cooking (2, 3).

The main factor affecting meat quality is the long-term or short-term exposure in animals to stress before slaughter. Stress causes depletion of glycogen storage in the muscles before slaughter and a high final pH in meat after slaughter. High final meat pH can cause undesirable effects on meat quality like dark cutting or lower water holding capacity. Body temperature is one of the indicators of the response of animals to external stimuli (4). Therefore, it could be potentially used to indicate poor animal welfare and meat quality in different species such as cattle, pig and poultry (4, 5, 6). In recent years, studies have been conducted on the possibility of using infrared thermography as a non-invasive tool to determine the stress level or welfare of animals (4, 7, 8). In these studies, the temperature change in the superficial capillaries around the eye is tried to be associated with the stress levels of animals.

The aim of this study was to assess whether IROT can be

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used as a non-invasive tool to predict meat quality in Karacabey Merino, Hungarian Merino, and Kivircik lambs by investigating the relationship between IROT value and meat pH, water holding capacity and colour variables.

Materials and Methods

Animals and management

The research was conducted on a commercial farm in Kirklareli providence, Türkiye. The animal material of the study consists of weaned male lambs from Karacabey Merino (24 head), Kivircik (24 head) and Hungarian Merino (22 head) breeds. Lambs weaned at an average age of 90 days were selected from healthy lambs reflecting their breed's average age and live weight. Each breed was kept in different boxes, designed to provide 1 m^2/ lamb during the fattening period. Fattening units were similar in terms of size, feeder, and drinker characteristics. During the fattening period, the lambs were fed *ad-libitum* concentrate and roughage and were provided with free access to clean and fresh water. Lambs were slaughtered at the end of the two different fattening period (6 and 10 weeks of period).

Determination of infrared orbital temperature

Infrared camera (FLIR, T540) were operated by a trained researcher to obtain infrared orbital temperature (IROT) images of lambs (Fig 1). Lambs' orbital temperature images were collected in the boxes inside the shelter, just before they were loaded onto the transport vehicle on the day of slaughter. The lens angle of the infrared camera used was 24°, its thermal resolution was 464×348 and its digital resolution was 1280×960. The image of right eye of lambs was taken from 24° angle. FLIR's infrared software (Flir Tools version 6.4.18039.1003) were used to analyze infrared orbital temperature images. The maximum eye temperature (°C) was taken from the 1 cm area surrounding the outside of the eye. While the eye images were taken, the ambient temperature (20° C), relative humidity (50%) and emissivity value (0.95) were simultaneously recorded and the maximum eye temperatures were corrected using those parameters.

Slaughter procedures and meat quality analyses

Lambs were slaughtered in a commercial abattoir in Kirklareli providence. The standard slaughtering process of the abattoir was followed during the research. Lamb carcasses were numbered and carcass pH0 were measured from *M. longissimus* dorsi at the 12-13th dorsal vertebrae by using a TESTO-205 model digital pH meter. After the carcasses were rested in a cold storage at 4°C for 24 hours, final carcass pH (pH24h) was measured again in the cold storage. In order to determine drip loss, expressed juice and meat colour the *M. longissimus lumborum* were used. Instrumental meat quality analyses were performed on meat samples on hold at 4°C for 72 hours after slaughter.

To measure drip loss (DL), meat samples were weighed after their surfaces were lightly dried with a paper towel. The weighing result was recorded as the initial weight (Wg1). The meat samples were placed in transparent bags so that they did not come into contact with the bags and were weighed again after holding for 24 h at 4°C (Wg2). Drip loss was calculated using the formula DL (%) = ((Wg1-Wg2) / Wg1) × 100 (9).

The modified Grau and Hamm method reported by Beriain et al. (10) was used to measure expressed juice (EJ). For this purpose, each meat sample was chopped into thin strips; approximately 5 g of the analysis sample was weighed, and the weighing result was recorded as the "initial sample weight" (Wg). For each analysis, two filter papers with previously recorded weights (Fi) were used. After placing the meat samples between two filter papers, a weight of 2250 g was applied to each sample for 5 min. In the end, the meat samples were removed from the filter pa-

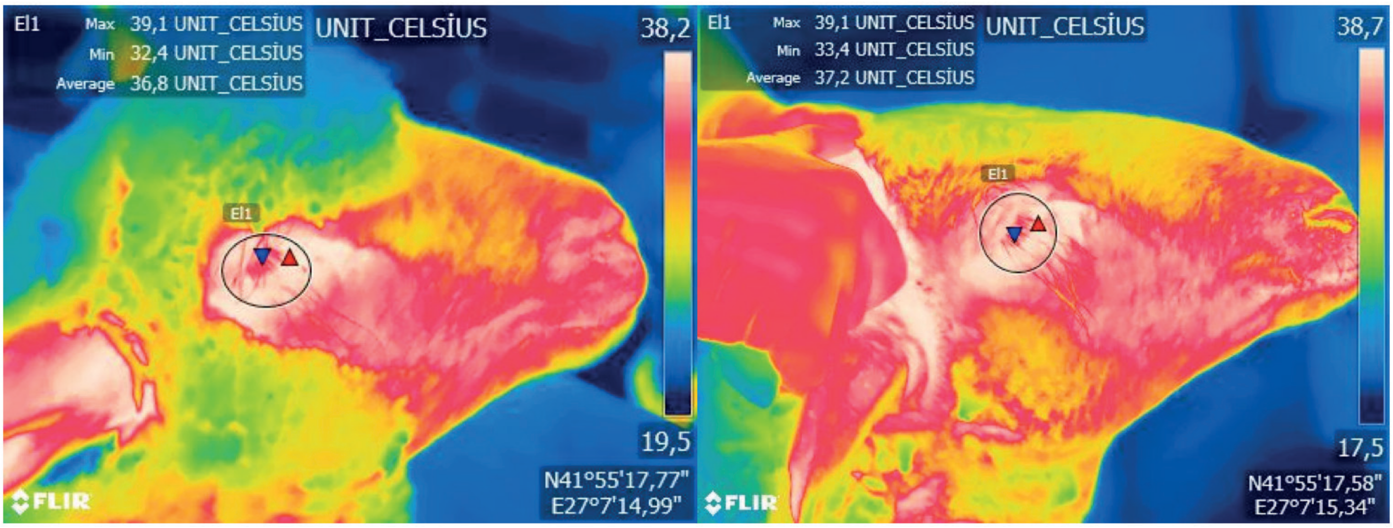

Figure 1: Infrared thermographic ocular images of lambs

per, and the papers were weighed again (Fs). The expressed juice was calculated using the formula EJ (%) = ((Fs-Fi) / Wg) × 100.

A Minolta CR 400 chromometer with the lightness (L*), redness (a*), and yellowness (b*) coordinate system was used for meat colour measurements. The standards reported by CIE (11) were applied in the measurements, and D65 was selected as the light source. For meat colour measurements, 3-cm-thick sections were taken from *M. longissimus lumborum*, and meat colour measurements were performed twice at 1 and 24 h after cutting the same samples. During this process, the samples were stored at 4°C under continuous white light. The Chroma and Hue angle were calculated using the red and yellow coordinates, following Murray (12).

Statistical analyses

The Jamovi 2.3.21 program (13) was used for the calculation of mean, standard deviation, minimum and maximum values for each variable and statistical analyses. Data from Karacabey Merino, Hungarian Merino and Kivircik lambs were analysed separately. In the statistical analysis phase, firstly, the compatibility of the IROT and meat quality characteristics with normal distribution and the homogeneity of the variance were checked using the Shapiro-Wilk test and the Levene test, respectively.

Linear and quadratic regression analysis were used to investigate the relationship of IROT with numearous meat quality variables. Correlations coefficients between IROT and meat qaulity characteristics were also determined using pearson correlation method. In order to assess the accuracy and precision of the regression models, the significance of the model was used as well as coefficient of determination (R^2) and root mean square error (RMSE) values (14). Models with higher R^2 and smaller RMSE values were evaluated better models explaining the variance in meat quality variables.

Results

Descriptive statistics for IROT values and numerous meat quality variables investigated in the study were presented in Table 1. The mean IROT value was 37.3, 38.9 and 39.2 °C in Karacabey Merino, Hungarian Merino and Kivircik lambs, respectively. Meat pH24h values in all three breeds do not indicate dark cuts (pH24h>5.80). Meat L* and a* values were also within the normal ranges for lamb meat.

Pearson correlation coefficients of IROT values with meat quality variables were given in Table 2. IROT value was weakly correlated with meat quality characteristics, except expressed juice for Karacabey Merino, and a*1h and Chroma1h values for Kivircik lambs. In the Hungarian Merino lambs, no significant correlation was found between any meat quality variable and IROT value. In Karacabey Merino lambs, IROT had negative and moderate correlation (r=-0.416, P<0.05) with EJ. In Kivircik lambs, positive and moderate correlation of IRAT with a*1h (r=0.407, P<0.05) and Chroma1h (r=0.411, P<0.05) values were determined. The a*1h and Chroma1h values were tended to be significantly correlated with IROT value (r=0.377, P=0.070 and r=0.375, P=0.071, respectively) in Karacabey Merino lambs.

Table 1. Descriptive statistics for maximum infrared orbital temperature (IROT) and meat quality characteristics in Karacabey Merino, Hungarian Merino and Kivircik lambs

Item[a]	Karacabey Merino			Hungarian Merino			Kivircik		
	Mean	SD	Min / Max	Mean	SD	Min / Max	Mean	SD	Min / Max
IROT	37.3	1.79	30.0 / 39.5	38.9	0.48	37.9 / 39.7	39.2	0.39	38.6 / 40.2
pH_0	6.68	0.18	6.11 / 6.92	6.63	0.15	6.17 / 6.87	6.66	0.10	6.46 / 6.87
pH_{24h}	5.61	0.07	5.46 / 5.72	5.61	0.11	5.45 / 5.77	5.67	0.010	5.52 / 5.83
pH_{0-24}	1.07	0.17	0.47 / 1.32	1.02	0.15	0.70 / 1.30	0.99	0.11	0.75 / 1.21
DL, %	1.85	0.60	0.72 / 2.68	2.15	0.79	1.03 / 4.41	2.23	1.11	1.30 / 6.45
EJ, %	10.3	1.35	7.56 / 12.9	11.2	2.05	6.99 / 14.9	11.0	1.18	8.66 / 13.5
L^*_{1h}	36.1	2.07	32.3 / 39.5	38.5	2.00	35.8 / 44.6	36.9	2.23	33.0 / 42.7
a^*_{1h}	16.8	0.87	15.0 / 18.4	16.4	1.25	13.9 / 18.4	15.9	1.56	13.2 / 18.7
b^*_{1h}	-0.78	0.55	-1.87 / 0.55	-0.21	0.57	-0.91 / 1.43	-0.76	0.75	-2.22 / 0.57
$Chroma_{1h}$	16.8	0.88	15.0 / 18.4	16.4	1.24	13.9 / 18.4	15.9	1.53	13.3 / 18.7
Hue_{1h}	-2.57	1.83	5.83 / 1.83	-0.72	2.14	-3.42 / 5.76	-2.84	2.95	-8.40 / 2.40
L^*_{24h}	36.9	2.12	32.3 / 40.4	38.8	2.04	36.0 / 45.0	37.8	2.08	34.0 / 42.9
a^*_{24h}	18.0	0.97	16.2 / 20.1	17.9	1.90	14.8 / 21.4	16.8	1.51	13.9 / 19.1
b^*_{24h}	2.22	0.71	1.02 / 4.28	3.56	1.52	1.49 / 6.54	2.29	1.08	0.56 / 4.26
$Chroma_{24h}$	18.1	1.00	16.3 / 20.1	18.3	2.10	15.1 / 22.1	17.0	1.60	13.9 / 19.5
Hue_{24h}	7.03	2.12	3.28 / 12.6	11.0	3.81	5.29 / 17.8	7.55	3.22	2.04 / 13.3

[a] IROT: maximum infrared orbital temperature, DL: Drip loss, EC: Expressed juice

Table 2. Correlation coefficients (pearson r) of infrared orbital temperature with meat quality characteristics in Karacabey Merino, Hungarian Merino and Kivircik lambs

Item	Karacabey Merino	Hungarian Merino	Kivircik
pH_0	0.130	0.176	-0.269
pH_{24h}	0.236	0.224	-0.036
pH_{0-24}	0.048	0.022	-0.211
DL, %	-0.205	0.103	-0.169
EJ, %	**-0.416***	-0.101	0.101
L^*_{1h}	-0.225	0.045	-0.343
a^*_{1h}	0.377	-0.086	**0.407***
b^*_{1h}	0.001	-0.112	-0.109
$Chroma_{1h}$	0.375	-0.084	**0.411***
Hue_{1h}	0.028	-0.104	-0.039
L^*_{24h}	-0.182	0.230	-0.322
a^*_{24h}	0.223	-0.076	0.403
b^*_{24h}	-0.024	0.054	0.190
$Chroma_{24h}$	0.216	-0.064	0.391
Hue_{24h}	-0.071	0.086	0.154

*:P<0.05, **: P<0.01, ***: P<0.001

Table 3. Prediction equations for meat quality characteristics in Karacabey Merino lambs.

Model	Dependent Variable	Equation	R^2	RMSE	*P* value
Linear	pH_0	Y = 6.180+ 0.013 × IROT	0.017	0.179	0.546
	pH_{24h}	Y = 5.284+ 0.009 × IROT	0.056	0.064	0.267
	pH_{0-24}	Y = 0.896+ 0.005 × IROT	0.002	0.166	0.824
	DL, %	Y = 4.398 - 0.068 × IROT	0.042	0.571	0.337
	EJ, %	Y = 21.969 - 0.313 × IROT	0.173	1.20	**0.043**
	L^*_{1h}	Y = 45.808 - 0.261 × IROT	0.051	1.98	0.291
	a^*_{1h}	Y = 9.995 + 0.183 × IROT	0.142	0.789	0.070
	b^*_{1h}	Y = -0.770 + 0.0003 × IROT	<0.001	0.541	0.996
	$Chroma_{1h}$	Y = 9.995 + 0.184 × IROT	0.141	0.795	0.071
	Hue_{1h}	Y = -3.621 + 0.028 × IROT	<0.001	1.79	0.898
	L^*_{24h}	Y = 44.891 - 0.215 × IROT	0.033	2.04	0.394
	a^*_{24h}	Y = 13.466 + 0.121 × IROT	0.050	0.928	0.295
	b^*_{24h}	Y = 2.580 - 0.009 × IROT	0.0004	0.699	0.912
	$Chroma_{24h}$	Y = 13.643 + 0.120 × IROT	0.047	0.953	0.310
	Hue_{24h}	Y = 10.179 - 0.084 × IROT	0.005	2.07	0.741
Quadratic	pH_0	$Y = -2.195 + 0.50 \times IROT - 0.007 \times IROT^2$	0.062	0.175	0.510
	pH_{24h}	$Y = 8.294 - 0.166 \times IROT + 0.003 \times IROT^2$	0.100	0.062	0.331
	pH_{0-24}	$Y = -10.488 + 0.666 \times IROT - 0.010 \times IROT^2$	0.101	0.157	0.325
	DL, %	$Y = 4.484 - 0.073 \times IROT + 0.0007 \times IROT^2$	0.042	0.571	0.637
	EJ, %	$Y = -13.988 + 1.775 \times IROT - 0.030 \times IROT^2$	0.189	1.19	0.111
	L^*_{1h}	$Y = 97.021 - 3.234 \times IROT + 0.043 \times IROT^2$	0.064	1.97	0.500
	a^*_{1h}	$Y = -40.294 + 3.103 \times IROT - 0.042 \times IROT^2$	0.215	0.754	0.078
	b^*_{1h}	$Y = 0.564 - 0.077 \times IROT + 0.001 \times IROT^2$	0.0001	0.541	0.999
	$Chroma_{1h}$	$Y = -40.538 + 3.118 \times IROT - 0.042 \times IROT^2$	0.214	0.76	0.080
	Hue_{1h}	$Y = -8.916 + 0.336 \times IROT - 0.004 \times IROT^2$	0.0001	1.79	0.990
	L^*_{24h}	$Y = 151.85 - 6.426 \times IROT + 0.089 \times IROT^2$	0.089	1.98	0.374
	a^*_{24h}	$Y = -69.961 + 4.965 \times IROT - 0.070 \times IROT^2$	0.211	0.846	0.083
	b^*_{24h}	$Y = -32.915 + 2.052 \times IROT - 0.030 \times IROT^2$	0.055	0.680	0.553
	$Chroma_{24h}$	$Y = -73.932 + 5.206 \times IROT - 0.073 \times IROT^2$	0.216	0.864	0.077
	Hue_{24h}	$Y = -72.752 + 4.731 \times IROT - 0.069 \times IROT^2$	0.039	2.03	0.660

R^2 : Coefficient of determination; RMSE: Root mean square error

Linear and quadratic prediction equations using IROT value for meat quality characteristics in Karacabey Merino, Hungarian Merino and Kivircik lambs were shown in Tables 3, 4 and 5. In Karacabey Merino lambs, expressed juice of meat samples can be predicted using the following formulae with the weak accuracy (R^2=0.173, P<0.05): Y = 21.969 - 0.313 × IROT. On the other hand, no quadratic model could be fitted to explain the variation in meat quality traits in Karacabey Merino lambs with statistical significance.

Table 4. Prediction equations for meat quality characteristics in Hungarian Merino lambs.

Model	Dependent Variable	Equation	R^2	RMSE	*P* value
Linear	pH_0	Y = 4.455+ 0.056 × IROT	0.031	0.148	0.446
	pH_{24h}	Y = 3.699+ 0.049 × IROT	0.050	0.101	0.328
	pH_{0-24}	Y = 0.756+ 0.007 × IROT	0.0005	0.148	0.926
	DL, %	Y = -4.349+ 0.167 × IROT	0.011	0.763	0.658
	EJ, %	Y = 27.935- 0.429 × IROT	0.011	1.99	0.663
	L^*_{1h}	Y = 31.262+ 0.186 × IROT	0.002	1.95	0.847
	a^*_{1h}	Y = 25.084 - 0.222 × IROT	0.007	1.22	0.711
	b^*_{1h}	Y = 4.931 - 0.132 × IROT	0.013	0.551	0.628
	$Chroma_{1h}$	Y = 24.877 - 0.217 × IROT	0.007	1.21	0.716
	Hue_{1h}	Y = 17.246 - 0.462 × IROT	0.011	2.07	0.653
	L^*_{24h}	Y = 1.022 + 0.971 × IROT	0.053	1.94	0.317
	a^*_{24h}	Y = 29.544 - 0.299 × IROT	0.006	1.85	0.743
	b^*_{24h}	Y = -3.025 + 0.169 × IROT	0.003	1.48	0.816
	$Chroma_{24h}$	Y = 29.124 - 0.279 × IROT	0.004	2.05	0.783
	Hue_{24h}	Y = -15.426 + 0.678 × IROT	0.007	3.70	0.711
Quadratic	pH_0	Y = 16.342 - 0.557 ×IROT+ 0.008 × $IROT^2$	0.031	0.148	0.753
	pH_{24h}	Y = 139.30 -6.941 ×IROT+ 0.090 × $IROT^2$	0.114	0.097	0.336
	pH_{0-24}	Y = -122.96 + 6.384 ×IROT- 0.082 × $IROT^2$	0.026	0.146	0.786
	DL, %	Y = -714.81 + 36.791 ×IROT- 0.472 × $IROT^2$	0.042	0.750	0.678
	EJ, %	Y = -5617.03 + 290.56 ×IROT - 3.75 × $IROT^2$	0.303	1.67	**0.039**
	L^*_{1h}	Y = -3036.17 + 158.31 ×IROT- 2.037 × $IROT^2$	0.094	1.85	0.413
	a^*_{1h}	Y = -1062.14 – 55.823 ×IROT- 0.722 × $IROT^2$	0.037	1.295	0.715
	b^*_{1h}	Y = -1316.61 + 67.992 ×IROT- 0.878 × $IROT^2$	0.222	0.490	0.105
	$Chroma_{1h}$	Y = -1052.45 + 55.32 ×IROT - 0.716 × $IROT^2$	0.036	1.19	0.717
	Hue_{1h}	Y = -4812.39 +248.5 ×IROT- 3.208 × $IROT^2$	0.209	1.86	0.122
	L^*_{24h}	Y = -2823.37 + 146.57 ×IROT- 1.876 × $IROT^2$	0.127	1.86	0.295
	a^*_{24h}	Y = -2609.02 + 135.72 ×IROT- 1.753 × $IROT^2$	0.081	1.78	0.470
	b^*_{24h}	Y = -3376.98 +174.09 ×IROT- 2.241 × $IROT^2$	0.195	1.33	0.142
	$Chroma_{24h}$	Y = -3202.87 + 166.33 ×IROT- 2.147 × $IROT^2$	0.096	1.95	0.405
	Hue_{24h}	Y = -9007.41 + 464.21 ×IROT- 5.963 × $IROT^2$	0.223	3.28	0.103

R^2 : Coefficient of determination; RMSE: Root mean square error

Table 5. Prediction equations for meat quality characteristics in Kivircik lambs.

Model	Dependent Variable	Equation	R^2	RMSE	*P* value
Linear	pH_0	Y = 9.447 - 0.071 × IROT	0.073	0.096	0.203
	pH_{24h}	Y = 6.033 - 0.009 × IROT	0.001	0.97	0.866
	pH_{0-24}	Y = 3.414 - 0.062 × IROT	0.045	0.108	0.321
	DL, %	Y = 21.240 - 0.485 × IROT	0.029	1.07	0.429
	EJ, %	Y = -1.130 + 0.309 × IROT	0.010	1.15	0.638
	L^*_{1h}	Y = 114.14 - 1.97 × IROT	0.117	2.05	0.101
	a^*_{1h}	Y = -48.20 + 1.63 × IROT	0.165	1.39	**0.049**
	b^*_{1h}	Y = 7.478 - 0.210 × IROT	0.012	0.725	0.611
	$Chroma_{1h}$	Y = -47.72 + 1.62 × IROT	0.169	1.37	**0.046**
	Hue_{1h}	Y = 8.807 - 0.297 × IROT	0.002	2.88	0.856
	L^*_{24h}	Y = 105.79 - 1.73 × IROT	0.104	1.93	0.125
	a^*_{24h}	Y = -44.56 + 1.56 × IROT	0.162	1.35	0.051
	b^*_{24h}	Y = -18.433 + 0.528 × IROT	0.036	1.04	0.374
	$Chroma_{24h}$	Y = -46.18 + 1.61 × IROT	0.153	1.44	0.059
	Hue_{24h}	Y = -42.63 + 1.28 × IROT	0.024	3.11	0.472
Quadratic	pH_0	Y = -140.33 + 7.546 ×IROT- 0.097 × $IROT^2$	0.106	0.094	0.308
	pH_{24h}	Y = -80.26 + 4.379 ×IROT- 0.056 × $IROT^2$	0.013	0.097	0.871
	pH_{0-24}	Y = -60.06 + 3.167 ×IROT- 0.041 × $IROT^2$	0.050	0.108	0.586
	DL, %	Y = 14.783 - 0.156 ×IROT- 0.004 × $IROT^2$	0.029	1.07	0.737
	EJ, %	Y = -272.98 + 14.134 ×IROT- 0.176 × $IROT^2$	0.011	1.15	0.890
	L^*_{1h}	Y = -2689.53 +140.61 ×IROT- 1.81 × $IROT^2$	0.142	2.02	0.200
	a^*_{1h}	Y = -1383.32 + 69.53×IROT- 0.863 × $IROT^2$	0.177	1.38	0.130
	b^*_{1h}	Y = -699.02 + 35.72 ×IROT- 0.457 × $IROT^2$	0.026	0.720	0.759
	$Chroma_{1h}$	Y = -1335.61 + 67.12 ×IROT- 0.833 × $IROT^2$	0.180	1.36	0.125
	Hue_{1h}	Y = -2951.97 + 150.28×IROT- 1.917× $IROT^2$	0.017	2.86	0.833
	L^*_{24h}	Y = -130.50 + 10.284 ×IROT- 0.153 × $IROT^2$	0.104	1.93	0.315
	a^*_{24h}	Y = -1890.96 + 95.47 ×IROT- 1.19 × $IROT^2$	0.186	1.33	0.116
	b^*_{24h}	Y = -1062.18 + 53.61 ×IROT- 0.675 × $IROT^2$	0.051	1.03	0.580
	$Chroma_{24h}$	Y = -2036.73 + 102.84 ×IROT- 1.29 × $IROT^2$	0.177	1.42	0.129
	Hue_{24h}	Y = -3099.32 + 156.73 ×IROT- 1.98 × $IROT^2$	0.038	3.09	0.667

R^2 : Coefficient of determination; RMSE: Root mean square error

In Hungarian Merino lambs, no linear model could be developed to explain the variation in meat quality traits. However, moderate accuracy with statistical significance for EJ value was obtained using quadratic equation ($Y = -5617.03 + 290.56 \times IROT - 3.75 \times IROT^2$). Supporting the Pearson correlation results in Kivircik lambs, the linear regression model fitted with IROT as a predictor was able to explain the variations in the meat colour variables a*1h (R^2=0.165, P<0.05) and Chroma1h (R^2=0.169, P<0.05) with statistical significance.

Discussion

Animal body temperature is used as a parameter to provide information about their physiological condition, health, or disruptions in their life activities in animal management. Many studies have proven that infrared thermography can be used as an effective tool in measuring the temperature of animals (15). Eye temperature is preferred, especially in studies measuring stress and welfare studies, because the eye area has less wool and is less affected by environmental conditions (4, 15). The mean infrared orbital temperature value was changed between 37.3 and 39.2°C for lambs in the current study. Similarly, Joy et al. (8) also reported 36.4-39.1°C eye temperature for Dorper sheep and Alamedia et al. (7) reported 37.13-37.54°C for Churra da Terra Quente and Ile de France sheep.

The ultimate pH should be between 5.5 and 5.8 to obtain desirable quality meat. Meat with a high ultimate pH (5.9 6.2) is dark coloured, firm and prone to bacterial spoilage, and also has a high water holding capacity (16, 17). In the current study, the mean ultimate pH of all lambs were below 5.68 indicating no negative effects on meat quality. There were no significant relationships between pH and IROT for all lamb breeds in the current study. Additionally, an accurate pH prediction could not be made using IROT in the study. No previous article was found in which IROT was used as a tool to predict meat quality in lambs. On the other hand, in light cattle carcasses, Horcada et al. (5) reported significant correlations between IROT and carcass pH. Moreover, they predicted carcass pH using IROT measurements with moderate accuracy (R^2=0.52, P<0.01). However, in a study using predictors other than IROT measurement, McGeehin et al. (18) predict 4h pH with high accurcy (R^2=0.74, RSD=0.11) in lamb by using prediction models include 0.5h pH, live weight, age, and ambient temperature.

Juiciness is an important parameter of meat quality and is related to sensory properties such as texture and taste (19). Because protein and flavor components are also lost along with meat juice loss, meats that lose less water during cooking have higher quality properties (16, 20). Water loss in meat can occur through passive water loss from the surface of the meat, as well as through pressure and cooking. Drip loss and expressed juice parameters were used to evaluate the water holding capacity of meats in the study. IROT was negatively correlated with expressed juice in Karacabey Merino lambs (r = -0.416; P<0.05). This means that the higher the IROT, the lower the expressed juice. Weschenfelder et al. (6) also reported IROT temperature was correlated with drip loss (r = 0.20; P<0.05) in the pigs. In contrast, Horcada et al. (5) found no relationship between IROT and water-holding capacity in young bull meat. Moreover, it has been reached that IROT can be used to predict the expressed juice of meat in Karacabey and Hungarian Merino lambs but with weak accuracy. No linear nor quadratic model to use IROT to predict water-holding capacity in lamb was found in the literature. However, Ekiz et al. (21) used the fatness class, conformation class and carcass weight to predict drip loss and expressed juice (R^2=0.29 and R^2=0.27, P<0.01) in Kivircik lambs. The disadvantage of this result is that the water holding capacity is predicted using the parameters after slaughter.

Although meat colour is slightly correlated to eating quality, it is the most important factor determining consumer preference during the purchasing stage (3). Consumers have a negative view of dark-coloured meat. They generally prefer bright and light red meat to dark meat. Stress factors during the pre-slaughter period (transport, loading/unloading, lack of feed, long lairage period) can cause depletion of muscle glycogen storage. In this case, ultimate meat pH remains high because there is not enough glycogen, and high pH (>5.8) results in dark-coloured meat (22). The mean pH24h values obtained in this study were below 5.8. The mean redness (16.8 – 18.0) and lightness (36.9 – 38.8) values in this study represent light and pink meat. Similarly, the redness and brightness values obtained for lamb were consistent with those of several studies on lamb (21, 20, 23). Moreover, IROT was positively correlated with meat redness (a*1h) and Chroma1h in Kivircik lambs (Table 2). In addition, linear regression equations for a*1h and Chroma1h in Kivircik lambs were significant (P<0.05), but with weak accuracy. The proportion of variation explained by IROT were 16.5% and 16.9% for meat redness and lightness. On the other hand, Ekiz et al. (21) achieved higher accuracy in predicting meat redness in Kivircik lambs (R^2=0.39, P<0.001) and Kangal Akkaraman lambs (R^2=0.37, P<0.01) by using regression equations that included fatness class, conformation class, and carcass weight.

Conclusion

This study tries to find out possible relationships between IROT and some meat quality parameters in different sheep breed. Although significant correlations were observed between some meat quality traits and IROT, these correlations were weak. In other words, when IROT was used as a predictor, significant equations were achieved for expressed juice, redness, and Chroma of meat, but the accuracies of the models were low. In conclusion, under the conditions of this study, IROT values were not effective for accurately predicting meat quality traits in Karacabey Merino, Hungarian Merino, and Kivircik lambs.

Ethical statement

The experimental procedures of the study were approved by the Ethics Committee of the Istanbul University-Cerrahpasa (Approval No: 2021/08).

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