Use of Infrared Thermography for Identifying Physiological and Hematological Conditions of Young Sapera Dairy Goats

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ABSTRAK

Pamungkas FA, Purwanto BP, Manalu W, Yani A, Sianturi RG. 2020. Aplikasi termografi inframerah sebagai indikator dalam penentu kondisi fisiologis dan hematologis kambing perah sapera dara. JITV 25(3): 120-130. DOI: http://dx.doi.org/10.14334/jitv.v25i3.2522

Termografi inframerah (IRT) merupakan salah satu solusi alternatif yang bisa digunakan untuk menggantikan metode invasif yang selama ini digunakan dalam memonitor parameter fisiologis dan hematologis kambing. Dalam konteks ini, penelitian ini bertujuan untuk mengevaluasi kondisi fisiologis dan hematologis kambing perah Sapera dara serta korelasinya dengan hasil penginderaan termografi inframerah. Empat ekor kambing perah Sapera dara dengan kisaran bobot badan 26-28 kg dipelihara pada kandang individu. Suhu permukaan kulit (Ts), suhu rektal (TR), suhu tubuh (Tb), denyut jantung (Hr), frekuensi respirasi (Rr), dan penginderaan termografi inframerah (area mata, mulut, hidung, kaki, tubuh bagian kanan, tubuh bagian kiri, vagina, dan vulva) diukur pada pukul 06.00-18.00 WIB dengan selang waktu pengukuran setiap 2 jam, sedangkan pengambilan sampel untuk pengukuran parameter hematologis dilakukan pada pukul 06.00 dan 18.00 WIB. Hasil penelitian menunjukkan adanya korelasi positif antara hasil penginderaan termografi IR pada berbagai bagian tubuh dengan parameter fisiologis (kecuali denyut jantung), sedangkan dengan parameter hematologis secara umum berkorelasi negatif. Korelasi tertinggi (r = +0.85) dimiliki oleh korelasi antara hasil termografi IR pada bagian kaki kiri belakang dengan suhu tubuh. Termografi inframerah secara umum dapat diterapkan untuk menilai kondisi fisiologis kambing terutama suhu tubuh.

Kata Kunci: Termografi, Inframerah, Parameter Fisiologis, Parameter Hematologis, Kambing Perah

ABSTRACT

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Infrared thermography (IRT) is an alternative solution that can be applied to replace invasive methods currently used in the monitoring of goats' physiological and hematological parameters. This study was done to compare and correlate the physiological and hematological conditions of young Sapera dairy goats and their correlations with results obtained by IRT. Four young Sapera dairy goats (weight of 26-28 kg) were kept in the individual rearing cage. Skin surface temperature (TS), rectal temperature (TR), body temperature (TB), heartbeat (HR), respiration rate (RR), and IRT at eyes, mouth, nose, legs, left body, right body, vagina, and vulva were monitored from 6 a.m. to 6 p.m. in 2 h intervals. Blood samplings were done at the beginning and the end of the obsevation time. Results showed that IRTs at several body parts were positively correlated with physiological parameters, except for heartbeat. Negatively correlation was observed in hematological parameters. The highest correlation (r = +0.85) was observed in the correlation between the results of the left rear leg IRT on TB. It was concluded that IRT can be applied to examine goats' physiological conditions especially body temperature.

Key Words: Thermography, Infrared, Physiological Parameter, Hematological Parameter, Dairy Goat

INTRODUCTION

Body resistance to heat stress is an important factor for dairy goat to maintain optimal productivity according to genetic characteristics. Tyler & Ensminger (2006) report that heat-resistant animals can preserve their body temperatures in a normal range without changing their physiological and productivity status. Goat is a homeothermic animal which can control its body temperature constantly, even in an extreme environmental condition, and can adapt better to the hot environment than other animals (Kawabata et al. 2013; Naandam & Kojo 2014; Hasin et al. 2017; Ribeiro et al. 2018; Façanha et al. 2020).

However, dairy goats can also experience stresses such as physical, nutritional, psychological, and environmental stresses. The most frequently occurred environmental stress is heat stress that indicated by physiologically uncomfortable conditions for the animal (Gupta et al. 2013; Silanikove & Koluman 2015). Dairy goats experience heat stress when there is an unbalanced between heat production in the body or heat obtained from the environment and heat loss to the environment. Homeostatic responses that are generally occurred due to heat stress in goats include the increase in respiration rate, body temperature, and water consumption as well as the reduction in food intake (Gupta et al. 2013; Caulfield et al. 2014), immunity (Tao & Dahl 2013), and even animal death (Sarangi 2018).

On the other hand, several assessments on physiological and metabolic parameters in animal production commonly use invasive methods like the measurements of rectal temperature, respiration rate, and heartbeat as well as blood sample collection (Stewart et al. 2008; da Costa et al. 2015). These methods showed relatively inaccurate results due to an anxiogenic response from the procedure itself that makes difficulties in the interpretation of results (Soerensen & Pedersen 2015). Invasive methods are also subjective, as well as time, and require a lot of labor consumption in the identification of animal production parameters and have less consideration in animal welfare (Blokhuis et al. 2013). Therefore, the use of IRT becomes a good option in the monitoring of goats' physiological and hematological parameters.

IRT is a non-invasive method used in the measurements of heat transfer and blood flow patterns by detecting body temperature changes (Kammersgaard et al. 2013; Alsaaod et al. 2014; Nääs et al. 2014; Roberto et al. 2014; Tattersall 2016). The result obtained from IRT device allows direct monitoring in the temperature distribution at certain objects (Blanik et al. 2014) which helps in understanding the thermoregulation process (Ghahramani et al. 2016). Therefore, the present study aimed to compare and correlate the results obtained from the IRT method at several body objects with the other invasive methods for the assessments of young dairy goats' physiological and hematological conditions.

MATERIALS AND METHODS

This study was conducted at Goat Research Section, Indonesian Research Institute for Animal Production, Ciawi, Bogor, Indonesia situated at the elevation of 450-500 meters above sea level and rain intensity between 3500 and 4000 mm per year. Using animals in this study has been approved by the Experimental Animal Ethics Committee, Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture, the Republic of Indonesia with Registration No. Balitbangtan/Balitnak/Rm/04/2019.

Four young Sapera dairy goats with an average body weight of 26-28 kg were kept in the individual cages of 1.6 m x 1.0 m in size. The cage was located inside an asbestos-roofed building and each cage was made of metal with boarded floor and food container. All goats were fed by C-Prolac concentrate produced by PT. Citra Ina Feedmill Jakarta about 1600 grams per day and king grass silage at the same amount alternately. The feeding schedule was twice a day at 7 a.m. and 3 p.m. Drinking water was given to the animals two hours before feeding schedule using a water bucket provided in each cage.

Physiological responses

Physiological response parameters measured were skin surface temperature (TS), rectal temperature (TR), body temperature (Tb), heartbeat (Hr), and respiration rate (Rr). The physiological responses data were measured from 6 a.m. till 6 p.m. in 2 h intervals. TR was measured by inserting Omron rectal thermometer model MC-245 (Omron Healthcare Co. Ltd., Kyoto, Japan) to the rectum about 5 cm deep. TS were measured by Omron digital thermometer model MC-720 specified for measuring skin temperature (Omron Healthcare Co. Ltd., Kyoto, Japan) at four observation points, *i.e*. back (A), chest (B), upper leg (C), and lower leg (D). The average of TS mean was obtained using formula modified from McLean et al. (1983), while Tb was calculated according to McLean *et al*. (1983) as follows:

$$TS = 0.25\ (A + B) + 0.32\ C + 0.18\ D$$

$$Tb = 0.86\ TR + 0.14\ TS$$

Hr is measured by placing the stethoscope near the left axillary bone, and then the heart rate calculation is performed for one minute. The Rr is measured by placing the stethoscope on the animal's chest, then the calculation of the amount of inspiration and expiration for one minute of respiration.

Hematological parameter profiles

Analysis in hematological parameters was carried out by collecting blood samples at the beginning and the end of heat measurement which was at 6 a.m. and 6 p.m. About 0.5 ml of blood samples were collected from a jugular vein after cleansing the area around the animal's neck with cotton dipped in 70% v/v alcohol so the veins can be easily identified and the blood collection area can be free from dung which may contaminate the samples. The target vein was gently pressed using thumb until puffed. A 20G sterile syringe was employed and injected into the jugular vein at about 1-inch deep. The needle was connected with a vacutainer tube after the blood came out and the angle of the syringe was set to 45º. A little attempt may be required to find the correct needle position for discharging the blood. Each goat was returned to their crib after blood collection and no extra bleeding or inflammation should be confirmed.

Following blood collection, each tube was kept in the iced box and stored in the laboratory for further analysis. Vetscan® HM5 hematology analyzer (Abaxis, Inc. Union City, CA, United States of America) was employed to check all blood profiles including white blood cell (WBC), red blood cell (RBC), lymphocytes (LYM), monocytes (MON), neutrophils (NEU), hemoglobin (HGB), hematocrit (HCT), mean cell volume (MCV), mean cell hemoglobin (MCH), mean cell hemoglobin concentration (MCHC), and red blood cell distribution width (RDWC).

Infrared thermography

Infrared thermography (IRT) was performed using an IR camera FLIR A320 (FLIR Systems Co. Ltd., St. Leonards, NSW, Australia). IRT was employed for thermographic sensing purposes with an emissivity coefficient of 0.98 and carried out in 2 hours interval starting from 6 a.m. till 6 p.m. The IRT was taken at several observation points of each goat including its eyes, mouth, nose, legs, the left side of the body, the right side of body, vagina, and vulva at the distance of about 1 meter from the goats standing point (Fig. 1). All sensing data were saved in the memory card before transferred to a laptop for further analysis using ThermaCAM Researcher Profesional 2.10.

Data analysis

All collected data followed MIXED procedure from SAS (V. 9.1; SAS Institute Inc., Cary, NC, USA). A coefficient correlation between IR thermographic sensing and physiological responses as well as hematological parameters were calculated using the CORR procedure also taken from SAS.

RESULTS AND DISCUSSION

Body temperature, heartbeat, and respiration rate have been extensively examined in goats. Previous investigations using an invasive method in the physiological parameter assessment (Ogebe et al. 1996) showed a coherent association with results produce by a non-invasive method such as IRT (Roberto et al. 2014; Siva et al. 2014; Lecorps et al. 2016). Descriptive analyses of physiological parameters as well as IRT are described in Table 1. Skin temperatures measured by thermometer have values close to the same parameter measured by IRT, particularly at the front and rear legs. Meanwhile, the body temperatures measured physiologically showed almost similar results with body temperature measured by IRT at the vulva. It is important to note that rectal temperature (39.0°C) has a higher value compared to the IR measurement at the vulva (37.7°C). IRT showed high values at vagina and vulva, but low values at body and legs, whereas at eyes and nose it showed medium-ranged temperatures. However, IR measurements at the vagina and vulva showed a less temperature increment (2.1°C) at all observation times compared to the other body parts.

The results obtained from IRT at the leg, either front or rear, closed to the results obtained by invasive method i.e., about ±1°C higher than the skin temperature.

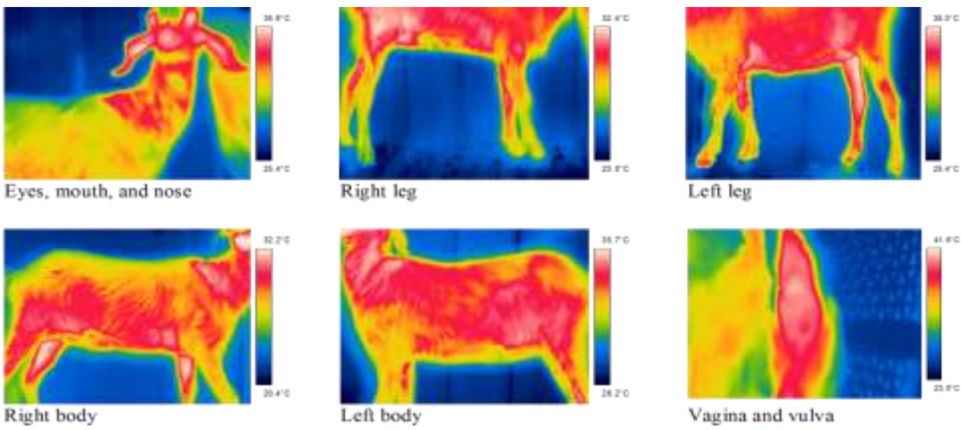

Figure 1. Image results from infrared thermography sensing at several body parts of young Sapera dairy goats

Table 1. Descriptive statistics of physiological condition and infrared thermography (IRT) sensing results of young Sapera dairy goats

Parameter	Mean ± SD	Minimum	Maximum
Physiological condition:			
TS (°C)	31.10 ± 1.84	27.90	33.50
TB (°C)	37.97 ± 0.42	37.10	38.30
TR (°C)	39.00 ± 0.29	38.60	39.30
HR (beat/minute)	95.50 ± 3.89	88.50	99.50
RR (times/minute)	52.64 ± 11.49	39.00	66.00
IRT (°C):			
Mouth and nose	35.90 ± 1.41	33.20	37.30
Right eye	35.57 ± 1.44	32.90	37.00
Left eye	35.73 ± 1.31	33.30	36.90
Right body	33.66 ± 2.26	29.80	36.40
Left body	33.67 ± 2.10	29.90	35.80
Right front leg	32.37 ± 2.27	28.50	34.90
Left front leg	32.43 ± 2.30	28.40	34.70
Right rear leg	32.60 ± 2.26	28.60	35.10
Left rear leg	32.63 ± 2.31	28.40	34.80
Vagina	36.70 ± 1.06	35.20	37.90
Vulva	37.67 ± 0.73	36.40	38.50

TS=Skin temperature; TB=Body temperature; TR= Rectal temperature; HR= Heartbeat; RR= Respiration rate

A similar finding was obtained by Paim et al. (2014) in the IRT at the neck of Santa Ines goat and its breed. In the other IRT studies, McManus et al. (2015) have identified results in a value of 31.29°C at the neck of crossbred goats of Dorset and Santa Ines as well as of 31.44°C at crossbred goats of Dorset and White Doper. The main reason for these similarities, as reported by Popoola et al. (2014), is that skin temperature is an adapted condition of the blood flow in the skin that ends up in the heat regulating process of the body and the skin, in which cattle usually release heat load from their bodies through skins at the neck, ears, and legs in a particular contribution to all body surface. Piccione et al. (2013) report that legs play an important role in the thermoregulation compared to the other body parts due to vasoconstriction in the legs can cause a better mechanism in the heat conversion.

The IRT result at the vulva (37.67°C) closed to the result obtained from body temperature measurement (37.97°C). Hoffmann et al. (2012) obtained a similar result in the IR thermographic sensing at cow's vulva (37.2°C). Different results have been reported by Stelletta et al. (2017) in which IRT at the vulva of Angora goats before lust synchronization is 36.78°C and decreases to 35.40°C at the end of the estrous period. Hoffmann et al. (2012) and Talukder et al. (2015) reported that vulva temperature was the indicator used to identify changes in body temperature as general features of animals' physiology and health. The difference in body temperature measured was due to the difference in the variety of goats used. Simoes et al. (2014) and Stelletta et al. (2017) reported an increase in vulva temperature during the estrous period until approaching ovulation, and then the vulva temperature decreased at the end of the estrous period. The absolute point of vulva temperature can be affected by an environmental condition such as relative humidity, wind speed, and solar radiation. According to Talukder et al. (2014), reduction in vulva temperature at the end of the estrous period is associated with a reduction in estrogen concentration.

The result found a higher rectal temperature compared to the IRT at the vulva. This difference can be acceptable due to rectal temperature measurement using a digital thermometer was considered as the best method to identify goats' condition. However, this method needs time and direct contact with the measured animals. Besides, the method of rectal temperature measurement using a digital thermometer depends on the depth of the penetration. Also, the type of the thermometer as well as the stress level of the animals may affect the value of temperature obtained (Burfeind et al. 2010; Naylor et al. 2012; Hoffmann et al. 2012).

The IRT at vulva showed the highest temperature (37.67°C) but the lowest temperature increased (2.1°C) across the observation time compared to those measured at the other body parts. This finding agrees with the finding reported by Hooper et al. (2018) in which they found the highest value (38.29°C) at vulva using IRT compared to the other body parts and the lowest temperature increment (0.66°C) was found at observation time from 6 a.m. to 6 p.m. In this present study, the lower temperatures at body and legs than at the vagina and vulva were possibly affected by the high thermal isolation due to the difference in skin thickness and fur compactness (Arkin et al. 1991). Moreover, Bianchini et al. (2006) and Radon et al. (2014) suggested that skin and fur may influence heat transfer depending on their color, compactness, diameter, and depth, as well as on heat transmissivity and absorption.

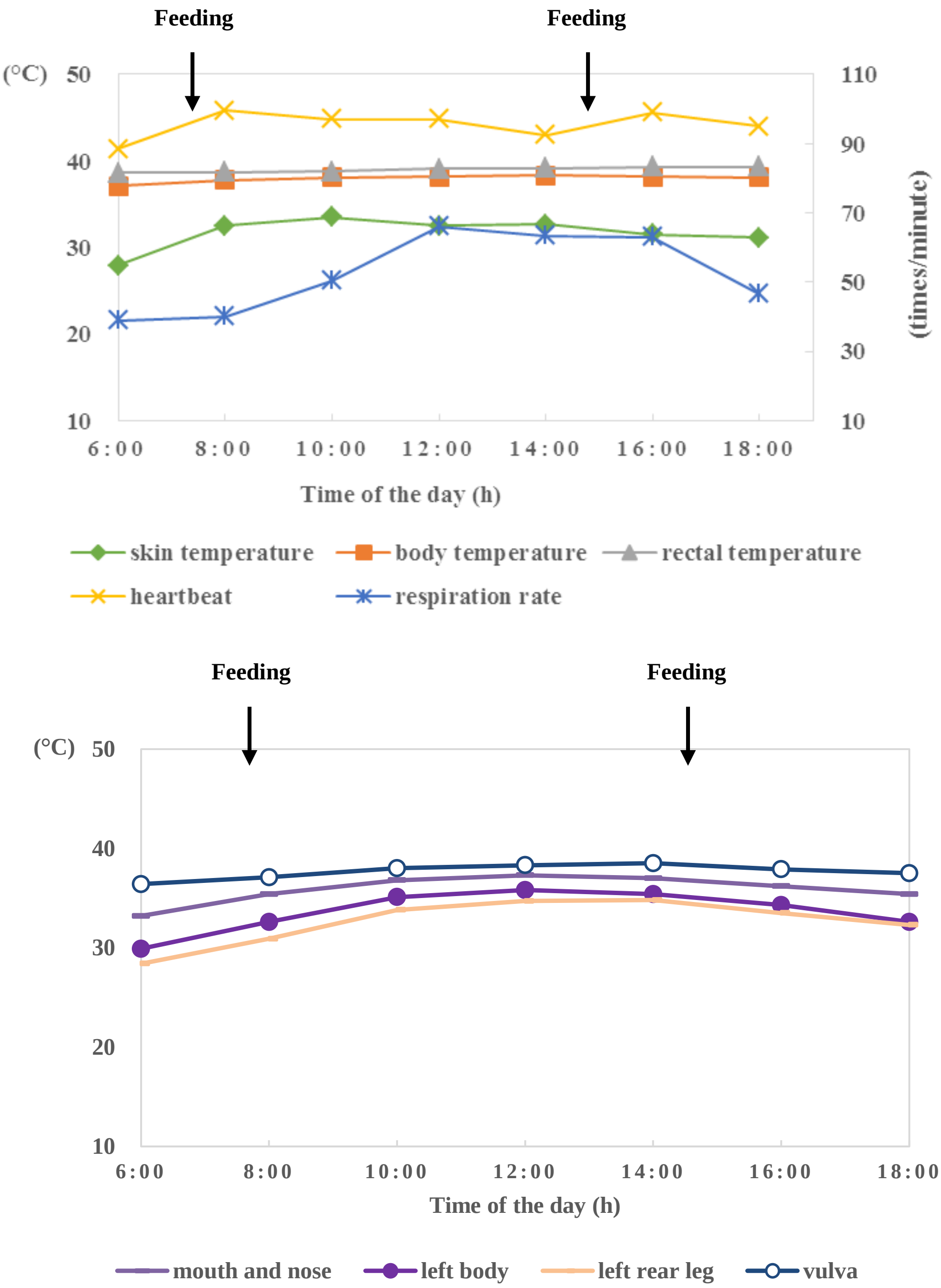

Figure 2. Changes in skin temperature, body temperature, rectal temperature, heartbeat, and respiration rate (A); IRT of mouth and nose, left body, left rear leg and vulva (B) of the goats during the observation

In general, results by IRT showed a similar curve pattern with the RR compared to the HR pattern along the observation time. The mean HR was 95 beats/minute and the RR was 52 times/minute. The IRT results at eyes, mouth, and nose, and the left/right body is in the range between the TS and TB (Fig. 2A). TR and TB have relatively stable changes and have an almost similar pattern with IR image results at the vulva. Similarly, the TS curve performs the same pattern with IRT at the left rear leg (Fig. 2B). All parameters showed significant increments in the feeding time at 7 a.m., but no increase in the feeding time at 3 p.m, except for HR which still showed a significant increase. HR showed two peaks during the whole day which occurred 1 hour after feeding time. A high increase was found in the respiration rate from 8 a.m. to 12 a.m., whereas a big decrease started from 4 p.m. to 6 p.m. (Fig. 2).

Two major peaks observed for the HR (Fig. 2) represents an increase in heat energy release due to feeding that usually occurs about 1 to 2 hours after feeding time. This condition is usually followed by an increase in the TS at several body parts (Montanholi et al. 2008) as is found also in this present study. The increase in heat energy release occurred for 3 to 4 hours after feeding (Puchala et al. 2007). This increase was associated with the protein mobilization process to trigger glucose synthesis (Lawler dan White, 2003). Puchala et al. (2007) suggested that the increase in an HR was caused by an intention to get food and hunger condition as a response of lateral *hypothalamus* and projected to the lateral *medulla* (as host for cells actuating autonomous system including parasympathetic vagal nucleus) and a group of sympathetic system cells in the bone marrow. Moreover, Olsson and Carlsson (1999) suggested that the provision of water and food at the same time may stimulate sensory input in the faring area caused by temporary activation of the sympathetic neural system which may increase HR.

In this study, the average HR about 95 (min 88.5 and max 99.5) beats/minute and RR of 52 (min 39 and max 66) times/minute were obtained. Afshar et al. (2005) reported an average RR and HR of Iranian female goats were as many as 20.2 and 114.2 times/minute, respectively. Hooper et al. (2018) obtained an average RR of Saanen goats about 49.5 times/minute, whereas de Lima et al. (2019) obtained the same from similar breed about 72.6 times/minute after giving birth. In another experiment, Phulia et al. (2010) found an increase in RR from 43.7 to 77.3 times/minute when Sirohi goats stood in a hot environment for six hours. HR and RR increased due to the effects of environmental conditions and body temperature. Increased respiratory action is an attempt to stabilize heat loss by evaporative cooling (Gupta et al. 2013), whereas increased HR is due to the increased muscle activity in combination with the increase in respiration speed and reduction in the peripheral resistance of blood vessel. The increased HR can cause increased blood flow to the body surface that could increase heat loss via conduction, convection, radiation, as well as diffusion from the skin (Marai et al. 2007; Spiers 2012; Okoruwa 2014). Al-Haidary et al. (2012) suggested that the RR could be used to estimate the negative effect of ambient temperature as an indicator of stress due to heat stress. Okoruwa et al. (2013) also suggested that the RR of more than 12-20 times/minute in goats and sheep could be used as an indicator of heat stress. Swollen breath is a mechanism of evaporation due to heat loss and respiration rate tends to follow heat loss because of that evaporation (Marai et al. 2007).

Evaluation in hematological parameters plays an important role to identify animals' prosperity because blood is an important indicator in response to stress due to heat (Okoruwa 2015). Hematological profiles of young Sapera dairy goats did not show significant changes across the observation time (from 6 a.m. to 6 p.m.). However, some changes were found in a few blood parameters, but the increments were very small (Table 2). The blood counts obtained in this present study were still in the reference hematological range for goats (Piccione et al. 2014; Arfuso et al. 2016) and higher values generally occurred in the morning. A study related to heat tolerance in goats has reported a decrease in few blood components in the evening such as HGB concentration (Correa et al. 2012).

Heat can reduce blood count due to hemodilution effect by which lots of water component will be transported by the blood circulation system to help evaporative cooling (Seixas et al. 2017). Almost similar HGB value was found in the experiment on West African Dwarf goats by Opara et al. (2010), whereas higher HGB, MCHC, and WBC values were found in the experiment on Etawah breed goats (Yupardhi et al. 2013) and on the crossbreeding of Saanen and Ettawah (Sarmin et al. 2019). Okonkwo et al. (2011) suggested that results on goat's hematology depended on the type and age of the goats. High HGB value tends to transport more oxygen to blood (Okonkwo et al. 2011). Similarly, higher erythrocyte (MCV, MCH, and MCHC) and WBC indices show a higher oxygen transport capacity on blood (Tsai et al. 2010) and a higher immune system to fight against infection agents (Piccione et al. 2014), especially on young goats than on does.

The associations between IRT results with physiological and hematological parameters are presented in Table 3 and Table 4. The results obtained from IRT sensing were positively correlated ($p < 0.0001$) with goats' physiological parameters (Table 3) such as TB ($r = 0.69$ to 0.85), TS ($r = 0.63$ to 0.76), and

Table 2. Hematological conditions of young Sapera dairy goats during study

Parameters	Observation time		Changes
	6 a.m.	6 p.m.	
RBC (10^6/µL)	15.58 ± 0.42	15.38 ± 0.79	-0.20
HGB (g/dL)	9.45 ± 0.35	9.35 ± 1.02	-0.10
HCT (%)	24.94 ± 0.87	24.63 ± 1.99	-0.31
MCV (fl)	16.25 ± 0.50	16.00 ± 0.82	-0.25
MCH (pg)	6.05 ± 0.17	6.08 ± 0.40	+0.03
MCHC (g/dL)	37.88 ± 1.02	37.93 ± 1.91	+0.05
RDWC (%)	35.30 ± 0.46	35.48 ± 1.40	+0.18
WBC (10^3/µL)	17.89 ± 2.15	17.02 ± 5.28	-0.87
LYM (10^3/µL)	8.39 ± 0.18	7.62 ± 2.17	-0.77
MON (10^3/µL)	0.15 ± 0.05	0.12 ± 0.03	-0.03
NEU (10^3/µL)	9.35 ± 2.03	9.28 ± 3.28	-0.07

RBC = red blood cell, HGB = hemoglobin, HCT = hematocrit, MCV = mean cell volume, MCH = mean cell hemoglobin, MCHC = mean cell hemoglobin concentration, RDWC = red blood cell distribution width, WBC = white blood cell, LYM = lymphocyte, MON = monocyte, NEU = neutrophil

TR (r = 0.48 to 0.67) as well as RR, except HR and hematology. A high positive correlation (r = 0.85) was found between IRT at the rear left leg with body temperature (Table 3). IRT was negatively correlated with hematological parameters (r = -0.01 to -0.71) as described in Table 4, except for neutrophil count (r = 0.32).

The data showed that IRT at different body parts have different correlations with skin temperature, rectal temperature, body temperature, heartbeat, and respiration rate as well (Fig. 2 and Table 3). The difference in the measured body parts is relevant to the heat storage and release (Kenny & Jay 2013). Fluctuations in rectal temperature and respiration rate across the observation time were also investigated by Hooper et al. (2018) with the lowest value occurred at 6 a.m. morning. Several studies (Paim et al. 2014; McManus et al. 2015; Seixas et al. 2017) reported that the lowest temperatures occurred in the morning and reached its peak at noon.

Temperature measurements at several body parts are important to identify the capacity of physiological adaptation of cattle to heat stress on the environment (Silanikove 2000). Experimental results showed a higher positive correlation between IRT testing with TB compared to that with TS or TR and no significant correlation was found between IRT with RR and HR. In this context, IRT is a possible non-invasive method to study temperature and metabolic response due to thermal stress on animals (Paim et al. 2013; Martello et al. 2016; Hooper et al. 2018). Evidence revealed that right and left legs, either front or back, showed a higher correlation with TB, TS, and TR. Piccione & Refinetti (2003) found a strong daily rhythm between TR and leg temperature due to the input rhythm from the suprachiasmatic nucleus at the *hypothalamus* that acts as a thermoregulating agent. D’Alterio et al. (2011) have described body extremity as the main factor in regulating heat storage or loss. Further, D’Alterio et al. (2011) report that goat’s legs play important role in the mechanism related to heat loss by which these body parts have vein tissue rich in branches that make heat transfer be possibly mediated by the increase in blood flow.

A nonsignificant correlation between IRT result and HR was probably due to the absence of thermal pressure during the observation period. Another study suggests that heat stress in animals’ cardiovascular systems may have an effect on the increase in heartbeat, and this effect is associated with the decrease in blood pressure that stimulates HR (Du Prezz 2000). In general, the results of IRT were negatively correlated with hematological parameters. Similarly, some studies found negative associations between ambient air temperature, as well as the temperature-humidity index (THI), and hematological parameters including RBC and HGB concentrations (Correa et al. 2012; Seixas et al. 2017). This finding was associated with hemodilution effect and low RBC count as well as HGB concentration in the animals’ performing high adaptation capacity to environmental condition and showing a negative effect with heat released by their bodies (Seixas et al. 2017).

Table 3. Correlation data between physiological parameters of young Sapera dairy goats and infrared thermography (IRT) results

Physiological parameters	Nose	Right eye	Left eye	Right body	Left body	Right front leg	Left front leg	Right rear leg	Left rear leg	Vagina	Vulva
TS	0.74 ***	0.76 ***	0.67 ***	0.72 ***	0.74 ***	0.73 ***	0.74 ***	0.76 ***	0.75 ***	0.63 ***	0.63 ***
TR	0.51 ***	0.49 **	0.55 ***	0.48 **	0.51 ***	0.57 ***	0.60 ***	0.61 ***	0.67 ***	0.52 **	0.62 ***
TB	0.76 ***	0.76 ***	0.73 ***	0.73 ***	0.76 ***	0.79 ***	0.81 ***	0.83 ***	0.85 ***	0.69 ***	0.75 ***
HR	0.29 ns	0.30 ns	0.38 *	0.27 ns	0.26 ns	0.20 ns	0.19 ns	0.28 ns	0.24 ns	0.19 ns	0.20 ns
RR	0.43 *	0.46 *	0.53 **	0.44 *	0.43 *	0.41 *	0.37 ns	0.45 *	0.41 *	0.39 *	0.57 **

TS=Skin temperature; TR= Rectal temperature; TB=Body temperature; HR= Heartbeat; RR= Respiration rate

*p < 0.05, **p < 0.01, ***p < 0.001, ns = non signifiant

Table 4. Correlation data between hematological parameters of young Sapera dairy goats and infrared thermography (IRT) results

	Nose	Right eye	Left eye	Right body	Left body	Right front leg	Left front leg	Right rear leg	Left rear leg	Vagina	Vulva
RBC	-0.16 ns	-0.16 ns	-0.17 ns	-0.05 ns	-0.16 ns	0.15 ns	0.12 ns	0.01 ns	-0.01 ns	-0.03 ns	-0.02 ns
HGB	-0.21 ns	-0.19 ns	-0.18 ns	-0.08 ns	-0.19 ns	0.09 ns	0.09 ns	-0.04 ns	-0.04 ns	-0.14 ns	-0.17 ns
HCT	-0.32 ns	-0.26 ns	-0.31 ns	-0.18 ns	-0.25 ns	-0.04 ns	0.02 ns	-0.08 ns	-0.07 ns	-0.11 ns	-0.28 ns
MCV	-0.41 ns	-0.32 ns	-0.40 ns	-0.29 ns	-0.33 ns	-0.18 ns	-0.12 ns	-0.16 ns	-0.16 ns	-0.13 ns	-0.39 ns
MCH	-0.20 ns	-0.17 ns	-0.15 ns	-0.08 ns	-0.18 ns	0.03 ns	0.07 ns	-0.06 ns	-0.04 ns	-0.20 ns	-0.23 ns
MCHC	0.04 ns	-0.02 ns	0.06 ns	0.09 ns	-0.03 ns	0.22 ns	0.16 ns	0.03 ns	0.02 ns	-0.12 ns	0.08 ns
RDW	0.19 ns	0.18 ns	0.25 ns	0.17 ns	0.25 ns	0.02 ns	-0.03 ns	0.07 ns	0.07 ns	0.00 ns	0.09 ns
WBC	-0.14 ns	-0.13 ns	-0.16 ns	-0.05 ns	-0.18 ns	0.13 ns	0.10 ns	0.02 ns	-0.02 ns	-0.09 ns	-0.10 ns
LYM	-0.35 ns	-0.35 ns	-0.39 ns	-0.33 ns	-0.45 ns	-0.21 ns	-0.21 ns	-0.27 ns	-0.31 ns	-0.34 ns	-0.36 ns
MON	-0.69 ns	-0.64 ns	-0.59 ns	-0.49 ns	-0.52 ns	-0.44 ns	-0.40 ns	-0.48 ns	-0.45 ns	-0.60 ns	-0.71 ns
NEU	0.01 ns	0.03 ns	0.01 ns	0.14 ns	0.00 ns	0.32 ns	0.29 ns	0.19 ns	0.16 ns	0.08 ns	0.07 ns

*p < 0.05, **p < 0.01, ***p < 0.001, ns = non significant. RBC = red blood cell, HGB = hemoglobin, HCT = hematocrit, MCV = mean cell volume, MCH = mean cell hemoglobin, MCHC = mean cell hemoglobin concentration, RDW = red blood cell distribution width, WBC = white blood cell, LYM = lymphocyte, MON = monocyte, NEU = neutrophil

CONCLUSION

Infrared themography (IRT) shows a curve pattern that was almost the same as the physiological parameters in young Sapera dairy goats from the beginning until the end of the observation. Significant correlations were found between physiological parameters (except HR and hematological) of goats on thermography measurements results at several body parts. The highest positive correlation (r = 0.85) was found between TB and IRT of the left rear leg. Therefore, it was concluded that IRT can be applied to measure goats physiological conditions especially body temperature.

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REFERENCES

Afshar FS, Baniadam A, Marashipour SP. 2005. Effect of xylazine-ketamine on arterial blood pressure, arterial blood pH, blood gases, rectal temperature, heart and respiratory rates in goats. Bull. Vet Inst Pulawy. 49:481-484.

Al-Haidary AA, Aljumaah RS, Alshaikh MA, Abdoun KA, Samara EM, Okah AB, Aluraiji MM. 2012. Thermoregulatory and physiological responses of Najdi sheep exposed to environmental heat load prevailing in Saudi Arabi. Pak Vet J. 32:515–519.

Alsaaod M, Syring C, Dietrich J, Doherr MG, Gujan T, Steiner A. 2014. A field trial of infrared thermography as a non-invasive diagnostic tool for early detection of digital dermatitis in dairy cows. Vet J. 199:281-285.

Arfuso F, Fazio F, Rizzo M, Marafioti S, Zanghì E, Piccione G. 2016. Factors affecting the hematological parameters in different goat breeds from Italy. Ann Anim Sci.. 16:743–757.

Arkin H, Kimmel E, Berman A, Broday D. 1991. Heat transfer properties of dry and wet furs of dairy cows. Trans. ASABE. 34:2550–2558.

Bianchini E, McManus C, Lucci CM, Fernandes MCB, Prescott E, Mariante AS, Egito AA. 2006. Body traits associated with heat adaptation in naturalized Brazilian cattle breeds. Pesq Gropec Bras. 41:1443–1448.

Blanik N, Abbas AK, Venema B, Blazek V, Leonhardt S. 2014. Hybrid optical imaging technology for long-term remote monitoring of skin perfusion and temperature behavior. J Biomedical Optics. 19:1-11.

Blokhuis H, Miele M, Veissier I, Jones B. 2013. Improving farm animal welfare Science and society working together: The Welfare Quality approach. Wageningen (NL): Wageningen Academic Publishers:71-89.

Burfeind O, von Keyserlingk MAG, Weary DM, Veira DM, Heuwieser W. 2010. Short communication: repeatability of measures of rectal temperature in dairy cows. J Dairy Sci. 93:624–627.

Caulfield MP, Cambridge H, Foster SF, Mc Greevy PD. 2014. Review: Heat stress: a major contributor to poor animal welfare associated with long-haul live export voyages. Vet J. 199:223-228.

Correa MPC, Cardoso MT, Castanheira M, Landim AF, Dallago BSL, Louvandini H, McManus C. 2012. Heat tolerance in three genetic groups of lambs in central Brazil. Small Rumin Res. 104:70–77.

Costa ANL, Feitosa JV, Montezuma Jr PA, Souza PT, Araujo AA. 2015. Rectal temperatures, respiratory rates, production, and reproduction performances of crossbred Girolando cows under heat stress in northeastern Brazil. Int J Biometeorol. 59:1647–1653.

Du Prezz JH. 2000. Parameters for the determination and evaluation of heat stress in dairy cattle in South Africa. J Vet Res. 67:263–271.

D’Alterio G, Casella S, Gatto M, Gianesella M, Piccione G, Morgante M. 2011. Circadian rhythm of foot temperature assessed using infrared thermography in sheep. Czech J Anim Sci. 56:293–300.

De Lima RN, de Souza Jr JBF, Batista NV, de Andrade AKS, Soares ECA, CAS Filho, da Silva LA, Costa LLM, Lima PO. 2019. Small Rumin Res. 171:87-91.

Facanha DAE, Ferreira J, Silveira RMF, Nunes TL, de Oliveira MGC, de Sousa JER, de Paula VV. 2020. Are locally adapted goats able to recover homeothermy, acid-base and electrolyte equilibrium in a semi-arid region?. J Therm Biol. 90:1-8.

Ghahramani A, Castro G, Becerik-Gerber B, Yu X. 2016. Infrared thermography of human face for monitoring thermoregulation performance and estimating personal thermal comfort. Build Environ 109:1-11.

Gupta M, Kumar S, Dangi SS, Jangir BL. 2013. Physiological, biochemical and molecular responses to thermal stress in goats. Int J Livest Res. 3:27-38.

Hasin D, Bora A, Goswami J, Barua A, Saleque A, Sarmah BK. 2017. Effects of direct sunshine and melatonin on physiological responses and haematological profiles in

Beetal and Assam hill goat in Assam. Vet Practitioner. 18:89-93.

Hoffmann G, Schmidt M. Ammon C, Rose-Meierhöfer S, Burfeind O, Heuwieser W, Berg W. 2012. Monitoring the body temperature of cows and calves using video recordings from an infrared thermography camera. Vet Res Commun. 37:91-99.

Hooper HB, Silva PS, de Oliveira SA, Merighe GKF, Negrão JA. 2018. Acute heat stress induces changes in physiological and cellular responses in Saanen goats. Int J Biometeorol. 62:2257–2265.

Jakper N, Kojo IA. 2014. Effect of coat colour, ecotype, location and sex on hair density of West African Dwarf (WAD) goats in Northern Ghana. Sky J Agric Res.. 3:25-30.

Kammersgaard TS, Malmkvist J, Pedersen LJ. 2013. Infrared thermography – a non-invasive tool to evaluate thermal status of neonatal pigs based on surface temperature. Anim. 7: 2026–2034.

Kawabata CY, Lindalva AJ, Silva APV, Sousa TV, Cruz LFB. 2013. Physiological responses of caprines raised under diferente types of covering. Revista Engenharia Agrícola. 34:910–918.

Kenny GP, Jay O. 2013. Thermometry, calorimetry, and mean body temperature during heat stress. Compr Physiol. 3:1689–1719.

Lawler JP, White RG. 2003. Temporal responses in energy expenditure and respiratory quotient following feeding in the muskox: influence of season on energy costs of eating and standing and an endogenous heat increment. Can J Zool. 81:1524–1538.

Lecorps B, Rödel HG, Féron C. 2016. Assessment of anxiety in open field and elevated plus-maze using infrared thermography. Physiol Behav. 157:209–216.

Marai IFM, El-Darawany AA. Fadiel A, Abdel-Hafez MAM. 2007. Physiological traits as affected by heat stress in sheep. A review. Small Rumin Res. 71:1–12.

Martello LS, da Luz e Silva S, da Costa Gomes R, da Silva Corte RRP, Leme PR. 2016. Infrared thermography as a tool to evaluate body surface temperature and its relationship with feed efficiency in *Bos indicus* cattle in tropical conditions. Int J Biometeorol. 60:173–181.

McLean JA, Downie AJ, Jones CDR, Strombough DP, Glasbey CA. 1983.Thermal adjustments of stress (*Bos taurus*) to abrupt changes in environments temperature. Camb J Agric Sci. 48:81-84.

McManus C, Bianchini E, Paim TP, de Lima FG, Neto JB, Castanheira M, Esteves GIF, Cardoso CC, Dalcin VC. 2015. Infrared thermography to evaluate heat tolerance in different genetic groups of lambs. Sens 15:17258-17273.

Montanholi YR, Odongo NE, Swanson KC, Schenke FS, McBride BW, Miller SP. 2008. Application of infrared thermography as an indicator of heat and methane production and its use in the study of skin temperature in response to physiological events in dairy cattle (*Bos taurus*). J Therm Biol. 33:468–475.

Naas IA, Garcia RG, Caldara FR. 2014. Infrared thermal image for assessing animal health and welfare. J Anim. Behav Biometeorol. 2:66–72.

Naylor JM, Streeter RM, Torgerson P. 2012. Factors affecting rectal temperature measurement using commonly available digital thermometers. Res Vet Sci. 92:121–123.

Ogebe PO, Ogunmodede BK, McDowell LR. 1996. Behavioral and physiological responses of Nigerian dwarf goats to seasonal changes of the humid tropics. Small Rumin Res. 22:213-217.

Okonkwo JC, Okonkwo IF, Ebuh GU. 2011. Effect of breed, sex and source within breed on the heamatogical parameters of the Nigerian goats. J Anim Feed Res. 1:8–13.

Okoruwa MI, Adewumi MK, Igene FU. 2013. Thermophysiological responses of West African dwarf (WAD) bucks fed *Pennisetum purpureum* and unripe plantain peels. Niger J Anim Sci 15:168-178.

Okoruwa MI. 2014. Effect of heat stress on thermoregulatory, live body weight and physiological responses of dwarf goats in southern Nigeria. Eur Sci J 10:255-264.

Okoruwa MI. 2015. Effect of coat characteristics on physiological traits and heat tolerance of West African dwarf sheep in Southern Nigeria. J Anim Sci. 5:351-357.

Olsson K, Carlsson E. 1999. Cardiovascular changes associated with dehydration and drinking in unrestrained, lactating goats. Exp Physiol. 84:571–578.

Opara MN, Udevi N, Okoli IC. 2010. Haematological parameters and blood chemistry of apparently healthy West African dwarf (WAD) goats in Owerri, South Eastern Nigeria. NY Sci J. 3:68-72.

Paim TP, Borges BO, Lima PMT. 2013. Thermographic evaluation of climatic conditions on lambs from different genetic groups. Int J Biometeorol. 57:59–66.

Paim TP, Martins RFS, Cardoso C, Dallago B, Louvandini H, McManus C. 2014. Thermal comfort index and infrared temperatures for lambs subjected to different environmental conditions. Sci Agric. 71:345-355.

Phulia SK, Upadhyay RC, Jindal SK and Misra RP. 2010. Alteration in surface body temperature and physiological responses in Sirohi goats during day time in summer season. Indian J Anim Sci. 80:340-342.

Piccione G, Refietti R. 2003. Thermal chronobiology of domestic animals. Frontiers in Bioscience. 8:258–264.

Piccione G, Gianesella M, Morgante M, Refinetti R. 2013. Daily rhythmicity of core and surface temperatures of sheep kept under thermoneutrality or in the cold. Res Vet Sci. 95:261–265.

Piccione G, Monteverde V, Rizzo M, Vazzana I, Assenza A, Zumb A, Niutta PP. 2014. Reference intervals of some electrophoretic and haematological parameters in Italian goats: comparison between Girgentana and Aspromontana breeds. J Appl Anim Res. 42:434–439.

Popoola MA, Sakab AA, Olaniyia TA, Yahaya MO, Adebisic GL. 2014. Influence of temperature-humidity index on skin temperature of West African Dwarf goats raised in Nigeria. Agric Adv. 3:28-32.

Puchala R, Luna IT, Goetsch AL, Sahlu T, Carstens GE, Freetly HC. 2007. The relationship between heart rate and energy expenditure in Alpine, Angora, Boer and Spanish goat wethers consuming different quality diets at level of intake near maintenance or fasting. Small Rumin Res. 70:183–193.

Radon J, Bieda W, Lendelova J, Pogran Š. 2014. Computational model of heat exchange between dairy cows and bedding. Computers Electron Agric. 107:29-37.

Ribeiro MN, Ribeiro NL, Bozzi R, Costa RG. 2018. Physiological and biochemical blood variables of goats subjected to heat stress – a review. J App Anim Res. 46:1036–1041.

Roberto JVB, Souza BB, Delfino LJB, Marques BB. 2014. Thermal gradients and physiological responses of goats in the Brazilian semi-arid using thermography infrared. J Anim Behav Biometeorol. 2:11–19.

Sarangi S. 2018. Adaptability of goats to heat stress: A review. Pharma Innov J. 7:1114-1126.

Sarmin, Widiyono I, Anggraini D. 2019. Effect of lactation on haematological constituents in Sapera and Ettawa crossbred goats. IOP Conf. Ser.: Earth Environ Sci. 387:1-4.

Seixas L, de Melo CB, Tanure CB, Peripolli V, McManus C. 2017. Heat tolerance in Brazilian hair sheep. AJAS. 30:593-601.

Silanikove N. 2000. The physiological basis of adaptation in goats to harsh environments. Small Rumin Res 35:181–193.

Silanikove N, Koluman N. 2015. Impact of climate change on the dairy industry in temperate zones: predications on the overall negative impact and on the positive role of dairy goats in adaptation to earth warming. Small Rumin Res. 123:27-34.

Simoes VG, Lyazrhi F, Picard-Hagen N, Gayrard V, Martineau GP, Waret-Szkuta A. 2014. Variations in the vulvar temperature of sows during proestrus and estrus as determined by infrared thermography and its relation to ovulation. Theriogenology. 82:1080–1085.

Siva EMN, Souza BB, Silva GA, Alcantara MDB, Cunha MGG, Marques BAA. 2014. Evaluation of the adaptability of dairy goats in the Brazilian semi-arid region with the aid of infrared thermography. J Anim Behav Biometeorol. 2:95-101.

Soerensen DD, Pedersen LJ. 2015. Infrared skin temperature measurements for monitoring health in pigs: a review. Acta Vet Scand. 57:1–11.

Spiers DE. 2012. Physiological basics of temperature regulation in domestic animals. In: Collier RJ, Collier JL. Editors. Environmental physiology of livestock. 1st Chichester (UK): John Wiley & Sons. p. 17–34.

Stelletta C, Tekin K, Tirpan B, Alemdar H, Cil B, Stelletta FO, Olgac KT, Inanc ME, Daskin A. 2017. Vulvar thermal pattern following synchronization of estrus is linked to fertility after timed artificial insemination in goat. Theriogenology 103:137–142.

Stewart M, Stafford KJ, Dowling SK, Schaefer AL, Webster JR. 2008. Eye temperature and heart rate variability of calves disbudded with or without local anaesthetic. Physiol Behav 93:789–797.

Talukder S, Kerrisk KL, Ingenhoff L, Thomson PC, Garcia SC, Celi P. 2014. Infrared technology for estrus detection and as a predictor of time of ovulation in dairy cows in a pasture-based system. Theriogenology 81:925–935.

Talukder S, Thomson PC, Kerrisk KL, Clark CEF, Celi P. 2015. Evaluation of infrared thermography body temperature and collar-mounted accelerometer and acoustic technology for predicting time of ovulation of cows in a pasture-based system. Theriogenology. 83:739–748.

Tao S, Dahl GE. 2013. Invited review: Heat stress effects during late gestation on dry cows and their calves. J Dairy Sci. 96:4079–4093.

Tattersall GJ. 2016. Infrared thermography: A non-invasive window into thermal physiology. Comp Biochem Physiol A Mol Integr Physiol. 202:78-98.

Tsai AG, Hofmann A, Cabrales P, Intaglietta M. 2010. Perfusion vs. oxygen delivery in transfusion with “fresh” and “old” red blood cells: The experimental evidence. Transfus Apher Sci. 43:69-78.

Tyler HD, Enseminger ME. 2006. Dairy Cattle Science. 4th edition. New Jersey (US): Pearson Education, Inc.

Yupardhi WS, Oka IGL, Mantra IB. 2013. Hematology and blood clinical chemistry of Etawah goat crossbredfed agriculture by products supplemented with optizym enzyme. J Vet. 14:99-104.