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Effects of Heat Stress on Growth Performance, Carcass Traits, Physiological Components, and Biochemical Parameters in Local Algerian Growing Rabbits

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ABSTRACT

Heat stress is a detrimental factor affecting the welfare of all livestock, especially rabbits, as they are sensitive to high temperatures. The current study investigated the effect of high ambient temperature on growth performance, slaughter traits, physiological indicators, and some hematological and biochemical parameters in Algerian local growing rabbits. A total of 48 local rabbits of both sexes (35 days old) were allotted into two groups (24 per group). The control group rabbits were exposed to an ambient temperature and humidity, averaging 21.8 ± 1.3°C and 51.7 ± 3.6%, respectively. Rabbits in the heat stress group were subjected to a warm ambient temperature and humidity of 30.5 ± 1.82°C and 65.5 ± 7.2%, respectively. The growth performance was measured and calculated from 35 to 91 days of age. Physiological indicators (rectal, skin, and ear temperatures, respiratory, and heart rates) were examined at 88 days of age. The carcass traits, blood metabolites, and hematological parameters of rabbits were measured and calculated at slaughter (92 days of age). The obtained results indicated a decrease in body weight, daily gain, and daily feed intake of rabbits in heat stress rabbits, compared to the control group. However, feed conversion ratio was significantly higher in the heat stress group, compared to the control. Heat stress group rabbits showed significantly higher blood metabolite levels, except the glycemia, which was similar in both groups. No significant effect of heat stress was found on the carcass yield, anterior, posterior, and intermediate parts of the carcass. However, the yield of the other components of the carcass (liver, kidney, peritoneal and inter-scapular fat) was significantly lower in the heat stress group. In the heat stress group, rectal, skin, and ear temperatures as well as heart and respiratory rates, were significantly higher than those of the control group. In the present experimental conditions, exposure of local rabbits to chronic heat stress could induce some changes to biological, physiological, and biochemical parameters leading to altered growth performance.

Keywords: Carcass yield, Growth performance, Heat stress, Local rabbit, Metabolic profile, Thermoregulation

INTRODUCTION

Rational rabbit farming is currently of great importance due to its potential contribution to satisfying the growing human population's need for animal proteins (Dalle Zotte, 2014; Cherfaoui, 2015). Rabbit production is advantageous due to the high prolificacy and short biological cycle of rabbits as well as nutritional and organoleptic qualities of rabbit meat (Lebas, 2007; Ibitoye et al., 2010; Dalle Zotte, 2014).

Despite the importance of rabbit breeding in Algeria, its breading system remains very traditional (Saidj et al., 2013). Production is almost entirely restricted to the local rabbit population and commercial hybrid rabbit descendants (Cherfaoui, 2015; Zerrouki et al., 2014; Belabbas et al., 2019). A few modern farms rear the selected rabbit strains in a small proportion (Moula and Yakhlef, 2007).

Algeria has a long hot climate season from May to October, with an ambient temperature ranging from 28 to 35°C corresponding to chronic heat stress with frequent acute peaks of about 40-45°C (Temim, 2000; Zerrouki et al., 2005). During the last three decades, the most important topic of animal production research has been the impact of heat stress on productivity, and studies have been concerned with ways to improve production under these conditions (Gonzalez-Rivas et al., 2020; Thornton et al., 2021), for different species such as cow (Srikandakumar and Johonson., 2004), chicken (Dahmani., 2009), pig (Mayorga et al., 2018) and rabbit (Ajao and Ola, 2021)

Rabbits are very sensitive to extreme environmental conditions, particularly high temperatures, due to their heavy fur coats and non-functional sweat glands, which complicate the excess body heat elimination processes (Verga et al., 2007; Adelodun, 2015; Khaled, 2017). With high tolerance to low temperatures (Fayez et al., 1994a; Verga et al., 2007; Ashour et al., 2017), the ideal safest temperature for rabbits ranges 16-21°C (thermo-neutrality zone, Fayez et al., 1994a; Marai and Habeeb, 1994; Ashour et al., 2017). When the rabbits are exposed to high temperatures (above 25-30°C), they try to dissipate the excessive heat by various mechanisms, including thermoregulatory reactions. These thermoregulatory

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reactions affect rabbits by disrupting their physiological functions and behavioral performance (El Sabry et al., 2021; Mutwedu et al., 2021; Liang et al., 2022), such as impairment of appetite, alteration of the feed efficiency and growth performance, milk yield, and reproduction in rabbits, leading to considerable production and economic losses (Plá et al., 1994; Zeferino et al., 2011). It was reported that a reduction of body temperature to 1°C or less suppresses both physiological and growth performance in livestock (Manca et al., 2018).

Several researchers have investigated the characterization of the local rabbit population in Algeria since it is a popular population used by family farms with low sensitivity to heat (Ilès, 2017; Belabbas et al., 2019; Saidj et al., 2019). However, only a few studies have focused on the effect of heat stress on rabbits' production and productivity traits. These studies investigated the impact of heat stress on zootechnical performance while overlooking the adaptive capacity of thermoregulation as well as physiological, biochemical, and hematological responses. Therefore, the current study aimed to investigate the effects of environmental temperature (thermo-neutrality and chronic heat stress) on growth performance, carcass yield, thermoregulatory parameters, plasma hematological parameters, and biochemical parameters in local Algerian rabbits during the growth and fattening period.

MATERIALS AND METHODS

Ethical approval

This research was approved by the scientific council of the High National Veterinary School of Algiers, Algeria, with certificate reference 204/FDRS/2022.

Study design

The present work was carried out at the rabbitry of the High National Veterinary School in Algiers, Algeria. The trial lasted 8 weeks during the hot months (July to August 2018). A total of 48 rabbits aged 35 days from the local Algerian population were checked by a veterinarian, then weighed and divided into two main groups of 24 rabbits with an average weight of 662 ± 9 g. These rabbits were born and bred within the rabbitry of the High National Veterinary school of Algiers and were subjected to a week of adaption (28-35 days). Each group was divided into six cages with a mean of four rabbits per cage (six replicates for each group). The animals were housed in standard fattening cages of 54 cm × 59 cm × 35 cm. The first group acted as the control (C) group and was kept in a partially air-conditioned house at thermo-neutrality with an average temperature of 21.8 ± 1.3°C and an average humidity of 51.7 ± 3.6%. The second group (HS) was kept in a different hutch and exposed to seasonal variations in the ambient temperature during the summe with an average temperature of 30.5 ± 1.82°C and an average humidity of 65.5 ± 7.19 %. Two hygro-thermometers were placed in the middle of the building for each hutch. To determine the average Temperature-humidity index (THI) values, ambient temperature and relative humidity (RH) were recorded five times daily at 8, 10,12,14, and 16 hours. The THI, an indicator of thermal comfort level for animals, was calculated using the following formula (Marai et al., 2001):

$$THI = db°C - [(0.31 - 0.31\times RH\%) \times (db°C - 14.4)]$$

Where, db°C is the dry bulb temperature in centigrade and RH denotes relative humidity (%).

The THI values were calculated to evaluate the intensity and severity of heat stress (HS) under the environmental conditions classified as the absence of heat stress (< 27.8 centigrade), moderate heat stress (27.8-28.8 centigrade), severe heat stress (28.9-29.9 centigrade), and very severe heat stress (> 30 centigrade). The rabbits in both groups had access to the same food and water *ad libitum* throughout the trial (which lasted from 28 to 91 days, including one week of adaptation from 28 to 35 days). A commercially available, well-balanced pelleted meal was fed to the rabbits. The composition and chemical analysis of the food were carried out using AFNOR-(1985) recommendations (Table1).

Growth performance

During the experimental period, the growth performance of rabbits was recorded and calculated as initial and final live body weights, the daily body weight gain, and the daily feed intake. Finally, the feed conversion ratio (FCR) was calculated for each group.

Physiological indicators

Thermoregulatory parameters of rabbits recorded include rectal temperature, skin temperature, ear temperature, respiratory rate, and heart rate. All efforts were made to ensure that measurements were taken under no additional environmental stress. Measurements were taken on day 88 (between 12 and 2 p.m. as the hottest time of the day) in 10 rabbits (with an average weight representative of the batch) from each group. The temperature measurements were taken using a digital medical thermometer (Thermoval Hartmann, Belgium). The rectal temperature was taken by introducing the thermometer 2-3 cm approximately in the rectum of the rabbit (Askar and Ismail, 2012). For the skin temperature, the thermometer was inserted inside a fold of skin, and the ear temperature was measured by placing the thermometer into the central internal surface area of the auricle (Marai et al., 2004). The respiratory rate was measured by counting the rabbit's flank abdominal movements for one minute using a stopwatch (Clock Mark1, Chine, Mousa-Balabel, 2004;

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Abdalla and Intsar, 2009). Finally, the heart rate was measured using a stethoscope (KaWe, Germany) for one minute (Mousa-Balabel, 2004).

Carcass traits

On the day after the experiment was over (day 92), 10 rabbits from each group were weighed and slaughtered (without fasting) to record slaughter yield and carcass quality measurements. The carcass dissection procedures and the carcass characteristics evaluation were carried out according to the World Rabbit Science Association (WRSA) recommendations, as described by Blasco and Ouhayoun (1993). Slaughter weight (SW) was recorded just after slaughter. After complete bleeding, slaughtered rabbits were skinned, and skin weight (S) was recorded, then the skin yield (S/SW) was calculated (skin weight as SW%). The slaughtered rabbits were eviscerated (the digestive tract and urogenital organs were removed), and their digestive tract was weighed. The intermediate and the fore and hind legs were kept to conform to the regulations of commercial carcass presentation in Algerian markets (Lounaouci, 2001). The remaining parts, which were considered hot carcasses, were chilled at 4ºC for 24 hours. After chilling, the carcasses were weighed. Chilled carcass (CC) and the carcass yield was calculated (CC weight as SW percentage). Subsequently, the liver, kidneys, perirenal fat, and inter-scapular fats were removed and weighed, and then the head was separated. The remaining parts of the carcasses were dissected into three anatomical parts (between the seventh and eighth thoracic vertebrae, and between the sixth and seventh lumbar vertebrae), also known as the fore part, intermediate part, and hind part, respectively. These parts were also weighed. Finally, the proportions of the different organs and parts (liver, kidneys, perirenal and inter-scapular fats, fore, intermediate and hind parts) to CC were calculated.

Blood sample

On day 92, 10 rabbits with similar average weights were slaughtered (in the fed state) and used to determine blood parameters. The blood samples were taken at the hottest time of the day (between 12-2 p.m.). Two blood samples, each 5 ml, were collected from each rabbit. The first blood samples from all the rabbits were put into tubes containing Ethylene diamine tetraacetic acid. They were analyzed shortly after collection for hematological parameters, namely hemoglobin concentration (Hb), hematocrit percentage (Hct), red blood cell count (RBC), white blood cell count (WBC), lymphocyte percentage, and monocytes percentage. These parameters were measured on fresh blood using automated hematology analyzers (automate Scil Vet abc Plus, France) as described by Post et al. (2003). The second blood samples were collected into heparinized tubes and centrifuged at 3000 rpm for 10 minutes (Sigma, Germany). The blood plasma was collected and put away at -20°C awaiting investigation. To determine the biochemical parameters, a Spectrophotometer (LKB Novastec, Austria) and a commercial kit (SPINREACT, SA, Spain) were used to analyze the blood plasma's glucose, cholesterol, triglycerides, total proteins, urea, and creatinine.

Statistical analysis

Statview software (Abacus Concepts, 1996, Incorporation, Berkeley, CA94704-1014, USA) was used to analyze all the measured parameters to find out how heat stress affects the parameters subjected to one-factor analysis (ANOVA). Fisher test was performed, and the data are shown as means ± standard error and the level of significance at $p < 0.05$.

Table 1. Composition and chemical analysis of the diet of local Algerian rabbits given to both groups

Ingredients	**Percentage**
Corn grain	4
Barley grain	17.7
Wheat bran	30
Soybean meal	8
Alfalfa	38
Limestone	0.5
Dicalcium phosphate	0.3
Sodium chloride	0.5
Premix*	1
Chemical composition (%DM)	**Percentage**
Dry matter	90.4
Crude protein	17.3
Crude fiber	13.9
Fat	2.2
Minerals	7
Crude energy (Kcal/kg)	3460
Digestible energy (Kcal/kg)	2460

DM: Dry matter, Premix: Mineral and vitamin complement. *1kg premix: Methionine (%) 10, Sodium (%) 9.9, Calcium (%) 20.3, Chlorine (%) 15.3, Vitamin A (IU/kg) 1000000, Vitamin D3 (IU/kg) 150000, Vitamin E (mg/kg)1000, Vitamin K3 (mg/kg)100, Vitamin B1 (mg/kg) 100, Vitamin B2 (mg/kg) 300, Vitamin B3(mg/kg) 2000, Vitamin B5 (mg/kg) 600, B6 (mg/kg)150, B9 (mg/kg) 20, Vit B12 (mcg) 1000, Choline Chloride (mg/kg) 25000, Iron (mg/kg) 5000, Manganese (mg/kg) 7000, Copper (mg/kg) 1000, Zinc (mg/kg) 5000; Iodine (mg/kg) 100, Selenium (mg/kg) 25, Antioxidant (mg/kg) 41.6.

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RESULTS

The temperature-humidity index

The average, maximum, minimum, ambient temperature, Relative humidity, and THI values are shown in Table 2. The daily average THI is shown in Figure 1 for the whole experimental period (35-91 days). The estimated average THI values were 31.3 and 22 for the HS and C groups, respectively. Minimum and maximum THI averages in both hutches were 27.4 and 34.7 for the HS group and 19 and 24.2 for the C group, respectively.

Physiological indicators

Heart rate, respiratory rate, rectal temperature, skin temperature, and ear temperature are shown in Table 3. Heat stress negatively affected all thermoregulatory parameters. Rectal temperature, skin temperature, ear temperature, and heart and respiratory rates were +1.34°C, +1.09°C, + 3.44°C, 34.8 beats/minute and 15.7 breaths/minute higher in the HS group than the control, respectively ($p < 0.05$).

Growth performance

The effects of chronic heat stress on body weight, body weight gain, feed intake, and FCR in local Algerian rabbits are presented in Table 4. At the beginning of the experiment (age of 35 days), the rabbits of both groups had almost similar initial live weights (control versus heat stress = 655.61 ± 23.19 g versus 668.88 ± 30.8 g, $p > 0.05$). At the end of the fattening period (day 91), decreases of 10%, 14%, and 13% were respectively recorded in the body weight, average daily gain, and average daily feed intake of the HS group, compared to the C group ($p < 0.05$). However, FCR was significantly higher in the HS group compared to the C group (+11%, $p < 0.05$).

Carcass traits

Table 5 compares carcass yield, weights and proportions of the perirenal and inter-scapular fats, kidney, liver, and different parts of the carcass. Statistical analysis revealed that rabbits subjected to heat stress had a lower average live weight at slaughter than rabbits reared at thermo-neutrality (-9%, $p < 0.05$). It has also been shown that the skin and the full digestive tract were both lighter in weight (-13% and -18%, $p < 0.05$, respectively). However, both groups recorded similar results for the chilled carcass weight, carcass yield, and skin yield. Average weights of the liver, kidneys, inter-scapular, and perirenal fats were lower (26%, 19%, 26%, and 40%, $p < 0.05$) in rabbits of the HS group than in the C group. The proportions of the liver, kidney, inter-scapular and perirenal fats to chilled carcass were significantly higher in the C group, compared to the HS group (19%, 12%, 19, 33%, $p < 0.05$, respectively). No differences were recorded in weights and proportions of different parts of the carcass except in the weight of the hind part, which was reduced by 9% in the HS group, compared to the C group (453.18g versus 498.51, $p < 0.05$).

Biochemical and hematological parameters

The effect of heat stress on blood biochemistry and hematological parameters is presented in Table 6. A significant increase in the concentrations of plasma triglyceride (36%, $p < 0.05$), cholesterol (21%, $p < 0.05$), total proteins (11%, $p < 0.05$), urea (11%, $p < 0.05$) and creatinine (15%, $p < 0.05$) were recorded in the HS group, compared to C group, whereas a significant difference was not observed in plasma glucose concentration between the two groups ($p < 0.05$). The hematological parameters were significantly influenced by the heat stress of local Algerian rabbits, compared to those under thermos-neutrality ($p < 0.05$). The present results are shown in Table 6. A significant increase in RBC count, Hb concentration, Hct percentage, and monocyte rate was recorded in the HS group, compared to the C group (36%, 9%, 5%, and 16%, $p < 0.05$, respectively). However, a decrease in WBC count (25%, $p < 0.05$) and an insignificant decrease in the lymphocyte level (10%, $P > 0.05$) were registered in HS group.

Table 2. The average temperature, humidity, and temperature-humidity index during the experimental period in rabbitries

Group	Temperature (°C)			Relative humidity (%)			THI		
	Min	Max	Av	Min	Max	Av	Min	Max	Av
Control	19.00	23.8	21.8 ± 1.28	44.4	60.6	51.7 ± 3.50	19	24.2	22 ± 1.37
Heat stress	26.9	33.6	30.5 ± 1.82	48.5	78.4	65.5 ± 7.19	27.4	34.7	31.3 ± 1.91

Min: Minimum, Max: Maximum, Av: Average, THI: Temperature-humidity index

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Table 3. Effect of heat stress on the thermoregulatory parameters of local Algerian rabbits

Items	Control	Heat stress	SEM	p-value
Heart rate (beats/minute)	85.2 ± 1.36	120 ± 2.50	1.93	p < 0.05
Respiratory rate (breaths/minute)	68 ± 2.18	83.7 ± 0.98	1.58	p < 0.05
Rectal temperature (°C)	38.74 ± 0.09	40.08 ± 0.12	0.10	p < 0.05
Skin surface temperature (°C)	38.15 ± 0.17	39.24 ± 0.17	0.17	p < 0.05
Ear surface temperature (°C)	33.46 ± 0.18	36.9 ± 0.15	0.16	p < 0.05

SEM: Standard error of the mean

Table 4. Growth performance of local Algerian rabbits subjected to heat stress

Traits	Control	Heat stress	SEM	p-value
Body weight at 35 days (g)	655.61 ± 23.19	668.88 ± 30.8	27	p > 0.05
Body weight at 91 days (g)	2269.67 ± 53.26	2052.28 ± 38.13	45.49	p < 0.05
Body weight gain (g)	28.88 ± 0.40	24.74 ± 0.57	0.48	p < 0.05
Feed intake (g)	87.79 ± 3.59	76.27 ± 2.77	6.36	p < 0.05
Feed conversion ratio	3.01 ± 0.06	3.39 ± 0.05	0.05	p < 0.05

SEM: Standard error of the mean

Table 5. Effect of heat stress on carcass traits of local Algerian rabbits

Traits	Control	Heat stress	SEM	p-value
Weight (g)				
Average live weight at slaughter	2259.49 ± 68.20	2045.82 ± 45.75	56.97	p < 0.05
Skin weight	211.89 ± 8.44	183.18 ± 4.83	6.63	p < 0.05
Full digestive tract weight	428.28 ± 15.07	349.58 ± 15.68	15.37	p < 0.05
Chilled carcass	1423.22 ± 48.69	1314.26 ± 31.09	39.89	p > 0.05
Liver	77.41 ± 2.58	56.94 ± 2.72	2.67	p < 0.05
Kidney	12.42 ± 0.44	10.09 ± 0.29	0.36	p < 0.05
Interscapular fat	7.01 ± 0.64	5.18 ± 0.43	0.53	p > 0.05
Perirenal fat	22.71 ± 2.20	13.59 ± 0.98	1.59	p < 0.05
Fore part	458.58 ± 13.59	425.65 ± 11.37	12.48	p > 0.05
Intermediate part	228.61 ± 12.07	220.08 ± 8.84	10.45	p > 0.05
Hind part	498.51 ± 17.59	453.18 ± 9.98	13.78	p < 0.05
Yield (%)				
CC/SW	62.89 ± 0.05	64.67±1.90	1.20	p > 0.05
S/SW	9.35 ± 0.17	8.96±0.13	0.15	p > 0.05
Proportion (%)				
L/CC	5.50 ± 0.21	4.42 ± 0.29	0.25	p < 0.05
K/CC	0.88 ± 0.02	0.77 ± 0.02	0.02	p < 0.05
PF/CC	1.55 ± 0.11	1.03 ± 0.06	0.08	p < 0.05
ISF/CC	0.48 ± 0.03	0.39 ± 0.03	0.03	p < 0.05
FP/CC	32.33 ± 0.28	31.53 ± 0.81	0.54	p > 0.05
IP/CC	15.90 ± 0.42	16.65 ± 0.41	0.41	p > 0.05
HP/CC	35.03 ± 0.25	34.54 ± 0.3	0.27	p > 0.05

CC: Chilled carcass, FP: Fore part, HP: Hind part, ISF: Interscapular fat, IP: Intermediate part, K: Kidney, L: Liver, PF: Perirenal fat, S: Skin, SW: Live weight at slaughter, SEM: Standard error of the mean

Table 6. Effect of heat stress on the biochemistry and hematological parameters of local Algerian rabbits

Parameters	Control	Heat stress	SEM	p-value
Biochemistry				
Glucose (mmol/L)	8.15 ± 0.33	7.77 ± 0.22	0.27	p > 0.05
Triglycerides (mmol/L)	1.36 ± 0.04	2.12 ± 0.06	0.05	p < 0.05
Cholesterol (mmol/L)	2.13±0.09	2.69 ± 0.11	0.10	p < 0.05
Total Proteins (g/L)	74.08 ± 2.08	83.43 ± 2.51	2.29	p < 0.05
Urea (mmol/L)	6.60 ± 0.22	7.42 ± 0.27	0.24	p < 0.05
Creatinine (mg/dl)	1.37 ± 0.04	1.61 ± 0.05	0.04	p < 0.05
Hematology				
Hemoglobin (g/dl)	10.46 ± 0.25	11.44 ± 0.19	0.22	p < 0.05
Haematocrit (%)	35.11 ± 0.63	36.94 ± 0.59	0.61	p < 0.05
Red blood cells count (*10^3/µl)	1.41 ± 0.09	2.21 ± 0.28	0.18	p < 0.05
White blood cells count (*10^3/µl)	8.23 ± 0.64	6.19 ± 0.56	0.60	p < 0.05
Lymphocytes (%)	65.91 ± 2.95	59.32 ± 2.21	2.58	p > 0.05
Monocytes (%)	13.51 ± 0.78	16.07 ± 0.73	0.75	p < 0.05

SEM: Standard error of the mean

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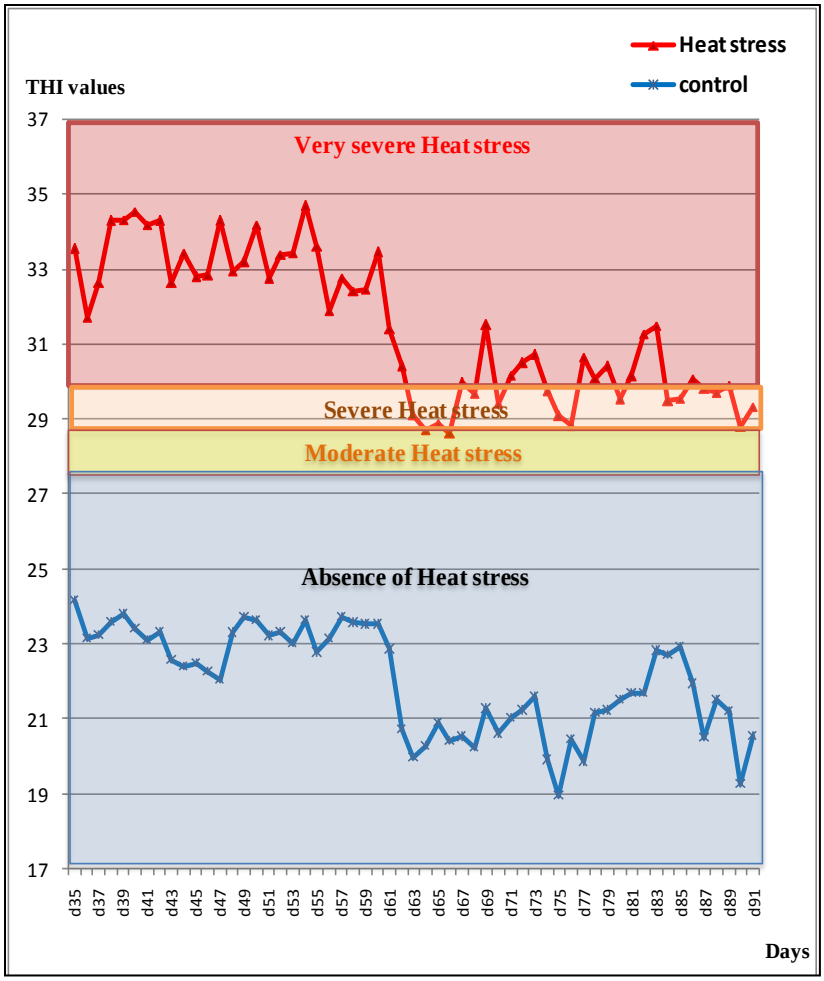

Figure1. Evolution of daily mean temperature-humidity index during the experimental period (35-91 days)

DISCUSSION

Temperature-humidity index

The recorded values of THI during this experiment strongly show that the control group was indeed raised in thermo-neutrality (22 ± 1.37) whereas the rabbits of the heat stress group were exposed to severe heat stress (31.3 ± 1.91). Similarly, a study by Marai et al. (2001) revealed that THI values <27.8 corresponded to the absence of heat stress, whereas THI values more than >30 indicated the presence of heat stress. The recorded temperatures for both groups showed that the control group was subjected to temperatures within the range of 18-21°C corresponding to thermoneutrality (comfort zone for rabbits) whereas the rabbits of the second group were indeed subjected to temperatures exceeding 30°C which in turn correspond to chronic heat stress (Fayez et al., 1994a; Marai and Habeeb, 1994).

Physiological indicators

All thermoregulatory parameters are affected by heat stress (Heart rate, respiratory rate, and body, skin, and ear temperatures). Abdelnour et al. (2020) considered that rabbits could keep their body temperature constant by regulating heat loss using physical and morphological processes. The results obtained in this study are similar to some previous studies (Khalil et al., 2014; Adelodun., 2015; Sabah et al., 2017). During heat stress, both indicators (rectal temperature and respiratory rate) suggested a compensatory response of the animals to the imposed thermal stress (Yamani and Khalil 1994). Verma et al. (2000) considered rectal temperature as one of the most sensitive indicators of heat tolerance This has also been confirmed by many other studies, concerned with physiological reactions conditions on animal species, such as cows (Srikandakumar and Johonson., 2004), chickens (Dahmani., 2009), pigs (Waltz et al ., 2014) and rabbits (Ajao and Ola, 2021)

Rabbits are very sensitive to extreme environmental conditions, particularly ear temperatures due to rabbit exposure to severe heat stress has been confirmed by previous studies on fattening rabbits during chronic heat stress (Adelodun, (2015), on adult rabbits in chronic heat stress (Asemota et al., 2017; Sabah et al., 2017; Ajao and Ola, 2021), and young rabbits during acute heat stress (Amici et al., 2000; Khalil et al., 2014).

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The rectal temperature values obtained in the current study are not in agreement with the values recorded by Zeferino et al. (2011), who showed no effect of heat stress on rectal temperature, and they assumed that rabbits have an efficient thermoregulatory system. Furthermore, rabbits raised in warm conditions increased their respiratory rate (16 breaths/minutes, $p < 0.05$), compared to rabbits raised in optimal conditions. Present results are in agreement with several studies on growing rabbit (Zeferino et al., 2011; Adelodun, 2015) and on adult rabbits (Popoola et al., 2014; Jimoh and Ewuola, 2016; Asemota et al., 2017). However, Marai et al. (1999) did not find a significant difference in respiration rate between rabbits raised in hot conditions and those raised under thermo-neutrality conditions.

It was reported that hyperthermia is associated with tachycardia (Juneet et al., 2013). Hyperthermia produces a hyper-metabolic state with increased catecholamine stimulation, tachycardia, and possibly an increased risk of ventricular fibrillation and ventricular tachycardia. The present study reported an accelerated heart rate in the rabbits subjected to chronic heat stress (35 beats/minutes). These results agree with the reports of Adelodun (2015), Jimoh and Ewuola (2016), Asemota et al. (2017), and Sabah et al. (2017). However, the study by Abdalla and Intsar (2009) reported a slower heart rate for rabbits raised in summer than in winter.

Rabbits are very sensitive to high temperatures (above 25-30°C) since they have few functional sweat glands limiting their ability to eliminate excess body heat (Adelodun, 2015; Abd El-Monem et al., 2016, Mousa-Balabel et al., 2017), in addition to their perspiration being hindered by their fur (Marai et al., 2001). When animals are exposed to high temperatures above 25-30°C, their body temperature rises. Rabbits try to balance the excessive heat load using different means to dissipate it as much as possible (Abdel-Hamid and Dawod, 2015; El Sabry et al., 2021; Mutwedu et al., 2021).

In order to dissipate heat, rabbits respond in a number of mechanisms, such as increasing vasodilatation with increased blood flow to the skin surface. Sweating and speeding their respiratory rate are other means that help rabbits release heat by vaporizing high moisture through respiratory air accounting for 30% of total heat dissipation (Mousa-Balabel, 2004). Rabbits stretch their ears to dissipate heat through radiation and convection, similar in function to a radiator (Marai et al., 2007). These responses make the heart work hard and result in the body's loss of salt and water through perspiration and urination, affecting the rabbit's efficiency, and causing haemo-concentration (Farghly et al., 2021; Oladimeji et al., 2022). Exposing rabbits to severe heat stress activates physiological mechanisms to balance the excessive heat load, leading to an increase in the thermoregulatory parameters (Adelodun et al., 2015; Jimoh and Ewuola, 2016; Abd El-Monem et al., 2016).

Growth performance

All growth performance parameters were lower in heat stress than in thermo-neutrality. A significant decrease was observed in final body weight, daily weight gain, and feed intake ($p < 0.05$).

The animals raised under heat stress had noticeably lost weight, especially during the last two weeks of the experiment, which is in agreement with the findings of the studies of Lakabi (2010), who reported a decrease of 13% in the live weight of local Algerian rabbits aged 11-14 weeks raised in summer, compared to those raised in optimal conditions. Similar results have already been reported in other studies conducted on rabbits of selected breeds during the growing period (Dalle Zotte and Paci, 2014; Terhes et al., 2018; Matics et al., 2021), and on the adult rabbits by Okab et al. (2008) and Khaled (2017) confirming that all rabbits show the same response regardless of breed, age or gender. The FCR was significantly higher in HS rabbits ($p < 0.05$) than in thermoneutrality rabbits during 35-91 days, which can be explained by better feed efficiency in thermoneutrality rabbits. The results are echoed in studies of Marai et al. (1999) and Ali and Abdel-Wareth (2014), who have reported a lower feed efficiency in HS rabbits leading to a higher FCR. On the other hand, Fayez et al. (1994b), Ayyat and Marai (1997), and Zeferino et al. (2011) did not find a significant effect of heat stress on FCR. On the contrary, other studies have found a lower FCR in rabbits raised in heat stress conditions leading to higher feed efficiency (Ondruska et al., 2011; Terhes et al., 2018; Matics et al., 2021).

The failure in the zootechnical performance of rabbits subjected to thermal stress is probably due to the reduction in feed intake (Ali and Abdel-Wareth, 2014; Liang et al., 2022). A decrease in feed consumption is a common reaction to heat stress conditions (Ali and Abdel-Wareth, 2014; Okab et al., 2008). This reduction is the result of the peripheral thermal receptors stimulation, which transmit suppressive nerve impulses to the appetite center in the hypothalamus, causing a decrease in feed intake (Dalle Zotte and Paci, 2014; Terhes et al., 2018; Liang et al., 2022), thereby a decreased feed efficiency and live weight (Farghly et al., 2021; Oladimeji et al., 2022). Ali and Abdel-Wareth (2014) suggested that the lower body weight may be due to the increase in energy consumption by increasing the respiratory rate during heat stress. Hence, low metabolizable energy is left for growth requirements, which explains the low weight of animals exposed to heat stress.

Carcass traits

The HS rabbits recorded a significantly lighter live weight at slaughter and lower skin and digestive tract weights than thermoneutrality rabbits. These findings probably resulted from a decrease in feed intake and poor feed efficiency, leading to the harmful effects of chronic heat stress ($p < 0.05$). Lakabi et al. (2004) reported similar results to those of

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the present study, indicating that local Algerian rabbits raised under heat stress recorded lighter weights of skin and digestive tract as well as a lighter live weight at slaughter. Other studies conducted on different rabbit breeds have revealed that heat-stressed rabbits had a lighter live weight and skin and digestive tract weights at slaughter (Dalle Zotte and Paci., 2014; Terhes et al., 2018).

However, Lakabi (2010) worked on the local Algerian population and did not find the same results and did not record a significant effect of the season on local rabbits' slaughter weight. At the same time, the present study recorded a similar carcass yield (Cf/PV) and chilled carcass weight in rabbits raised in optimal conditions to those reared in a warm climate ($p > 0.05$). According to the results of the current study, the similarity in the weight of the carcass yield while the slaughter weight is different was due to the low weights of the skin and the digestive tract in the HS group in comparison to the control group, this is also attributed to the loss of water during the carcass bleeding as well as the blood volume after bleeding and draining of the carcass which was more significant in the control group.

In the heat-stressed rabbits, the low weights of the perirenal and inter-scapular fat and their proportions recorded during the experiment could be explained by their low feed intake, which reduced the amount of energy available for the animal to meet its maintenance requirements and to regulate its internal temperature better. It decreased adipogenesis and increased adipolysis by hydrolysis, reducing fatty deposits and favouring the loss of water, consequently resulting in less adiposity (Marai et al., 1999; Ayyat and Marai, 1997; Chiericato et al., 1996). These results are in agreement with previous studies, indicating that rabbits raised under heat stress had less perirenal and interscapular fat weights than those raised under thermoneutrality (Marai et al., 1999; Terhes et al., 2018). On the other hand, Lakabi (2010), Matics et al. (2021), and Zeferino et al. (2013) have reported no significant effect of heat stress on adiposity in fattening rabbits.

In the present study, heat stress significantly reduced liver and kidney weights and their proportions ($p < 0.05$). Some studies reported negative effects of heat stress on rabbits' organs yields in fattening rabbits of selected breeds (Chiericato et al., 1993; Bhatt et al., 2002; Zeferino et al., 2013) and in the local Algerian population fattening rabbits (Lakabi et al., 2004). In accordance with the present results, Bhatt et al. (2002) found that the weights of livers and kidneys were directly proportional to their respective chilled carcass weights on day 84, but no such trend existed for liver weight on day 98. In contrast to the present findings, other studies showed no significant effect of heat stress on liver weight and yield, but they found lower kidney weight and proportion in heat group rabbits compared to those in the control group (Ayyat and Marai, 1997; Marai et al., 1999). According to Chiericato et al. (1993) and Bhatt et al. (2002), the reduced weights and proportions of the liver and kidneys in rabbits subjected to chronic heat stress are probably due to them being proportional to the live weight of the animal at slaughter. At high ambient temperatures (30.5°C), the current study revealed that rabbits reduced their feed intake, and consequently, fewer quantities of nutrients were available for the internal organs, which compromised their development.

Concerning the different parts of the carcass (fore part, Intermediate part; andhind part), the proportions and the recorded weights were similar for the two batches except for the hind part weight, which was slightly reduced in the heat stress batch ($p < 0.05$) These findings are in agreement with those found by Marai et al. (1999) and Zeferino et al. (2013), as well as Terheset al. (2018), who did not find differences in the proportions and weights of different parts of the carcass as a result of season. In contrast to the current findings, Ayyat and Marai (1996) noted a significant effect on the proportions of the fore and the hind parts, which were higher in rabbits reared in thermoneutrality, with no effect recorded on the intermediate part.

Biochemical and hematological parameters

Results of the present study clearly showed that heat stress significantly ($p < 0.05$) affected almost all of the biochemical and hematological parameters (blood plasma's cholesterol, triglycerides, total proteins, urea, and creatinine, Hb, Hct, RBC, WBC, and monocytes percentage). Heat stress significantly increased blood metabolites, compared to those recorded under control temperature, except glycemia which was similar for both groups ($p < 0.05$). The increase in total proteins in hyperthermic animals recorded during the current study is in accordance with the results reported by Okab and El-Banna (2008), which indicated that this increase helps rabbits resist heat stress by helping the body retain water in the intravascular fluids, and so sustain the blood viscosity which compensates for the water that is lost through evaporation. This non-evaporative heat dissipation mechanism efficiently shifts the heat from inside the skin (holding the water inside the body to make up for evaporated lost water). On the other hand, the results of the present study do not corroborate with the results of some studies, which affirm the reduced level of the total plasma proteins of animals in conditions of heat stress. As these studies suggested, this decrease is linked to the decline of globulin levels and the concentration of T4 during heat stress which could significantly affect the reduction of protein biosynthesis (Fayez et al., 1994b; Marai et al., 1999; Okab et al., 2008). Another explanation is that higher water consumption leads to plasma dilution and thus lowers the concentration of proteins (Ondruska et al., 2011; Abdel-Hamid and Farahat, 2015).

Heat stress significantly increased plasma triglycerides and cholesterol concentration ($p < 0.05$). These results are similar to those shown by Ondruska et al. (2011) and Okab et al. (2008), who reported that plasma cholesterol and total lipid concentrations were significantly higher during the summer than in winter. Ondruska et al. (2011) explained that

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the increase might be related to the increased activity of hydroxy-methyl-glutaryl coenzyme (A HMG-CoA) reductase and the stimulation of cholesterol synthesis.

The plasma creatinine and urea levels are considered indicators of renal function. Changes in their levels reveal a dysfunction of the glomerular filtration of the kidneys (Mostafa et al., 2007). Marai et al. (2004) and Mostafa et al. (2007) recorded results similar to the results of the current study. Marai et al. (2004) have also found an increase in the plasma urea and creatinine levels of rabbits raised in warm conditions (THI = 33.9), compared to animals raised in thermo-neutrality (THI = 18.5) (47 ± 2.1 mg/dl versus 38.2 ± 0.9 mg/dl and 1.6 ± 0.1 mg/dl versus 1.4 mg/dl, respectively). The increase in the concentration of urea and creatinine may be a result of two factors. The first is the increase in protein catabolism, which leads to an increase in glucocorticoid hormones, and the second factor is the decrease in protein anabolism which results from the decrease in T3 hormone Marai et al. (2004). In the present study, a very high proteinemia was recorded; hence the former explanation does not justify the increase of urea and creatinine. Therefore, more probable that the hemoconcentration is due to hyperventilation. Okab et al. (2008) did not find a significant effect of heat stress on creatinemia, although they recorded a decrease in uremia in summer, compared to winter in adult male rabbits. Nevertheless, Marai et al. (1999) recorded a reduction in creatinine and blood urea levels.

This study did not find a significant effect of heat stress on glycemia ($p > 0.05$), while Ondruska et al. (2011) recorded a significant effect on growing New Zealand rabbits, and indicated a difference of +7.5% in rabbits raised in heat, compared to rabbits raised in thermoneutrality. According to Ondruska et al. (2011), the increase in glycemia is due to the decrease in the use of glucose as a source of energy in order to reduce heat production. However, Mostafa et al. (2007) and Okab et al. (2008) noted a decrease in glycemia in rabbits subjected to heat due to increased respiration rate. This increase in respiration rate caused a rapid utilization of blood glucose by the respiratory muscles. Thus, it decreased blood glucose under heat stress (Okab et al., 2008). In the present study, it is speculated that rabbits subjected to chronic heat stress have used blood glucose during acceleration of respiration, while at the same time, they have decreased the use of glucose by reducing their movements inside their cages, and therefore they produced less heat, which helped to balance glycemia. This could also be due to hemoconcentration.

Hematological parameters were significantly influenced by heat stress in the growing rabbits ($p < 0.05$). The results obtained by Waltz et al. (2014) on growing pigs exposed to thermal stress are in agreement with results of the present study on local rabbits raised in warmth. They observed an increase in the levels of RBC, Hb, and Hct. The same authors explained this increase by the fact that heat stress increases blood circulation in the skin to promote heat loss, which can cause a reduction in blood flow to other tissues and lead to tissue hypoxia. Consequently, an increase in the synthesis of reticulocytes and their liberation takes place to increase the level of Hb and protect the tissues from hypoxia, which results in a high level of Hct. They have also found that the elevations of these parameters were in a positive correlation with physiological parameters. Other authors have explained this increase as a result of an increase in blood viscosity due to the excessive water loss induced by hyperventilation (acceleration of respiration) and urinary loss, which caused dehydration and hemoconcentration in rabbits (Nakyinsige et al., 2013). However, Askar and Ismail (2012) noted a significant decrease in the level of hemoglobin, red blood cells, and white blood cells of New Zealand rabbits raised in chronic heat stress conditions (7%, -4%, and -9%, respectively). Similarly, Mostafa et al. (2007) and Okab et al. (2008) recorded a decrease in the level of Hb, RBC and Hct, but they noted an increase in WBC in summer compared to winter. On the other hand, Ondruska et al. (2011) did not record a heat stress effect on the RBC and WBC counts and the rate of monocytes in the growing rabbits, but they recorded a significant decrease in the rate of lymphocytes in hot-growing males, and WBC count in growing females. The studies of Khalil et al. (2014) and Dyavolova et al. (2014) during acute heat stress did not reveal a significant effect of heat on WBC, RBC, Hct, and monocytes except for the lymphocyte and Hb levels which decreased significantly. The decline in WBC recorded during present experimentation in growing local rabbits subjected to a hot climate can be considered an indicator of stress, as described by Dhabhar et al. (1995). In fact, it has been described that chronic heat stress can negatively affect the immune response in several production animal species (Ferrian et al., 2012). According to Khalil et al. (2014), the reduction in WBC can be interpreted either by the destruction of these cells (cell apoptosis), or probably by the redistribution of leukocytes to other organs to enhance the animal's immunity of target organs. A decrease in WBC can be due to the redistribution of leukocytes between the blood and other immune compartments (Dhabhar et al., 1995). Such redistribution may significantly affect the ability of the immune system to respond to potential or ongoing immune challenges.

Overall, this study recorded a concentration of most biological components of the blood (metabolites and blood cells), which can be attributed to one of two factors or both. First, it can be due to the fact that the blood samples were taken during the hottest hours of the day. The results can be explained by the acceleration of the respiratory rate, loss of water by evaporation, and decrease in blood volume leading to an increase in the concentration of the various metabolites and hematological parameters. Second, it can be attributed to the increase in the heart's workload due to the rise of blood flow to the skin, leading to a loss of salt and water from the body. These two factors impair working efficiency, overload the heart, and cause haemo-concentration. According to Fortun-Lamothe et al. (2015), the respiratory rate accelerates when the ambient temperature rises, allowing the rabbit to evaporate more water when the

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ambient temperature passes from 18°C to 30°C. This acceleration of the respiratory rate makes it possible to increase the quantity of water evaporated in 24 hours from 95 to 150 ml, which participates in the thermoregulation of the rabbit. This elevated water loss can therefore cause a high concentration of all blood elements (Okab et al., 2008).

CONCLUSION

The obtained results of the present study affirm that the exposure of local Algerian rabbits to chronic heat stress deteriorates the growth performance by reducing feed intake and the average daily gain and hence results in poor feed efficiency with a low final slaughter weight. This study substantiates the fact that thermoregulation is considered a priority physiological function. It can lead rabbits to mobilize all thermoregulatory parameters to resist high ambient temperatures to regulate their internal temperature by modifying physiological parameters (acceleration of respiratory rate, heart rate, and losing as much heat as possible by radiation and convection). Thus, biochemical and hematological parameters are altered by exhausting its adiposity without recourse to the exhaustion of its muscle mass and without affecting the carcass quality. Nevertheless, technical solutions, feed, or therapeutic solutions by the use of additives seem necessary to minimise animal stress, improve production, and maintain animal welfare.

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Authors' contribution

Dahmani Yamina, Benali Nadia, Ain Baziz Hacina, and Temim Soraya designed the study, and the experiment was carried out by Dahmani Yamina, Benali Nadia, Saidj Dyhia, Chirane Manel, Ain Baziz Hacina, and Temim Soraya curated the data. Laboratory analyses were done by Dahmani Yamina, Benali Nadia, Saidj Dyhia, and Chirane Manel. Data analyses by Dahmani Yamina and Benali Nadia. Dahmani Yamina wrote the draft of the manuscript. Dahmani Yamina, Saidj Dyhia, and Temim Soraya revised the manuscript. All authors checked and approved the final version of the manuscript for publishing in the present journal.

Competing interests

The authors have not declared any conflict of interest.

Ethical consideration

All authors have checked ethical issues (including plagiarism, double publication and/or submission, and redundancy, data fabrication and/or falsification, consent to publish, misconduct)

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