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Mitigation of chronic heat stress in growing rabbits by hair shearing: effects on meat quality traits and heat-shock proteins expression

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Introduction: Heat stress (HS) represents a major challenge for rabbit production, particularly in regions characterized by high environmental temperatures. The present study investigated the impact of hair shearing on the meat quality traits of growing rabbits exposed to chronic HS conditions.
Methods: A total of 150 weaned Pannon Ka rabbits were equally divided into three experimental groups (50 animals/group) and allocated into two rooms. In the first room, a temperature of 20 °C was applied and the control group (unsheared, CON) was housed. In the second room, a temperature of 28 °C was applied and two groups of rabbits were housed: an unsheared heat-stressed group (HET) and a sheared group (SHR). At slaughter (12 weeks of age), both hind legs (HL) and *longissimus thoracis et lumborum* (LTL) muscles from 15 carcasses per treatment were collected for physicochemical analyses, sensory evaluation, and heat-shock protein (HSP) expression analysis.
Results: Heat stress affected rabbit bone development by decreasing both femur length ($P<0.05$) and weight ($P<0.01$). HS also reduced redness and yellowness of the *biceps femoris* muscle ($P<0.01$) and increased LTL lightness ($P<0.05$). Moreover, HS increased LTL meat protein ($P<0.05$) and ash ($P<0.01$) contents while reducing lipid content ($P<0.05$). In contrast, sensory traits of rabbit meat were not affected by HS. Hair shearing partially mitigated most of the observed changes, with sheared rabbits generally showing intermediate values for most traits, except for LTL moisture content, which was the lowest ($P<0.05$). Gene expression analysis revealed a higher induction of HSP70_1b ($P<0.05$) and HSP70_8 ($P<0.05$) in the HET group compared with the CON group, whereas no significant differences were observed in the SHR group compared with either of the other groups. No significant differences were detected in the expression of HSP90 family members.

Discussion: Overall, the study confirmed that HS impacts carcass and meat quality of rabbits and that hair shearing can be considered an effective low-cost strategy to alleviate part of the negative effects caused by chronic HS conditions. Hair shearing is particularly applicable in rural production rather than in industrial contexts where this practice would represent a significant labor cost.

KEYWORDS

fattening rabbits, hair shearing, heat stress, heat-shock proteins, meat properties, sensory traits

1 Introduction

Global average temperatures continue to rise annually, especially at lower latitudes, leading to more frequent and intense heatwaves that particularly affect many developing and Mediterranean countries, as well as numerous temperate regions (Intergovernmental Panel on Climate Change, 2023). Such adverse phenomena pose significant challenges to the livestock industry, as high environmental temperatures have been shown to markedly decrease welfare and performance of most livestock species (Renaudeau et al., 2012; Gonzalez-Rivas et al., 2020). Among homeothermic mammals, the rabbit is particularly vulnerable to heat stress (HS) condition due to the presence of a thick coat of fur covering the entire body, as well as a limited number of functional sweat glands (Maya-Soriano et al., 2015), thus allowing only a minimal heat release through the body surface. This sensitivity is reflected by a markedly narrow thermoneutral zone (15-21 °C; Marai et al., 2002), beyond which different physiological and behavioral adaptive mechanisms are triggered, disrupting the animal's homeostasis. In fact, prolonged exposure of rabbits to temperatures above 27-28 °C (independently from relative humidity) was reported to cause disruptions in homeostatic mechanisms, thereby causing damage to various organs and performance depression (Oladimeji et al., 2022). Also, these changes eventually result in depressed welfare and behavior too (Mady et al., 2018; Liang et al., 2022). This susceptibility represents a pivotal challenge for rabbit production, especially in tropical regions where the rabbit continues to play an important role in subsistence farming (Johnson et al., 2024). To alleviate the detrimental effects of HS various strategies have been tested with the majority of them being based on dietary interventions, including feeding time, supplementation and restriction (Szendrő et al., 2018; Liang et al., 2022; Ebeid et al., 2023; Khaleel et al., 2025; Pontalti et al., 2025a), or genetic selection (Ragab et al., 2022; Dalle Zotte et al., 2025; Pontalti et al., 2025b).

Hair shearing has been explored as a management practice to mitigate HS in growing rabbits (Finzi et al., 1992; Lukefahr and Ruiz-Feria, 2003; Matics et al., 2020) and lactating does as well (Szendrő et al., 2007), showing promising results. Schlolaut (1995) showed that after shearing of angora rabbits, their feed intake suddenly rose and decreased again in parallel with the length of wool. In fact, fur contributes to HS in rabbits since it insulates rabbit's body surface thus hampering their possibility to dissipate body heat through convection and radiation. However, to date, no scientific studies have evaluated the impact of hair shearing on meat quality traits of heat-stressed rabbits, representing a relevant scientific gap given the known impact of this environmental stressor (Zeferino et al., 2013).

Based on the above-mentioned considerations, the present study assessed the impact of hair shearing on rabbit meat physicochemical and sensory profile, as well as the expression of different heat-shock proteins (HSPs). The present research completed the first part of the work conducted by Matics et al. (2020), which investigated the effects of hair shearing as a low-cost mitigation strategy of chronic HS on the performance and carcass traits of rabbits.

2 Materials and methods

2.1 Ethics approval

The study was approved by the Institutional Animal Welfare Committee as the animal welfare body of Kaposvár University (MATE KC MÁB/5-5/2021). All animals were handled according to the principles stated in the European Directive 86 609/EEC regarding the protection of animals used for experimental and other scientific purposes (European Commission, 2010).

2.2 Animals and experimental design

The trial was conducted at the experimental rabbit farm of the Hungarian University of Agriculture and Life Sciences in Kaposvàr (Hungary). At 5 weeks of age, a total of 150 weaned male Pannon Ka rabbits (Matics et al., 2014) were randomly assigned to three experimental groups (50 rabbits/group) and housed in two climate-controlled rooms. Inside the room at 20 °C, the control group (CON) remained unsheared. In the room at 28 °C, one group of rabbits was left unsheared (HET), whereas the other group (SHR) was sheared fortnightly on the back and on both sides of the body. The shearing procedure was performed at weeks 5, 7 and 9, lasted approximately 2 minutes/rabbit and, at the end of the process, hair length was about 2 mm. Throughout the trial (12 weeks of age), the average environmental conditions were: in the standard temperature room, temperature was 20.5 ± 1.1 °C and relative humidity was 54 ± 11%; in the high temperature room, temperature was 28.8 ± 0.2 °C and relative humidity was 35 ± 8%. These environmental conditions resulted in the following calculated temperature-humidity indexes: 19.7 ± 1.01 and 25.9 ± 0.47 in 20 and 28 °C rooms, respectively (Marai et al., 2002).

During the experiment rabbits were housed in wire mesh cages (length: 40 cm, width: 38 cm, height: 30 cm; 2 rabbits/cage) and

received the same commercial diets, with *ad libitum* access to both feed and water throughout the entire growth period. In both rooms 16 h light and 8 h dark was scheduled. Detailed information regarding the experimental design, housing conditions, diet formulation and chemical composition are available in the work by Matics et al. (2020).

2.3 Meat physicochemical analyses

When the rabbits reached 12 weeks of age, they were transported to a slaughterhouse following a 4-hour fasting period during transit. The animals were electrically stunned and euthanized through exsanguination of the carotid arteries and jugular veins. The carcasses were then refrigerated at 4 °C for 24 hours before being dissected according to the World Rabbit Science Association (WRSA) guidelines outlined by Blasco and Ouhayoun (1996). At slaughter, n=15 carcasses per treatment group (n=45 in total) were randomly selected to assess meat physicochemical traits. From each carcass, both hind legs (HL) and *longissimus thoracis et lumborum* (LTL) muscles (section between the 7th and 8th thoracic vertebra and 6th and 7th lumbar vertebra) were dissected. Then, they were packed and transported under chilled conditions to the Department of Animal Medicine, Production and Health (MAPS) of the University of Padova (Italy). Upon arrival, left-side HL and LTL samples were individually vacuum-packed in polyethylene bags (CSV-41n ORVED machine; 99% vacuum level) and stored at -40 °C for sensory analysis and heat shock protein (HSP) expression, respectively. Right-side HL and LTL samples were used within 24 h post-mortem to determine their physical traits. Ultimate pH (pHu) and L*a*b* CIE color values were both measured in triplicate on LTL muscles and on the *bicep femoris* (BF) surface of HLs. The pHu was measured by means of a FE20 pH-meter (Mettler Toledo, Switzerland), calibrated with pH 4.00 and 7.00 solutions, while L*a*b* color values were determined using a RM200QC colorimeter (X-Rite, Co., Neu-Isenburg, Germany. Measuring Area: 8 mm; Measuring Geometrics: 45/0 Image Capture; Illuminant/Observer: D65/10), calibrated with a white reference plate. Subsequently, all HLs and an aliquot of LTL muscles (5 per treatment) were individually vacuum-packed and frozen at -40 °C for testing water holding capacity (WHC). After an overnight thawing at 4 °C, HL and LTL samples were both removed from packaging, dried with towel paper, and weighed to determine thawing losses. Samples were then resealed under vacuum and cooked in a water bath at 80 °C. Once cooked, samples were cooled down to room temperature in iced water, removed from the bags, dried, and reweighed to calculate cooking losses. From the cooked HLs, the femur was dissected, measured in both length and thickness, weighed, and subjected to Warner-Bratzler fracture toughness (expressed in Newtons) using a dynamometer Texture TA-HD (Stable Micro System), equipped with a 6 cm wide cell and a 0.5 mm/s load rate.

The remaining LTL muscles (10 per treatment) were coarsely ground using a Retsch Grindomix GM 200 mincer, freeze-dried, and then re-ground in a powder form to conduct proximate composition analyses. The latter were performed following the Association of Official Analytical Chemists (2012) methods to determine moisture (method n. 943.01), protein (method n. 2001.11), and ash (method n. 967.05). Ether extract was instead determined after acid hydrolysis (European Commission, 1998).

2.4 Sensory analysis

After one month of storage, the left HL samples were subjected to a descriptive sensory analysis conducted by 5 staff members (n=2 males, n=3 females) of the MAPS Department, all pre-screened as healthy and rabbit meat consumers. Before the analysis, panelists underwent a two-hour training session to evaluate the sensory traits of fresh HL meat. During training, panelists familiarized themselves with the descriptors (tenderness, juiciness, fibrousness, minerality, and greasiness) and learned to identify various off-flavors (liver, metallic, rancid, onion, and wild), following the guidelines of the International Organization for Standardization (International Organization for Standardization 13299, 2003). The sensory analysis was performed over 5 sessions, with 15 samples per treatment assessed under controlled conditions inside individual booths (every session, each panelists evaluated three samples, one/treatment). Each panelist received the necessary utensils, towel paper, water, crackers, and three samples (1 per treatment) simultaneously. Samples were served warm after being thawed (at 4 °C for 24 h), vacuum-sealed, labeled with three-digit codes, and cooked in a water bath (30 min at 80 °C). Panelists received a list of sensory descriptors, including potential off-attributes, to be evaluated on a 15-cm continuous scale ranging from 1 (lowest intensity) and 9 (highest intensity). Scores were recorded by measuring the position on the scale and expressed in millimeters for statistical analysis.

2.5 Heat-shock proteins expression

Total RNA was extracted from LTL muscle using the High Pure RNA Isolation Kit (Roche Diagnostics, Marnes-la-Coquette, France) according to the manufacturer's instructions. Complementary DNA (cDNA) was synthesized starting from 5 µL of total RNA using random hexamer primers and the Maxima™ H Minus cDNA Synthesis Master Mix (Thermo Fisher Scientific, Waltham, MA, USA). A DNase treatment step was included during reverse transcription to eliminate potential genomic DNA contamination. The resulting cDNA was kept at 4 °C and used for downstream relative quantification within one hour of synthesis. The expression levels of stress-related genes were assessed by relative quantification using the ΔCt approach. Gene expression levels were normalized using ACTIN and GAPDH as reference genes (ACTIN forward: 5′-ggacctgaccgactacctca-3′; ACTIN reverse: 5′-ggcagctcgtagctcttctc-3′; GAPDH forward: 5′-tcaccatcttccaggagcga-3′; GAPDH reverse: 5′-cacaatgcccgaagtggtcgt-3′). Target genes included HSPA1B (HSP70_1b) (forward: 5′-cgacctcaacaagagcatca-3′; reverse: 5′-ctcgtacacctggatcagca-3′), HSPA8 (HSP70_8) (forward: 5′-tcaagcaaccaaagatgctg-3′; reverse: 5′-attcggttgtcgaagtcttct-3′), HSP90AA1 (HSP90_A) (forward: 5′-aacgaggagtacggggagtt-3′; reverse: 5′-cagctcctcacagttgtcca-3′), and HSP90B1 (HSP90_B) (forward: 5′-gttctacaagagcctcacca-3′; reverse: 5′-ggcacttcttcacgatgttc-3′). Quantitative PCR assays were performed using PowerUp™

SYBR™ Green Master Mix (Thermo Fisher Scientific, Waltham, MA, USA) on a LightCycler 95 platform (Roche, Basel, Switzerland). All target and reference genes for each sample were analyzed within the same amplification run. Each reaction was carried out in a final volume of 10 µL, containing 2 µL of cDNA, 1× SYBR™ Green Master Mix, 0.8 µL of each primer, and nuclease-free water. The thermal cycling protocol consisted of an initial activation step at 95 °C for 2 min, followed by 45 amplification cycles at 95 °C for 15 s, 55 °C for 15 s, and 72 °C for 1 min. A melting curve analysis was subsequently performed, increasing the temperature from 40 °C to 90 °C at a rate of 0.1 °C/s, with continuous fluorescence acquisition to verify amplification specificity. Previously established amplification efficiencies were applied to correct Cq values, which were then used to calculate the relative expression of each target gene with respect to the housekeeping genes.

2.6 Statistical analysis

Data were statistically analyzed using the general linear model (GLM) procedures of the SAS software for Windows (version 9.1.3) (Statistical Analysis Systems Institute, 2008). Meat physicochemical traits were analyzed through a one-way analysis of variance (ANOVA), with the experimental group (CON vs. HET vs. SHR) as fixed effect, whereas the cage was considered as random effect.

Separately, sensory analysis results were evaluated using a mixed model (PROC MIXED), where experimental groups (CON vs. HET vs. SHR) were treated as fixed effects, while panelists were included as a random effect. The obtained least square means were adjusted using a Bonferroni correction, and significance was considered at a 5% confidence level. For the analysis of off-traits perception, a chi-square (χ^2) test was performed according to the procedures described by Marascuilo (1996). Variation in HSP expression level was assessed performing a Kruskal–Wallis test for each gene, followed by Wilcoxon rank-sum tests with Benjamini–Hochberg correction for multiple testing. Differences were considered statistically significant at $P < 0.05$.

3 Results

3.1 Physicochemical and sensory traits

Results presented in Table 1 indicated that chronic HS affected different physical traits of the HL and LTL muscles. Considering the HL meat cut, femur length was greater in CON rabbits than HET ones (P = 0.0139), whereas SHR did not differ from CON (P = 0.0617) and HET (P = 1.000): 93.4 vs. 92.0 vs. 91.6 mm for CON, SHR and HET rabbits, respectively (P = 0.011). Femur weight was higher in CON compared to HET (P = 0.0053) and SHR (P = 0.0116) groups, whereas HET did not differ from SHR (P = 1.000): 11.8 vs. 11.0 vs. 10.9 g for CON, SHR and HET rabbits, respectively (P = 0.002). Diversely, thawing loss (P = 0.064), cooking loss (P = 0.193), total loss (P = 0.163), femur thickness (P = 0.566) femur incidence on the HI (P = 0.062), and femur fracture toughness (P = 0.736) were not affected by treatment.

Focusing on the physical traits of the *biceps femoris* muscle, it was highlighted that CON rabbits exhibited a higher a* value than HET rabbits (P = 0.0075), while SHR ones did not differ from CON (P = 0.2291) and HE (P = 0.5733) groups: 4.64 vs. 4.17 vs. 3.82 for CON, SHR and HET rabbits, respectively (P = 0.009). The b* value was affected by treatment too, with CON showing a lower b* than HET (P = 0.001) and SHR (P = 0.0333): -5.46 vs. -4.53 vs -4.07 for CON, SHR and HET rabbits, respectively (P = 0.001). Diversely, there was no treatment effects for *biceps femoris* pHu (P = 0.317) and L* value (P = 0.919).

The treatment influenced the L* index of the LTL muscle, with HET showing a higher value than CON (P = 0.0299), while SHR did not differ from both CON (P = 0.4099) and HET (P = 6782): 42.2 vs. 43.0 vs. 43.6 for CON, SHR and HET rabbits, respectively (P = 0.034). Concerning the variables thawing loss (P = 0.096), cooking loss (P = 0.160), total loss (P = 0.272), pHu (P = 0.699), a* index (P = 0.071) and b* index (P = 0.671) they were not affected by treatment.

As shown in Table 2, treatment affected the proximate composition of LTL meat. CON meat had a higher moisture content than SHR (P = 0.0388), while HET was similar to both CON (P = 0.1118) and SHR (P = 1): 75.8 vs. 73.8 vs. 74.1 g/100 g meat for CON, SHR and HET, respectively (P = 0.029). For protein content, SHR (P = 0.0342) and HET (P = 0.0451) meat had higher amounts than CON, but SHE and HET had similar values (P = 1.000): 21.7 vs. 23.6 vs. 23.6 g/100 g meat for CON, SHR and HET groups, respectively (P = 0.017). Lipids content of LTL meat was higher in in CON compared to HET (P = 0.4650), whereas SHR did not differ from the CON (P = 1.000) and HET (P = 0.0813) groups: 1.45 vs. 1.43 vs. 1.10 g/100 g meat for CON, SHR and HET groups, respectively (P = 0.032). Lastly, it was depicted a higher ash content in SHR (P = 0.0130) and HET (P = 0.0211) groups compared to CON, while SHR and HET values did not differ (P = 1.000): 1.13 vs. 1.24 vs. 1.23 g/100 g meat for CON. SHR and HET groups, respectively (P = 0.006).

The studied treatment had no effect on the sensory traits of HL meat (Tables 3, 4), both in terms of texture and flavor attributes. Specifically, tenderness (P = 0.243), juiciness (P = 0.083), fibrousness (P = 0.397) and minerality (P = 326) were similar in all three groups. In addition, the panelists did not detect any off-traits at both texture and flavor levels. In detail, greasiness (P = 0.129), liver (P = 0.621), metallic (P = 0.839), rancid (P = 0.131), onion (P = 0.356) and wild (P = 0.599) were not affected by treatment.

3.2 Heat shock proteins expression

Relative gene expression of selected HSPs was significantly affected by treatment (Table 5; Figure 1). HSP70_1b expression was higher in CON than HET rabbits (P = 0.011), while SHR was similar to both CON (P = 0.158) and HET (P = 0.787): 0.00296 vs. 0.0126 vs. 0.0131 for CON, SHR and HET rabbits, respectively (P = 0.0197). HSP70_8 expression was higher in HET than CON rabbits (P = 0.018) while, also in this case, SHR did not differ from both CON (P = 1.000) and HET (P = 0.095) groups: 0.3857 vs. 0.539 vs. 0.9974 for CON, SHR and HET rabbits, respectively

TABLE 1 Physical traits of the hind leg, biceps femoris and *longissimus thoracis et lumborum* muscles of unsheared and sheared rabbits reared under Standard (20 °C) and High (28 °C) environmental temperatures.

Groups	CON	SHR	HET	RSD[1]	P-value
N.	15	15	15		
Hind leg:					
Thawing loss, %	0.26	0.43	0.30	0.19	0.064
Cooking loss, %	16.1	17.2	17.4	1.95	0.193
Total loss, %	16.4	17.7	17.8	2.05	0.163
Femur length, mm	93.4^{a}	92.0^{ab}	91.6^{b}	1.53	0.011
Femur thickness, mm	6.36	6.26	6.28	0.26	0.566
Femur weight, g	11.8^{Aa}	11.0^{ABb}	10.9^{B}	0.71	0.002
Femur, % hind leg	4.75	4.78	5.01	0.32	0.062
Femur fracture toughness, N	330	322	323	27.4	0.736
biceps femoris muscle:					
pHu	6.18	6.20	6.12	0.14	0.317
L*	48.8	49.0	48.9	1.57	0.919
a*	4.64^{A}	4.17^{AB}	3.82^{B}	0.66	0.009
b*	-5.46^{Aa}	-4.53^{ABb}	-4.07^{B}	0.87	0.001
longissimus thoracis et lumborum muscle:					
Thawing loss, %[2]	2.43	3.28	2.91	0.99	0.096
Cooking loss, %[2]	34.3	31.6	32.7	2.02	0.160
Total loss, %[2]	37.5	34.5	36.1	2.78	0.272
pHu	5.83	5.82	5.84	0.09	0.699
L*	42.2^{b}	43.0^{ab}	43.6^{a}	1.27	0.034
a*	4.76	5.64	4.82	1.09	0.071
b*	2.36	2.40	2.16	0.76	0.671

CON: rabbit housed at 20 °C and unsheared; HET: rabbits housed at 28 °C and unsheared; SHR: rabbits housed at 28 °C and sheared fortnightly on the back and on both sides of the body.
[1]RSD, residual standard deviation; [2]n=5 samples/treatment;
[a-b] Means in the same row with different superscript letters differ for $P < 0.05$.
[A–B] Means in the same row with different superscript letters differ for $P < 0.01$.

TABLE 2 Proximate composition (g/100 g meat) of the *longissimus thoracis et lumborum* meat of unsheared and sheared rabbits reared under Standard (20 °C) and High (28 °C) environmental temperatures.

Groups	CON	SHR	HET	RSD[1]	P-value
N.	10	10	10		
Moisture	75.8^{a}	73.8^{b}	74.1^{ab}	1.68	0.029
Protein	21.7^{b}	23.6^{a}	23.6^{a}	1.58	0.017
Lipids	1.45^{a}	1.43^{ab}	1.10^{b}	0.29	0.032
Ash	1.13^{b}	1.24^{a}	1.23^{a}	0.08	0.006

CON: rabbit housed at 20 °C and unsheared; HET: rabbits housed at 28 °C and unsheared; SHR: rabbits housed at 28 °C and sheared fortnightly on the back and on both sides of the body.
[1]RSD, residual standard deviation;
[a-b] Means in the same row with different superscript letters differ for $P < 0.05$.
[A–B] Means in the same row with different superscript letters differ for $P < 0.01$.

TABLE 3 Sensory profile scores (expressed in mm) of hind leg meat from unsheared and sheared rabbits reared under Standard (20 °C) and High (28 °C) environmental temperatures.

Groups	CON	SHR	HET	RSD[1]	P-value
N.	15	15	15		
Texture:					
Tenderness	90.0	98.8	94.5	3.66	0.243
Juiciness	66.1	73.8	66.7	2.65	0.083
Fibrousness	87.3	82.2	83.9	2.70	0.397
Flavor:					
Minerality	13.1	11.1	10.2	1.35	0.326

Sensory attributes were evaluated by descriptive sensory analysis using a 15-cm continuous scale; CON: rabbit housed at 20 °C and unsheared; HET: rabbits housed at 28 °C and unsheared; SHR: rabbits housed at 28 °C and sheared fortnightly on the back and on both sides of the body.
[1]RSD, residual standard deviation;

TABLE 4 Sensory profile scores (expressed in mm) of hind leg meat from unsheared and sheared rabbits reared under Standard (20 °C) and High (28 °C) environmental temperatures.

Groups	C	SHR	HET	χ^2	P-value
N.	15	15	15		
Texture:					
Greasiness	94.7	92.0	85.3	4.10	0.129
Flavor:					
Liver	24.0	30.7	25.3	0.96	0.621
Metallic	74.7	77.3	78.7	0.35	0.839
Rancid	9.33	13.3	4.00	4.06	0.131
Onion	2.67	5.33	1.33	2.06	0.356
Wild	41.3	37.3	33.3	1.03	0.599

Sensory attributes were evaluated by descriptive sensory analysis using a 15-cm continuous scale; CON: rabbit housed at 20 °C and unsheared; HET: rabbits housed at 28 °C and unsheared; SHR: rabbits housed at 28 °C and sheared fortnightly on the back and on both sides of the body.

(P = 0.0159). Diversely, treatment did not affect HSP90_A (P = 0.604) and HSP90_B (P = 466) genes expression.

4 Discussion

The updated THI proposed by Oladimeji et al. (2022) evidenced that the rabbits housed at 28 °C experienced "very severe" HS conditions, due to a THI exceeding 25.5. To this regard it must be emphasized that relative humidity and THI are surely important information when discussing about HS condition, but primarily for animal species whose bodies are not or barely covered by fur. In the case of such animal species, sweating (the amount of heat released on the body surface) is of great importance and relative humidity has a great effect on this. However, thermoregulation is extremely poor in rabbits because they lack sweat glands on their body. Moreover, they are covered by thick fur, so there is no or minimal heat release through the body surface (to achieve thermoregulation, rabbit loses body heat through conduction, convection, and radiation). That is why relative humidity is not a decisive factor in establishing the HS threshold. Prolonged exposure of rabbits to temperatures above 27-28 °C is known to cause disruptions in homeostatic mechanisms, thereby causing damage to various organs and performance depression (Oladimeji et al., 2022).

TABLE 5 Relative gene expression of selected HSPs in rabbits reared under different thermal and shearing conditions (20 °C, no shearing; 28 °C, shearing; 28 °C, no shearing). Values represent normalized expression levels.

Groups	CON	SHR	HET	P-value[1]
Gene:				
HSP70_1b	0.00296^{a}	0.0126^{ab}	0.0131^{b}	0.0197
HSP70_8	0.3857^{b}	0.539^{ab}	0.9974^{a}	0.0159
HSP90_A	0.3640	0.2456	0.2255	0.604
HSP90_B	1.260	1.322	1.771	0.466

CON: rabbit housed at 20 °C and unsheared; HET: rabbits housed at 28 °C and unsheared; SHR: rabbits housed at 28 °C and sheared fortnightly on the back and on both sides of the body.
[1]Overall differences among groups were assessed using the Kruskal–Wallis test (P-value). When overall comparison was significant, pairwise comparisons were performed using the Wilcoxon rank-sum test and the different superscript letters within the same row indicate statistically significant differences among groups (P < 0.05).

To date, HS in growing rabbits has been extensively examined in different recent studies (Liang et al., 2022; Oladimeji et al., 2022; Ebeid et al., 2023). This environmental stressor has been shown to harm rabbits' growth essentially by suppressing the animal's appetite, a thermoregulatory mechanism to reduce metabolic heat. This involuntary behavior eventually leads to a depressed growth rate, which consequently reduces the rabbit's final body weight and overall efficiency (Farghly et al., 2020). This degradation in growth performance aligned with what was observed in the first part of the study by Matics et al. (2020). Nonetheless, shearing rabbits' hair has been shown to partially mitigate these adverse effects in different studies carried out on fattening rabbits (Lukefahr and Ruiz-Feria, 2003; Matics et al., 2020), bucks (Finzi et al., 1992) and rabbit does (Szendrő et al., 2007).

Regarding meat quality, the impact of HS was appreciable. Considering meat physical traits, HS reduced the surface color (a* and b* values) of the BF muscle and increased the lightness of the LTL muscle, which is consistent with the results by Zeferino et al. (2013). In the latter, results were attributed to a partial degradation of myoglobin. Instead, sheared rabbits (HS) exhibited intermediate meat color values, suggesting that this practice somewhat alleviated the pigment degradation. Furthermore, it must be emphasized that color variations were not related to the pHu, since no significant variations were found across treatments, as also observed in other studies on heat-stressed rabbits (Zeferino et al., 2013; Dalle Zotte et al., 2025). However, given the limited research on the impact of HS condition on the meat quality of rabbits, solid hypotheses on this can hardly be drawn. Both femur length and weight were reduced under HS, but hair shearing partially alleviated also these changes, reflecting the trend evidenced for rabbit body weights (Matics et al., 2020). These changes suggested that HS could have hampered the bone structure development, and not only muscle tissue deposition. However, it was hypothesized that this finding could be more probably attributable to the different feed intake (lower nutrient availability) exhibited in the three groups of rabbits: HET<SHR<CON (Matics et al., 2020). Conversely, the research conducted on lamb and sheep subjected to severe HS condition and shared to alleviate its effects, seems to exclude a direct hormonal effect, since cortisol levels resulted unaffected under the tested extreme climatic condition (Moslemipur and Golzar-Adabi, 2017; Pulido-Rodríguez et al., 2025). The WHC of both HL and LTL muscles remained unaffected by HS, which was in accordance with other literature contributions on this topic (Zeferino et al., 2013; Pontalti et al., 2025a, b).

The proximate composition analysis of meat highlighted that HS modified its chemical composition, by decreasing its lipid content in favor of that of protein and ash. Conversely, hair shearing alleviated the impact of HS on the lipid content of meat to the detriment of moisture, without affecting protein and ash

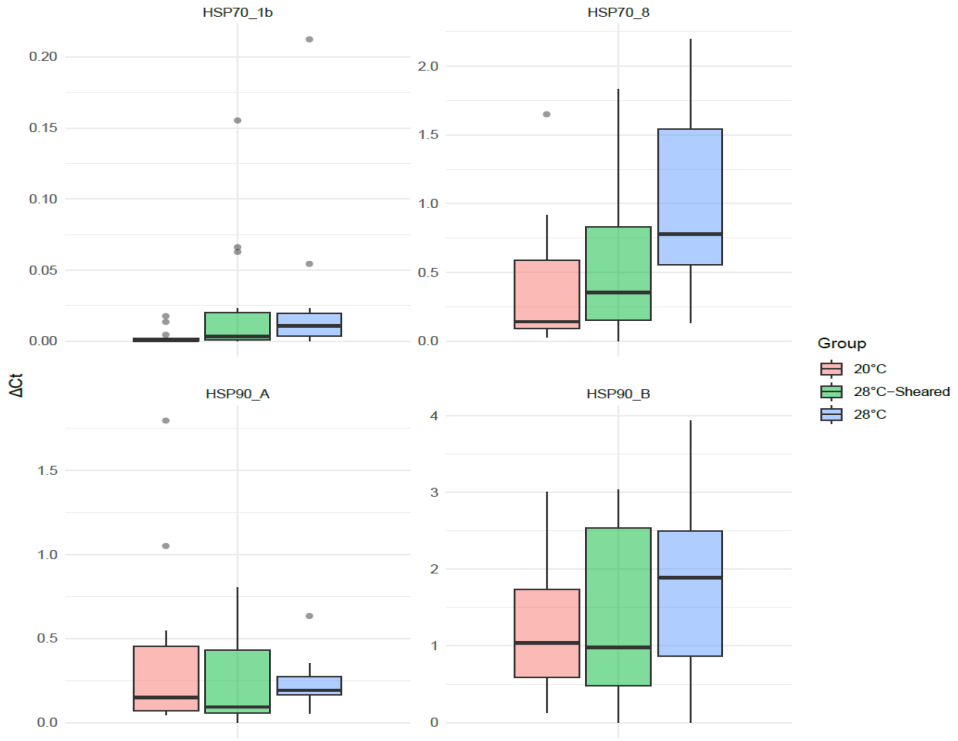

FIGURE 1
Distribution of ΔCt values for HSP70_1b, HSP70_8, HSP90_A, and HSP90_B across experimental groups. Boxplots represent gene expression levels in rabbits maintained at 20 °C (Group CON), exposed to 28 °C with hair shearing (Group SHR), and exposed to 28 °C without shearing (Group HET).

fractions. This trend appeared linked to the amelioration in rabbits' appetite observed in the first part of the research (Matics et al., 2020), with sheared rabbits consuming on average 11% more feed compared to their unsheared counterparts. This increase was then reflected in carcass fat depots and, consequently, in LTL meat, corroborating the findings of Dalle Zotte et al. (2025) and Pontalti et al. (2025a, b).

Finally, HS did not affect the sensory traits of HL meat. Texture remained comparable across the treatment groups, an evaluation that matched the lack of significant differences in HL WHC. Furthermore, no off-flavors were reported by the panelists during the sensory sessions. These findings suggested that HS had minimal influence on the sensory quality of rabbit meat, a conclusion confirmed by other studies evaluating the impact of HS on rabbit meat sensory attributes (Dalle Zotte et al., 2025; Pontalti et al., 2025b).

HSPs represent a group of molecular chaperones involved in the regulation of cellular proteostasis and in the protection of cellular components against a wide range of stressors. They are highly heterogeneous in terms of structure, function, cellular and tissue distribution, and may be either constitutively expressed or inducible in response to stress (Csermely et al., 1998; Tavaria et al., 1996; Gomez-Pastor et al., 2018).

In the present study, a significant increase in the expression of HSP70 was observed in the H group compared with C, affecting both the inducible isoform (HSP70_1b) and the constitutive one (HSP70_8). While the up-regulation of the inducible form was expected, the increase in HSP70_8 might appear counterintuitive. However, similar findings have been reported in rabbits exposed to different stressors, and HSP70_8 has been shown to respond to HS, albeit with variable relevance among isoforms depending on the tissue examined and the experimental conditions (Deane and Brown, 2017). Accordingly, a role for the constitutive form in the long-term adaptation to persistent stressful conditions, such as those evaluated in the present study, can be hypothesized.

Notably, hair shearing in the heat-stressed group markedly limited the up-regulation of both HSP70 genes, whose expression levels were not statistically different from those observed in the C group. This finding supports a relevant protective effect of shearing in preventing, or at least mitigating, tissue damage induced by chronic HS.

Instead, treatment did not affect the HSP90 isoforms. Nevertheless, a trend towards higher expression levels in the heat-stressed groups was detected, particularly for HSP90B, which, although constitutively expressed, can be up-regulated in response to cellular damage, including thermal injury, although with tissue variability (Quraishi et al., 1996). Therefore, the contribution of long-term adaptive mechanisms in response to persistent stressful conditions may also be hypothesized for HSP90, further supporting the beneficial role of shearing under adverse thermal conditions.

5 Conclusions

Compared to its impact on growth performances, HS had a milder effect on meat quality traits, primarily affecting meat colorimetric characteristics and proximate composition. In this study, hair shearing demonstrated to be an effective strategy to partially mitigate most of the observed effects due to chronic HS condition in rabbits.

Together, these two studies provide a comprehensive evaluation of hair shearing as a possible low-cost management practice for growing rabbits exposed to HS conditions in rural production contexts, where mechanical cooling is unaffordable. Nonetheless, further investigation is needed to determine whether hair shearing represents a cost-effective strategy for rabbit farming, either at the rural level when there is no possibility of cooling.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was approved by Institutional Animal Welfare Committee as the animal welfare body of Kaposvár University (MATE KC MÁB/5-5/2021). The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

ZsS: Conceptualization, Funding acquisition, Writing – review & editing. EP: Investigation, Writing – original draft. MC: Investigation, Writing – review & editing. ZsM: Data curation, Formal Analysis, Investigation, Validation, Writing – review & editing. ZsG: Writing – review & editing, Investigation, Validation. GF: Formal Analysis, Resources, Writing – review & editing. CT: Investigation, Writing – review & editing. BP: Investigation, Visualization, Writing – review & editing. ADZ: Conceptualization, Funding acquisition, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

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Glossary

HL	Hind leg	pHu	ultimate pH
LTL	*longissimus thoracis et lumborum;* HSPs, Heat-shock proteins	BF	*Biceps femoris;* THI, Temperature-humidity index
MAPS	Department of Animal Medicine, Production and Health		