

EFFECT OF HEAT STRESS ON RABBITS – LITERATURE REVIEW

Dorota Kowalska

National Research Institute of Animal Production, Department of Small Livestock Breeding,
32-083 Balice near Krakow, Poland

<https://orcid.org/0000-0002-4435-4244>, e-mail: dorota.kowalska@iz.edu.pl

Abstract

Meat rabbit production is becoming an increasingly common choice because global consumption of rabbit meat is rising year by year. Rabbits are relatively easy to rear; however, because of their exceptionally poor thermoregulation, caused by an almost complete absence of sweat glands and by a dense hair coat that additionally hinders heat loss, they are highly sensitive to high ambient temperatures. As homeothermic animals, when kept in an environment optimal for the species they maintain a relatively constant body temperature (38.5–39.5°C), irrespective of ambient temperature. This is achieved at the cost of a high metabolic rate and considerable energy expenditure. When an animal is unable to dissipate sufficient heat, both that generated by the body and that absorbed from the external environment, to maintain thermal balance, heat stress occurs. This article reviews studies on the adverse effects of heat stress on rabbit production, taking into account that, as a consequence of global warming, the problem is no longer limited to hot tropical and subtropical regions but is also emerging in temperate-climate countries. Increasingly severe spring and summer heat, accompanied by so-called tropical nights during which air temperature does not fall below 20°C even at the coolest time, is becoming a growing challenge for rabbit production. The literature reviewed indicates that heat stress adversely affects welfare and adaptation, feed intake and utilization, immunity and health status, as well as growth, reproduction and rabbit meat quality. Consequently, it causes substantial economic losses in rabbit production.

Keywords: rabbits, heat stress, reproduction, meat quality, blood parameters, immune response

Introduction

Rabbits are a livestock species that is relatively easy to rear. Owing to their high prolificacy and short gestation period, depending on the mating system and housing and feeding conditions, one doe can produce 20 to 60 young per year. Rabbit meat is generally accepted and is not subject to cultural taboos. It is classified as white, fine-grained, dietary and non-allergenic meat, with a low cholesterol content (30–50 mg/100 g) and a high protein content (22–25%) rich in essential amino acids (Chipo et al., 2019). Rabbit production is therefore becoming an increasingly common choice. The rabbit is considered one of the livestock species that could help narrow the gap between food demand and supply.

In recent years, weather anomalies, especially higher ambient temperatures during summer, have become a problem for rabbit breeders. As homeothermic animals, rabbits kept under optimal species-specific conditions maintain a relatively constant body temperature (38.5–39.5°C) regardless of ambient temperature (Szendrő et al., 2018). This requires a high metabolic rate and substantial energy expenditure. If the animal cannot dissipate enough internally generated and externally absorbed heat to maintain thermal equilibrium, heat stress develops, adversely affecting welfare and adaptation, feed intake and utilization, immunity and health, as well as growth and reproduction.

Until recently, heat stress in rabbit production mainly concerned hot tropical and subtropical regions. With global warming, however, it is increasingly encountered in temperate countries as well. The growing frequency of extreme weather events, including short periods of intense rainfall and warmer, drier summers increasingly accompanied by tropical nights, during which the minimum air temperature does not fall below 20°C, presents a major challenge. When high humidity accompanies heat stress, the effect of high temperature is intensified because heat dissipation by evapotranspiration is reduced (Lin et al., 2000; Marai et al., 2007a). Numerous studies have described the negative effects of heat stress on rabbits and the resulting economic losses.

Thermoregulation in rabbits

Rabbits are very sensitive to high ambient temperatures, primarily because their thermoregulation is exceptionally inefficient. This is due to the almost complete absence of sweat glands and the presence of a dense hair coat that further impedes heat loss (Yagci et al., 2006). They possess only small sweat glands on the lips, which are largely ineffective. Continuous exposure to extreme temperatures disrupts homeostatic mechanisms and may consequently damage various organs (Farghly et al., 2022).

The ears are an important thermoregulatory organ in rabbits and account for about 12% of total body surface area. Enlarged pinnae are an adaptive feature facilitating heat loss (Stott et al., 2010). The largest arteriovenous vessels are located there. Vascular responses in the pinna differ from those in other vessels of the systemic circulation, a characteristic feature of this species. In the common carotid and femoral arteries, the effects of noradrenaline and serotonin are comparable, whereas in the external carotid artery and its branches, including the auricular artery, the action of noradrenaline as a vasoactive agent is about 700 times stronger than that of serotonin (Apperly et al., 1976).

The thermoneutral zone in rabbits is approximately 18–21°C (Marai et al., 2002). When ambient temperature rises to 27°C, the body must dissipate the additional heat load to maintain a constant body temperature. The upper critical temperature for a resting rabbit is 27–28°C. Keeping rabbits at such temperatures may raise rectal temperature to 41.6°C within only 50 minutes (Jimoh and Ewuola, 2016). Zeferino et al. (2011) showed that ambient temperature is positively correlated with skin-surface temperature, ear-surface temperature and respiratory rate.

Depending on ambient temperature and humidity, rabbit ear temperature may range from 5 to 35°C (Kluger et al., 1971; Gonzalez et al., 1971) and is also closely related to age. Newborn rabbits display behavioural and physiological thermoregulatory responses within the first hours of life. Although the doe prepares a nest for her offspring, she does not remain in it after kindling. Hairless kits either huddle together in the nest to conserve heat or move apart when the temperature is high. At this stage, temperature has a much stronger influence than touch or smell. The preferred ambient temperature decreases with each day of life as the hair coat develops and improves heat retention. Hull and Hull (1982) showed that kits exhibit clear thermotaxis in the first days of life and accurately select the ambient temperature at which they settle, thereby minimizing physiological thermoregulatory responses.

In older kits aged 10–20 days, the ears are still small and poorly vascularized, while the primary hair coat provides less thermal insulation than the mature coat; consequently, they tolerate heat better. As rabbits grow, the role of the ears in thermoregulation gradually increases (Łapiński et al., 2011). During overheating, auricular blood vessels dilate markedly and the ear becomes warmer and more intensely pink, particularly in breeds with light-coloured ears. Nasal vessels also contribute to temperature regulation by dilating substantially at high temperatures. Increased respiratory rate (panting) further promotes cooling. At ambient temperatures of 27–30°C, rabbits stretch out to maximize heat loss by radiation and convection, increase ear temperature, extend the pinnae and hold them away from the body to expose the greatest possible surface area. Above 35°C, rabbits are

no longer able to regulate their internal temperature effectively, while at 40°C pronounced panting and salivation occur (Lebas et al., 1986).

The relationship between ambient temperature, relative humidity, energy intake and heat production in growing rabbits is therefore an important consideration in successful and well-organized rabbit production (Daader et al., 2016; Farghly et al., 2020). Some rabbit breeds are more susceptible to heat stress, especially synthetic, genetically improved breeds characterized by rapid growth and a higher metabolic rate (Marai et al., 2007b).

Effect of heat stress on reproductive performance in rabbits

Numerous studies indicate that heat stress negatively affects the reproductive performance of both female and male rabbits by reducing fertility, impairing embryo development, decreasing litter size and weight, and reducing milk production (Para et al., 2020). Marco-Jiménez et al. (2017) reported that pregnant does exposed to high ambient temperatures increase blood flow through skin vessels to dissipate heat and maintain core temperature. This reduces blood supply to the uterus and umbilical circulation, resulting in insufficient fetal perfusion and affecting both fetal weight and mortality. García and Argente (2017) investigated the adverse effects of heat stress on embryogenesis and found a reduced ovulation rate and proportion of normal embryos, arrested embryo development and increased zona pellucida thickness, which hindered embryo hatching and uterine implantation. Ragab et al. (2022) found that a high ambient temperature of 30°C caused marked impairment of physiological responses, oxidative stress and reproductive performance in does. Mady et al. (2018) studied seasonal effects on behaviour and reproductive and productive performance. Rabbits were randomly allocated to two groups: one kept in summer at 28.7–31.8°C and 44.1–65.7% relative humidity, and the other in winter at 13–20.4°C and 51.55–63.3% relative humidity. Heat-stressed summer does gave birth to lighter kits; weaned kits were also lighter, and the females nursed and groomed them less frequently.

Many studies show that heat stress markedly increases reactive oxygen species (free radicals) in rabbits while reducing cellular antioxidants (Ruder et al., 2009). It also increases corticosteroid levels and decreases secretion of luteinizing hormone (LH) and follicle-stimulating hormone, thereby affecting ovarian development and ovulation rate (Arabameri et al., 2017). Some studies have shown that heat stress lowers plasma progesterone, disrupting follicular development and leading to early embryonic mortality because implantation in the uterine lining is impaired (Dash et al., 2016). Sirotkin et al. (2021) and Mutwedu et al. (2021) demonstrated that prolonged exposure of female rabbits to high temperatures induces oxidative stress, with subsequent deterioration of endocrine function and physiological ovarian activity. Heat stress also reduced relative ovarian weight, impaired ovarian granulosa-cell responsiveness and decreased plasma progesterone. Tang et al. (2022) reported that heat stress adversely affects female physiology by reducing ovarian weight and plasma concentrations of interleukin (IL)-2, IL-8, catalase (CAT) and glutathione peroxidase (GSH-Px), while accelerating ovarian apoptosis and altering miRNA expression. CAT and GSH-Px are key antioxidant enzymes in the early stages of rabbit folliculogenesis; therefore, exposure to high temperatures inhibits follicle formation, ovarian maturation and ovulation (Somuncu et al., 2008). Para et al. (2020) observed a reduction in the number of ova per ovulation from an average of 9.2 in females kept at 23°C to 7.4 in the heat-stress group kept at 30°C. This difference was attributed to the lower body weight of young females reared at 30°C.

Male rabbits are more sensitive to high temperatures than females. Thermoregulatory failure leading to heat stress can reduce sperm quality and increase the risk of infertility. Spermatogenesis occurs optimally at a temperature slightly lower (by 2–8°C) than body temperature (Banks et al., 2005; Danno et al., 2000). The degree of heat-induced sperm-cell damage depends on the intensity, frequency and duration of heat exposure (Paul et al., 2008). Hypothalamic synthesis and secretion

of gonadotropin-releasing hormone (GnRH) are inhibited at high temperature, significantly affecting testicular function (Daader et al., 2016). Heat stress can also impair sexual behaviour (libido) \ and negatively affect semen motility, viability, morphology and metabolic activity. Marai et al. (2002) showed that heat stress in bucks decreases testosterone concentration, spermatogenesis, sexual drive, ejaculate volume, sperm motility, sperm concentration and total sperm number, while increasing sperm abnormalities and the proportion of immotile sperm. Maya-Soriano et al. (2015) concluded that male rabbits are among the livestock animals most sensitive to high ambient temperature.

Prolonged heat stress often leads to temporary or permanent infertility in bucks. Exposure to 30°C for only 3 hours per day significantly increases the proportion of sperm subpopulations with reduced motility. Sabés-Alsina et al. (2016) collected rabbit sperm and incubated it for 3 hours at scrotal temperature (32.5°C), body temperature (37°C) or hyperthermic temperature (42°C). Incubation at 42°C significantly ($P < 0.05$) reduced mean sperm motility, curvilinear velocity and overall movement velocity, as well as sperm metabolic activity, compared with incubation at 32.5°C and 37°C.

As noted above, oxidative stress is a consequence of heat stress. Excess reactive oxygen species can oxidize lipids and proteins, cause oxidative DNA damage and ultimately contribute to tissue dysfunction. Toxic oxidation products exert cytostatic effects, damage cell membranes and may cause cell death by apoptosis or necrosis. Because of the composition of their cytoplasmic membranes and their high mitochondrial content, spermatozoa are particularly susceptible to oxidative damage. Durairajanayagam et al. (2015) reported that excessive reactive oxygen species damage sperm membranes and DNA, causing chromatin fragmentation, inhibiting motility and reducing fertilizing capacity. Pei et al. (2012) studied chronic heat stress in the male reproductive system by placing rabbits in controlled climatic chambers assigned to control, heat-stress and recovery conditions. During 9 weeks of heat exposure, both libido and sperm concentration declined markedly. Histomorphological findings showed significant changes in testicular microscopic structure and a pronounced increase in germ-cell apoptosis in the seminiferous tubules. These adverse effects were transient, however, because all measured parameters returned to control levels after a 9-week recovery period. Histological studies by Aldemir et al. (2014) and Bharti et al. (2014) also revealed altered testicular cell and membrane structures and impaired spermatogenesis. El-Sobhy (2000) reported marked focal degeneration in both seminiferous tubules and interstitial cells in testes of heat-exposed animals.

Effect of heat stress on body weight, growth and feed utilization in rabbits

Many studies in rabbits indicate that heat stress is one of the factors that substantially impair the growth and viability of young animals. For rabbit production to be economically justified, the rearing period cannot be excessively long. Production is efficient when animals achieve high performance and a favourable feed conversion ratio while maintaining good health.

Ondruska et al. (2011) found that total and daily feed intake, feed conversion ratio, and total and daily body-weight gain in growing rabbits were significantly reduced at high temperatures (36°C $\pm$ 3°C). Heat exposure adversely affected internal homeostasis, which was reflected in growth rate and physiological signs. Matics et al. (2021), keeping rabbits from birth to slaughter (13 weeks) at 28°C, found adverse effects on feed intake, body-weight gain and feed conversion. Under heat stress, rabbits attempted to reduce additional endogenous heat production by lowering feed intake by about 28–38%. Belhadj Slimen et al. (2016) showed that heat stress, independently of reduced feed intake, decreases metabolic rate and alters metabolism. It disrupts the balance of free radicals, causing oxidative damage to cells and mitochondria; growth, production, reproduction and health therefore cease to be physiological priorities.

The severity of heat-stress effects depends on duration and intensity. Bakr et al. (2015) showed that prolonged heat stress damages intestinal histomorphology and the microbiome, suppresses the

hypothalamic appetite and satiety centre, and increases leptin and adiponectin secretion, thereby reducing feed intake and body-weight gain. Leptin stimulates the hypothalamic-pituitary-adrenal axis and reduces feed intake, whereas adiponectin regulates feeding behaviour. Al-Sagheer et al. (2017) demonstrated that increased ambient temperature and humidity significantly reduce digestion and absorption, leading to poorer growth rate, final body weight, meat-quality traits, antioxidant status and immune response in growing rabbits. Sirotkin et al. (2021) reported that exposure of adult females to 36°C from mating until weaning inhibited growth in the young, reduced feed intake, worsened feed conversion and increased mortality in both mothers and offspring. Serum insulin-like growth factor 1 (IGF-I) decreased and corticosterone increased. Other studies showed that heat stress impairs thyroid activity by reducing serum triiodothyronine (T3) and thyroxine (T4), inhibiting protein synthesis and increasing protein degradation, ultimately reducing growth rate (Liu et al., 2022; Hassan et al., 2011). In those studies, fattening rabbits were kept at 34°C and 30.3°C, respectively, with humidity of about 76%. Ragab et al. (2022) reported that heat stress reduces daily body-weight gain by about 20–25%, changes feed conversion by 8–15% and increases mortality by 9–12%. Dahmani et al. (2022), at $30.5 \pm 1.82^\circ\text{C}$ and $65.5 \pm 7.2\%$ humidity, found significant reductions in final body weight, daily gain and daily feed intake, although feed conversion ratio was significantly higher rather than lower in the heat-stressed group.

Many authors have reported reduced feed intake under heat stress (Marai and Habeeb, 1998; Okab and El-Banna, 2003; Marai et al., 2008; Okab et al., 2008), explaining it by stimulation of peripheral heat receptors that transmit inhibitory nerve impulses to the hypothalamic appetite centre. Liu et al. (2024) investigated the effect of heat stress on performance and skeletal-muscle protein metabolism in 160 meat rabbits aged 80 days, divided into control and heat-stress groups for a 20-day experiment. The reduced daily gain in heat-stressed rabbits was associated with a significant decrease in feed intake from 215.31 to 185.76 g/day, which could reduce protein biosynthesis and fat deposition.

Heat stress during lactation may affect postnatal development of kits through reduced milk production. Szendrő et al. (2018) transferred does immediately after kindling to climatic chambers at 5, 15, 23 and 30°C and standardized litters to seven kits. Doe body weight, milk production, feed intake and water intake were recorded. Heat stress significantly reduced milk yield and feed intake but increased water intake. Doe body weight at 23°C and 30°C decreased by 5.6% and 8.5%, respectively, compared with 15°C. The effect was less pronounced in kits than in does. The authors concluded that high ambient temperature reduced feed intake and consequently milk production. Similar conclusions were reached by Fernández-Carmona et al. (1995) and Bakr et al. (2015). Pascual et al. (2000) recorded a 30–40% reduction in milk yield in does kept at 30°C compared with conventional conditions.

Effect of heat stress on the rabbit gut microbiome

Gut bacteria play a major role in maintaining rabbit health, including through metabolic functions. They support digestion of poorly digestible complex carbohydrates and short-chain fatty acids that are a major nutrient source for the intestinal epithelium. Gut bacteria also enable biosynthesis of vitamins K, B1, B6 and B12 and folic acid. The intestinal microbiota provides antigens that stimulate the gut immune system, whose task is to recognize and distinguish harmful pathogens from microorganisms necessary for normal host function. Correct recognition of pathogens is essential for triggering an appropriate immune response and eliminating the threat (Lee and Mazmanian, 2010). Gastrointestinal microorganisms form a specific ecosystem in which populations occupying different ecological niches use other populations or their metabolic products as nutrients and often compete for food, influencing substrate transformations. Normal microflora limits the development of pathogenic bacteria, among other mechanisms by competing for nutrients, whereas disturbances in microbiota composition may lead to gastrointestinal disease. Fang et al. (2020) estimated that gut

microbiota can account for 10.42% of variation in weaning weight. Belhadj Slimen et al. (2016) reported that heat stress increases free-radical production in livestock, resulting in more pathogenic and fewer beneficial bacteria. Patra and Kar (2021) also documented damage to mucosal epithelial structure and deterioration of intestinal barrier function, increasing permeability to toxins and pathogens and susceptibility to oxidative stress and inflammation. High-performing animals are particularly vulnerable; in rabbits this mainly concerns hybrid breeds characterized by high female prolificacy and fertility and rapid juvenile growth.

Environmental stressors, particularly heat stress, can alter the balance of intestinal flora in growing rabbits, especially in young post-weaning animals whose bacterial flora is not yet stable. Bai et al. (2022) found that heat stress at 30–32°C in rabbits weaned at 35 days significantly altered gut microbiota by increasing Firmicutes, Proteobacteria and Verrucomicrobiota and decreasing Bacteroidota. This was accompanied by numerous cases of diarrhoea compared with controls kept at 22–24°C. Under heat stress, gut-microbiota imbalance was closely associated with intestinal dysfunction and serum markers of oxidative stress. Liu et al. (2022) examined the effect of $34 \pm 2^\circ\text{C}$ for 7 days on caecal microflora and found a significant increase in Gram-negative *Proteus* bacteria, opportunistic pathogens capable of causing various infections, compared with controls at $24 \pm 1^\circ\text{C}$. Yasoob et al. (2021) likewise showed that heat stress caused caecal dysbiosis, increased oxidative stress and increased expression of inflammatory genes in the mucosa. It disrupted the intestinal barrier, allowing lipopolysaccharide, an integral component of the outer membrane of Gram-negative bacteria, to enter the blood. In bacteria, lipopolysaccharide forms a protective barrier against environmental factors such as antibiotics and toxic substances; in infected organisms it is a potent immune stimulus that activates immune cells and triggers an inflammatory cascade. El-Badawi et al. (2018) found that keeping growing rabbits for 6 weeks at an average temperature of 33.1°C and 43% relative humidity increased the total numbers of pathogens including *Salmonella*, *Escherichia coli*, *Staphylococcus aureus*, *Clostridium perfringens* and moulds in the small intestine and caecum.

Effect of heat stress on carcass traits and meat quality

Meat is an important component of the daily diet of much of the world population and contains many compounds that determine its nutritional value. As consumers become more aware of the risks associated with high intakes of saturated fatty acids, trans isomers of unsaturated fatty acids and cholesterol-rich products, they increasingly choose foods generally regarded as healthy, low-calorie and low-fat (Dinh et al., 2011). White meats, which contain relatively little fat and cholesterol, are therefore often preferred. In rabbit meat, carcass and meat-quality traits such as tenderness and colour are crucial to consumer acceptance. Matics et al. (2021) showed that keeping growing rabbits at 28°C adversely affected slaughter weight, hot carcass weight and chilled carcass weight. Zeferino et al. (2013) found that heat stress reduced slaughter weight, carcass weight and relative internal-organ weights and altered meat colour: lightness (L^*) increased, redness (a^*) decreased and meat juiciness declined. Muscle myoglobin determines colour, suggesting that high ambient temperature may reduce meat pigment content. The differences were small enough, however, that consumers might not notice them. In that experiment, heat stress did not affect other meat-quality traits, including pH at 24 and 48 h, muscle water content or shear force. According to Dalle Zotte (2002), meat-quality traits are less dependent on thermal conditions than growth rate and carcass traits. Chiericato et al. (1996) described increased lightness (L^*) and reduced redness (a^*) at 28.8°C compared with 20.8°C in three muscles, including longissimus. Results for yellowness (b^*) were inconsistent: it was lower at the higher temperature in biceps femoris but higher in longissimus.

Liu et al. (2024) found that heat stress adversely affected growth and slaughter performance, altered physical properties of skeletal muscle and significantly increased meat yellowness (b^*). They also reported significant increases in serum leptin and HDL and LDL cholesterol and decreases in total protein and immunoglobulins IgH, IgM and IgA. Dahmani et al. (2022), in contrast, found no significant effect on slaughter yield or the weights of cuts (forelegs, hind legs and loin), but ob-

served significant reductions in the percentage weights of the liver, kidneys, perirenal fat and inter-scapular fat.

Effect of heat stress on biochemical blood parameters

Blood parameters in rabbits are used as an auxiliary tool in diagnosing organic, infectious and parasitic diseases. Haematological and biochemical indices may be affected by sex, age, reproductive status and seasonal climatic variation. Many authors have reported adverse effects of summer heat stress on haematological parameters. El-Sawy et al. (2014) found significant summer decreases in red and white blood cells and haemoglobin. Al-Eissa (2011) showed deterioration of several haematological and biochemical components: erythrocyte count and haemoglobin concentration were significantly reduced in July, whereas haematocrit and mean corpuscular volume were significantly higher. Okab et al. (2008) compared physiological performance and blood biochemical parameters of 16 adult six-month-old New Zealand White bucks in spring and summer. Maximum/minimum ambient temperatures were 27.1/18.9°C in spring and 32.2/26.5°C in summer, with mean relative humidity of 86.1% and 89.5%, respectively. Haemoglobin (Hb), packed cell volume (PCV) and red blood cell count (RBC) decreased, whereas white blood cell count (WBC) increased in summer. Plasma total protein (TP), globulins (G), total lipids (TL) and cholesterol increased. Plasma alanine aminotransaminase (ALT) and alkaline phosphatase (ALP) activities decreased significantly, whereas lactate dehydrogenase (LDH) activity increased. Liu et al. (2022) found that exposure to $34 \pm 2^\circ\text{C}$ significantly increased serum heat-shock protein 70 kDa (HSP70), alkaline phosphatase and cortisol, while protein, glucose, triiodothyronine and tetraiodothyronine levels decreased significantly.

Thyroid hormones act on almost all organs and tissues and influence growth, development and metabolism. HSP70 plays an important role in antioxidant cell protection and in reducing inflammation. Ayyat and Marai (1997) showed that heat stress reduces blood total protein, glucose and triglycerides while markedly increasing cholesterol. Amici et al. (2000) exposed bucks acclimated to $18.0 \pm 0.5^\circ\text{C}$ and $45 \pm 4\%$ relative humidity to 42°C for 1 hour at the same humidity. Blood was sampled before exposure and 0.5, 6, 30 and 54 hours after heat stress. Plasma glucose decreased throughout observation, cholesterol decreased after 36 hours, and triglycerides and urea increased 0.5 hour after stress. Aminotransferase activity, vitamin C, sulphhydryl groups and total antioxidant radical-trapping capacity increased during the first hours after stress. Immune-cell proliferation and immunoglobulin synthesis decreased after 0.5 hour. Mutwedu et al. (2021), exposing adult females daily for 30 days from 08:00 to 16:00 to $27\text{--}28^\circ\text{C}$, $31\text{--}32^\circ\text{C}$ or $35\text{--}36^\circ\text{C}$, found that at temperatures above 30°C haemoglobin, red blood cells, haematocrit and total protein decreased by 23.64%, 12.73%, 11.93% and 12.02%, respectively, whereas mean corpuscular volume, white blood cells, lymphocytes, creatinine, urea and aspartate aminotransferase increased by 10.73%, 42.37%, 15.53%, 28.98%, 53.2% and 23.31%, respectively, compared with controls.

Effect of heat stress on the immune response

According to Ebeid et al. (2013), under thermoneutral conditions there is a balance between generation and elimination of free radicals such as reactive oxygen species (ROS) by the antioxidant system. Enzymes including superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and catalase (CAT) scavenge ROS, which are neutralized by antioxidant defences. Under heat stress, redox balance is disrupted and ROS generation increases, producing oxidative stress and impairing physiological functions in rabbits (Mutwedu et al., 2021). Bai et al. (2022), keeping rabbits for 15 days at $30\text{--}32^\circ\text{C}$, found increased concentrations of 4-pyridoxic acid, kynurenine, 20-OH-leukotriene B4 and dopamine and decreased pyridoxal. In the rabbit intestine, these compounds are mainly associated with vitamin B6 and tryptophan metabolism, neutrophil activation and prolactin pathways. They are important markers of inflammatory response and oxidative stress. Jimoh et al. (2018) re

ported that oxidative stress markedly impairs animal physiology, with high accumulation of ROS and their metabolites (ROS-M) in blood and seminal fluid of males during heat stress. ROS-M accumulation reflects a decline in antioxidant defences, particularly enzymatic antioxidants and total antioxidant activity.

Some studies indicate that heat exposure suppresses the hypothalamic-pituitary-thyroid axis, lowers serum T3 and T4 and ultimately reduces the immune response in growing rabbits (García and Argente, 2017; Liu et al., 2022). Saghir et al. (2023) found that heat stress increased pro-inflammatory cytokines including tumour necrosis factor α (TNF- α), interleukin 1 β (IL-1 β), myeloperoxidase and protein carbonyl in growing rabbits. Abdelnour et al. (2020) demonstrated adverse effects on immunity and homeostatic profiles and increased inflammatory cytokines. El-Desoky et al. (2017) and Sheiha et al. (2020) similarly showed that rabbits continuously exposed to heat stress had higher non-specific immune responses and pro-inflammatory cytokine parameters. Abdel-Latif et al. (2018) observed adverse effects on expression of interferon gamma (IFN- γ), tumour necrosis factor (TNF- α) and heat-shock protein 70 (HSP70), with negative consequences for infiltration of regulatory T lymphocytes and natural killer (NK) cells in growing rabbits. Heat exposure suppresses the hypothalamic-pituitary-thyroid axis, decreases serum T3 and T4 and ultimately lowers immune responsiveness (García and Argente, 2017; Liu et al., 2022).

Summary

Heat stress that compromises welfare is one of the major problems affecting rabbit productivity not only in tropical and subtropical countries but also in temperate climates, especially during hot summers. It adversely affects body-weight gain, feed intake, meat quality, reproductive performance, milk production in does, antioxidant capacity, immune response, intestinal histomorphology and the microbiome. Consequently, it causes substantial economic losses in rabbit production.

References

- Abdel-Latif M., Sakran T., Badawi Y.K., Abdel-Hady D.S. (2018). Influence of *Moringa oleifera* extract, vitamin C, and sodium bicarbonate on heat stress-induced Hsp70 expression and cellular immune response in rabbits. *Cell Stress Chaperone*, 23: 975–984.
- Abdelnour S.A., El-Saadony M.T., Saghir S.A.M., Abd El-Hack M.E., Al-Shargi O.Y.A., Al-Gabri N., Salama A. (2020). Mitigating negative impacts of heat stress in growing rabbits via dietary prodigiosin supplementation. *Livest. Sci.*, 240: 104220.
- Aldemir M., Okulu E., Kosemehmetoglu K., Ener K., Topal F., Evirgen O., Gurleyik E., Avci A. (2014). Evaluation of the protective effect of quercetin against cisplatin-induced renal and testis tissue damage and sperm parameters in rats. *Andrologia*, 46: 1089–1097.
- Al-Eissa M.S. (2011). Effect of gestation and season on the haematological and biochemical parameters in domestic rabbit (*Oryctolagus cuniculus*). *British Biotechnol. J.*, 1: 10–17.
- Al-Sagheer A.A., Daader, A.H., Gabr H.A., Abd El-Moniem E.A. (2017). Palliative effects of extra virgin olive oil, gallic acid, and lemongrass oil dietary supplementation on growth performance, digestibility, carcass traits, and antioxidant status of heat-stressed growing New Zealand White rabbits. *Environ. Sci. Pollut. Res.*, 24: 6807–6818.
- Amici A., Franci O., Mastroiacono P., Merendino N., Nardini M., Tomassi G. (2000). Short term acute heat stress in rabbits: Functional, metabolic and immunological effects. *World Rabbit Sci.*, 8: 11–6.
- Apperly E., Humphrey P.P., Levy G.P. (1976). Receptors for 5-hydroxytryptamine and noradrenaline in rabbit isolated ear artery and aorta. *Br. J. Pharmacol.*, 58: 211–221.
- Arabameri A., Sameni H., Bandegi A. (2017). The effects of propolis extract on ovarian tissue and oxidative stress in rats with maternal separation stress. *Int. J. Reprod. Biomed*, 15: 509.

- Ayyat M.S., Marai I.F.M. (1997). Effects of heat stress on growth, carcass traits and blood components of New Zealand White rabbits fed various dietary energy–fibre levels, under Egyptian conditions. *J. Arid. Environ.*, 37: 557–68.
- Bai X., Shi Y., Tang L., Chen L., Fan H., Wang H., Wang J., Jia X., Chen S., Lai S. (2022). Heat stress affects faecal microbial and metabolic alterations of rabbits. *Front. Microbiol.*, 12: 817615.
- Bakr M.H., Tusell L., Rafel O., Terré M., Sánchez J.P., Piles M. (2015). Lactating performance, water and feed consumption of rabbit does reared under a Mediterranean summer circadian cycle of temperature v. comfort temperature conditions. *Animal*, 9: 1203–1209.
- Banks S., King S.A., Irvine D.S., Saunders P.T.K. (2005). Impact of a mild scrotal heat stress on DNA integrity in murine spermatozoa. *Reproduction*, 129: 505–514.
- Belhadj Slimen I., Najar T., Ghram A., Abdrrabba M. (2016). Heat stress effects on livestock: molecular, cellular and metabolic aspects, a review. *J. Anim. Physiol. Anim. Nutr.* 100: 401–412.
- Bharti S., Misro M.M., Rai U. (2014). Quercetin supplementation restores testicular function and augments germ cell survival in the estrogenized rats. *Mol. Cell. Endocrinol.*, 383: 10–20.
- Chiericato G.M., Rizzi C., Rostellato V. (1996). Meat quality of rabbits of different genotypes reared in different environmental conditions. *Proceedings of the 6th World Rabbit Congress*, 9–12 July 1996, Toulouse, France, pp. 141–145.
- Chipo M.M., Tapiwa K.A. (2019). Challenges and opportunities to rabbit (*Oryctolagus cuniculus*) production and marketing. *Int. J. Agric. Agribus.*, 5: 7.
- Daader A.H., Yousef M.K., Abdel-Samee A.M. (2016). Recent trends in rabbit does reproductive management: special reference to hot regions. In: *Proceedings 11th World Rabbit Congress* (Qingdao, China), pp. 149–166.
- Dahmani Y., Benali N., Saidj D., Chirane M., S. (2022). Effects of heat stress on growth performance, carcass traits, physiological components, and biochemical parameters in local Algerian growing rabbits. *World Vet. J.*, 12 (4): 405–417.
- Dalle Zotte A. (2002). Perception of rabbit meat quality and major factors influencing the rabbit carcass and meat quality. *Livest. Prod. Sci.*, 75: 11–32.
- Danno S., Itoh K., Matsuda T., Fujita J. (2000). Decreased expression of mouse Rbm3, a cold-shock protein, in Sertoli cells of cryptorchid testis. *Am. J. Pathol.*, 156: 1685–1692.
- Dash S., Chakravarty A.K., Singh A., Upadhyay A., Singh M., Yousuf S. (2016). Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. *Vet World*, 9 (3): 235–244.
- Dinh T.T.N., Thompson L.D., Halyean M.L., Brooks J.C., Patterson K. Y., Boylan L.M. (2011). Cholesterol content and methods for cholesterol determination in meat and poultry. *Comprehensive Reviews in Food Science and Food Safety*, 10 (5): 269–289.
- Durairajanayagam D., Agarwal A., Ong C. (2015). Causes, effects and molecular mechanisms of testicular heat stress. *Reprod. Biomed.*, 30: 14–27.
- Ebeid T.A., Zeweil H.S., Basyony M.M., Dosoky W.M., Badry H. (2013). Fortification of rabbits diets with vitamin E or selenium affects growth performance, lipid peroxidation, oxidative status and immune response in growing rabbits. *Livest. Sci.*, 155: 323–331.
- El-Badawi A.Y., El-Wardany I., Abd El-Moez S.I., Helal F.I.S., Ali N.G.M., Shourrap M.I.,
- Aboelazab O.M. (2018). Impact of dietary *Moringa oleifera* leaves on intestinal pathogenic load and histological structure of growing rabbits raised under heat-stress conditions. *Anim. Prod. Sci.*, 58: 1901–1907.
- El-Desoky N.I., Hashem N.M., Elkomy A., Abo-Elezz Z.R. (2017). Physiological response and semen quality of rabbit bucks supplemented with *Moringa* leaves ethanolic extract during summer season. *Animal*, 11 (9): 1549–1557.
- El-Sawy M.A., Ali Kh.A.A., Hassanein M.N.F., El-Kholy K.H. (2014). Effect of interaction between season and *Arak* (*Salvadora persica*) supplementation on rabbits: 1- productive and some physiological performance of growing rabbits. *J. Agric. Sci. Mansoura Univ.*, 7 (5): 249–267.

- El-Sobhy H.E. (2000). Physiological responses and histochemical changes of some endocrine glands of NZW rabbit bucks exposed to 34°C. *Egyptian J. Rabbit Sci.*, 10: 19–41.
- Fang S., Chen X., Pan J., Chen Q., Zhou L., Wang C., Xiao T., Gan Q.F. (2020). Dynamic distribution of gut microbiota in meat rabbits at different growth stages and relationship with average daily gain (ADG). *BMC Microbiol.*, 20: 116. Farghly M.F.A., Mahrose K.M., Mahmoud G.B., Ali R.M., Daghash W., Metwally K.A., Abougaba M.S. (2020). Lighting programs as an appliance to improve growing New Zealand White rabbit's performance. *Inter. J. Biometeorol.*, 64: 1295–1303. Farghly M.F.A., Mahrose K.M., Peris S.I., Abou-Kassem D.E., Metwally K.A., Abougabal M.S., Abd El-Aziz A. (2022). Effects of lighting source as an environmental strategy for heat stress amelioration in growing Californian rabbits during summer season. *Anim. Biotechnol.*, 33 (1):159–166.
- Fernández-Carmona J., Cervera C., Sabater C., Blas E. (1995). Effect of diet composition on the production of rabbit breeding does housed in a traditional building and at 30°C. *Anim. Feed. Sci. Technol.*, 52: 289–297.
- García M.L., Argente M.J. (2017). Exposure to high ambient temperatures alters embryology in rabbits. *Int. J. Biometeorol.* 61: 1555–1560.
- Gonzalez R.R., Kluger M.J., Hardy J.D. (1971). Partitional calorimetry of the New Zealand White rabbit at temperatures 5–35 degrees. *C. J. Appl. Physiol.*, 31: 728–734.
- Hassan R.A., Ebeid T.A., Abd El-Lateif A.I., Ismail N.B. (2011). Effect of dietary betaine supplementation on growth, carcass and immunity of New Zealand White rabbits under high ambient temperature. *Livest. Sci.*, 135: 103–109.
- Hull J., Hull D. (1982). Behavioral thermoregulation in newborn rabbits. *J. Comp. Physiol. Psychol.*, 96 (1): 143–147.
- Jimoh O.A., Ewuola E.O. (2016). Thermoregulatory response of exotic rabbit breeds during peak temperature-humidity index of Ibadan. *Trop. Anim. Prod. Invest.*, 19: 41–47. Jimoh O.A., Ayedun, E.S., Oyelade W.A., Oloruntola O.D., Daramola O.T., Ayodele S.O.,
- Omoniyi I.S. (2018). Protective effect of soursop (*Annona muricata* linn.) juice on oxidative stress in heat stressed rabbits. *J. Anim. Sci. Technol.*, 60: 28.
- Kluger M.J., Gonzalez R.R., Mitchell J.W., Hardy J.D. (1971). The rabbit ear as a temperature sensor. *Life Sci. I.*, 10: 895–899.
- Lebas F., Coudert P., Rouvier R., De Rochambeau H. (1986). The rabbit husbandry, health and production. *FAO Animal Production and Health Series 21*, Rome.
- Lee Y.K., Mazmanian S.K. (2010). Has the microbiota played a critical role in the evolution of the adaptive immune system? *Science*, 330: 1768–1773.
- Lin H., Du R., Gu X.H., Li F.C., Zhang Z.Y. (2000). A study of the plasma biochemical indices of heat stressed broilers. *Asian-Australas. J. Anim. Sci.*, 13: 1210–1218.
- Liu H., Zhang B., Li F., Liu L., Yang T., Zhang H. (2022). Effects of heat stress on growth performance, carcass traits, serum metabolism, and intestinal microflora of meat rabbits. *Front. Microbiol.*, 13: 998095.
- Liu G., Liu C., Sun H., Bai L., Yang L., Zhang Y., Gao S. (2024). Effects of heat stress on production performance and protein metabolism of skeletal muscle in meat rabbits. *Research Square*, pp. 1–22.
- Łapiński S., Augustyn J., Lis M., Kanik W., Niedbała P., Lisowska-Lis A. (2011). Zmiany w obrazie termograficznym królika domowego (*Oryctolagus cuniculus*) w zależności od wieku i stanu fizjologicznego. *PAK*, 57 (10): 1154–1156.
- Mady E.A., Karousa M.M., El-Laithy S.M., Souad A. Ahmed (2018). Effect of season on New Zealand White (NZW) rabbit's behavior and reproductive and productive performance. *Benha Vet. Med. J.*, 35 (1): 274–284.
- Marai I.F.M., Habeeb A.A.M. (1998). Adaptation of *Bos taurus* cattle under hot climate conditions. *Ann. Arid Zone*, 37: 253–281.
- Marai I.F.M., Habeeb A.A.M., Gad A.E. (2002). Rabbits' productive, reproductive and physiological performance traits as affected by heat stress. *A Review. Livest. Prod. Sci.*, 78: 71–90.

- Marai I. F.M., El Darawany A.A., Fadiel A., Abdel Hafez M.A.M. (2007a). Physiological traits as affected by heat stress in sheep: a review. *Small Rumin. Res.*, 71: 1–12.
- Marai I.F.M., Haebe A.A.M., Gad A.E. (2007b). Biological functions in young pregnant rabbit does as affected by heat stress and lighting regime under subtropical conditions of Egypt. *Trop. Subtrop. Agroecosyst.*, 7: 165–176.
- Marai I.F.M., Askar A.A., Bahgat L.B. (2008). Tolerance of New Zealand White and Californian doe rabbits at first parity to sub-tropical environment of Egypt. *Livest Sci.*, 104: 165–172.
- Marco-Jiménez F., García-Diego F.J., Vicente J.S. (2017). Effect of gestational and lactational exposure to heat stress on performance in rabbits. *World Rabbit Sci.*, 25: 17–25. Matics Z., Gerencsér Z., Kasza R., Terhes K., Nagy I., Radnai I., Dalle Zotte A., Cullere M., Szendrő Z. (2021). Effect of ambient temperature on the productive and carcass traits of growing rabbits divergently selected for body fat content. *Animal*, 15: 100096. Maya-Soriano M.J., Taberner E., Sabes-Alsina M., Ramon J., Rafel O., Tusell L., Piles M., Lopez-Bejar M. (2015). Daily exposure to summer temperatures affects the motile subpopulation structure of epididymal sperm cells but not male fertility in an in vivo rabbit model. *Theriogenology*, 84: 384–389.
- Mutwedu V., Nyongesa A., Oduma J., Kitaa J., Mbaria J. (2021). Thermal stress causes oxidative stress and physiological changes in female rabbits. *J. Therm Biol.*, 95: 102780.
- Okab A.B., El-Banna S.G. (2003). Physiological and biochemical parameters in New-Zealand White male rabbits during spring and summer seasons. *Egypt J. Basic Appl. Physiol.*, 2: 289–300.
- Okab A.B., El-Banna S.G., Koriem A.A. (2008). Influence of environmental temperatures on some physiological and biochemical parameters of male New-Zealand rabbits. *Slovak J. Anim. Sci.*, 41: 12–19. Ondruska L., Rafay J., Okab A., Ayoub M., Al-Haidary A., Samara E., Parkanyi V., Chrastinova L., Jurcik R., Massanyi P. (2011). Influence of elevated ambient temperature upon some physiological measurements of New Zealand White rabbits. *Vet. Med. Czech*, 56 (4): 180–186. Para I., Dar A. P., Malla A.B., Punetha M., Rautela A., Maqbool I., Mohd A., Shah A. M., War A. Z., Ishaq R. (2020). Impact of heat stress on the reproduction of farm animals and strategies to ameliorate it. *Biol. Rhythm Res.*, 51: 616–632.
- Pascual J.J., Fonfria M.J., Alqedra I., Cervera C., Fernandez-Carmona J. (2000). Use of lucerne-based diets on reproductive rabbit does. *Proceeding 7th World Rabbit Congress, Valencia, Spain*, C: 379–384.
- Patra A.K., Kar I. (2021). Heat stress on microbiota composition, barrier integrity, and nutrient transport in gut, production performance, and its amelioration in farm animals. *J. Anim. Sci. Technol.*, 63 (2): 211–247.
- Paul C., Murray A.A., Spears N., Saunders P.T. (2008). A single, mild, transient scrotal heat stress causes DNA damage, subfertility and impairs formation of blastocysts in mice. *Reproduction*, 136 (1): 73–84.
- Pei Y., Wu Y., Cao J., Qin Y. (2012). Effects of chronic heat stress on the reproductive capacity of male rex rabbits. *Livest. Sci.*, 146: 13–21.
- Ragab M.A., Shazly S.A., Ibrahim M.A., El-Kholany M.E., Khalil W.A. (2022). Black maca (*Lepidium meyenii* Walp.) hydroalcoholic extract as an ameliorating agent against heat stress conditions of V-line rabbit does. *Sustainability*, 14: 15154.
- Ruder E.H., Hartman T.J., Goldman M.B. (2009). Impact of oxidative stress on female fertility. *Curr. Opin. Obstet. Gynecol.*, 21: 219–222.
- Sabés-Alsina M., Tallo-Parra O., Mogas M.T., Morrell J.M., Lopez-Bejar M. (2016). Heat stress has an effect on motility and metabolic activity of rabbit spermatozoa. *Anim. Reprod. Sci.*, 173: 18–23. Saghir S.A.M., Hroob A.M., Majrashi K.A., Jaber F.A., Abduh M.S., Al-Gabri N., Albaqami N.M., Abdelnour S.A., Alqhtani A.H., Abd El-Hack M.E., Swelum A., A., Simal-

- Gandara J. (2023). Effects of alginates on the growth, haematological, immunity, antioxidant and pro-inflammatory responses of rabbits under high temperature. *Res. Vet. Sci.*, 155: 36–43. Sheiha A.M., Abdelnour S.A., Abd El- Hack M.E., Khafaga A.F., Metwally K.A., Ajarem J.S., Maodaa S.N., Allam A.A., El-Saadony M.T. (2020). Effects of dietary biological or chemical-synthesized nano-selenium supplementation on growing rabbits exposed to thermal stress. *Animals*, 10: 430.
- Sirotkin A.V., Parkanyi V., Pivko J. (2021). High temperature impairs rabbit viability, feed consumption, growth and fecundity: Examination of endocrine mechanisms. *Domest Anim. Endocrinol.*, 74: 106478.
- Somuncu S., Cakmak M., Dikmen G., Akman H., Kaya M. (2008). Ischemia-reperfusion injury of rabbit ovary and protective effect of trapidil: An experimental study. *Pediatr. Surg. Int.*, 24: 315–318.
- Stott P.G, Jennings N., Harris S. (2010). Is the large size of the pinna of the ear of the European hare (*Lepus europaeus*) due to its role in thermoregulation or in anterior capital shock absorption?. *J. Morphol.*, 271: 674–681
- Szendró Z., Papp Z., Kustos K. (2018). Effect of ambient temperature and restricted feeding on the production of rabbit does and their kits. *Acta Agraria. Kaposváriensis*, 22: 1–17.
- Tang L., Bai X., Xie X., Chen G., Jia X., Lei M., Li C., Lai S. (2022). Negative effects of heat stress on ovarian tissue in female rabbit. *Front Vet. Sci.*, 9: 1009182.
- Yagci A., Zik B., Uguz C., Altunbas K. (2006). Histology and morphometry of white New Zealand rabbit skin. *Indian Vet. J.*, 83: 876–880
- Yasoob T.B., Yu D., Khalid A.R., Zhang Z., Zhu X., Saad H.M., Hang S. (2021). Oral administration of *Moringa oleifera* leaf powder relieves oxidative stress, modulates mucosal immune response and cecal microbiota after exposure to heat stress in New Zealand White rabbits. *J. Anim. Sci. Biotechnol.*, 12 (1): 66.
- Zeferino C.P., Moura A.S.A.M.T., Fernandes S., Kanayama J.S., Scapinello C., Sartori J.R. (2011). Genetic group × ambient temperature interaction effects on physiological responses and growth performance of rabbits. *Livest. Sci.*, 140: 177–183.
- Zeferino C.P., Komiyama C.M., Fernandes S., Sartori J.R., Teixeira P.S., Moura A.S. (2013).

Approved for publication: 23 October 2024

EFFECT OF HEAT STRESS ON RABBITS – LITERATURE REVIEW

Dorota Kowalska

SUMMARY

Meat rabbit breeding is an increasingly common choice due to the increasing consumption of their meat from year to year in the world. These animals are easy to keep, however, due to their extremely poor thermoregulation caused by an almost complete lack of sweat glands as well as having a thick hair coat, which additionally hinders heat loss, they are very sensitive to high ambient temperatures. As homeothermic animals, when they are in the optimum environment for their species, they maintain a relatively constant body temperature (38.5–39.5°C), regardless of the ambient temperature. This is done at the expense of a high metabolic rate, which requires a large expenditure of energy. However, when the animal cannot dissipate sufficient heat both generated and absorbed from the external environment to maintain the body's thermal balance, heat stress occurs. This article presents an overview of work on the negative impact of heat stress on rabbit breeding, taking into account the fact that, due to global warming, this problem does not only affect hot regions of the world located in the tropical and subtropical climate zones, but is also emerging in countries located in the temperate climate zone. The increasing heat in spring and summer, accompanied by the so-called tropical nights, during which the air temperature does not fall below 20°C at the coldest moment, is a growing challenge for rabbit breeders. The presented literature review shows that heat stress adversely affects welfare and adaptation, feed intake and conversion, immunity and health

status as well as growth, reproduction and meat quality. Thus, it causes great economic losses in the breeding of these animals.

Keywords: rabbits, heat stress, reproduction, meat quality, blood parameters, immune response