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REVIEW PAPER

Environmental heat stress in rabbits: implications and ameliorations

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Abstract
Profitable production of rabbit meat requires comfortable environment for expression of good quality traits embedded in the genetic components of rabbits. One of the major problems facing rabbit production is heat stress, especially in hot regions of the world. This is further aggravated by global warming being experienced as a result of climate change. Rabbits have no or few sweat glands, complicating the problem of heat dissipation, thereby predisposing the animals to heat stress (HS). Heat stress adversely affect welfare and adaptation, feed consumption and utilization, immunity and health status, growth, reproduction, and milk production in rabbits. Rabbits are homoeothermic animals. They should be capable of body temperature regulation within a narrow range. Thermoregulation is extremely poor in rabbits because of lack of sweat glands. Rabbits are highly sensitive to high ambient temperature. The presence of thick insulator fur on the skin further impedes heat loss in rabbits. This review summarizes data available literatures in the last two decades (2000–2020). Short compilation on management techniques adopted in rearing rabbits under hot conditions is included.

Keywords Adaptation · Carcass yield · Global warming · Heat stress · Meat quality · Tropics

Introduction

Responses of animals to elevated environmental temperature that exceeds thermal comfort zone are termed heat stress (Kang et al. 2020; Saracila et al. 2020). It is a major problem in rabbit production, especially in the tropics and during summer heat spells in the temperate regions (Farghly et al. 2020). Rabbits, unlike other livestock species, are easy to rear with less competitiveness for human food materials (Haque et al. 2016). The meat is of good quality, acceptable, and free from cultural taboo. High prolificacy with short gestation period and being noiseless and convenient for rearing at the backyard make the production of rabbit a choice for many people. Rabbits have high efficiency in converting forage to meat (Chipo et al. 2019). However, with all these benefits, rabbit production is greatly affected by elevated environmental temperature. The problem is further complicated by the ensuing climate change (Lamarca et al. 2018). Various impacts of HS on productivity in rabbits are highlighted as they occur in literatures in this review.

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Rabbit production

The three needs of humanity (food, fuel, and fiber) are always in short supply. The United Nations Organization in the year 2015 predicted that by year 2030, the world population would have increased to 8.5 billion provided the level of fertility in human remains unchanged (UNO 2015). This heightens the risk of widespread poverty and hunger if the vast needs of human population are not met. The demand for food increases as the world population increases. Meeting the global food demand adequately calls for urgent steps toward rapid production of good quality and quantity of food materials in a sustainable manner. Livestock product is expected to increase by 100% by mid-twenty-first century (Hurst et al. 2005). One of the livestock species that could help bridge the gap between the food demand and supply is rabbit.

Rabbit (*Oryctolagus cuniculus*) is non-ruminant herbivorous animal with large and well-developed caecum which permits an increase in the efficiency of the utilization of fibrous diets (Sabatakou et al. 2007). Its production is easy because of its low cost of management. Rabbit is a quiet and highly prolific animal with short gestation period between 31 and 33 days (Mahrose et al. 2010). It is widely acceptable because of the quality of its meat. In addition, rabbit production is encouraged because of the small body size, early maturity, early marketability, high efficiency in converting forage to meat, low cost of feeding and housing requirements, and limited competition with humans for grains unlike chickens (Haque et al. 2016; Chipo et al. 2019). Furthermore, talking about its nutritional quality, rabbit meat contains high protein content, low purine content, high content of monounsaturated fatty acid, less level of cholesterol, and essential amino acids and vitamins (Dalle Zotte 2014). The consumption of 100 g of rabbit meat supplies around 8% of the riboflavin (vitamin B_2), 12% of the pantothenic acid (vitamin B_5), 21% of the pyridoxine (vitamin B_6), and 77% of the niacin (vitamin B_3) required daily (Hernández and Dalle Zotte 2010). Its mineral and fatty acid content makes it essential and recommendable for people suffering from hypertension and helps to prevent vascular diseases, respectively (Dalle Zotte 2014; El-Medany and El-Reffaei 2015).

Small-animal husbandry can be a very lucrative operation for both landed and landless small farmers, providing work for women, children, and the handicapped (the least privileged social strata), producing substantial income, and helping to upgrade the family diet (FAO 1997). Annually, a rabbit can produce between 40 and 60 kits (that is approximately 8–12 kits per birth). Another advantage of this micro-livestock is the ability of the doe to mate immediately after kindling or some days later due to its great receptivity at this period of time (Dalle Zotte 2014).

In developing countries like Egypt and Nigeria, rabbit production is a veritable way of reducing poverty due to its low cost of production, high growth rate, and high efficiency in the conversion of forage to meat. Aside from meat production, rabbit is also raised for fur and wool production, research purposes, pets, and exhibition (Ajasin et al. 2004). The consumption of rabbit meat does not violate any religious or social taboos (El-Raffa 2004).

Thermoregulation in rabbits

Rabbits are homoeothermic animals. They should be capable of body temperature regulation within a narrow range (Szendrő et al. 2018). However, thermoregulation is extremely poor in rabbits because of lack of sweat glands (Yagci et al. 2006). Rabbits are highly sensitive to high ambient temperature (Marai et al. 2002; Maertens and Gidenne 2016). The presence of thick insulator fur on the skin further impedes heat loss in rabbits (Marai et al. 2001). For thermoregulation to occur, there must be a balance between heat gain and heat loss (Kumar et al. 2011). Sources of body heat include metabolic heat production from ingested feed materials; heat gain from the environment through conduction, convection, and radiation; and to little extent, heat gain from warm feed and water consumed (Collier and Gebremedhin 2015). Jimoh and Ewuola (2016) stated that rabbits usually use body positioning, increment in breathing rate, and heat loss via vasodilatation in the ear as major devices for thermolysis. Enlarged pinnae in rabbits are an adaptive feature for heat loss (Stott et al. 2010). The thermoneutral zone (TNZ) for rabbits is around 18 to 21 °C (Marai et al. 2001). As environmental temperature increases up to 27 °C, heat load in the body must be shed to facilitate constant body temperature. To achieve thermoregulation, rabbit loses body heat through conduction, convection, and radiation. This soon gets exhausted as temperature further increases. The upper critical temperature for rabbit at rest is 27 to 28 °C. Vasomotor via the pinnae and cardiorespiratory mechanisms are employed in this situation. Continuous exposure of rabbits to extremes of heat leads to disruptions in homeostatic mechanisms, thereby causing damages to various organs (Farghly et al. 2021).

The responses of rabbit when the body heat load exceeds the heat loss capability are termed heat stress. Heat stress causes losses in productivity in rabbits. Bouwknecht et al. (2007) explained that when an animal is exposed to a stressor, the general adaptation syndrome response takes place, while heart rate and body temperature increase.

Clinical thermometers have been historically in use to monitor body temperature in rabbits. These have disadvantages in that contact must be maintained with the animals to take readings which create fear in rabbits (Jaén-Téllez et al. 2020). However, the use of infrared thermography (IRT) in recent times could also be employed for quick monitoring of the temperature of the rabbits and the hutches. Infrared thermography is a useful and novel technique for identifying changes in temperature emissivity from different parts of the body (Kunc and Knizkova 2012). de Lima et al. (2013) reported a work done to ascertain the possibility of usage of IRT in monitoring animal's body surface temperature under diverse ambience. The authors found out that IRT could be a good tool to assess heat stress in animals housed on typical rabbit houses. IRT has been in use to measured body temperature in other species of farm animals (Kunc and Knizkova 2012; Bloch et al. 2020) and rabbits (Agea et al. 2021). Jaén-Téllez et al. (2020) stated that body temperature with IRT in rabbit could best be taken from the ear and eyes.

Temperature-humidity index

Temperature-humidity index (THI) could be used to assess the intensity of HS inflicted by the environment (Igono et al. 1992; Kang et al. 2020). THI is the combination of both environmental temperature and relative humidity to appraise the seriousness of HS. Daader et al. (2016) and Farghly et al. (2020) opined that operating a group of two or more climatic components is essential to perfectly determine the intensity of HS. The US National Weather Service exercises the THI index to advise animal breeders in the MINK states (Missouri; Indiana; Nebraska; and Kansas) of the predictable HS acuteness (Hahn et al. 2009).

It was recommended that the ideal THI for rabbit breeding is 27.8 (Marai et al. 2001, 2002). The association of environmental temperature, relative humidity, energy intake, and heat production in growing animals is essential issue that must be studied in planning a successful, well-organized livestock farming (Daader et al. 2016; Farghly et al. 2020). The THI is extensively exhausted in hot and humid places worldwide to evaluate the effect of HS in rabbit (Oseni and Lukefahr 2014). Temperature-humidity index could be estimated with Marai et al. (2001) expending the next formula, THI = db °C-{(0.31–0.31RH)(db °C-14)}, where db °C is the dry bulb temperature in degree Celsius and RH is the relative humidity in percent. The assessed values of THI were categorized as follows: < 22.2 = lack of HS, 22.2–23.2 = reasonable HS, 23.3–25.5 = severe HS, and 25.5 or more = very severe HS.

Effects of heat stress in rabbits

Phenotypic expression is a product of inherent genotypic potentials as influenced by environment. The environmental impact goes a long way in expression of the inherent traits in rabbits. Effects of HS on rabbit productivity in literatures are discussed below and illustrated in Fig. 1.

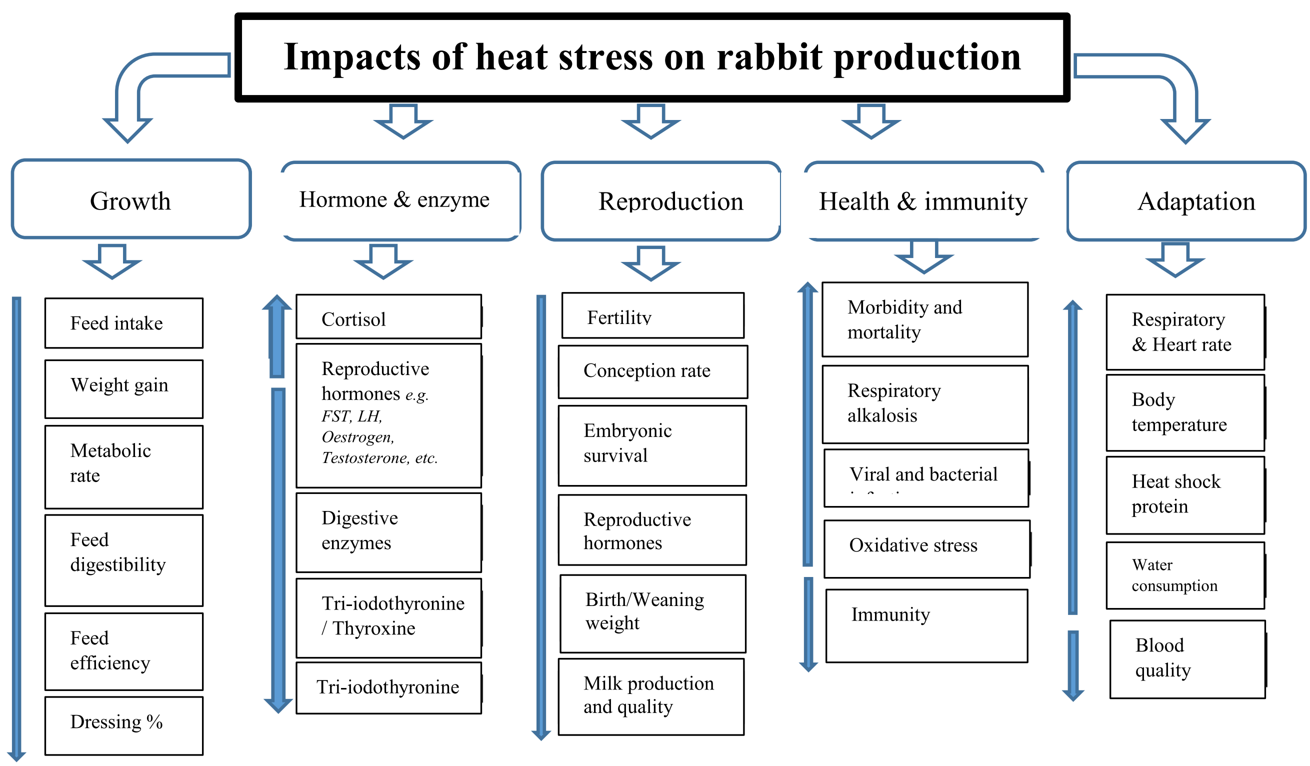

Fig. 1 Impacts of heat stress on rabbit production

Welfare and physiological adaptation

Rabbit productivity is directly affected by elevated environmental temperature (Fouad 2005). Elevated temperature beyond TNZ causes compromises in homeostatic mechanisms in rabbits, impairing their welfare. The rectal temperature of rabbits kept under TNZ ranges between 38.8 and 39.1 °C, but may rise up to 41.6 °C when exposed to elevated ambient temperature within 50 min (Jimoh and Ewuola 2016). Table 1 shows variations in body temperature of rabbits exposed to elevated ambient temperature beyond TNZ. Jimoh and Ewuola (2016) reported that both core and ear temperatures are elevated as the ambient temperature increases from morning to afternoon. There exists seasonal variation in body temperature of rabbits (Asemota et al. 2017). Mousa-Balabel (2004) reported that rabbits kept in air-conditioned room had lower respiratory rate than those in hot environment. Heat stress causes increment in ear and rectal temperature, respiratory and pulse rates, PCV, hemoglobin concentration, blood cell counts, and thyroid hormones in pregnant does (Shebl et al. 2008). Great perturbation was recorded in both hematological and serum biochemical parameters in New Zealand rabbits exposed to hot temperature (Okab et al. 2008). Red blood cell, PCV, total protein, and glucose were lowered by ambient temperature of 36 °C over a month in adult NZ rabbits (Ondruska et al. 2011) below the values obtained under TNZ. With expected elevation in global surface temperature, the welfare of rabbits in hot regions would be adversely affected.

Feed intake, digestion, and utilization

It is natural for animals to go off feeding in hot environments. Voluntary feed consumption (Mousa-Balabel 2004; Abdal-Rahman and Baqey 2016; Mousa-Balabel et al. 2017) and digestion (Al-Sagheer et al. 2017) are reported to dwindle in rabbits kept under HS conditions. Marai et al. (2001) compared the productive traits in rabbits between winter and summer periods and found that 17-week-old winter rabbits had higher daily weight gain (23.3 g/d), feed intake (122.8 g/d), and liveweight (2683.8 g) than the summer rabbits with 17.5 g/d, 94.6 g/d, and 2230.0 g, respectively. Reduction in feed intake is pinned down on the need for physiological adjustment in metabolic heat production. Even with lowered nutrient ingestion, digestibility of feed is affected. Significant differences in dry matter and crude protein digestibility coefficients were reported in rabbits raised during winter (65.0 and 66.1%, respectively) and summer (57.1 and 58.0%, respectively) conditions (Marai et al. 2001).

Immunity and health status

Heat stress elicits perturbations in oxidative balance (between production of antioxidant enzymes and reactive oxygen species) in rabbits (Jimoh et al. 2017). Livestock diseases and disease vectors: increase in the rate of pathogens developments (Harvell et al. 2002), effects on vectors and epidemiology (Thornton et al. 2009) were found. Plasma proteins are portion of the immune reaction where antibodies are created from albumin which is the main protein component of serum (Hassan et al. 2016). Globulin concentration was increased in the rabbits exposed to heat shock (36 ± 1 °C for 3 h from 12:00 to 15:00 for 3 successive days, at 3 and 25 days of age) when compared to the control group rabbits. The significant increase of globulin concentration is used as an indicator of immune response and source of antibodies production (Sakr et al. 2019).

Growth and production efficiency

HS in rabbits affects growth (Marai et al. 2001, 2002; Okab and El-Banna 2003; Okab et al. 2008; Ondruska et al. 2011). The kits from heat-stressed does had decreased post-natal growth during lactation (Marco-Jiménez et al. 2017). Rabbits are very vulnerable to raised heat and heat stress is connected with reductions in body weight gain, feed intake, and feed efficiency (Farghly et al. 2020). A significant reduction in slaughter, carcass, and organ weight was recorded in rabbits subjected to heat stress (Zeferino et al. 2013). HS exerts

Table 1 Body temperature of rabbits under different environmental temperature conditions

S/N	Description of environmental conditions	Part of the body	Temperature range (°C)	References
1	Morning	Ear	34.09–34.51	Jimoh and Ewuola (2016)
		Rectal	36.70–37.20	
	Afternoon	Ear	37.04–37.75	
		Rectal	37.83–39.00	
2	Late dry (THI: 32.0)	Rectal	38.37	Asemota et al. (2017)
	Early rainy (THI: 30.9)	Rectal	38.83	
	Late rainy (THI: 29.0)	Rectal	38.45	
	Early dry (THI: 31.0)	Rectal	37.83	

Table 2 Performance of rabbits under different environmental temperatures

S/N	Description of environmental conditions	Performance parameter	Value	References
1	TNZ (18 ± 2.5 °C)	Live weight (g)	2637 ± 244.4	Ondruska et al. (2011); during 8–12 weeks of age
	HS (36 ± 3 °C)		2174 ± 158.9	
	TNZ (18 ± 2.5 °C)	Feed intake (g/d)	159 ± 4.6	
	HS (36 ± 3 °C)		67 ± 1.9	
	TNZ (18 ± 2.5 °C)	Weight gain (g/d)	36 ± 0.7	
	HS (36 ± 3 °C)		25 ± 0.5	
	TNZ (18 ± 2.5 °C)	Feed conversion ratio	4.5 ± 0.1	
	HS (36 ± 3 °C)		2.7 ± 0.1	
2	Air-conditioned room	Water intake (ml/d)	270 ± 0.1	Mousa-Balabel (2004); during 38–48 weeks of age
	Ambient temperature		385 ± 0.0	
	Air-conditioned room	Feed intake (g/d)	159 ± 0.0	
	Ambient temperature		122 ± 0.0	

TNZ thermoneutral zone, *HS* heat stress

negative effect on meat quality traits (Zeferino et al. 2013). Growth performance of rabbit under different conditions is shown in Table 2.

Reproduction and milk production

Heat stress, whether acute or chronic, has profound and drastic effects on the reproductive efficiencies of both male and female rabbits. Sabés-Alsina et al. (2016) found out that acute heat exposure of 3 h at 42 °C compromised sperm functions. Maya-Soriano et al. (2015) on the other hand experimented with long period of heat exposure and reported that heat stress had negative effects on prolificacy of female rabbits exposed. Litter size at birth (6.9 vs. 7.8 live young), litter size at weaning (5.95 vs. 7.08), and pre-weaning mortality (16.94% vs. 9.60%) are affected by environmental temperature (Frangiadaki et al. 2003). Marco-Jiménez et al. (2017) reported reduced litter size, litter weight, and kit birth weight in kits whose dams were exposed to heat stress during gestation compared to unstressed does. Occurrence of stillbirth was higher in does stressed during pregnancy. Mady et al. (2018) reported differences in birth and weaning weights in rabbits between winter and summer seasons. Rabbits had heavier weight at birth (53.38 g) and weaning (374.44 g) during winter than in summer (37.56 g and 304.78 g), respectively.

Heat stress causes lowered male reproductive efficiency (Turner and Lysiak 2008). Spermatogenesis is efficiently successful in rabbit bucks when the testicular temperature is kept below body temperature. This becomes impossible under hot climatic conditions. HS causes damage to the spermatogonia and other stages of sperm formation. High temperature lowers sperm quality and viability. The fertilizing capacity and resulting embryos are negatively affected by high environmental temperature (Yaeram et al. 2006). Oxidative stress elicits the apoptosis process in the germ cells. Histological studies on the testes of heat-stressed bucks revealed altered testicular cell and membranous structures (Aldemir et al. 2014; Bharti et al. 2014). It leads to decrease in reproductive efficiency and animal health. Libido of rabbit and sperm density was decreased by exposure to heat stress (Pei et al. 2012). In a review done by Marai et al. (2002), reproductive hormonal (testosterone) concentration, sperm output, semen quality, and fertility were listed among reproductive traits affected by HS in male rabbits.

Garcia and Argente (2017) reported negative effects of heat stress on embryogenesis. The authors discovered that subjecting the female rabbits to heat stress resulted in lowered ovulation rate, percentage normal embryo, embryo development and area, and thicker zona pellucida than in those kept under thermal comfort zone.

In a review on non-dietary factors affecting milk quantity and quality in rabbits, Maertens et al. (2006) gave the issue of heat stress a prominent right of place as a major factor, especially when the minimum daily temperature remains around 25 °C. Elevated ambient temperature has negative influence on milk yield in lactating does (Mahrose et al. 2010). A drop in milk yield of up to 30–40% was recorded in rabbits kept at 30 °C condition compared those in conventional conditions (Pascual et al. 2000).

Amelioration of heat stress impacts in rabbits

Numerous tries were implemented to diminish the harmful impacts of heat stress in rabbits through several ways (Mahrose 2000; Mahrose et al. 2010; Jimoh and Ewuola 2016, 2018; Farghly et al. 2017, 2020, 2021; Abdelnour et al. 2020). Presently, investigation attempts are concentrated on management and nutritional approaches to aid rabbits better survive HS encounters and preserve body's health and productivity (Sheiha et al. 2020).

Management approaches

The use of air conditioners, fan, sprinklers, fogger, ventilators, and other climate control equipment may be adopted in areas where the cost is not too exorbitant (Mousa-Balabel 2004; Ume et al. 2018). A natural ventilated building with semi-opened window and comfortable cages (El-Raffa 2004) are also suggested. Roofs and outer walls can be sprayed with water carefully. In this case, the rabbits must be kept dry to avoid respiratory diseases. By doing this, the amount of evaporative cooling from animals is maximized (El-Raffa 2004). Heat-resistant roofing materials such as asbestos, thatch, long grasses, palm fronds, etc. could be used instead of corrugated iron roofing sheets (Ume et al. 2018).

Cage stocking density is an important issue and should be amended at the hot season. Abdel-Monem et al. (2009b) concluded that the greatest growth performance of New Zealand White rabbits could be gained when 800–1200 cm^2 are delivered to each rabbit. It was found that high density had adverse influences on growth performance traits and the stress-related parameters (serum glucose, cortisol, and creatinine) and the expression of HSP70 gene was increased, with a notable decrease in IGF-I gene expression in the high stocked rabbits (El-Bayoumi et al. 2018).

Feeding times have an important effect on rabbit's performance under HS conditions (Mahrose 2000; Abdel-Monem et al. 2007; Badr 2015). Feeds should be given during the coolest period of the day, early in the morning or late in the evening (El-Raffa 2004; Mahrose et al. 2010; Farghly et al. 2017). Rabbits favor to eat nocturnally and spend 60–70% of the feed at dark (Abdel-Monem et al. 2007). Farghly et al. (2017) stated that altering feeding period in growing New Zealand White rabbits through 22:00–04:00 h during summer season had advantageous influences on their productive performance. The latter investigators indicated that growing rabbits fed during 22:00–4:00 presented the greatest body weight gain and percentages of dressed carcass weight and the lowest values of body temperature, albumin/globulin ratio, and neutrophil/lymphocytes ratio when compared with their counterparts. Feed restriction is also a well plan to mitigate the harmful impacts of HS in rabbits. In the study carried out by Mousa-Balabel et al. (2017), the authors showed that applying 30% feed restriction or adding honeybee to the drinking water (20 ml/l drinking water) caused an improvement in conception rate, gestation period, litter size at birth and at weaning, milk yield, and kits weight at weaning.

Mating also should be done at the coolest periods of the day during summer season, where Mahrose et al. (2010) reported that mating or collecting semen at the morning (around 8 a.m.) resulted in an enhancement in doe and buck productive and reproductive performances under hot environments.

Lighting regimens are probably exhausted as an approach to advance rabbit production in tropical areas (Mahrose et al. 2010). Farghly et al. (2020) found that the application of photoperiod of afternoon (from 22.00 to 10.00 h) for over a short period of time in rabbits farm resulted in useful impacts on growth performance, carcass traits, and the physiological parameters of growing rabbits. As well, lighting source has an impact on growth performance of rabbits. Light-emitting diode as lighting source might be suitable for change of incandescent and fluorescent light sources in rabbit farms to enhance growth performance without affecting rabbit's carcass and welfare during summer season (Farghly et al. 2021).

Nutritional approaches

During heat stress, energy metabolism is shifted toward carbohydrates use and decreased lipid oxidation which makes glucose beneficial as a nutritional supplement (Daader et al. 2016). Abdel-Monem et al. (2009a, b) postulated that intensifying dietary energy up to 3050 kcal digestible energy/kg diet displayed possibility to enhance litter size and weight at weaning and reduce pre-weaning mortality of New Zealand White rabbits and Flander during HS. The use of vitamin E and selenium in rabbits exposed to heat stress at 35 °C caused a reduction of the rectal and skin temperature (Al-Zafry and Medan 2012). According to Sharaf et al. (2019, 2021), vitamin E and selenium positively affected the final live body weight and feed and water intake of growing male rabbits and improved reproductive traits of the doe. Organic selenium at the rate of 0.3 mg/kg feed countered the impact of heat stress on semen quality and fertility in male rabbit (Hosny et al. 2020). Ascorbic acid also known as vitamin C has been widely studied as one of the vitamins also used to lessen the damage caused by heat stress. Vitamin C can be added in the drinking water or in the diet (Mousa-Balabel 2004; Yassein et al. 2008; Anoh et al. 2017) since it is a water soluble vitamin for higher litter weights which indicated an increase in milk production by the doe (Shebl et al. 2008; Zeweil et al. 2009) as well as increasing growth rates of fattening rabbits (Daader et al. 2018). In the studies conducted by Anoh et al. (2017, 2018), it was decided that baobab (*Adansonia digitata*) fruit pulp meal (has high content of vitamin C) is applicable in diminishing HS in growing rabbits and can be used up to 5.5% as an addition level.

Probiotics (yeasts and their extracts) have been illustrated as outstanding suppliers of ordinary antioxidants, and could endorse growth and lessen oxidative stress in rabbits kept under HS conditions (Abd El-Aziz et al. 2021). Growing rabbits fed diet supplemented with *Saccharomyces* *cerevisiae* (8×10^9 colony forming units/kg) ate more feed, achieved the greatest body weight gain, and has low serum malondialdehyde (MDA) concentration (Shehu et al. 2018).

Several studies recommended newly the valuable impacts of resulting microbial metabolites, particularly microbial dyes on animal health (Panesar et al. 2015; Abdelnour et al. 2020). These compounds such as fucoxanthin- and astaxanthin-rich yeast enhanced the health status and had reasonable influences on growth performance (Perenlei et al. 2014; Gumus et al. 2018). In this context, Abdelnour et al. (2020) indicated that dietary prodigiosin supplementation (50, 100, 150 mg/kg diet) boosted body weight at marketing, feed conversion ratio, plasma levels of total antioxidant capacity, and decreased total bilirubin and MDA.

Using grape seed in rabbit diets could be considered a useful way to enhance rabbit's productivity during summer season. Hassan et al. (2016) stated that dietary supplementation of grape seed extract at 100, 200, and 300 mg/kg of diet is beneficial as an ordinary defensive from HS through summer season to preserve performance, carcass characteristics, and antioxidant status. Moreover, grape seeds are considered a valuable source of phenolic and flavonoid complexes which enhance growth performance and carcass characters, stimulate the antioxidant enzyme scheme, and decrease the undesirable impacts of HS in rabbits. El-Ratel et al. (2021) reported in a study that the inclusion of 200 mg per kilogram feed could help in amelioration of the negative effects of heat stress by improving sexual desire, semen quality, and oxidative status in rabbit bucks.

Effect of using soursop juice (*Annona muricata* linn.) in diminishing oxidative stress produced by HS was investigated in growing rabbits. Jimoh et al. (2018) postulated that soursop juice established hypocholesterolemic impact in a dose-dependent way, where the inclusion of soursop juice to growing rabbits under HS showed advantageous, as soursop juice decreased serum lipid peroxidation and improved antioxidant status. Administering quercetin, a common flavonoid, in the diet of heat-stressed rabbits had been found to be efficacious in ameliorating the negative effects (Naseer et al. 2017). Quercetin improved follicle number, total recovered oocytes, number of high grade oocytes, and oocyte dimensions in treated group compared to the control group, though the oocyte maturation rate was not different. As well, it reduced cell apoptosis during embryo development. Abdelnour et al. (2020) reported that administering prodigiosin, a natural pigment, in the diet of rabbits as a novel feed additive could help improve the growth and state of health of rabbit. It was reported that productivity was improved after shortening the long and thick skin coverage of rabbits (Lukefahr and Ruiz-Feria 2003; Askar and Ismail 2012). The use of fresh and cool water (iced water) is recommended. Loss in reproductive efficiency of heat-stressed rabbits was derived from conception rate, pre-weaning mortality, and litter weight at weaning to be 73% compared to unstressed rabbits. However, provision of cool could restore up to 91.7% of the loss (Marai et al. 2001). Stocking density of the rabbit needs attention during hot spells. Villalobos et al. (2008) recommended that under HS conditions, stocking density in fattening program should not exceed 18 rabbits/m^2 or 34 kg/m^2. To allow normal rabbit behavior, the EFSA (2005) recommended 14–23 kits/m^2. During HS, a maximum density of 18 rabbits per square meter was recommended.

A research report stated that Chinese royal jelly supplementation between 50 and 150 mg/kg feed twice per week for 20 weeks to the diet of heat-stressed male rabbits can counteract summer infertility and improve their physiological status. Royal jelly treatment increased total antioxidant capacity and reduced MDA and TBARS in heat-stressed bucks (El-Hanoun et al. 2014). It is generally suggested that dietary provision of mixtures of natural antioxidants will help in combating the oxidative stress and its damaging effects on spermatogenesis caused by heat stress (El-Hanoun et al. 2014). Resistant strain of rabbits that can tolerate heat should be bred (Ume et al. 2018). As much as possible, rabbits should be handled with care during the hours of high heat load. Rough handling will increase metabolic heat production associated with muscular activity (Daader et al. 2016).

Dietary *Emblica officinalis* (is extensively consumed in conventional Indian medicine) enables the growing rabbits in mitigating HS deprived of creating unfavorable impact on the liver, where *Emblica officinalis* (300 mg/rabbit/day for 6 weeks) could reduce level of total cholesterol and increase high density lipoproteins (Virmani et al. 2019).

At present, there is an attention in the usage of seaweeds in animal and poultry nutrition, and could be a profitable way to ameliorate the deleterious effects of HS. Seaweeds comprise polysaccharides, proteins, essential amino acids, minerals, vitamins, lipids, polyunsaturated fatty acids, pigments such as carotenoids (carotene xanthophyll), chlorophylls, phycobilins (e.g., phycoerythrin), and many antioxidant compounds, containing principally polyphenols (Michalak and Chojnacka 2015; Øverland et al. 2018; Corino et al. 2019). These bioactive particles display prebiotic, antimicrobial (antibacterial, antifungal, antivirus), antioxidant, and anti-inflammatory immunomodulatory impacts (Michalak and Chojnacka 2015; Michalak and Mahrose 2020). In this concern, El-Ratel and Gabr (2019) confirmed that using *Spirulina platensis* at 300 mg/kg diet improved the reproductive performance of the doe (conception rate, kindling rate, and litter size), lipid profile, antioxidant and immunity status, and ovulatory response as ovulation rate. Hassan et al. (2021) indicated that growing rabbits fed diet supplemented with zinc- and/or selenium-enriched *Spirulina platensis* caused an enhancement of globulin (as indicator of immunity), high density lipoprotein cholesterol and total antioxidant capacity, and reduced thio-barbituric acid reactive substances, plasma lipids, and total triglycerides under heat stress conditions of summer season.

Conclusion

One of the major problems facing rabbit production is heat stress, especially in hot regions of the world. The adverse effect of climate change on rabbit has led primarily to heat stress, thereby reducing its productivity and efficiency. Heat stress adversely affects welfare and adaptation, feed consumption and utilization, immunity and health status, growth, reproduction, and milk production in rabbits. Rabbits are homoeothermic animals. They should be capable of body temperature regulation within a narrow range. Ameliorative measures such as addition of vitamins to their drinking water or some dietary supplementations, as indicated in this work; good housing facilities that are well ventilated with either air conditioners or fan; using management approaches; and rearing of resistant breeds of rabbit, among other measures, have been effective in combating heat stress.

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Data availability Not applicable.

Declarations

Ethics approval All investigational processes respected the instructions of the ethical board of the Department of Animal Physiology, College of Animal Science and Livestock Production, Federal University of Agriculture, PMB 2240 Abeokuta, Nigeria.

Consent to participate Not applicable.

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