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CLIMATE CHANGES EFFECTS ON RABBIT PRODUCTION

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ABSTRACT

One of the major problems facing rabbit production is heat stress in hot regions of the world, especially in Egypt through summer season. This is further aggravated by global warming being experienced as a result of climate change. Climate change is a variation or change in the climate (temperature, wind, precipitation patterns) in a specific location, region, or the entire planet. This change in weather patterns persists for a long period of time ranging from decades to millions of years.

Heat stress adversely affect welfare and adaptation, feed consumption and utilization, immunity, health status, growth, reproduction, and milk production in rabbits. Rabbits have no or few sweat glands and thicker fur, increasing the heat dissipation complexity. Thermoregulation is extremely poor in rabbits because lack of sweat glands so, they are highly sensitive to high temperatures. This review summarizes available literatures in the last few decades (1990–2023).

Keywords: Climate change, heat stress, rabbit production.

INTRODUCTION

Rabbits are an important micro and monogastric livestock raised for meat, fur, wool production, as laboratory animals, pets and exhibition (Ajasin *et al.*, 2004). It has features of being highly prolific; limited competition with humans for a like food, feeds easily, outstanding adaptive abilities, suitable for breeding, and meat production with small capital investment (Hassan and Owolabi, 2009). Moreover, the dietetic and gustatory properties of rabbit meat are highly appreciated, as short gestation interval (30-32 days), as well as the ability to utilize diverse forage (Nworgu and Hammed, 2009). Rabbit meat has characteristics of being tender, fine quality and a high nutritional value with high protein, low fats, low cholesterol, sodium and calories and contains phosphorus, iron, zinc, riboflavin (B_2), thiamin (B_1), cobalamin (B_{12}) and niacin (B_3) - making it ideal meat for hypertensive patients (Ozor and Okorie, 2011). The above potentials of this animal endeared it as among the category of underutilized livestock species in developing countries that could be most suitable and sustainable means of producing high quality meat (protein) to combat animal protein shortage in the diet of people in developing economy (Okorie, 2011). Nevertheless, the production of rabbit was constrained in most developing countries by among others climate change (Ozor and Madukwe, 2005 and FAO, 2008).

Climate change according to Mertez *et al.*, (2009) and Onyekuru and Marchant (2017) is long term gradual change in weather variables such as temperature, rainfall, relative humidity, wind, sunshine and pressure. Climate change is caused by increase in greenhouse gases [in form of carbon-di-oxide, methane and nitrous oxide (N_2O)] primarily due to industrialization, foil fuel use, land use change and change in agricultural activities (Nhamachena and Hassan, 2007). Generally, in tropical climates, temperature seems to be the dominant factor, but variations in length of daylight cannot be excluded. In sub-tropical climate (such as in Egypt), the ambient temperature, relative humidity and diurnal light seemed to be involved (Habeeb *et al.*, 1993 and Marai *et al.*, 1996). The effects of climate change often reported among studies in rabbit production are lack of portable water for the livestock use, incidence of diseases and pests, extinction of the animal at extreme heat stress situation, changes in grazing behavior, feed intake, feed digestibility and efficiency of feed utilization (Marai *et al.*, 1996 and Ajasin *et al.*, 2004). Other effects are lower rabbit carcass quality, increase in incidence of parasite and reduction in the storage and handling of animal products (Ozor and Madukwe, 2005).

1-Climate change definition:

Climate change is a variation or change in the climate (temperature, wind, precipitation patterns) in a specific location, region, or the entire planet. This change in weather patterns persists for a long period of time ranging from decades to millions of years. Climate change may be caused by a variety of factors including natural processes; however, scientific evidence shows that the current period of climate change is caused by human activities. In 2015, the 2030-agenda for sustainable development was under the patronage of the UN. This agenda is considered to be a roadmap to get rid of poverty and hunger across the world through specific actions, including the elimination and adaptation to global warming effects. Global warming impacts both agricultural and animal production and alters the distribution of different animal species. Animals, particularly rabbits, will experience increasing problems as global warming will alter their physiological and behavioral status over the coming decades.

2- Importance of rabbit production:

The three needs of humanity (food, fuel, and fibers) 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 and Chipo *et al.*, 2019). Furthermore, talking about its nutritional quality, rabbit meat contains high protein content, low fat content, high content of monounsaturated fatty acids, less level of cholesterol, and contains essential amino acids and vitamins (Dalle Zotte 2014). The consumption of 100 g of rabbit meat supplies around 8% of the riboflavin (B_2), 12% of the pantothenic acid (B_5), 21% of the pyridoxine (B_6), and 77% of the niacin (B_3) required daily (Hernandez and Dalle Zotte 2010). Its minerals and fatty acids content make it essential and recommendable for people suffering from hypertension and helps to prevent vascular diseases, respectively (Dalle Zotte 2014 and El-Medany and El-Reffaei 2015). Annually, a rabbit can produce between 40 and 60 kits (that is approximately 8–12 kits/parity). 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, 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.

3-Rabbits and global warming:

Rabbits are highly susceptible to high ambient temperature and face a risk of overheating as their few functional sweat glands do not let them effectively sweat, moreover, their bodies are covered with fur that decreases heat dissipation, and also, panting is not efficient for cooling (Weisbroth *et al.,* 2013). The ears are a vital heat-regulating organ in rabbits because they represent about 12% of the body's surface area and are highly vascular. Accordingly, the problem to produce rabbits on a commercial scale in the Southern Mediterranean regions, such as Egypt, is the susceptibility of rabbits to heat stress. Global warming negatively affects different agricultural commodities in direct and indirect ways including a decline in rainfall rates, an increase in drought areas, and an increase in the temperatures of many regions worldwide. These abnormal climate changes negatively impact the distribution, productivity, and reproductive performance of all animal species. The requirements and behavior of rabbits are highly influenced by their geographical origin. Therefore, the geographical origin should be considered when the effect of global warming on commercial rabbit breeds is discussed. Since the rabbit originated in the Mediterranean region, it has been benefited from its geographical area to be adapted to the Mediterranean climate. A great part of this adaptation was derived from the wild rabbit behavior, where it spends the hot hours of the day in its burrows, and goes outside only during the colder early and late hours of the day (El-Raffa, 2004). Hot climate areas are the obvious and clearest restriction to rabbit production; the susceptibility of this species to heat stress induces a sequence of extreme changes in their biological functions that initiate diminishing of production and reproduction (Smitha *et al.,* 2014).

Such adverse effects are stressed during summer, resulting in a restraining breeding period of the rabbits from September to May each year in the Southern Mediterranean region. High ambient temperature in the Southern Mediterranean region challenges the animal's ability to maintain energy, water, hormonal, and mineral balances. Nowadays, most of the high-productivity rabbit breeds were developed in Europe due to the advanced breeding programs and optimal growing temperatures. However, the adult body weight of commercial rabbits is reduced by about 20-25% in hot countries. Heat stress can indirectly disturb the functions of the immune system by increasing diseases susceptibility, for instance, disturbance of homeostasis by acute infection activates fibroblasts, leukocytes, and endothelial cells (Abdelnour *et al.,* 2020). Furthermore, Marai *et al.,* (1994) reported that there is possible extinction of rabbit under extreme heat, hence opined that ideally temperature in the hutch should not be higher than 85°f (29.4°C) degrees while in closed buildings where temperature and humidity are controlled, the desirable combination is 60-78°f (15.5-25.5°C) degrees and 30-40% humidity. Harkness, (1988) reported that optimal climatic conditions for rabbits would be: air temperature 13° to 20°C (average 15°C), relative humidity 55 to 65% (average

60%), wind velocity 5 to 18 km/h, ventilation capacity of at least 0.17 m^3/minute (6 cfm) air flow per rabbit housed and a moderate level of sunshine.

4-Thermoregulation of rabbits:

Rabbits can regulate the heat input and output of their bodies using physical, morphological, and behavioral processes to maintain a constant body temperature (Abdelnour *et al.,* 2020). Many studies considered temperatures over 24°C as above optimal. Starting from 25°C, rabbits stretch out trying to lose heat by radiation and convection. It was reported that the jumping movements of rabbits completely disappear at 32°C. At temperatures above 34°C, rabbits stretch ear pinnae and panting can be noticed (Lebas *et al.,* 1997).

The thermo-neutral zone of temperature in rabbits is around 18-22°C, thus, a relative increase in the ambient temperature, higher than 24-25°C, induces a reduction in feed intake (Lebas *et al.,* 1997). However, at 30°C, rabbits are heat-stressed and feed intake is reduced by about 25%. Little and incomplete research work are focusing on the effect of acute thermal stress in rabbits (Amici *et al.,* 2000). Furthermore, instabilities in feed digestion, water metabolism, blood metabolites, and enzymatic reactions, hormonal secretions, in addition to protein, energy, and mineral imbalances were reported to be interrupted in heat-stressed rabbits (Marco-Jiménez *et al.,* 2017). For thermoregulation to occur there must be a balance between heat gain and heat loss. Sources of body heat include metabolic heat production from ingested feed materials; heat gain from the environment through conduction, convection, and radiation; and too 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 thermo neutral 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. 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. Rabbit kits at birth are virtually hairless, with sealed eyelids and ear canals, little crawling ability and body mass ranging between 40 and 80 g (Harkness, 1988). They crouch, shiver and rock from side to side, as the temperature drops. After 30 minutes at 20.0°C, the rectal temperature drops from 37.7° to 32.7°C (Cardasis and Sinclair, 1972). If the dam is present, the neonates seek warmth through maternal contact, apparently guided by thermo-receptors on the nose. This search is directed towards the mammary and occurs at nest temperatures of 32.7°C and below, while it may be absent at 36.1°C and above.

Young without a doe placed in a low temperature (20.0-30.0°C), are grouped and curled up, although this grouping do not prevent chilling or moving in search of a warm area. However, Skrivanova and Marouneck (1997) considered that 25° C is above the optimum temperature for young rabbits aged 30 days. Finzi *et al.,* (1992) found that jumping movements disappeared completely at 32°C ambient temperature, while the small movements were reduced to bare minimum. In warm environment (37.2-42.2°C), the young dispersed and assumed an extended position conducive to loose body heat. Bunnies of 5-10 weeks of age prefer cramming into the box to share warmth in cold weather, while on hot days in summer; they were all spread on their sides on the floor. A smooth PVC floor with holes should replace all wire flooring (McCroskey, 2000), whereas activity of rabbits was found to be higher on a litter floor than on plastic slats, regardless of the temperature (Bessei *et al.,* 1999). Adult rabbits exposed to ambient temperatures below 10°C, curl up to minimize their total body's surface area exposed and lower their ear temperature and the ear pinnae are folded to avoid internal surface from contact with air. At the same time, it drags the ear to bring it closer to the body. At temperatures above 25-30°C, rabbits stretch out to lose as much heat as possible by radiation and convection, step up their ear temperature, stretch ear pinnae and spread it far from the body to expose the surface to the surroundings to increase heat dissipation, since rabbits do not sweat. Above 35°C, rabbits can no longer regulate their internal temperature and heat prostration sets in, while at 40°C, considerable panting and salivation occurred (Lebas *et al.,* 1986).

5- Effect of heat stress on rabbits production:

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 (Jaen-Tellez *et al.,* 2020).

5-1- Growth traits:

El-Sawy *et al.,* (2017) reported that season had high significant effect ($P \leq 0.01$) on FBW. They also showed significant differences ($P \leq 0.05$) between summer and winter groups in live body weight, body weight gain and feed efficiency of weaned NZW male rabbits. Total and daily weight gains in growing NZW rabbits affected negatively by exposure to heat stress (Ondruska *et al.,* 2011). Ondruska *et al.,* (2011) found that total body weight gain was larger (749.20 g) in the winter than that in the summer (527.90 g). The reduction in daily weight gain was due to a drastic decrease in rabbit total feed intake (1412.88 vs. 3337.32 g) and in the feed conversion ratio (2.68 vs. 4.45%) compared with the winter group. Bahga *et al.,* (2010) showed that heat stress leads to decreased performance of growing rabbits in terms of decreased growth rate. The reduction in BWG during summer season was due to a drastic decrease in rabbit feed intake (FI) and feed conversion (FC) as compared with winter season, which might have led to less protein biosynthesis and less fat deposition (Okab *et al.,* 2008 and Ogunjimi *et al.,* 2008). Marai *et al.,* (2008) found that live body weight and daily body weight gain of NZW male rabbits were significantly lower in summer than in winter and the significant lower final body and daily gain weights during summer were probably due to the lower feed intake (10.4%) and feed conversion (8.3%). This reduction in daily gain may be due to less protein biosynthesis and less fat deposition (Okab *et al.,* 2008).

The exposure to ambient temperatures above the thermal comfort zone has a negative impact on animal performance by decreasing body weight (Marai *et al.,* 2001). Rabbits reared in summer showed a reduction in live body weight and daily body weight gain compared to those reared in winter (Ayyat and Marai, 1997). In addition, a decrease in feed intake and feed utilization and the consequent reduction in substrates and hormones are responsible for the depression in gain weight (Habeeb *et al.,* 1992). The feed cost, return and final margin values for growing rabbits were significantly lower in summer than in winter due to the decrease in feed intake and body gain (Marai *et al.,* 2005 and 2008).

On the other hand, Daader *et al.,* (1999) reported that difference in BWG between winter and summer was not significant.

5-2- Feed intake:

Many studies were conducted in different countries on relations between ambient temperature and the rabbit's nutritional requirements. An accurate conception of the diet can reduce the negative effect of hot environments, mainly through an increase of the protein/digestible energy of the diet, but in no case, the composition of the rabbit's feed can alleviate the negative effect of hot temperatures. Feed consumption drops off, water consumption increases and heat production is reduced, during heat stress (Marai and Habeeb, 1994). Feed intake decreased by 40-50% at 30-32 °C (Rafai and Papp, 1984 and Wittorf *et al.,* 1988) and by 30% in summer than in winter (Marai *et al.,* 1994) and in hot (>32 °C) conditions (Hermes *et al.,* 1999). El-Sawy *et al.,* (2017) reported that the reduction of feed intake under summer hot conditions may be due to that the high ambient temperature stimulates the thermal receptors center in the hypothalamus causing a decrease in feed intake as mentioned by Marai *et al.,* (1994 and 2006). Also, heat stress cause depression in feed intake (Okab *et al.,* 2008).

In contrast, the increased feed intake during winter may be due to the appetite increase of rabbits (Ashour *et al.,* 2005).

5-3- Carcass traits:

Carcass characteristics and meat quality parameters of rabbits are very important criteria for consumer acceptance. Several studies elucidated that heat stress negatively affected carcass and meat quality traits (Liang *et al.,* (2022). Matics *et al.,* (2021) noted that a high ambient temperature decreased slaughter weight, hot carcass weight, chilled carcass weight, and reference carcass weight in growing rabbits. Zeferino *et al.,* (2013) observed that heat stress reduced slaughter weight, carcass weight, and relative weights of internal organs (thoracic viscera, liver, and kidneys), decreasing meat juiciness and meat color (redness and yellowness) while increasing cooking loss. Contrarily, Dahmani *et al.,* (2022) postulated that heat stress did not significantly influence the carcass yield %, forelegs %, hind legs %, and loin %. In contrast, the liver %, kidney %, peritoneal fat %, and inter-scapular fat % were reduced in fattening rabbits. Similarly, Matics *et al.,* (2021) noted that heat stress harmed perirenal and scapular fat percentages in growing rabbits. Additionally, Zeferino *et al.,* (2013) concluded that heat-stressed rabbits had lower fat depots. Meanwhile, Liu *et al.,* (2022) elucidated that chronic heat stress decreased the liver index (%), while the shoulder fat % and kidney fat % were increased. El-Sawy *et al.,* (2014) and Zeferino *et al.,* (2013) noticed that season had significant ($P \leq 0.01$) effect on carcass traits. However, rabbits in winter season showed higher significant ($P \leq 0.01$) values of carcass weight, dressing percentage and internal organs weight than those in summer season. These might be due to reduced DFI and deterioration of DWG, resulted in stressful hot conditions during summer season. El-Sawy *et al.,* (2017) reported that season had high significant effect ($P \leq 0.01$) on all internal genitalia organs weight, except that insignificant effect on relative epididymus weight (REW). Where, all other sexual organs means were higher in winter than summer.

On the hand, Marai *et al.,* (2006) showed insignificant differences in carcass traits between summer and winter season except in head and hind weight.

5-4- Fertility of does:

Ahmad Para *et al.,* (2020) reported heat stress was found to affect the fertility of both bucks and does of 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. When young females were raised until 16 weeks of age, and ovulation rate was measured, a reduction in the number of ova per ovulation was observed, where the number of ova was 7.4 for does raised at 30°C, compared to 9.2 observed for those raised at 23°C (Lebas, 2005).

This difference in the number of ova was attributed to the lower live weight of young does raise at 30°C. Verga (1992) indicated that hot climate was the main cause for abnormal maternal and sexual behavior and postulated that the doe that was capable to produce 10 litters a year may give only 4 to 5 litters in hot climate. Exposure to high ambient temperature induces rabbits to try to balance the excessive heat load by using different means to dissipate, as much as possible, their latent heat. Above 35° C, rabbits can no larger regulate their internal temperature and heat prostration sets in (Lebas *et al.,* 1986). At high levels of humidity, the event consequences mentioned above occur at lower temperatures than those recorded, due to that the feeling of warmth under hot ambient temperature increases with high relative humidity, although the temperature is interrelated with other climatic factors such as solar radiation, wind, photoperiod,…*etc*. Such relationship (between ambient temperature and humidity) induced (Lphsi, 1990) to propose a measurement of the level of severity of heat stress by using both factors and was termed temperature-humidity index (THI). This parameter was modified by Marai *et al.,* (2001) for rabbits (as small animals). Protection from cold winds may be required, but it must not be at the expense of adequate ventilation. Conception rate of doe rabbits appears to be affected by seasonal variations (Ayyat and Marai, 1996). The authors found that exposure of adult female rabbits to severe heat of stress adversely affects their reproductive rates, ovulation rate, number of implantation sites per doe and number of viable embryos per doe. Conception rate was lower in hot summer than in winter by 76.8% (Marai *et al*., 2001).

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.

5-5- Fertility of bucks and semen quality:

El-Sawy *et al.,* (2017) found that testosterone levels were reduced in stressful hot conditions during summer season in compared with winter. The adverse effect of summer season on late of age at maturity, testicular index and testosterone concentration may be related to decrease on relative of testes weight for rabbits reared under summer season (El-Sawy *et al.,* 2017). High ambient temperatures decreased motility, curvilinear, velocity and metabolic activity of rabbits spermatozoa incubated at 42°C, compared to 32.5°C (Sabés-Alsina *et al.,* 2016). Sabes-Alsina *et al.,* (2016) found out that acute heat exposure of 3 h at 42 °C compromised sperm functions. Heat stress, whether acute or chronic, has profound and drastic effects on the reproductive efficiencies of both male and female rabbits.

Histological studies on the testes of heat-stressed bucks revealed altered testicular cell and membranous structures (Aldemir *et al.,* 2014 and Bharti *et al.,* 2014). Libido of rabbit and sperm density was decreased by exposure to heat stress (Pei *et al.,* 2012). 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. Heat stress 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). Testosterone concentration, sperm output, semen quality, and fertility were listed among reproductive traits affected by heat stress in male rabbits (Marai *et al.,* 2002). El-Sobhy (2000) found that the testes of heat exposed animal's revealed significant focal degeneration in both seminiferous tubules and interstitial cells. Baglioicca *et al.,* (1987) reported that male fertility was impaired when ambient temperature was about 28°C and some individuals began to die at 35°C. In addition, Jegou *et al.,* (1984) mentioned that the reduction in testosterone level during summer season resulted from reduction in the ability of leydig and sertoli cells responding to luteinzing hormone. However, Katongola *et al.,* (1974) reported that decline in testosterone level during summer season causing disorders in accessory glands secretion and spermatogenesis.

El-Sawy *et al.,* (2017); Lavara *et al.,* (2013) and Safaa *et al.,* (2008) reported that the libido, mating activity and the physical semen quality of NZW rabbit bucks during the winter season were highly significant ($P \leq 0.01$) better than those observed in the summer season. Semen volume increased and motility indexes decreased during summer (Roca *et al.,* 2005). Mate rabbits are extremely sensitive to heat stress therefore a rise in testicular temperature in rabbits leads to reduced spermatogenesis; temporary sterility; decreased sexual desire, ejaculate volume, motility, sperm concentration, and total number of spermatozoa in an ejaculate; and increased sperm abnormalities and dead sperm (Marai *et al.,* 2001). Also, Finzi *et al.*, (1995) reported that the daily exposure of rabbits in a climatic chamber to high ambient temperature (30 ^{o}C) and humidity (70%) for 21 hr over a 60 days period increased the number of abnormal spermatozoa.

5-6- Litter size and weight:

Litter size is defined as the number of progenies born per parturition. Average litter size can be calculated on a yearly basis to be consistent with the annual rate of fertility. Mady *et al.,* (2018) reported differences in birth and weaning weights in rabbits between winter and summer seasons. Litter size and litter weights of does reared in temperate climates are usually higher than those kept under hot climatic conditions as heat stress results in declining energy metabolism and calorigenic hormones which consequently reduces milk yield and so the litter weight gain. The hyper thermic pregnant mothers have inhibited feed intake and so milk yield with depressed thyroid activity and hence metabolic rate leading to decreased embryonic weight at birth. Litter size at birth (6.9 vs. 7.8 live young), litter size at weaning (5.95 vs. 7.08) (Mady *et al.,* 2018). Marco-Jimenez *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 and occurrence of stillbirth was higher in does stressed during pregnancy. Exposure of NZW doe rabbits to severe heat stress under Egyptian environmental conditions affected negatively significantly on litter size at birth, litter weight of kits at birth, 21 days and weaning (Abdel Monem *et al.,* 2016). Significant effects of season on litter weight at birth, at 21 days and at weaning and the lowest values were observed during summer (Marai *et al.,* 2007). Exposure of rabbits to a high ambient temperature decreases embryonic weight and length (Marai *et al.,* 2001). Litter size at birth was found to be affected significantly by the season of kindling and the highest values were recorded during winter and the lowest during summer (Habeeb *et al.,* 1999). The values of litter size at birth as 6.6 kits in winter and 5.8 kits with a reduction of 14% in summer season in NZW rabbits (Ayyat and Marai, 1998). The litter weight at birth was higher during winter than in summer (Farghaly and EL-Darawany, 1994).

5-7- Pre weaning mortality rate:

Increasing of disease incidence, mortality is the most obvious sings of heat stress (Bani *et al.,* 2005 and Marai *et al.,* 2006). Pre-weaning mortality (16.94% in summer vs. 9.60% in winter) as affected by environmental temperature (Frangiadaki *et al.,* 2003). Most studies showed that the highest values of mortality rate percentage were in summer and the lowest percentage was in winter (Habeeb *et al.,* 1999). The mortality rate from birth up to weaning increased significantly with the increase in ambient temperature from 19.5°C in January to 34.8°C in July and the lowest and highest mortality rate values were recorded on the 1st week in January and on the 4th week in July, respectively (Habeeb *et al.,* 1999). The averages of pre-weaning mortality rates were found to be as high as 71.9% in summer and 27.3% in winter (Bassuny, 1999). During the post-weaning phase, the mortality rate was 18% in summer while no mortality was recorded during winter (Habeeb *et al.,* 1999). During 5-9, 9-13 and 5-13 weeks of age intervals, mortality rate values were higher in summer and lowered in spring than in autumn and winter (Shehata *et al.,* 1998). The recorded high values for mortality rate in summer may be attributed to the high ambient temperature and direct effect of heat stress on the sensitive offspring (Habeeb *et al.,* 1999).

5-8- Milk production of does:

Elevated ambient temperature has negative influence on milk yield in lactating does (Mahrose *et al.,* 2010). 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. 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). A reduction of milk production as well as due to the general depression of metabolic activity in the summer (Habeeb *et al.,* 1999).

5-9- Heamatological status and blood parameters:

El-Sawy *et al.,* (2014) found that values of RBCs, WBCs and Hb were significantly higher (P≤0.05) in rabbits reared in winter season than those in summer season. Many authors indicated that the negative effects of summer heat stress on hematological parameters (Al-Eissa, 2011; Okab *et al.*, 2008 and Marai *et al.,* 2002). Also, Möstl and Palme (2002) reported that heat stress in animals decreased the level of adrenocorticotropic hormone (ACTH), which might then result in decreases in RBC counts, Ht and Hb concentration. In addition, the depression of Ht during summer season was also reported to be related to a reduction in cellular oxygen requirement for reducing metabolic heat production in order to compensate the elevated environmental heat load (Okab *et al.*, 2008). Herz and Shenhauf (1985) showed that the high temperature may induce haemodilution and increase of break-down in erythrocytes. Ashour *et al.*, (2004) demonstrated that the reduction in Hb and Ht could be attributed to the increase of plasma volume by water retention to enable proper water supply for evaporation as the major way for heat dissipation in hot conditions.

5-10- Effect of heat stress on blood biochemical and immune responsiveness:

El-Sawy *et al.,* (2017) found that blood biochemical parameters (within normal range) such as serum TP, Alb, Glob, ALT and AST were significantly ($P \leq 0.05$) higher in winter season than in summer one. These changes in the blood biochemical parameters due to season effect was similar to that of El-Sawy *et al.,* (2014) and Abdel-Monem *et al.,* (2013) who found that blood biochemical traits were significantly lower ($P \leq 0.01$) in rabbits exposed to heat stress in summer season as compared to those reared in winter one. The decrease in serum TP for weaned NZW rabbits in summer season group may be due to the decrease in DFI and dilution of serum proteins or both (Ondruska *et al*., 2011). They add that, the decrease in the protein synthesis can be due to a depression of anabolic hormonal secretion such as growth hormone, thyroxin and insulin. In addition, Amici and Merendino (1996) showed that the decrease of TP has to be considered as an important biological indicator of deficiency in activity of the immune system function in heat stressed rabbits. El-Sawy *et al*., (2017) showed that serum ALT and AST means were significantly higher during winter than summer that may be related with feed intake, which has the same trend. The more feed intake provides the body with more amino acids by protein digestion, and this result came in harmony with El-Maghawry *et al.,* (2000) who found that ALT and AST are dependent on alanine and glutamine taken by the liver and reflect metabolism changes in liver which associated with glucose synthesis.

Inhibition of humoral and cell-mediated immune responses was seen in rabbits exposed to cyclic or chronic heat stress (El-Desoky, *et al.,* 2021 and Madkour, *et al.,* 2020). Heat stress inhibits the immune system components and disturbed homeostasis in rabbits Abdelnour *et al.,* (2020). Liu *et al.,* (2022) noted that heat stress harmed growing rabbits' thymus index (%). Saghir *et al.,* (2023) indicated that heat stress induced the raising of proinflammatory cytokines containing tumor necrosis factor-α (TNF-α), IL-1β, and interferon gamma (IFNγ) in growing rabbits. These results conform with reports postulated that heat stress stimulated inflammatory signaling, including TNF-α, IL-1β, and IFNγ in heat-stressed rabbits (Sheiha *et al.,* 2020; Bai *et al.*, 2022; Madkour *et al.,* 2020 and Abdelnour *et al.,* 2020). Yasoob *et al.,* (2021) noted that heat stress adversely affected the mucosal immune response and increased caecal concentrations of TNF-α, IL-1α, and IL-1β as markers of caecal mucosa inflammation in growing rabbits. Additionally, in fattening rabbits exposed to heat stress, the serum lysosome activity and nitric oxide levels were reduced (Saghir *et al.,* 2023). Moreover, heat stress disturbed the equilibrium between anti-inflammatory and pro-inflammatory cytokines (Saghir *et al.,* 2023), which might be connected with a progressive inflammation response (Madkour *et al.,* 2023). Abdel-Latif *et al.,* (2018) observed that heat stress had a negative influence on IFN-γ, TNF-α, and heat shock protein 70 (HSP70) expression leading to affect the infiltration of regulatory T cells adversely and NK cells in New Zealand White (NZW) growing rabbits. From another point of view, normal thyroid hormone concentrations are essential for the proper function of the immune system (Hassan *et al.,* 2011). Exposure to heat stress suppresses the hypothalamic–pituitary–thyroid axis and reduces the serum concentrations of T_3 and T_4 (Liu *et al.,* 2022 and García and Argente 2017), and finally, depressing the immune response in growing rabbits.

Furthermore, considering the link between oxidative stress and inflammation, it might be indicated that rabbits exposed to heat stress are under a penalty of oxidative stress, which might adversely affect their health status.

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التغيرات المناخية وتأثيراتها على إنتاج الأرانب

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من أهم المشكلات التي تواجه إنتاج الأرانب هو الإجهاد الحراري في المناطق الحارة من العالم، خاصة في مصر خلال فصل الصيف. ويتزايد هذا الأمر بشكل أكبر بسبب ظاهرة الاحتباس الحراري التي يعاني منها العالم نتيجة لتغير المناخ. التغير المناخي هو تباين أو تغير في المناخ والذى يشمل (درجة الحرارة - الرياح وأنماط هطول الأمطار) في موقع أو منطقة معينة أو الكوكب بأكمله. ويستمر هذا التغير في أنماط الطقس لفترة طويلة تتراوح من عقود إلى ملايين السنين.

ونظرا لأن الأرانب ليس لديها غدد عرقية أو لديها عدد قليل منها وفراء أكثر سمكًا فإن ذلك يزيد من صعوبة التخلص من الحرارة. التنظيم الحراري ضعيف للغاية في الأرانب بسبب عدم وجود غدد عرقية، لذلك فهي حساسة للغاية لدرجات الحرارة المرتفعة. يؤثر الإجهاد الحراري سلبًا على الرفاهية والتكيف، واستهلاك العلف واستخدامه، والمناعة والحالة الصحية، والنمو، والتكاثر، وإنتاج اللبن في الأرانب. تلخص هذه المقالة المعلومات المتوفرة في العقود القليلة الماضية (١٩٩٠-٢٠٢٣).