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REVIEW ARTICLE

Heat stress and poultry: adaptation to climate change, challenges and opportunities for genetic breeding in Kenya

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ABSTRACT

The Earth's ambient climatic factors, such as temperature, humidity, solar radiation, and precipitation, vary through time and space due to climate change. Heat stress, one of the major factors affecting poultry production, is a direct result of climate change, resulting in enormous losses for the poultry sector. As a result of heat stress, several physiological changes such as suppressed immunecompetence, oxidative stress, and acid-base balance lead to reduced feed intake, feed efficiency, body weight, meat, egg quality, and sometimes mortality. Adverse effects have necessitated several adjustments in animal husbandry practices such as housing and feeding regimes to be implemented. Modifying the environment in poultry production systems can cushion exposure and compensate for losses in poultry fitness in heat-stressed environments. Some of the modifications that have been tested and shown to be successful in attenuating heat stress in poultry include shade, sprinkling cold water on their bodies, and adjusting diets to reduce metabolic heat production. The extensive genetic diversity of indigenous poultry is essential for climate change adaptation and the continuous enhancement of the genetic stock through breeding adaptive features like heat stress tolerance. The naked neck (*Na*) and frizzle (gene F) gene have been given attention in recent times in their role to withstand heat stress in poultry. A better understanding of indigenous poultry acclimatization to severe environments, together with methods and tools available for the selection, breeding, and matching indigenous poultry ecotypes to suitable environments, should help to minimize the effects of heat stress on indigenous poultry genetic resource growth, production, and reproduction to sustain food security.

Keywords: Adaptive traits, Climate-smart, Horn of Africa, Indigenous poultry, Thermotolerance

1.0 Introduction

Global warming as a result of climate change is likely to exceed 1.5°C by 2040, while the average air temperature is forecast to rise by 1.88-4.08°C (Pachauri *et al*., 2015). Air temperature is one of the bioclimatic parameters that determine heat stress levels in poultry

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(Thornton *et al*., 2009). Under normal conditions, poultry's body temperature rises from 41.3℃ to 42.4℃ when exposed to acute heat and 41.7℃ when exposed to chronic heat (Barrett *et al*., 2019; Goel, 2020). The term "thermotolerant" refers to an animal's ability to maintain thermal equilibrium in the presence of excess heat load (Carabaño *et al*., 2019). Feather coverage in poultry and lack of sweat glands makes it hard for the poultry to disperse heat to the environment, making them more prone to heat stress (Tamzil, 2014). This leads to a change in the poultry's physiological and behavioral mechanisms to adapt to harsh environmental conditions. Poultry is susceptible to heat stress if it cannot remove excess endogenous heat to maintain sufficient homeostasis (Bernabucci, 2019).

Poultry's behavior, welfare, and immunity are adversely affected by heat stress (Bhadauria *et al*., 2014; Nyoni *et al*., 2019; Winsemius *et al*., 2014). When poultry are exposed to high temperatures, it has been observed that they tend to pant, close their eyes, lie down, and engage in cannibalism (Vandana *et al*., 2021). In poultry, physical parameters such as rectal temperature, respiration rate, and heartbeat rise due to heat stress (Vandana et al., 2021). A drop in feed intake, body weight, feed conversion ratio, and egg production has also been reported in poultry subjected to heat stress (Zaboli *et al*., 2019). The hormonal changes that have been reported in poultry as a result of heat stress include an increase in heat shock protein genes, a decrease in the expression of TLR 7 and IgG production (Goel, 2020). Physiological changes in poultry subjected to heat stress include an increased H/L ratio and erythrocyte number, decreased haemoglobin, and damage to the intestinal mucosa (Vandana *et al*., 2021). Several modifications in poultry husbandry practices must be made for poultry to survive in heat-stressed environments. Some of these practices include the construction of poultry structures in a proper orientation to prevent direct sunlight and the use of appropriate housing material that prevents heat load build-up (Daghir, 2008; Gaughan *et al*., 2010). Modification of poultry feeding regimes like the addition of minerals and vitamins to their diets and feeding them when the heat load is minimal in the early morning and evenings have also been shown to reduce the adverse effects of heat stress (Goel, 2020; Sahin *et al*., 2006; Sahin and Kucuk, 2003).

Indigenous poultry in Kenya is characterized by nine ecotypes comprising several phenotypes like the frizzled, naked neck, dwarf, and feathered shanks (Chesoo *et al*., 2021; Moraa *et al*., 2015). Indigenous poultry is hardy and can withstand harsh environmental conditions when compared to exotic poultry breeds. The dwarf, frizzle, and naked neck phenotypes are important in thermo-tolerance and can be used to develop poultry species with a superior thermo-tolerance ability (Chen et al., 2016; Vandana *et al*., 2021). However, most of these phenotypes have a small population size and are at risk of extinction due to unsupervised crossbreeding programs that lead to genetic erosion (FAO, 2013). There is a need for proper documentation and characterization of these ecotypes since they are important in breeding programs and genetics exchange (Hoffmann, 2013). Despite the importance of indigenous poultry ecotypes in Kenya, there is a paucity of information on genetic breeding programs. This review discusses heat stress adaptation of poultry ecotypes in response to climate change as well as the opportunities and challenges for genetic breeding in Kenya.

2.0 Poultry ecotypes in Kenya

Indigenous poultry ecotypes are poultry from one agro-ecological zone or area as distinguished from another. The names are either derived from ecological zone names or regional names (Gondwe, 2005). Each ecotype comprises a unique set of adaptive and productive traits (Ngeno *et al*., 2015). Kenya has the following poultry ecotypes that vary significantly in their phenotypic attributes: Turkana basin ecotype, Mt. Elgon catchment ecotype, Western Kenya ecotype, Lake Victoria basin ecotype, Rift valley ecotype, Central highlands ecotype, Eastern plains ecotype, Coastal ecotype, and Lamu ecotype *(Chesoo et al*., 2021; Moraa *et al*., 2015). Ecotypes found in the arid and semi-arid lands like the Turkana ecotype are characterized by reduced feather coverage. They comprise the dwarf, frizzled, and naked neck phenotype (Kingori *et al*., 2010; Moraa *et al*., 2015; Ngeno *et al*., 2015). The dwarf gene is a sex-linked recessive gene for dwarfism. It is responsible for the small body size, which increases their surface area, making heat balance easy to attain by reducing the metabolic heat production of the poultry (Deeb *et al*., 1993). Even if the advantages of the dwarf gene in heat tolerance outweigh the reduced output per bird, it is not clear whether this gene will provide a long-term solution (Deeb *et al*., 1993). The frizzle gene in poultry is completely dominant, resulting in a curled feather that extends outwards from the body. This feather structure has a reduced total weight, thus providing less insulation and allowing poultry bodies to dissipate heat more efficiently. The naked neck gene is a dominant gene that reduces overall feathering, with the neck area being totally featherless, resulting in better heat tolerance (Leenstra and Cahaner, 1992). Highland ecotypes have dense plumage, which is an adaptation to survive the cold environment, and they include the crested, bearded, and feathered shank phenotypes (Moraa *et al*., 2015). Other distinct poultry ecotypes have also been reported in Ethiopia (Dessie and Ogle, 2001) and Tanzania (Mussa, 2015). Abundant phenotypic variation in indigenous poultry ecotypes promotes the selection and breeding of climate smart ecotypes equivalent to the various agro-ecological zones.

3.0 Strategies to alleviate heat stress in poultry

3.1 Housing

When building poultry structures in heat-stressed environments, one should consider the location, space, light, and ventilation. The poultry house should be constructed so that the long axis is in the east-west direction to prevent direct sunshine over the poultry (Oloyo and Ojerinde, 2020; Wasti *et al*., 2020). The structures should be built near a shade to reduce the potential for heat stress by limiting the amount of solar radiation reaching the birds. Shades can be naturally provided by trees or artificially provided by cloth. The materials used for constructing the shade should effectively reduce the heat load (Gaughan *et al*., 2010). To minimize heat from solar radiation, shade is one of the most basic and cost-effective solutions. However, it does not eliminate all the adverse effects of heat stress.

The width of the poultry houses should not exceed 12m, while the length can vary depending on the number of poultry and land availability (Wasti *et al*., 2020). In long poultry houses, doors should be placed at 15-30m intervals. A sidewall of at least 2.1m long with flexible curtains that can be raised or lowered easily for sufficient ventilation should also be constructed. The roof should slope at 45°C since this has been shown to reduce heat gain of the roof from direct solar radiation (Daghir, 2008). Roof insulation is provided by various native materials, including thatch and bamboo. Sprinkling cold water on uninsulated metal roofs may help lower heat load in poultry houses (Daghir, 2008). Additionally, in-house fans, interior fogging, cool perches, and cooling pads effectively attenuate the adverse effects of heat stress in closed housing systems, where natural airflow is not sufficient (Daghir, 2008). However, this is an expensive venture only afforded by the farmers practicing extensive farming and is unrealistic to poor rural farmers.

The floor of the poultry houses in heat-stressed environments should be made of material that is well-drained and easy to clean, like wood, bamboo, or bricks. In some cases, the floor is raised for proper ventilation and easy cleaning (Saeed *et al*., 2019). Since poultry prefers to roost at night on perches, perching space of 15cm to 20cm should be considered for each poultry. The space should also be enough for the poultry to move around easily. Each bird should be allocated about 2 to 3 square feet inside the poultry structure and about 8 to 10 square feet per bird in an outside run (Vandana *et al*., 2021).

3.2 Feeding modification and strategies for poultry in heat-stressed environments

Poultry reduces their feed intake during heat stress, and therefore, modifications in their feeding that aim at lowering metabolic heat production should be adopted (Vandana *et al*., 2021). The micronutrient composition of the poultry feeds should be considered when developing or feeding heat-stressed poultry. Mineral supplements like ammonium and potassium chloride are vital since they correct the acid-base balance disturbed when poultry pants during heat stress. Vitamin supplements are involved in fixing oxidative injuries induced by heat stress. Vitamin A, C, and E have anti-stress effects, and they are used in poultry diets to reduce the adverse impact of heat stress (Kucuk *et al*., 2003). These vitamins enhance egg production, hatchability, prevents egg breakage, and reduce mortality in laying hens raised in heat-stressed environments (Sahin and Kucuk, 2003). Zinc inhibits NADPH-dependent lipid peroxidation by working as a cofactor and suppressing free radicals. Zinc also enhances the serum vitamin C and E concentration, thus improving the antioxidant status in poultry (Goel, 2020; Sahin *et al*., 2006). A combination of minerals and vitamins has been shown to have a synergistic effect in reducing the adverse effects of heat stress in poultry. An increase in body weight, carcass quality, feed conversion, a reduction in blood glucose and cholesterol levels were reported in poultry whose diet was supplemented with vitamin E, C, and zinc (Goel, 2020; Sahin *et al*., 2006; Yanchev *et al*., 2007). These minerals and vitamins can be bought at the agrovets or obtained from weeds/vegetables, insects, termites, and worms.

Restricting poultry feeding before or during heat exposure decreases metabolic heat production, thus improving heat tolerance. Because of this, it is possible to increase poultry's intake of nutrients by limiting their feed intake during the peak hours of heat stress and moving their feeding period to the evening (Bhadauria *et al*., 2016). Feeding poultry in the early morning and late evenings prevents the coincidence of maximum metabolic heat production with high environmental temperatures (Vandana *et al*., 2021). Water plays an essential role in poultry during heat stress. If water is restricted, the adverse effects of heat stress in poultry are enhanced. Therefore, ingesting cool water placed under shade reduces the poultry's body temperature and improves their performance (Goel, 2020). Moreover, drinking water contains electrolyte solutions like sodium and potassium, which increases electrolyte supplementation, thereby adjusting the acid-base balance and enhancing the heat tolerance capacity in poultry (Balnave and Muheereza, 1997; Goel, 2020). These methods have been used by poultry farmers across the globe and have shown to be successful.

4.0 Molecular breeding strategies

4.1 Use of genetics and genomic tools for breeding for thermotolerance

Genetic selection for thermotolerance in poultry demands a thorough understanding of the underlying genetics of poultry's response to heat stress. The levels of thermo-tolerance vary between various poultry breeds, making genetic modification a potential method to relieve heat stress in poultry (Melesse *et al*., 2011; Vandana *et al*., 2021). Genetic tools and technologies like the recent Omics technologies have been used to study the genetic basis of various processes like heat stress tolerance across multiple poultry breeds (Cho *et al*., 2021; Wang *et al*., 2017; Weimann *et al*., 2016). Over the years, improvements on the high-throughput sequencing platforms have lowered the cost of acquiring genetic data, thus leading to a large amount of genetic information on poultry that is easily accessible (Perini *et al*., 2021). The availability of numerous poultry genome sequences has made it easy to categorize genetic markers linked with heat stress tolerance. This has shed light on the various mechanisms involved in heat stress regulation and the detection of valuable biomarkers that can improve the various poultry breeding programs (Wang *et al*., 2017).

Currently, functional genomics research may give fresh insights into how heat stress affects adaptive capabilities by identifying genes that are upregulated or downregulated during heat stress. A study by Cedraz *et al*. (2017) reported an increase in the *HSP70* and *HSP90* genes in chickens subjected to heat stress conditions. Taiwan chickens have also been shown to have a higher expression for heat shock proteins like *HSP25*, *HSP70*, and *HSP90AA1* (Wang *et al*., 2015). Srikanth *et al*. (2020) also reported some differentially expressed genes that belong to the *HSP70* family in Kenyan chickens subjected to acute and chronic heat stress. When it comes to thermoregulation, transcriptome data provide a comprehensive picture of all the processes and genes involved and their respective roles. This makes transcriptome data the most appropriate technology (Rao *et al*., 2021). Incorporating the functional genomics/transcriptomics/epigenomics data into molecular markers allows researchers to discover potential candidate genes and mutations. This helps explain the mechanisms in the pathways responsible for heat stress tolerance. Signatures of selection on genomic data have been used to locate genomic regions that have undergone natural selection *(*Randhawa *et al*., 2014). Single nucleotide polymorphisms (SNPs) and the runs of homozygosity have also been utilized to assess genome-based associations and inbreeding coefficients. These methods can design low-density custom panels for breeding at a relatively low cost (Lachance and Tishkoff, 2013). To get reliable genomic breeding values, these approaches need a large number of phenotypic and genotyped poultry breeds (Goddard and Hayes, 2009).

4.2 Capital interrelation factors

An epigenetic trait is a heritable phenotype resulting from chromosomes changes without any underlying changes in DNA sequence (Perini *et al*., 2021). These changes lead to a particular cellular phenotype usually affected by nutrients and the environment and can be transmitted across generations, thus leaving a mark on the offspring phenotype (Jablonka and Raz, 2009; Nayak *et al*., 2016). The body uses epigenetic mechanisms to manage adaptive developmental reprogramming (Duncan *et al*., 2014; Perini *et al*., 2021). Environmental factors such as temperature affect the animals' physiology during the developmental stages, which modifies the thermoregulatory process, thus leading to epigenetic adaptation (Tzschentke and Basta, 2002). Methylation is one of the most significant epigenetic modifications that control gene expression at the DNA level (Yang *et al*., 2011). Various poultry breeds subjected to heat stress treatment showed differences in the heat shock protein gene expression levels. This may be attributed to the variations in the methylation levels in the promoter region of the same heat shock protein genes (Perini *et al*., 2021). Kisliouk and Meiri, (2009) concluded that several epigenetic mechanisms affect the transcription of key thermoregulatory genes leading to the acquisition of thermotolerance.

Exposure of poultry to heat stress during early incubation has been shown to alter the expression of the thermoregulatory genes, thus enhancing physiological adaptability (Nayak *et al*., 2016). Post-hatch exposure to heat stress triggers epigenetic changes in heat stress-tolerance genes, thus improving the thermotolerance in poultry (Nayak *et al*., 2016; Rajkumar *et al*., 2015). It has been reported that manipulating the temperature during embryogenesis may alter poultry's vasomotor activities, improving heat loss under hot conditions (Goel, 2020; Nichelmann and Tzschentke, 1997). All these studies have indicated that the epigenomic era brings exciting discoveries and challenges that can potentially be included in poultry breeding programs.

5.0 Challenges and opportunities in genetic breeding for indigenous poultry

5.1 Lack of goodwill from private breeding companies

To maintain poultry production, climate change adaptations, mitigation techniques, and policy frameworks are essential (Rojas-Downing *et al*., 2017). Heat stress may be mitigated by using preventive measures. However, until the preventive measures are included in national and regional policy, they will have little influence (FAO, 2018). Poultry producers should consider adaptation and mitigation techniques since they are one of the most important stakeholders (Gaughan *et al*., 2019). Most poultry breeding companies have greater interests in large poultry breeds generally bred for commercial purposes. The commercial poultry breeds take a short time to attain maturity and have been bred to produce more meat and eggs. To be successful, efforts to select poultry breeds with a focus on productivity must also consider future robustness and, most crucially, heat stress tolerance. For the case of indigenous poultry, the government, through its various institutions like the Kenya Agricultural and Livestock Research Organization (KARLO) and the National universities that undertake poultry genetic research, ought to take up the genetic breeding programs for heat stress tolerance in indigenous poultry breeds. This can be done by increasing funding to relevant government institutions to improve their infrastructure and capacity by collaborating with other disciplines and stakeholder institutional partners (Osei-Amponsah *et al*., 2019).

5.2 Need of skilled manpower in poultry breeding programs

Poultry breeding utilizes a cutting-edge technology that requires a multidisciplinary approach and expertise at every stage of its execution (Gaughan *et al*., 2019). This requires training but unfortunately, most of these training are expensive and take a long time. However, the governments can sponsor the training of selected individuals from key institutions who will be required to do capacity building in their home country upon completion of the courses offered. Tertiary institutions in Kenya should diversify their programs in breeding to align with the current worldwide trends in poultry breeding. For instance, curriculum development and hands-on training in recent technologies in quantitative genetics, genomics, and bioinformatics (Helmy *et al*., 2016; Karikari, 2015; Rothschild and Plastow, 2014). The government could also consider offering scholarships/fellowships to researchers involved in breeding activities in some research institutions. This can be facilitated by collaborations between the South-South and North-South co-operations (Ducrocq *et al*., 2018; Osei-Amponsah *et al*., 2019). Upon completion, the skills acquired can improve the poultry breeding sector.

5.3 Genetic erosion of indigenous poultry ecotypes

In the 1950s, a genetic improvement program known as the cockerel and pullet exchange program was introduced in most African countries (FAO, 2013). It was aimed at substituting indigenous chickens with exotic chicken breeds. The program did not pick up since it was poorly structured, and the chickens did not adapt well to the local climatic conditions. Recently, various improved chickens have been introduced, like the Kuroiler and the KARI super chicken in Kenya (Ngeno, 2015). Due to poor extension services, there has been minimal follow-up on the performance of these chicken breeds. Consequently, this has made most farmers crossbreed indigenous poultry with commercial poultry to improve productivity and adaptability. This practice has led to genetic erosion and displacement of indigenous poultry breeds. For long term sustainability and conservation of indigenous poultry genetic material, breeding has to be done responsibly.

5.4 Value addition to create a niche market for indigenous poultry

The demand for poultry products is steadily rising in Kenya. Commercial poultry breeds mostly meet this demand. However, a niche market for indigenous poultry products within Kenya needs to be exploited. Over the years, people have become health conscious and are

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keen on consuming indigenous products. For a continuous supply of indigenous poultry products in the market, farmers need to be trained on the importance of indigenous poultry farming. They can be educated on the value of indigenous poultry for their nutrition and their unique attributes like disease and heat stress tolerance (Osinowo *et al*., 1988). Extension services from the government should engage closely with farmers to help them embrace complementary strategies like marketing and exploitation of local poultry breeds to achieve profit (FAO, 2013).

6.0 Conclusions and recommendations

Indigenous poultry breeds face many challenges in the face of climate change due to heat stress. This poses many challenges in sustaining or growing their population sizes to avoid extinction. Although their output is lower than commercial poultry breeds, they have a wide range of adaptive traits. This, however, may be enhanced through niche marketing.

Indigenous poultry represents an essential genetic reservoir of phenotypes more adapted to heat stress. There are no studies on sustainable genetic breeding programs for heat stress tolerance utilizing indigenous poultry breeds. Access to knowledge on indigenous poultry adaptation to severe environments, matching diverse poultry ecotypes to suitable environments, and tools for selection and genetic breeding should be made more widely available. This information should help minimize the effects of heat stress on indigenous poultry genetic resource growth, production, and reproduction to sustain food security. A successful breeding program needs the support and contributions of the government and several other stakeholders from all facets of society.

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