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ABSTRACT

This review summarizes the available information on the adaptation and the performance of White Fulani cattle in tropical environments. White Fulani cattle is an indigenous breed of cattle widely distributed in the humid tropical regions of Africa and plays significant roles in meat and milk production, as well as draught purposes. Poor management and the harsh environmental conditions in the tropics encumber the optimal productive and reproductive performance of the breed, having about 4.75 years age at first calving, 57% calving rate, 18 months calving interval and 3 to 4 calves are born in a reproductive lifetime. The cattle breed adapts to these climatic patterns via physiological, morphological, behavioral, genetic, and metabolic responses. Different physiological mechanisms and morphological features such as their white coat color, hair coat thickness, and lengthy rump appear to play an important adaptive role. The distinct genetic traits (including the possession of seven genetic variants of HSP 90 gene) of the breed afford them some levels of thermotolerance and high resistivity to some endemic diseases (such as trypanosomiasis, liver fluke, brucellosis and foot and mouth disease) in the tropics constitute inherent characteristics that should be explored in detail using molecular assisted approaches. The productive performance of the breed under different systems is discussed. A better understanding of the adaptive characteristics of White Fulani cattle could provide crucial information on the best management approach/ techniques that should be adopted to improve the performance, productivity, and sustainability of this cattle breed. Therefore, this review aims to compile the various production, reproduction and adaptation traits of the breed and presents vital information underlying their thriving and survivability in tropical environments.

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1. Introduction

Cattle are a major source of meat and milk supply globally, and they contribute a significant proportion to the dietary protein intake of humans. The world population of cattle is estimated at 1.5 billion (FAO,

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Abbreviation

HSP	Heat Shock Protein
NBS	National Bureau of Statistics
AGTR	Animal Genetics Training Resources
THI	Temperature humidity index
PCV	Packed cell volume
HSP90AA1	Heat Shock Protein 90 Alpha Family Class A Member 1
HSPD1	Heat Shock Protein Family D (Hsp60) Member 1
DNA	Deoxyribonucleic acid
BoLA-DRB3.2	Bovine Lymphocyte antigen
CD	Cluster differentiation
SMO	Smoothened
mRNA	Messenger ribonucleic acid
NAPRI	The National Animal Production Research Institute

2022), and about 300 million heads are found in Africa, constituting approximately one-fifth of the world's cattle population (Dessie and Mwai, 2019). In Nigeria, a 2011/2012 survey data from 28 states provided an estimated total figure of 18,871,399 cattle, with Zamfara State recording the highest population (16.8%), followed by Jigawa and Katsina states (11.61% and 10.6%, respectively), indicating that majority of Nigeria's cattle production was dominated in the North-West zone (52.4%) (NBS, 2012).

In Africa, the cattle population are subjected to extreme environmental conditions alongside diverse and severe disease outbreaks (Kim et al., 2017, 2020). Accordingly, indigenous cattle populations exhibit unique adaptive traits that enable their survival and reproduction, such as the trypanotolerance of the N'Dama cattle and thermo-tolerance of White Fulani cattle. Although the production potential of the indigenous African cattle is lower than most exotic breeds, they are widely reared by farmers in the agro-pastoral systems, especially where most exotic breeds exhibit poor performance under traditional (extensive) management systems (Kim et al., 2017). By taking advantage of their adaptations, cattle productivity in hot climates might be increased and the effects of warm periods might be ameliorated in cooler climates. The White Fulani cattle are the most populous cattle breed in West Africa, with substantial socioeconomic importance. They are largely raised by nomadic Fulani dwellers who occupy regions between the Sahara and the rainforest belt in several West African countries (Tawah and Rege, 1996). Physically, they have tall, narrow bodies, well-shaped and large-sized udder, well-developed hump and dewlap; and they possess a unique coat color of white on a black skin with black ears, eyes, muzzle, hooves, horn tips, and the tip of tail (AGTR, 2021). Amidst these unique features, the performance and production of these cattle are not well-characterized (Tawah and Rege, 1996; Norezzine et al., 2019). Interestingly, the basic productivity of White Fulani cattle and the management practices have remained relatively similar in the last four decades (Ducrotoy et al., 2016). The traits of White Fulani cattle populations present a unique resource to the adaptive features to various agro-ecosystems. Sustainable livestock production relies on agro-ecological zone-specific climate resilient thermo-tolerant animals. Therefore, the review aims to collate available information on the performance and production of this breed of cattle in order to identify potential research areas.

2. White Fulani cattle: population and distribution

The 'Fulbe' migratory ethnic group called Fulani in the Hausa language rears the majority of the cattle in Nigeria. White Fulani cattle are Zebu cattle with long legs and long horns, primarily reared by the nomadic Bororo people (Tawah and Rege, 1996; Kubkomawa, 2017). The cattle originated from Northern and Southern Nigeria and northern Cameroun, from where they migrated to other West Africa and beyond (Glowatzki-Mullis et al., 1995) and they are the major beef cattle in the Sahel region of Africa (Santoze and Gicheha, 2019). In addition, White Bororo, White Kano, and White Fulani of the Republic of Cameroon are closely related to the White Fulani breed (Norezzine et al., 2019). The white Fulani cattle population is widespread in Africa (Fig. 1), and they are one of the most abundant breeds of cattle in Nigeria (Babayemi et al., 2014). Alphonsus et al. (2012) reported that White Fulani cattle constituted 37% of the Nigerian total national herd, with approximately 95% of them as a pure breed. Furthermore, statistics of Nigerian cattle breeds reported a closing population of 10,117,681 White Fulani cattle (Fig. 2), which constituted 54% of the total cattle population in the year 2012 (NBS, 2012). Nomadic herders living in Sub-Saharan Africa who usually migrate to the southern region of the Guinea savannah in search of pasture during the dry season conventionally manage the White Fulani cattle. In a study (Fig. 3) conducted in North-Central Nigeria and Southern Jos by Majekodunmi et al. (2016), the authors revealed that males made up 29.1% and females 70.9% of studied cow herds. By age group, calves under a year old made up 19.5% of the herd, of which 9.7% were males and 9.8% were females. 1–3 years old cattle made up 35.2% of the herd, with 14.1% of males and 21.1% of females. 5.3% of the male and 40.0% of the female livestock were older than three years. An average breeding herd has an equal sex ratio at birth; however, females account for a substantial portion of the herd because males are mostly sold as soon as they reach maturity.

3. Performance characteristics of White Fulani cattle

Mature body weights for the bull and cow of White Fulani reach approximately 500 and 325 Kg, respectively (Kubkomawa, 2017; Ouédraogo et al., 2021). Most literature has classified White Fulanai as a dual-purpose breed (milk and beef) (Mwai et al., 2015; Santoze and Gicheha, 2019), while others classified them as triple-purpose (Kubkomawa, 2017; Jimoh et al., 2017; Wuanor et al., 2018) because their bull is docile, tractable with good body conformation that makes them fit for draught purpose (Payne, 1970). Concerning the carcass and non-carcass output, White Fulani cattle compares favourably with other African breeds (Lamidi et al., 2004). For instance, Salako (2014) reported a consistent weight difference between white Fulani and N'dama cattle breeds from birth to maturity in favour of White Fulani cattle. White Fulani cattle have desirable carcass and non-carcass characteristics, with bulls showing heavier live weight, carcass weight, the quantity of beef, and hump muscles than cows (Lamidi et al., 2004; Salako 2014). In a study to characterize indigenous cattle genotypes at 99–124 weeks of age, White Fulani cattle showed superior phenotypic traits having longer body length, hip height, heart girth, horn length, tail length, and neck lengths compared to crossbred cattle (N'Dama and White Fulani), suggesting that White Fulani breed would be profitable for implementation in long-term cattle genetic improvements (Nosike et al., 2020).

Among other indigenous cattle breeds, White Fulani has been rated highest for their size, milk yield, ease of handling, and market value. They contribute about 90% to the annual domestic milk product (Walshe et al., 1991) and their meat is consumed all over Nigeria (Alphonsus et al., 2012). The majority of White Fulani cattle are reared by the Fulani extensively (termed nomadic style), migrating them through different humid regions over a distance while cattle feed as they move. This cattle breed is cherished for their hardy genetic makeup and they surpass other breeds in disease resistivity, thermo-tolerance as well as their ability to cope with different harsh conditions (Meghen et al., 1999), and their ability to adapt to prevailing local conditions (Alphonsus et al., 2012). According to Ayantunde et al. (2005), a lactation yield of 1087 Kg in a lactation length of 286 days was recorded in White Fulani cattle, whereas a crossbred of Friesian–Bunaji recorded a lactation yield of 2000 kg (Alhassan et al., 1985), indicating a viable

Fig. 1. Geographic distribution of White Fulani in African regions (Native Breed.org, 2018).

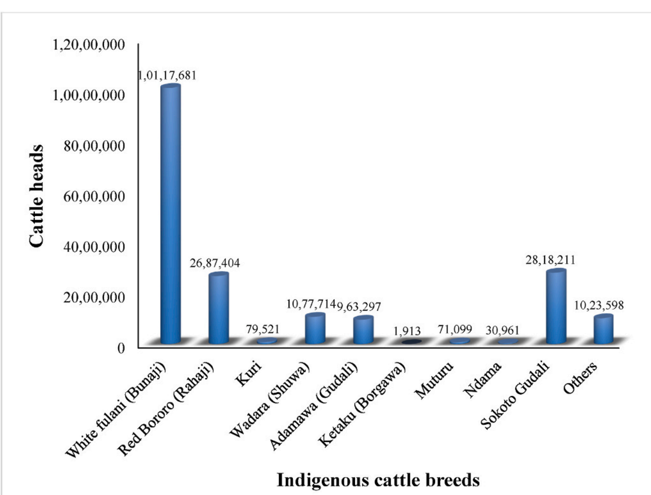

Fig. 2. Distribution of indigenous cattle breeds in Nigeria (NBS, 2012).

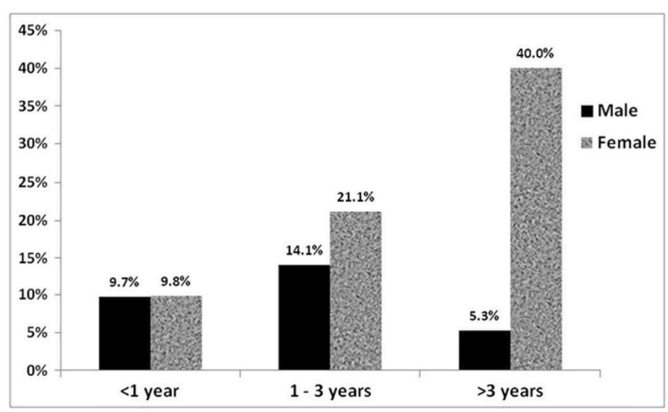

Fig. 3. Herd composition of White Fulani cattle in North-Central Nigeria and Southern Jos Plateau (Majekodunmi et al., 2016).

option to improve the performance of this breed by crossbreeding with the exotic breeds in the tropical environments. Additionally, in comparison with other tropical cattle, Dettermers and Williams (1979) demonstrated that White Fulani cows had a better herd efficiency than Horro, Hariana and Blanco Orejinegro. The authors indicated that White Fulani ranked better than the Criollo of Colombia and Ethiopian and Indian zebu. In order to assess the performance of White Fulani cattle at four different locations in Nigeria, Rege et al. (1993) carried out on-farm research for 12 years between the years 1979 and 1990. The authors reported that at birth, 9 months, and 12 months, the average weights of the animals were 19–6 kg, 76-2 kg, and 93-1 kg, respectively. Mortality can occur at perinatal and postnatal growth phases in White Fulani cattle, but the existing data indicate that mortality is common between parturition and one year postpartum. In Cameroon, Tawah and Mbah (1989) reported 15.4% in calves of less than one year and 0.9% in adults, while 4.2, 2.6, 3–11.2% died at pregnancy, stillbirth, and calves of less than a year, respectively in Shika, Nigeria (Umoh and Jagun, 1981; Aganga et al., 1986). Moreover, in similarity to the findings of Majekodunmi et al. (2014), Ducrotoy et al. (2016) recorded an average calf mortality of 13.3% in Kachia grazing reserve in Nigeria. Calf mortality has been attributed to under-nutrition and/or disease in the first year of growth (Ducrotoy et al., 2016).

The average age for first calving was 62–65 months, with a 22-25-

month lag between successive calving. Pullan (1980) recorded a first calving at 60 months in traditional herds. Table 1 shows the comparison between some quantitative traits of White Fulani and Sokoto Gudali cattle. The findings of the author (Mbap and Bawa, 2001) showed that the lactation yield of Sokoto Gudali was higher than that of White Fulani cows. Generally, literature shows that the lactation yield of White Fulani cows varies at different locations/countries and environments. For instance, Alphonsus et al. (2011) recorded 1322.3 Kg milk (total yield) and 4.24 Kg daily milk yield with the use of hand milking in a station in Zaria, Nigeria. In Ghana, Osman et al. (2019) reported a daily milk yield of 4.50 L. In Cameroon (Bambul), Tawah and Mbah had 3.2 Kg daily milk yield and a total yield of 563.5 Kg, while Mrode (1988) recorded a daily milk yield of 3.8 Kg and a total yield 932.5 Kg in Ibadan, Nigeria. The effect of the environment on the milk yield of the cows is indicated by the significant effect of season on milk production, implying that inadequate management and other environmental factors can alter the milk yield characteristics of these cows. The findings of Alphonsus et al. (2011) (Table 2) revealed that White Fulani cows were able to take advantage of the lush pasture growth that coincides with the commencement of the rains as their milk yield was higher ($p < 0.05$) during the early wet season. The differences in milk yield at different seasons could be attributed to changes in the quality and quantity of pasture available to the cows (Akpa et al., 2006).

The weight at birth of White Fulani calves ranges between 20 and 23 Kg and their weights can be up to 63, 102 and 129 Kg at 3, 6 and 9 months, respectively (Table 3). A live weight of 336.5 Kg was recorded by Wheat et al. (1972). Variation in the weights may be attributed to nutrition, management, environments and genotype-environment interaction. Fig. 4 depicts the average growth rates of surveyed White Fulani cattle and those under improved management (Pullan and Grindle, 1980). Male animals, unlike females, continued to grow at an unbroken rate until they were 6 years old (the oldest recorded). On government farms, the authors reported that there were insufficient male animals to make an appropriate comparison, although one 5-year-old bull weighed 734 kg, more than twice the weight of a similar-aged animal housed under conventional management. The productivity of White Fulani cattle has relatively remained the same for several decades. The observation of Ducrotoy et al. (2016) revealed that productivity and herd composition of the breed were similar to those obtained 40 years earlier.

4. Tropical environments

The tropical climate zones cover 40% of the earth's surface and are located between the Tropics of Cancer (23.5°N) and Capricorn (23.5°S), usually having constant high temperatures and air humidity as the principal biological driving forces (Kellman and Tackaberry, 1997; Val et al., 2005). Tropical climates vary, but 90% of tropical ecosystems are hot and humid, either seasonal or permanent, while 10% are dry and hot, primarily desert-like (Val et al., 2005). Tropical environments are known for their harsh climatic condition characterized by a high ambient temperature that hinders the optimal performance of animals (Oke et al., 2017, 2021; Oke, 2018; Kpomasse et al., 2021). The average monthly temperatures and precipitation in Nigeria between 2015 and 2022 are shown in Fig. 5. The hottest period of the year is between November and April.

Table 1
Comparison between some quantitative traits of White Fulani and Sokoto Gudali cattle.

Trait	White Fulani	Sokoto Gudali	Significance
Age at first calving (days)	1552.00	1438.93	NS
Daily milk yield (litres)	1.08	1.78	NS
Lactation yield (litres)	195.0	321.0	*
Lactation length (litres)	204.13	216.32	NS
Number of days dry	129.86	104.80	*
Calving interval (days)	408.00	398.00	NS
Length of productive life (yrs)	7.46	6.42	NS
Mature weight (Kg) male	617.7	726.8	NS
Mature weight (Kg) female	634.6	758.5	*

(Mbap and Bawa, 2001), *: $P < 0.05$.

Table 2
Effect of season on the milk yield of White Fulani cows.

Milk yield Characteristics	Season				
	Early dry	Late dry	Early wet	Late wet	SEM
Initial Milk Yield (kg)	12.56^b	12.93^b	17.13^a	10.99^b	1.619
Peak Yield (kg)	50.41^c	52.46^c	71.06^a	64.95^b	2.758
End of Lactation Yield (kg)	8.80^d	9.37^c	10.43^b	14.29^a	0.911
Total Milk Yield (kg)	1227.60^c	1525.00^b	1954.20^a	2053.40^a	79.530
Lactation Length (days)	298.20^d	321.36^c	332.06^b	343.54^a	4.997
Number of observation	10	11	16	13	50

Values bearing different superscript at the same row differ significantly ($P < 0.05$); *. $P > 0.05$.
Alphonsus et al. (2011)

Prevailing global warming due to climate change has also amplified the global increase in temperature by 5 °C (WMO, 2019), which in turn has severe impacts in the tropics (Nigeria inclusive). In addition to temperature rising, a decline in rainfall has also been reported, thereby adversely affecting animal wellbeing, productivity, and survival (Scholtz et al., 2013). Therefore, a greater concern about the harmful effects of thermal stress on livestock has arisen worldwide. The physiological mechanisms that ensure animals' survival under environmental stress is at the expense of their optimal performance. The susceptibility of an animal to environmental stress depends on nutritional status, management, genetic potential and species (Das et al., 2016). In addition, weather seasonality in the tropics has contributed to the lack of uniform availability of good quality and quantity of forages throughout the year. Consequently, this has increased the need for supplementary diets during forage scarcity (Schmid, 2013).

Adaptive characteristics of White Fulani cattle to the tropical environments.

Adaptation of animals refers to the extent to which they can adjust to different environments by genetic, physiological or behavioral adjustments or their survivability and reproduction in a particular environment (Barker, 2009). Adaptation to the local environment is multifaceted and involves several genes (Hanotte et al., 2002; Mwai et al., 2015). The hot, dry, and humid tropical climate of the African continent has had a significant influence on the African cattle population, giving them the ability to exhibit unique adaptive traits to cope with the environment (Kim et al., 2017). Acquisition of thermo-tolerance at the cellular and physiological levels has been noted in the cattle (Hansen, 2004).

White Fulani cattle are widely raised in extensive pastoralist systems across northern Nigeria, which is largely dictated by the seasonal distribution of grass and water (Akpa et al., 2012). The main climatic condition of the areas habituated by White Fulani is tropical with two distinct seasons which could be the dry or wet season. Despite the harsh environmental condition in the tropics especially during the dry season, White Fulani cattle remains hardy with a greater ability to regulate their body temperature for a period of thermal challenge (Hansen, 2004; Alphonsus et al., 2012). This is due to their several years of adaptation to the humid tropics and this feature has made them the most numerous cattle in West Africa. They possess a higher heat loss capacity to the environment and lower heat production (Hansen, 2004), therefore, White Fulani cattle possess a better thermo-tolerance than exotic cattle. They are well endowed and suitable for tropical environments. Temperature humidity index (THI) between 65 and 90 has been reported in

Table 3a
Pre-weaning growth of White Fulani cattle at different ages, management systems and locations.

Location	Management	Weight at birth (Kg)	Weight at 3 months	Weight at 6 month	Weight at 9 month	Reference
Bambui, Cameroon	Station	23.1	60.2	88.7	98.5	Tawah and Mbah (1989)
Mando, Nigeria	Ranching	20.1	–	97.8	128.7	Otchere (1983)
Shika, Nigeria	Station	22.3	63.2	101.7	126.5	Oyenuga (1967), Oni et al. (1988)
Abet, Nigeria	Village	20.2	–	61.6	76.9	Rege et al. (1993)
Biri, Nigeria	Village	20.0	–	74.1	77.9	Otchere (1983), Rege et al. (1993)

Table 3b
Post-weaning growth of White Fulani cattle at different ages, management systems and locations.

Location	Management	Weight at 12 months (Kg)	Weight at 18 months	Weight at 24 month	Weight at 30 month	Weight at 36 month	Weight at 48month	Source
Kudu, Nigeria	Station	180.5	236.5	278.1	300.0	322.0	335.2	Wheat and Broadhurst (1968)
Shika, Nigeria	Station	145.1	188.8	226.8	267.0	302.4	336.5	Wheat et al. (1972
Mando, Nigeria	Ranching	136.0	174.8	–	–	–	–	Otchere (1983)
Biri, Nigeria	Village	96.5	114.3	–	–	–	–	Otchere (1983), Rege et al. (1993)
Abet, Nigeria	Village	92.5	113.4	–	–	–	–	Otchere (1983), Rege et al. (1993)

Adapted from Tawah and Rege (1996).

Fig. 4. Average growth rates of survey cattle and those under improved management.

the environments where the animals are raised in the tropics (Menegassi et al., 2016; Santana et al., 2016; Onasanya et al., 2021) while Buvanendran et al. (1992) reported heat tolerance coefficient of 90.7. Outside this THI, cattle comfort is disturbed and this evokes some physiological adjustments in an attempt to maintain a balanced internal environment termed homeostasis. The different aspect of the adaptive traits of White Fulani cattle are discussed below:

5. Physiological adaptation of White Fulani cattle

Adaptation to humid climates encompasses different physiological adjustments, including adaptations to external parasites, attributes of heat exchange like sensible and non-sensible heat loss, and metabolic heat production. Pulse rate, rectal temperature and respiratory rate are some physiological determinants of adaptations to heat stress in animals (Costa et al., 2015; Indu and Pareek, 2015). In a study designed to evaluate the thermoregulatory parameters of indigenous Nigerian cattle

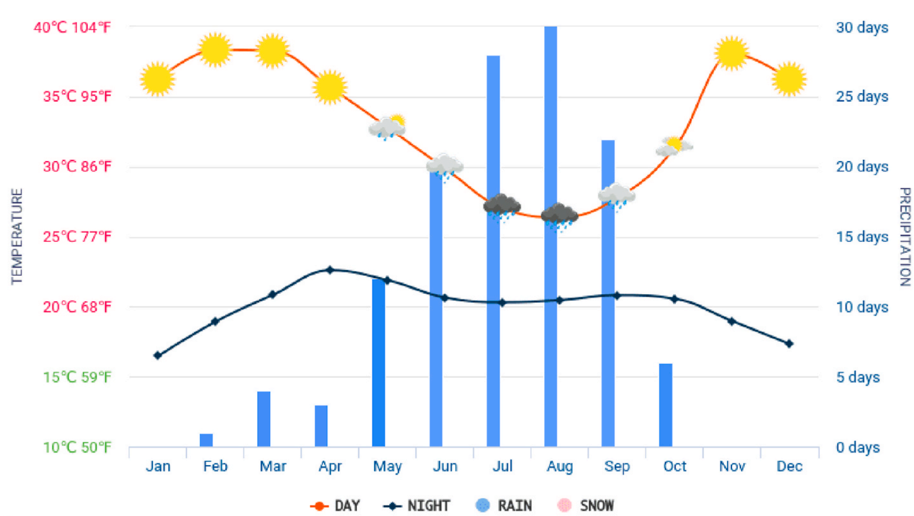

Fig. 5. Average monthly temperatures and precipitation in Nigeria between 2015 and 2022.
(Source: Hikersbay, 2022)

breeds at different seasons, the highest values for respiratory rate (27.85 breaths/min), pulse rate (27.62 beats/min) and heat tolerance coefficient (2.19) were reported in the late dry season (Abbaya et al., 2020). The heat tolerance coefficient used was Benezra (1954). Some of the adaptive characteristics of White Fulani cattle have been linked to heat tolerance. Research on the physiology and thermotolerance of Nigerian indigenous cattle has shown that White Fulani cattle is more thermotolerant than Gudali and Muturu (Yakubu et al., 2015). In a comparative study on the thermal challenge with other breeds of cattle such as Holstein Friesians, N'Dama, Gudali and Muturu, White Fulani cattle exhibited superior thermotolerant indices (Amakiri and Onwuka, 1980). Their rectal temperature is between 38.3 and 38.9 °C (Igono and Aliu, 1982). A recent study by Onasanya et al. (2021) showed that White Fulani cattle breed had lower body temperature and rectal temperature than Sokoto Gudali and Ambala breeds, indicating that White Fulani breed had a better thermo-tolerance and adaptability to heat stress. Moreover, comparing the thermotolerance of two breeds of cattle under two seasons, Buvanendran et al. (1992) indicated that White Fulani cattle had a skin temperature of 38.9C during the hot season and 30.4C during the cool season. Whereas skin temperatures of 42.6C and 38.9C were recorded for Sokoto Gudali in hot and cool seasons, respectively. Additionally, the findings of Bature et al. (2021) revealed that White Fulani and Red Bororo cattle had better thermotolerance under different seasons in Nigeria. Some heat tolerance characteristics of White Fulani Cattle have been collated (Table 4) (Tawah and Rege, 1996).

White Fulani cattle exposed to thermal stress have been shown to possess a better sweating rate when compared with exotic cattle. Egbunike et al. (1983) reported the sweating rate of 454 g/m^2/h in White Fulani cattle compared to 300 gm/h in German cows exposed to solar radiation. This may be attributed to their high sweat gland density, which may also contribute to a high evaporative loss because cattle lose evaporative heat primarily through sweat (Mcewan, 1972). This suggests a better heat dissipation mechanism for heat stress relief. Based on the coefficient of adaptation (Benezra, 1954), the findings of Amakiri and Funsho (1979) revealed that White Fulani cattle had a significantly higher heat tolerance (2–01) than the N'Dama (2–19), the German Brown/N'Dama (2–50) and the German Brown (2–72) and Friesian (2–79). According to Buvanendran et al. (1992), the respiratory rate of White Fulani cattle is between 15 and 30 flank movement/minute. Likewise, White Fulani cattle recorded lower salivation and panting during thermal stress (Buvanendran et al., 1992) and may sweat more profusely than Ndama, Muturu, Sokoto Gudali, and Holstein Friesians when subjected to the same thermal condition (Amakiri and Onwuka, 1980). White Fulani cattle were thereby reported as the least stressed cattle in Nigeria with a superior thermal tolerance mechanism suitable for tropical environments (Igono and Aliu, 1982). Under the four quarters of Nigeria's hot humid seasonal tropical climate, Adeyemo et al. (1981) demonstrated that White Fulani heifer had low plasma cortisol, similar to those of Holstein-Friesian and Brown Swiss, indicating adaptation to the hot temperature and a protective mechanism against excessive metabolic heat.

Table 4
Heat tolerance characteristics of White Fulani Cattle.

Trait	Value	Reference
Sweat gland measurements		
Length, μm	354.0	Amakiri (1974)
Diameter, μm	105.0	Amakiri and Mordi (1975)
Volume (μm^3 X 10^6)	3.1	Amakiri (1974)
Density (number/cm^2)	1584.0	Amakiri and Mordi (1975)
Sweating rate (gm/m2/hr)	105.8	Igono and Aliu (1982)
Moisture loss/gland (x10^{-6}/g/hr	7.0–10.6	Igono and Aliu (1982)
Rectal temperature °C	38.3–38.9	Amakiri and Funsho (1979)
Respiratory rate (flank movement/min)	15–30	Buvanendran et al. (1992)
Coefficient of adaptability (heat tolerance index)	2–2.3	Amakiri and Funsho (1979)

6. Morphological features of adaptation in White Fulani cattle

Phenotypically, the breed has a large hump with lyre-shaped horns that are 80–105 cm long (Kubkomawa, 2017) and a white coat color that is usually interspersed with black dots. Their ears are erect and some have red patches on the ears, legs, and sides (Onasanya et al., 2021). In addition to having a long, wide forehead and a straight or concave shape, the adult wither height is 130 cm; the neck is strong enough to support the head upward; and the horns are long, slender (81–107 cm), and lyre-shaped: curved outwards and upwards, having an outward curve at the tip (Faulkner and Epstein, 1957). The udder is well-shaped, well-developed, and strongly attached (Tawah and Rege 1996).

In tropical environments with intensive solar radiation and high ambient temperature, coat pigmentation may play a role in adaptability (Peters et al., 1982). The diverse coat colors of animals have varying heat absorption and radiation capacities, therefore, they are capable of influencing the body's physiological responses to ambient temperature. White Fulani cattle usually have a white coat on a black background with black ears, eyes, muzzles, hooves, horn tips, and tail tips (AGTR, 2021). The white coat color forms an adaptive feature because white color has a lesser degree of melanin pigment responsible for black coloration. More so, increased heat absorption and body temperature are linked to the black coat color instead of white coat color (Bianchini et al., 2006; Baena et al., 2019). According to Katiyatiya and Muchenje (2017), white coat color could limit the direct effect of thermal stress by reflecting more incident solar radiation away from the body. In addition, the hair coat thickness of White Fulani cattle is a crucial determinant of non-sensible heat loss on the body surface (Bennett, 1964). Accumulation of subcutaneous fat and increase or decrease in skin thickness has been identified as a response to temperature. Tucker et al. (2008) reported a reduced shade-seeking behaviour in the white colored cows than the black and this is mainly due to the high radiation capacity of their coat color. Also, coat type also has a role to play in the thermal adaptation of animals. The short coats of White Fulani cattle with bristle hair lying sleekly against the skin is also a form of adaptation to the tropical region.

While most animals have a narrow rump, the breed has a generally leggy appearance due to its shallow body and lack of width (Fig. 6).

Fig. 6. Morphological features of White Fulani cattle.

Adaptation to long-distance trekking in pastoral management has been attributed to this characteristic of the breed (Capitaine, 1972; Tawah and Rege, 1996). In comparison with two other breeds, the findings of Ahmed et al. (2021) demonstrated that morphological features of White Fulani cattle were superior to those of Muturu and Pasundan (a breed from Indonesia) (Table 5). In a recent study, Morenikeji et al. (2021) reported that the body length of N'Dama (male) cattle was similar to those of White Fulani and Muturu cattle breeds but higher than the Keteku breed. The authors also reported that the heart girth of White Fulani cattle was higher than Keteku but similar to that of N'Dama and lower than that of the Muturu breed.

7. Biochemical adaptation of White Fulani cattle

The haematological and blood biochemical indices are essential parameters in evaluating the health status of animals and the diagnosis of several diseases in animals (Puppel and Kuczyńska, 2016). Olayemi and Oyewale (2002) observed that White Fulani cattle had some higher biochemical parameters than the N'dama cattle, as shown in Table 6. Generally, Olbrich et al. (1971) indicated that zebu cattle utilize dietary protein more efficiently ($P < 0.05$) than the other breeds. Differences in rearing systems influenced the haematological indices of the Nigerian White Fulani cattle since cattle raised under intensive management had higher blood parameters compared to the cattle under extensive management (Olayemi and Oyewale, 2002). A comparative study on Kuri and White Fulani cattle found higher PCV and haemoglobin values in the Kuri than White Fulani cattle (Olayemi et al., 2006). In a study conducted by Awolaja et al. (1997), the PCV and haemoglobin values were not significantly different between the Keteku and White Fulani cattle. In a study to determine the influence of breed and time of day on plasma leptin and glucose concentrations, White Fulani breed had higher leptin levels (8.5 ± 3.2 ng/ml) than the Muturu, Ndama and Muturu x White Fulani crosses(Okwelum et al., 2019).

8. Molecular basis of adaptation in White Fulani Cattle

Zebu cattle breeds have a superior thermotolerance compared to the non-zebu breeds due to their adaptation to humid tropics (Hansen, 2004). This reported thermo-tolerance may be explained by their differential expression of heat shock proteins (HSP) during thermal stress compared to the non-zebu breeds (Deb et al., 2014; Hansen, 2004; Archana et al., 2017). These genes function by eliciting cellular signaling which helps coordinate cellular metabolism when animals are out of their thermo-critical zones (Collier et al., 2008). Variation has been recorded in the expression of *HSP90AA1* and *HSPD1* genes in zebu and non-zebu cattle and this variation has shown that zebu cattle are better adaptive to various environmental conditions. Up-regulation of this *HSP90AA1* during heat stress occurs due to high translation of HSP90 protein in a way to confer protection to the cells (Collier et al., 2008). *HSP90AA1* upregulation due to climatic and physiological conditions has previously been reported in zebuine and taurine cattle (Kumar et al., 2015; Hooper et al., 2018). In an investigation to assess the genetic diversity of the White Fulani cattle and Red Bororo breeds in Nigeria and Cameroon, Ibeagha-Awemu and Erhardt (2006) reported that these animals had a high potential for increased productivity. The authors reported that this could be achieved by implementing a practical pastoral system of management which can limit uncontrolled genetic exchanges between breeds, maintain current high levels of diversity, and increase productivity.

There is a high degree of genetic diversity among the white Fulani cattle and their first filia generations have been shown to form a common cluster (Norezzine et al., 2019). The microsatellites possess multiple alleles and can reveal a minimum of 70% heterozygosity frequencies (Norezzine et al., 2019). In a comparative study, Mohammed et al. (2019) indicated that the White Fulani cattle had a higher genetic diversity and Single nucleotide polymorphisms values (14) than N'Dama and Muturu cattle. Generally, there is a scarcity of data on the evaluation of thermotolerance genes in the indigenous cattle. However, evaluating the polymorphisms at Heat Shock Protein 90 gene for heat tolerance in the cattle, Onasanya et al. (2020) recorded 11 genetic variants of HSP 90 gene, indicating genetic diversity. Similarly, a recent study (Onasanya et al., 2021) examined the HSP 70 gene polymorphisms in Nigeria zebu cattle including White Fulani cattle and detected 12 genetic variants in the DNA samples. This can be explored as an essential genetic resource for improving adaptation and thermo-tolerance cattle in the harsh tropical environments.

Table 5
Morphometrical measurements in White Fulani, Muturu and Pasundan breeds cattle.

Trait (cm)	Breed		
	White Fulani	Muturu	Pasundan
Body length	113.38 ± 11.53a	91.74 ± 8.52^{b}	101.76 ± 8.55^{c}
Chest girth	153.43 ± 12.96^{a}	110.61 ± 13.47^{b}	140.42 ± 10.51^{c}
Withers height	120.06 ± 14.85^{a}	73.81 ± 7.52^{b}	114.07 ± 7.40^{c}
Rump length	39.62 ± 8.05^{a}	29.94 ± 5.55^{b}	38.18 ± 3.94^{a}
Chest depth	60.93 ± 8.69^{a}	48.00 ± 5.92^{b}	55.86 ± 4.11^{c}

Ahmed et al. (2021).

Table 6
Comparative assessment of the biochemical parameters of the White Fulani and N'dama cattle.

Parameter	White Fulani	N'dama
Haemoglobin concentration (g/dL)	12.28 ± 1.48	9.88 ± 1.33***
Mean corpuscular haemoglobin (pg)	23.11 ± 5.29	19.00 ± 5.01**
Plasma sodium (mmol/L)	142.26 ± 9.07	126.15 ± 19.15**
Total protein (g/L),	90 ± 8.10	74.2 ± 18.2**
Albumin (g/L)	28.9 ± 4.3	23.4 ± 6.70**
Globulin (g/L)	62 ± 8.80	51.4 ± 15.40*

Values differ along the row at: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.
Olayemi and Oyewale (2002).

9. The resistivity of White Fulani cattle to tropically endemic diseases

Adaptation to tropical environments and diseases is dependent on the stress response, olfactory receptors, and immune system (Bahbahani et al., 2017). Bovine Lymphocyte antigen (BoLA-DRB3.2), which has been reported to be involved in disease resistance, is polymorphic in White Fulani cattle (Ahmed et al., 2020a). Despite the pastoralist traditional system of production adopted for White Fulani cattle whereby they receive infrequent medical attention or even feed supplementation, White Fulani cattle still have some level of resistance to some diseases. For instance, tsetse fly distribution is quite variable within the tropical environment and this significantly affects the availability of White Fulani cattle in a particular region. The findings of Achukwi and Musongong (2009) revealed that the infection rate of trypanosomiasis in the white Fulani cattle (11.9%) was lower than that of Doayo (16.4%) cattle in Cameroun. Compared to the N'Dama cattle, it has been recently identified that White Fulani cattle has a significantly lower single nucleotide polymorphisms density at the cluster differentiation antigen 14 (CD14) gene promoter region, which is necessary to facilitate bacterial molecules and provide an adaptive protective mechanism against disease (Morenikeji et al., 2020). Recent studies have uncovered an autosomal taurine background in all African cattle which may contribute to their environmental adaptation, disease tolerance, and success during pastoralism (Kim et al., 2020). In addition, polymorphisms in BoLA genes have been associated with parasite, bacterial and viral infections (Takeshima et al., 2008; Untalan et al., 2007). Molecular studies have identified the highly polymorphic and distinct expression of the BoLA-DRB3 allele in White Fulani which is associated with the Bovine leukaemia virus and mastitis resistance in cattle (Ahmed et al., 2020a). The observation of Paguem et al. (2020) revealed the presence of 9 high and moderate impact variants of BoLA genes in White Fulani. This knowledge may be expedient in understanding the genetic basis of disease tolerance/resistance in White Fulani cattle. Furthermore, the polymorphism of the smoothened (SMO) candidate gene which is known to influence body size and body measurement traits was demonstrated in White Fulani cattle breed. Additionally, this would form a vital tool in improving breeding practices to promote cattle productivity (Ahmed et al., 2020b).

Another adaptive feature of White Fulani cattle is their greater resistance to intestinal helminths (Ross et al., 1959). This cattle breed has also been reported to have higher resistance to dermatophilosis than N'Dama and Muturu breeds (Nwufoh and Amakiri, 1981). These thereby indicate the higher resistivity of White Fulani cattle to diseases and suggest their ability to adapt and survive in different environmental conditions.

10. Behavioral adaptation of White Fulani cattle

Behavioral responses in heat-stressed ruminants include shade seeking, increased standing duration, decreased feed intake, increased water intake, drinking frequency, grazing patterns, and reduced laying period (Gaughan et al., 2018). Jimoh et al. (2017) revealed that White Fulani cattle spent more time (87.33 min) grazing in a dense pasture than exhibiting other behaviour repertoires. This observation corroborates the findings of Minka and Ayo (2017), who reported that White Fulani crossbred cattle could stand to feed for a longer time (66 ± 3.5%) compared to the Sokoto Gudali breed (56 ± 4.5) (Minka and Ayo, 2017). Season affects the grazing bevavior in White Fulani cattle. Akewusola et al. (2017) found that White Fulani heifers spent less time grazing in the dry season (57%) and more time (66%) in the rainy season. The authors observed a longer period of rumination in the rainy season (12%) than the dry season (4%). Whereas, walking and grazing behaviour was higher during the rainy season (19 and 66%, respectively) than the dry season (9 and 57%, respectively). During the hot, dry season, feed availability is limited and White Fulani cattle spend more time on continuous grazing, which hinders their shade-seeking behaviour and limits resting time (Lewis, 1978). With regards to the biomass spatial distribution, it has been shown that White Fulani calves spent more time (87.33 min) grazing pasture with dense biomass (15 cm height) than calves raised on sparse biomass (10 cm height) which had higher idle, resting, and rumination time (18.33 min) (Jimoh et al., 2017). White Fulani calves' grazing behaviour can be influenced by plant species, age, and spacing. Enwete et al. (2020) indicated that Grazing time on the M. maximus plot was longer (6765.10 s) than it was on the *C. purpureus* plot. Grazing duration on the 0.5m × 1m plant spacing plot was longer (6591.60 s) than on the 1m × 1m plant spacing plot (6311.30 s). At 6 weeks after cutback (6769.00 s), grazing time was greater than it was at 3 weeks after cutback. The calves spent more time standing (638.20 s), grooming (113.83 s), and stamping their feet at 3 weeks following cutback than they did at 6 weeks.

11. Breeding and reproductive traits of White Fulani cattle in the tropics

Reproductive output is an important adaptation criterion because a high ambient temperature could hinder the fertility and reproductive potential of animals. With respect to male fertility, Nafarnda et al. (2005) obtained a similarity in the fertility rates following artificial insemination with the use of semen from the exotic breed (Friesian cattle) (91%) compared to White Fulani (89%), indicating a comparable fertilising potential. Reproductive performance is generally low in Nigerian indigenous cattle (Olaloku, 1999). The age at first calving in Kachia Grazing Reserve in Nigeria was between 3 and 5 years, with an average calving interval and calving rate of 17.4 months and 69%, respectively (Tawah and Rege, 1996). Akpa et al. (2012) also reported 4.75 years as the age of first calving in Zaria. A high calving rate is a measure of prolificacy. Ahamefule et al. (2007) recorded a significantly higher ($P < 0.05$) calving rate in the White Fulani cattle (61.21%) than in the N'dama cattle (21.22%). In addition, a shorter calving interval was recorded in the White Fulani cattle (446.88 days) than in N'dama breed (6533.77 days). However, the author reported a higher age at first calving in White Fulani cattle (48.88 months) than in N'dama breed (38.22 months). Birth weight is associated with the survivability and finishing weight of cattle. The birth weight and weaning weights were significantly higher ($P < 0.05$) in White Fulani calves (19.66 Kg and 79.88 Kg, respectively) than N'dama (13.93 Kg and 63.66 Kg, respectively) or crossbred (White Fulani x N'dama) (17.33 Kg and 70.88 Kg, respectively). These traits suggest that White Fulani cattle perform better than some indigenous cattle. A study on 148 White Fulani calves (66 males, 82 females) showed that the average birth weight was 23.82 kg and that the male calves (24.54 ± 0.51 kg) were significantly heavier than females (23.19 + 0.48 kg) (Olawumi and Salako, 2010). Also, heritability estimates of birth weight and calving interval in White Fulani cattle were reported as 0.21 ± 0.26 and 0.012 ± 0.16, respectively (Mbap, 1996). In a comparative study, Raheem et al. (2016) demonstrated that the weights of right and left ovaries and the length of the uterine horn in White Fulani cows were significantly higher ($P < 0.05$) in than those of Red Bororo breed. This suggests a superior reproductive apparatus of the breed. Additionally, oestrus synchronization is effective with the use of prostaglandin F2α and progesterone-releasing intravaginal device in White Fulani cows (Voh et al., 2004), indicating their potential viability under an intensive programme.

Existing data indicate that White Fulani cows have 26.2 months at first service, 5–5.8 number of lactation (productive life), 20.8 days oestrus cycle length and the duration of 8.3 h (Johnson and Gambo, 1979), 74 days interval between parturition and first oestrus (Dawuda et al., 1987; Adamu et al., 1990). Also, White Fulani cow has a conception interval of 48.8 days, a conception rate of 48.8% (60–90 days postpartum) (Eduvie and Dawuda, 1986), 43.3 days interval between the first follicle to first ovulation, 44.9 days postpartum before the detection of the first follicle and 26 days uterine involution postpartum (Eduvie, 1985). Ducrotoy et al. (2016) recorded 3–5years of age at first calving and 3–4 calves in a reproductive lifetime at the Kachia grazing reserve in Nigeria.

12. Nutrition of White Fulani cattle in the tropics

Nutrition, including the availability of quality grazing land, affects fertility in cattle. In a comparative study on the fertility of White Fulani cattle, Pullan and Grindle (1980) demonstrated that the White Fulani cattle that received cottonseed meals in the study herd were similar to those of the government herd receiving the conventional supplement. The authors reported that the fertility of the control group was lower. In the Kachia grazing reserve in Nigeria, the low productivity of cattle during the dry season is related to their lack of grazing land (Ducrotoy et al., 2016). In addition, the impact of thermal stress on cattle depends on their physiological state. For instance, due to the higher metabolism in lactating cows, they are more vulnerable to the adverse effect of thermal stress than heifers (Ahmed et al., 2015). Moreover, exposure to heat stress before insemination could affect the conception rate in cows (Al-Katanani et al., 2002). Therefore, despite the adaptability of White Fulani cattle and its better reproductive output compared to some other indigenous breeds, the limitations posed by their environment prove unfavourable to their optimal performance and productivity.

It has been identified that inadequate nutrition, inbreeding, age, and bodyweight negatively impacted the milk production rate of White Fulani cattle (Adeneye, 2021). Peak milk production was recorded during the second month of lactation for early dry season calvers producing an average of 2.5 kg of milk that contained 12.6% total solids, 3.8% fat, 8.9% solids-not-fat, 4.2% protein, 4.0% lactose, and 0.7% total ash (Adeneye, 2021). Also, White Fulani cattle had a higher number of dry days, that is, 129.9 days compared to the Sokoto Gudali breed (104.8 days) (Mbap and Bawa, 2001). According to the World Dairy Standard, milk production from White Fulani cattle is relatively low, although it ranks best among other indigenous Nigerian breeds. Molecular identification of selected candidate genes for milk production showed that the indigenous White Fulani cattle had higher prolactin, beta-lactoglobulin, and kappa-casein gene expression compared to the Angus and N'dama cattle breeds and that based on their mRNA expression for milk genes, White Fulani and Holstein cows were in the same cluster (Morenikeji et al., 2019). Therefore, based on transcriptomic profiling, White Fulani cattle possess a higher potential for milk production in the tropics through improvement using targeted selection and breeding programs similar to Holstein breed in the temperate region. In line with this, efforts have been made to promote the milk production of this breed. In the tropics, crossbreeding has been highlighted as one of the most important ways for improving the genetics of indigenous cattle for milk production (Agyemang and Nkhonjera 1990; Mackinnon et al., 1996; Tawah et al., 1999). White Fulani breed has been upgraded by crossing their cows, using semen from Holstein Friesian bulls (Lanari et al., 2003). At NAPRI-Shika, Alphonsus et al. (2012) reported that the crossbred of White Fulani cows x Holstein improved age at first calving milk production.

13. The future perspectives

The evolutionary adaptations that the White Fulani cattle have acquired to thrive in tropical environments over the years have made them particularly relevant for tropical production. It is important to develop strategies to manage and utilize the breed efficiently in the face of climate change so that various traits, including animal health, fertility, conception rates, milk production, growth and feed intake, can be improved (Onasanya et al., 2020). Concerted efforts should be made to optimize the genetic potential of the cattle breed. It is necessary to carry out further genetic characterization of the breed to ensure the provision of vital genetic resources for their improvement. Multiple genomic applications could significantly influence the genetic progress of cattle production in the tropics in terms of quality, efficiency, and sustainability (Fernandes Júnior et al., 2022). There is a growing interest in genomic evaluations in tropical cattle production. This could influence the selection strategy in White Fulani cattle (Fernandes Júnior et al., 2022). It is necessary to bridge the productivity gap of the indigenous cattle breed in the tropics. Efforts are needed to ensure that the genetic resources of the White Fulani are not eroded via crossbreeding in order to avoid the loss of their adaptive traits.

More adult females are in the herds of White Fulani cattle, reflecting breeding practices focused on producing milk. Therefore, there is a need to focus on the commercial production of milk to minimize losses. Additionally, cattle production in West Africa is lagging behind; therefore, governmental and non-governmental support should be provided for the transition from an extensive to a more productive, integrated and intensive system of production.

14. Conclusion

This review highlights some attributes of White Fulani cattle that make them adapted to the tropical environments. The breed plays a significant role in beef and milk production in Nigeria, being also the most numerous cattle breed. White Fulani cattle have a strong potential for increased production; a management program that ensures their controlled breeding and guarantee their productivity and diversity should be encouraged. Due to the discrepancy in the their performance under different locations and management systems, further studies are needed to evaluate the adaptive attributes in relation to different environmental conditions. High losses of calves characterize White Fulani cattle production across different locations in West Africa, affecting their productivity. Over the years, the productivity of the cattle has remained relatively constant; hence, there is a need for concerted efforts to improve and exploit their potential as they may play an important role in the beef-upgrading programme in Africa. Additionally, there is a need to conduct a survey on the present population distribution of the breed in Africa.

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Declaration of competing interest

The authors declare that we do not have competing interests whatsoever.

Data availability

Data will be made available on request.

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