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REVIEW ARTICLE

Physiological adaptation to the humid tropics with special reference to the West African Dwarf (WAD) goat

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Abstract West African Dwarf (WAD) goats are widely distributed in the subhumid and humid zones of Africa but are particularly associated with less favourable environments. Adaptive features such as feeding behaviour, efficiency of feed use and disease tolerance enable WAD goats to thrive on natural resources left untouched by other domestic ruminants. In marginal environments this goat remains the only domestic species that is able to survive. Among its physiological features small body size and low metabolic requirements are important traits that enable the animal to minimize its requirements in area or season where food sources are limited in quality and quantity. Specialized feeding behaviour and an efficient digestive system enable the animal to maximize food intake. Coat colour plays an important role in the evolved adaptation of this goat type. Reproductive fitness as manifested by prolific breeding is a major factor of adaptation. Defence mechanisms against infectious agents enable this type to thrive well in the hot humid tropics. The mechanisms involved in the regulation of these physiological functions of WAD goat are discussed. An understanding of these mechanisms could result in the development of improved techniques for enhancing goat productivity in humid environments.

Keywords Heat stress · Achondroplastic dwarf · Disease resistance · Digestive efficiency · Water use · Thermoregulation

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Introduction

Goats are one of man's principal sources of meat and milk. Most goats are found in the drier areas of the developing world. The total world population in 2007 was estimated at about 850 million goats of which 728 million were in low income food deficit countries (FAOStat 2008). Asia is home to about 545 million goats and Africa to about 245 million: these two areas, therefore, are the major repositories of the goat. The 14 countries of West Africa contain about 81 million goats. Many of this number south of latitude 14^{o}N which is humid and provides an environment favourable to high disease challenge are of the West African Dwarf (WAD) type. The WAD has many recognized subtypes (Wilson 1991) (Fig. 1). Under this humid tropical climate heat stress and disease challenge are compounded by inadequate nutrition, poor housing and rudimentary management (Adeloye and Daramola 2004). Under these conditions it is to be expected that animals are often in poor condition

Fig. 1 The Ghana, Côte d'Ivoire and Cameroon subtypes of the West African Dwarf goat

and often fail to perform to their potential. Physiological changes occur when animals are stressed but paramount and fundamental are loss of form (weight), loss of performance (production) and loss of life (death). This notwithstanding the WAD is hardy and thrives in harsh conditions of management (Adeloye 1998) which is largely possible because of the innate adaptogenic power of the animal to react to a particular quantum stressors (Adeloye and Daramola 2004).

The abundance of WAD goats in the tropical humid areas of the West African coastal and hinterland areas reflects a better adaptation of this species to these environments when compared to sheep (which in Nigeria and elsewhere) are usually confined to the drier areas. The tropical humid agroclimatic zone is infested with tsetse fly and the dwarf goat thrives well and reproduces with twin and triplet births in this ecological niche. The breed is often referred to as achondroplastic as it has disproportionately short legs which are often bent and the body length appears long for the size (Epstein 1953). The coat is short and shows a range of colours from black to brown and white and there are many mixtures of these colours (Odubote 1994a). It is believed that coat colour and certain breed characteristics provide this breed with unique abilities (Odubote 1994b). The ears are short and erect and point forwards. In its home area the WAD is a preferred meat animal but milk production is poor (Adeloye 1998). The male stands 22 cm at the withers and weighs 18 kg at maturity whereas the female stands 18 cm and weighs 15 kg at maturity (Adeloye 1998).

The West African Dwarf goat is acceptable to all religions. It features prominently as a slaughter animal at ceremonial occasions and festivals. It serves as source of income and investment against failure of cash crops. Ecological conditions, feed resources and interactions with the cropping subsystem determine the goat management system. With few exceptions goats are allowed to range free during the drier parts of the year but are tethered or stall fed in the cropping season: at night goats are kept in open camps or confined in pens or houses (Wilson et al. 1983; Sumberg and Mack 1985). Much of the feed of these goats is scavenged from the local environment but most are also given some kitchen waste (Adeloye and Daramola 2004). There appears to be a general consensus that goats indigenous to harsh environment perform better than other domestic ruminants in different environmental conditions (Shkolnik and Silanikove 1981; King 1983; Adeloye 1998; Devendra 1990).

This review integrates information documented on various aspects of the physiological adaptation of the WAD to hot humid agroecological zone of West Africa.

Broad spectrum of adaptability

The terms hardiness and adaptability are attached to the WAD because of its ability to inhabit a harsh environment where management practices such as feeding with balanced diet, good housing and regular health treatment including vaccination are performed infrequently. In spite of these deficiencies the WAD attains relatively high production and reproduction performance. In a review of osmoregulation in large herbivores they were classified into three main physiological ecotypes: the goat fell into the category of arid zone animals with low rates of energy and water turnover and with medium to high urine concentrating ability (Maloiy et al. 1979). Yet the goat is found under a much wider range of climatic conditions. In addition to thriving in arid desert areas it is known to succeed in tropical rain forests and is, indeed, the domestic animal with the largest ecological distribution (Epstein 1971). Although no reference is made to the WAD goat *per se* in the literature cited it would be logical to assume that this goat breed is perfectly adaptable to such similar conditions.

In spite of the contrasting and variable environments in West Africa the dwarf goat is one of the most outstanding examples of a breed shaped by this environment to be an unsurpassable prolific breeder and provider of red meat of high nutritional quality (Adeloye 2004) even under less favourable conditions.

Adaptability to ecological conditions

Goats are able to produce under varying and frequently unfavourable environmental conditions. The most important adaptive features enabling them to adjust to the environment in which they are reared are feeding behaviour, body size and fleece structure. Goats are not only able to select a high quality diet and to compensate for their limited rumination capacity but they also consume more plant species than other domestic livestock (Demment and Van Soest 1983). Their unique feeding behaviour allows them to overcome the effects of limited feed availability and select palatable parts of plants with high crude fibre content (such as the fast-growing grasses of the humid zone).

Another important adaptation of goats to ecological conditions is their variable body size. Goats inhabiting hot humid environments have small bodies (dwarfs) whereas those living in dry environments or in areas with a wide diurnal temperature range usually have larger bodies (Horst 1984). The combined effect of appropriate body size and feeding behaviour enables goats to withstand environmental stress and may be one reason for the relatively high disease tolerance attributed to goats under unfavourable environmental conditions.

Fleece structure shows a remarkable association with environmental conditions. In the semi-arid to humid zones short coats of coarse fibre enable goats to withstand high rates of radiation or humidity. Goats inhabiting the arid zones have long-haired, coarse-fibre fleeces to protect against heat during the day and cold at night. In the mountainous areas of central Asia goats have a top coat of long coarse fibres and a seasonal undercoat of short, fine fibres to protect against extreme cold. Angora or mohair goats have long, white and wavy fleeces and live in mid-altitude (Turkey) and dry, high-altitude areas (Lesotho). In West Africa the dwarf goat is characterized by small size compared to other goat breeds (Adeloye 1998, 2004). This is an adaptive measure that increases the body surface area to heat dissipation (Adeloye 1998).

Heat stress

The most direct effect of climate is temperature stress, either hot or cold. Both are important to goats. Most African goats appear to have a high level of heat tolerance and certainly greater than the sheep with which they usually graze. Goats (even young suckling kids) are often content to remain in full sun at midday when sheep have sought available shade. Cold stress — sometimes associated with rainfall — does appear, however, to play a major role in the incidence of several respiratory infections that are of great important to goats suggesting that the tolerance at this end of temperature range may be low (Mack 1983; Horst 1984).

Smooth hair is found on 62 per cent of goats compared to 38 per cent for the woolly hair (Odubote 1994b). Variations in qualitative traits of WAD goats are not restricted to geographical area but may be influenced by selection pressure. The higher incidence of smooth, short and straight hair in extensively managed WAD goats in this zone relative to the curly woolly-type suggests, however, that smooth hair is an adaptive feature for the breed. Smooth hair probably facilitates body temperature regulation under the hot humid conditions. The classic concept that coat type is a function of heat absorption and heat loss (Turner and Schleger 1960) suggests that coat type is important in heat absorption and heat loss and thus for the adaptability of this type of goat.

High heat tolerance in the WAD may be partly attributable to their relatively small size and therefore larger surface area, particularly in the case of those WADs of the forest zone. WADs of the more northerly latitudes of the Guinea savanna tend to have different coat characteristics and show more grazing activity during the hours of maximum solar radiation. This is in general agreement with the positive correlation between cattle size and the climatograph for the area of breed distribution (Pagot 1974).

Dwarfism

Hereditary dwarfism is common in the humid tropical zone and is the characteristic genotype of the West African Dwarf goat (Devendra and Burns 1970). This character appears to Bergmann's Rule which states that "In warm blooded animals, races from warm regions are smaller than races from cold regions" (Bergmann 1847). This has been interpreted as amounting to a correlation between morphological variation and ambient temperature whereby the relatively larger body surface area of the smaller races serves as an efficient heat dissipater in warm climates whereas small body surface areas help to conserve heat in cold climates (Mayr 1970; Searcy 1980). Correlation between size changes in fossil mammals from various parts of the world with palaeoclimatic changes is in accordance with this rule (Dayan et al. 1991). Other scientists have suggested that body size is better correlated with primary plant productivity (Rosenzweig 1968), desiccation (James 1970) and the type and quality of food (Calder 1984) than with temperature. It is possible, however, that it may be a combination of all these factors because they are highly interrelated in a matter concerning body size. The selection process seems to be the most probable single factor of body size because under unfavourable conditions dwarfed individuals are better adapted than the bulk of the ordinary stock. Selection pressure towards a smaller size explains the widespread dwarfism in domestic ruminants occupying the same niche. In accordance with Bergmann's rule even non-dwarfed breeds of ruminants in the humid tropics are in most cases much smaller than tropical exotic breeds (Epstein 1971; McNab 1971).

Performance under and resistance to locally endemic diseases

In what may appear to be a paradox both the West African Dwarf goat (Mack et al. 1984) and West African Dwarf Shorthorn cattle (Ferguson 1966) it seems that trypanotolerant livestock in village situations perform best when not managed at all. This information can be useful if it indicates where management improvements may be achieved within the framework of production priorities and resources of local livestock owners.

It is generally believed that the WAD is relatively resistant to disease. The physiological mechanisms that enable this type of small ruminant to thrive well in the ecozone which favours high prevalence of disease have been reported elsewhere (Daramola et al. 2005). The WAD has high Packed cell volume (PCV) values compared with other goat types in Nigeria (Akerejola et al. 1979; Tambuwal et al. 2002; Daramola et al. 2005). The WAD goat has a tendency for compensatory accelerated production (CAP) of PCV in case of infection. This allows a rapid return to normal PCV levels following an infection (Dargie and Allonby 1975). Early conception of does following peste des petits ruminants (PPR) shows that WAD does that recover from this disease conceive as soon as they regain physiological normality. That all such does carried pregnancy successfully to term indicates that PPR does not cause important structural damage to the doe's reproductive system (Ezeibe and Wosu 1999). WAD goat also have relatively high haemoglobin values (Daramola et al. 2005) which is an advantage in terms of the oxygen carrying capacity of the blood. The WAD goat has higher white blood cell values (Daramola et al. 2005) than other breeds of ruminant in Nigeria (Oduye and Fasanmi 1971; Olusanya et al. 1976; Tambuwal et al. 2002) and seems to possess a protective system that provides a rapid and potent defence against any infectious agent. This is probably the physiological basis for the adaptation of this breed to this eco-zone characterized with high prevalence of disease. In goats, as in other ruminants, there are more lymphocytes than neutrophils in circulation (Olusanya et al. 1976). The values obtained for the WAD fall within the broad range suggestive of a well developed immune system (Daramola et al. 2005).

Data on the performance traits and disease resistance of trypanotolerant livestock in West and Central Africa have been extensively surveyed (FAO 1980a, b; Trail and Wissocq 1982). The relative tolerance of the WAD to trypanosomosis is well recognized. It is likely that this tolerance is innate rather than acquired (Stewart 1937, 1951; Mulligan 1951) but there is need for further investigation of the nature and specificity of this aspect of breed adaptation. Superior innate and apparently highly heritable resistance within the WAD has been well established (Roberts and Gray 1973; Hill and Esuroso 1976; Murray and Trail 1984) and general field observations confirm the capability of West African Dwarf breeds to develop a useful degree of tolerance to trypanosomosis (ILCA 1979).

An outstanding feature of the WAD is the low sodium level (Daramola et al. 2005) compared with the other common types of West African goat (Tambuwal et al. 2002) and of those from temperate climates (English et al. 1969). In this respect the WAD is similar to man (Macfarlane et al. 1963) and cattle (Oduye and Fasanmi 1971) that have been shown to have lower sodium levels in tropical environments. This close association between tropical environment and lower sodium level in man has been attributed to the variable dietary intake of salt and loss of sodium and chlorine ions in the urine under tropical conditions (Macfarlane et al. 1963). It will be a worthwhile exercise to determine the rate of loss of sodium ions in the urine of the West African Dwarf goat.

The goat is known to have the widest ecological range of all domestic animals, inhabiting as it does, the tropical rainforest as well as the desert (Silanikove 2000). The WAD adapts so outstandingly to the toughest conditions of the forest zone. Of much importance is the social attribute of goat's milk. No other young animal has been found to be as active, smart and calculating as the goat kid. The secret of this attribute lies in the quality of the milk. In goat milk the incidence of "tubercular bacciliare" is rare and there is a high proportion of smaller fat globules which facilitate easy digestion. The therapeutic properties of goat's milk are in part because of its anti-allergy properties and the fact that it does not contain β-lactoglobulin which is the main stimulant of allergenic reactions (Adeloye 2004). These attributes are probable factors responsible for the goat's tolerance to disease and suggest that goats can survive over a wide range of environmental conditions.

Feeding strategies

The essential distinguishing factor between the goat and most other ruminants is feeding behaviour. Goats devour grass, leaves, twigs, short and bark and aromatic herbs rich in crude fibre which even sheep do not eat. In other words they consume a considerably wider spectrum of plant parts and species. Goats gather browse that is ignored by cattle and graze grass which is too short for cattle. In the absence of better feed they make do with the drier coarser grazing unacceptable to sheep (Oppong 1965). They can even subsist on refuse and this special feeding habit of the goat is due to the extraordinary motility of the upper lip and to the prehensile tongue.

The goat is remarkably adapted to digesting coarse plant materials. Together with the high digestive capacity for roughage the attributes of the mouth contribute to the important ability of goats to adapt outstandingly to the toughest conditions. The goat's ability to maintain a bipedal stance affords it a wider foraging range. WAD goats have been observed to dig out roots and tubers and push over stands of sorghum or cassava plants in the dry season when feed is scarce (Adeloye 2004). The small size of the WAD is directly associated with other important traits such as early maturity, quality of products (meat, milk) and nutrient requirements for maintenance. Low per head nutrient requirements mean that the dwarf goat fits the limited resources of small farmers or marginal grazing lands which cannot sustain large ruminants throughout the production cycle.

Use of high-fibre and lignocellulosic materials

Studies comparing the performance of sheep and goats on poor quality roughage, aquatic macrophytes and crop residues have indicated that the two species have similar digestive efficiency on good quality feeds but that goats perform better than sheep on low grade roughage (Adebowale 1988; Aregheore 1996). Better use of nutrients in goats than in sheep on low grade feeds could be ascribed to efficient fibre digestibility (Payne and Wilson 1999; Aregheore 1996). It is also established that the rumen protozoa play a significant role in fibre digestibility since this is much reduced in defaunated animals (Ushida and Jouany 1990). A comparative assessment of protozoan population and types in the two small ruminant species would contribute towards delineating the differences in fibre digestibility.

The lignification of plant cell walls is the most important single factor in limiting the digestibility in structural carbohydrates and lignin itself is considered to be indigestible (Van Soest 1982). In goats fed on low quality roughage, however, lignin undergoes extensive modification, degradation and absorption during its passage through the gastrointestinal tract. This enhances the release and microbial fermentation of structural carbohydrates (Silanikove 1986; Silanikove and Brosh 1989). Delignigfication may thus possibly reduce the encrustation of structural carbohydrates by lignin and render it more susceptible to microbial degradation. The formation and release of ligno-hemicellulose complexes to the water-soluble form would also expose them to the influence of extracellular hemicellulases. The removal of hemicellulose and lignin may cause larger pores to be produced in the fibre wall thereby rendering the remaining structural carbohydrates more accessible to the rather large molecule size of cellulase (Silanikove and Brosh 1989).

Goats indigenous to woody areas are capable of consuming browse sources that are richer in tannins than can be tolerated by sheep and digest it much more efficiently (Wilson 1977; Kumar and Vaithiyenathan 1990; Silanikove 1994, 1996). The capacity of goats to eat browse species not consumed by sheep has been used in many parts of the world to open dense bush and to control noxious weeds. The advantage of the goat over other ruminants while consuming tannin-rich plants relates to their superior capacity to neutralize the negative effect of tannins on palatability and digestibility (Silanikove et al. 1996). Because lignin and tannins are both complex phenolic compounds there is analogy between the ability of goats to deal effectively with lignin and tannin.

The West African Dwarf goat is physiologically adapted to digesting coarse plant material (Adeloye (1992). Particularly significant is its ability to live on lignocellulosic materials where quantity and quality of feeds are low, as occurs in the humid tropics (Adeloye 1992). In quest of cheaper and lesser known sources of feedstuffs otherwise not directly used by man, attention has been diverted to crop residues (Aregheore 1996) and agroindustrial by-products (Akinsoyinu and Adeloye 1987).

Ruminants are classified into a flexible system of three morphophysiological types: concentrate selectors, grass and roughage eaters and intermediate opportunistic mixed feeders (Hofmann 1989). The evolution of different feeding strategies suggests that the digestive efficiencies of certain ruminant species or breeds within a species are optional under forage conditions where their adaptive ability can best be expressed. Grass and roughage eaters are considered to be the most efficient exploiters of lignocellulosic material. The capacity of intermediate selectors to digest lignocellulosic material is intermediate between the two extreme groups. Domestic goats are a classic example of an intermediate feeder with a strong preference for browse feeding (Hofmann 1989). There are two schools of thought regarding the ability of goats efficiently to digest lignocellulosic material. The first is that goats are not truly efficient exploiters of cellulosic matter and their success in tropical areas relates to their ability to exploit forage with differentiated leaves of less lignified material and streams (Van Soest 1982). Accordingly, goats have a smaller proportion of the gut in relation to body weight, resulting in rapid movement of digesta from the rumen and along the entire gastrointestinal tract. The second is that with high fibre low quality forages goats have better digestive efficiency than other ruminants, for which one of the main reasons is the longer mean retention time of digesta in the rumen (Devendra 1990; Tisserand et al. 1991). An evaluation of the results of comparative digestion studies in conjunction with the evaluation of the quality of the diet available to goats under free ranging conditions might provide the solution to these contradictory views. Numerous experimental results strongly suggest that in most areas in which goats are raised the forage available to them is highly fibrous with relatively high cell wall and lignin contents and a moderate to low protein content. In addition the forages available to goats frequently contain secondary metabolites like tannins which further inhibit the use of nutrients (Lu 1988; Mill 1990; Kakabuya 1994). These situations concord with the finding that in most cases goats indigenous to tropical areas are able to use low quality high fibre food more efficiently than other types of ruminants (Tisserand et al. 1991).

Water use

The goat and the camel are the most able of the ruminants to withstand dehydration because of their capacity to undergo prolonged periods of water deprivation (Macfarlane et al. 1963; Kay and Maloiy 1989; Silanikove 1994). The physiological mechanism that enables goats to cope with severe water deprivation is consistent with an unusual ability to withstand and to minimize water losses via urine and faeces. Under isotonic conditions net absorption of water from the rumen to the blood depends on active absorption of Na+ (Dobson et al. 1976). Na+ absorption from the rumen is closely connected to the presence of volatile fatty acids (the major product of fermentation in the rumen) in the rumen fluid (Holtenius 1991). It is reasonable to assume, therefore, that the reduction in Na + and water absorption from the rumen at the last stage of dehydration is a consequence of severe reduction in food intake and volatile fatty acid production. Survival during severe water deprivation could therefore be due to the better ability to use most of the water left in the rumen during dehydration and such use must also have involved the absorption of Na+ from the rumen. Induction of Na+ absorption upon rehydration increases the tonicity of the absorbate and prevents water intoxication (Silanikove and Brosh 1989). The advantage of goats in using rumen fluid during dehydration relates to the large ruminal volume, better capacity of the kidney to desalt the water absorbed from the gut and on the maintenance of a salivary flow to the rumen. These physiological responses are suited to animals that experience routine intermittent availability of water (Silanikove 1994). The capacity of goats to secrete large amounts of saliva allows them to achieve efficient retention of water following dehydration (Seth et al. 1976; Dominigue et al. 1991).

The relative importance of the different sources of water intake varies with weather, diet and management within and among species or breed (King 1983). Under confinement in a tropical environment the mean daily water intake by the WAD goat is 1.3 kg with the contribution from feed being 10.99 g and the remaining 1.20 kg representing the daily drinking water (Adeloye 1985). This value is 34 per cent higher than the mean daily drinking water requirement (Classen 1977; King 1979). An explanation for this could be that goats on open range are able to select their diet and feed on herbage that has a considerable moisture content and therefore they require less drinking water (Adeloye 1985).

Thermoregulation

The variations in qualitative traits of the WAD are not restricted to geographical areas but are probably influenced by selection pressure. The higher incidence of smooth, short and straight hair in extensively managed goats in southwestern Nigeria relative to the curly, woolly type suggests that smooth hair is an adaptative feature that facilitates body temperature regulation under hot humid conditions (Ozoje 2002). The importance of coat type in heat absorption and heat loss and thus adaptability to harsh environments has been stressed elsewhere (Turner and Schleger 1960; Peters et al. 1982).

Coat colouration in the WAD goats varies widely, ranging from black to brown and white and combinations of these in different proportions. This large variation is an indication of a traditional population where selection has not been practised (Odubote 1994a,b). Coat colour is a highly repeatable character with a heritability estimate of about 53 per cent (Schleger 1962). In humid and subhumid environments with high ambient temperatures and intensive solar radiation characteristics such as coat pigmentation tend to play a vital role in the productive adaptability of livestock species (Peters et al 1982). Positive effects of coat colour on weight gain have been observed in Australia with darker animals growing faster (Schleger 1962). White Karakul crossbred sheep had lower reproductive performance, survival and growth rate than coloured ones (Greeff et al. 1984). In contrast an increase in milk yield has been observed with a decrease in the intensity of pigmentation (Schleger 1967). A significant effect of coat colour on body weight of WAD goats has also been observed whereby there was increased weight with a decreased degree of pigmentation or pigmentation intensity (Odubote 1994b). Prolificacy, fecundity and litter size at birth and at weaning as well as weaning weights have been shown to be significantly affected by coat colour in the WAD (Ebozoje and Ikeobi 1998). Age at first kidding and birth weight increased with pigmentation intensity. Black does gave birth at a younger age (447 days) compared with brown (468 days) and white (519 days) ones. Black does also had the largest litters both at birth and at weaning and percentage mortality was higher among white does (Ebozoje and Ikeobi 1998). Selection of breed identification mark on the basis of coat colour would likely favour the black goats following the results of their performance.

The incidence of unilateral expression of wattles is lower than that of bilateral expression (Odubote

1994a; Ozoje 2002) and these traits in West African Dwarf goat may probably have a role in thermoregulation. The presence of wattles may be associated with other traits as Saanen does with these appendages had significantly higher litter size and milk yield compared to those with no wattles (Shongjia et al. 1992). No significant correlation between wattles and litter size was, however, found in goats in Mali (Trevor Wilson, pers.comm.).

Reproduction

Reproductive fitness may be regarded as the most important criterion relating to adaptation. From the onset of its reproductive life the WAD goat has established itself as a most productive and prolific breeder. The WAD goat attains puberty at the relatively early age. Although age at puberty is highly variable and is dependent on the genetic type of the animals and the management system in the tropical environment puberty in indigenous goats occurs at 8 to 14 months of age (Delgadillo and Malpaux 1996). An older age at puberty has been given for WAD goats but this appears to result from poor management conditions (Ademosun 1987). Puberty begins when at least some of the morphological traits (testes size over 6 g, appearance of seminiferous tubules and commencement of spermatogenesis) are present (Chakraborty et al. 1989; Delgadillo and Malpaux 1996; Bielli et al. 2001).

The economic viability of livestock exploitation is closely related to animals attaining sexual maturity at a precocious age which means more offspring could be produced during an animal's life (Becker-Silva et al. 2000). Attempts have been made to induce puberty in WAD bucks. Melatonin, a hormone produced by the pineal gland has been reported to have an effect on the activity of the testes, semen production and puberty (Chemineau 1992; Asher et al. 1993; Mukasa-Mugerwa and Lahlou-Kassi 1995). WAD buck-kids display onset of spermatozoa release in the ejaculate at 5 months old when administered with exogenous melatonin (Daramola et al. 2007). Although WAD goats display interesting reproductive characteristics and could attain puberty at an early age there exists a strong influence of the environment which does not allow these potentials to be fully expressed.

Not withstanding the fact that the WAD goat is generally left to scavenge and cater for its own nourishment (Adeloye 1985) this breed is prolific with a litter size of as much as 1.85 (Tuah et al. 1992). "Improvement" beyond this to higher litter sizes may be counterproductive as mortality rates of kids can be high with prolificacy values exceeding 2.00 especially when kids which have no access to teats are not artificially fed. High mortality rates of kids (36.34 per cent, Tuah et al. 1992) are a source of wastage but this can be reduced with proper management practices. There can be a substantial increase in reproductive performance of WAD goats kept under a highly intensive model. Productivity (live weight production per goat) more than doubles from 10.9 kg live weight per goat year in the extensive model to 24.2 kg in the high intensive model (Mack 1983). The difference has been linked to higher average litter size at birth and higher survival rate of weaners and growers (Huijsman 1987).

Daily sperm production (DSP) values obtained by both quantitative histology and from testicular homogenates was higher in WAD bucks (Bitto et al. 2000) than values reported for Red Sokoto Maradi bucks (Carew and Egbunike 1980). Breed differences could be attributed to the variations observed in the sperm production rates and suggest a higher sperm production potential in the WAD buck.

In the humid tropics most research workers have observed dwarf goat breeding throughout the year. The seasonal peaks that do occur are more likely the result from fluctuations in feed availability rather than changes in photo-intensity. Gonadal sperm reserves in all seasons have been reported to be higher in WAD bucks than values observed for Red Sokoto Maradi bucks (Ogwuegbu et al. 1985). The same trend has been observed in extra gonadal sperm reserves (Bitto et al. 2000) thus confirming earlier observations that the WAD bucks might have a higher reproductive capacity in the humid tropical zone than other ruminant species and could be used for breeding purposes all year round.

Conclusions

The West African Dwarf goat occupies an important place in subsistence agriculture in the West African subregion. It has unique adaptation to its native humid tropical environment. In addition to being the most popular of all breeds of goats in the humid zone of West Africa in general and Nigeria in particular this genotype has the advantage of being trypanotolerant and is highly prolific with a remarkably high reproductive potential in terms of young produced per female per year. In marginal environments the breed remains the only domestic species that is able to survive.

The tolerance of this breed to heat stress, its adaptive physiology of food digestion consequent on small body size and high digestive efficiency, coat colour, reproductive fitness as manifested by prolific breeding and the defence mechanisms against infectious agents in the ecozone characterized by high prevalence of disease are the most important physiological traits of adaptation.

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