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Seminal Characteristics, Sperm Morphology, and Reproductive Organ Morphometrics of Kano Brown Bucks Fed Diets Containing *Pleurotus ostreatus*–Biodegraded Sugarcane Scrapings

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Abstract

This study evaluated the effects of replacing maize bran with *Pleurotus ostreatus*-biodegraded sugarcane scrapings (BSS) on organ morphometrics and seminal characteristics of Kano Brown bucks, with the aim of assessing its suitability as a sustainable non-conventional feed ingredient. Twenty-one healthy bucks aged 6–7 months (9.44 ± 0.39 kg) were randomly assigned to three dietary treatments: a control diet without BSS, a diet containing 15% BSS replacing 50% of maize bran, and a diet containing 30% BSS replacing 100% of maize bran on a dry matter basis. The feeding trial lasted 12 weeks. Results showed that dietary inclusion of BSS had no significant ($p > 0.05$) effect on the proportion of morphologically normal sperm cells, testicular weights, testicular volumes, or testicular lengths. Likewise, sperm abnormalities, including midpiece droplets, coiled tails, detached heads, free tails, and bent tails, did not differ among treatments. Body and tail weights and lengths, as well as epididymal morphometric parameters, remained comparable across all dietary groups. These findings indicate that replacing maize bran with BSS supports normal reproductive organ development and maintains seminal quality without adversely affecting sperm morphology. Therefore, *Pleurotus ostreatus*-biodegraded sugarcane scrapings represent a safe, nutritious, and sustainable alternative feed resource for goat production in feed-limited regions such as West Africa.

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Introduction

Small ruminants, particularly goats, play an important role in food security for low- to middle-income families due to their key phenotypic adaptive tolerance to harsh environmental conditions and their use of low-input production methods. Furthermore, they help to strengthen livelihoods in poor and underdeveloped countries [1, 2]. With an estimated population of 34.5 million, goats are Africa's second most important livestock species, primarily in Nigeria. Goats of various breeds are generally raised in large-scale smallholder systems, such as those used by the Fulani tribe, which are characterized by inadequate nutrition and scavenging, limiting their natural capacity to reproduce and produce efficiently [3-6]. Furthermore, in tropical areas where dry-season feed resources are typically fibrous, lignified (indigestible), and deficient in essential nutrients, these challenges are exacerbated by significant seasonal variations in forage availability and quality, thereby limiting nutrient intake, rumen fermentation efficiency, and overall animal productivity [7-9].

The alternative and infrequent use of crop residues and processing end products (agro-industrial by-products), which normally constitute environmental waste and clog drainage systems and water channels in rural and urban areas, has grown in popularity as the cost and scarcity of conventional feed ingredients have increased. Sugarcane scrapings (SSG), which are abundant and concentrated in Northern Nigeria, are a major example in the current research. However, this SSG has high fiber content, as well as lignification and anti-nutritional properties, which limit its nutritional value [10-12]. Biological treatment methods (biodegradation), particularly solid-state fermentation with white-rot fungus such as *Pleurotus ostreatus*, have been widely researched to enhance consumption and nutrient content. This method improves the substrate's digestibility, nutritional availability, and fermentability by selectively breaking down lignin linkages and supplementing it with microbial protein [13–21].

Adequate dietary provision in the feed is critical for maintaining normal functions, physiological stability, and reproductive efficiency. Improving nutrition in breeding males reduces vulnerability of reproductive functions, such as sperm production (spermatogenesis) and semen quality, to oxidative stress [22-25]. A previous study has indicated that biologically treated residues improve growth and metabolic responses, but little is known about how they alter reproductive parameters in small ruminants. To therefore examine the nutritional potential of Pleurotus ostreatus-biodegraded sugarcane scrapings as a sustainable, cost-effective, and climate-smart feeding technique for increasing goat production in the tropics, reproductive responses of bucks fed these scrapings must be assessed.

Materials and Methods

Experimental site

The University of Abuja Teaching and Research Farm in Giri, Abuja, Nigeria, served as the research site. This area is situated close to the International Airport between latitudes 8º 55'N and 9º 00'E and longitudes 7º 00'N and 7º 05'E, with an elevation/upland of approximately 456 meters. The expected annual precipitation and temperature in this area range from 1100 to 1650 mm and 25.8 to 42°C, respectively [26–28].

Preparation and biodegradation of sugarcane scrapings

Pleurotus ostreatus spawn was purchased from a reliable Nigerian farm linked to the National Mushroom Research Center. Local sugarcane processing facilities produced fresh sugarcane scrapings (SS), which were manually cut into 1-2 cm particles with a machete or sharp knife and air-dried at room temperature (25-30°C) until a stable moisture content was achieved [4, 5]. After being thoroughly cleaned to remove superfluous materials such as dust and grime, the dry material was placed in heat-resistant containers for further processing [21].

The moisture level (content) of the prepared SS was reduced to approximately 67-70% before fungal inoculation for the solid-state fermentation process (SSF) by thoroughly mixing the substrate with distilled water at a 1:1 (w/v) ratio. To remove native localized bacteria and provide an aseptic fermentation environment (conditions), the wet SSG was autoclaved twice at a constant temperature of 121 °C for 15 minutes, with a cooling period in between cycles. This was done to ensure a proper aseptic substrate. In addition, substrates were sterilized to prevent microbial growth, cooled to room temperature in an aseptic laboratory setting, and inoculated with P. ostreatus spawn at a substrate-to-spawn ratio of 25:1 (w/w).

To encourage mycelial colonization and lignocellulosic biodegradation, the inoculated substrates were incubated in a controlled fermentation room at 30°C and nearly 100% relative humidity. As evidenced by the clear container, active fungal growth and substrate changes occurred during the 21-day solid-state fermentation period, as observed as whitish strands [12]. Following the fermentation process, the biodegraded material was autoclaved again to prevent future mycelial development (proliferation and enzymatic activity). Before being administered to experimental meals, the biodegraded sugarcane scrapings (BSS) were oven- or air-dried to a uniform weight, stored in airtight containers, and kept dry and sanitary [2, 8, 9, 11, 12, 29-33].

Experimental animals, management and diets

To conduct the experiment, 21 male Kano Brown goats weighing 9.44 ± 0.39 kg at six to seven months of age were obtained from the open market. The goats were housed in individual 1.2 m^2 cages within a 6m × 8m × 4m corral. Two weeks before the arrival/transfer of animals to the experimental site, the pens and their immediate surroundings were thoroughly cleaned, disinfected, and fumigated with Hypo® (sodium hypochlorite, caustic soda, and demineralized water) and Morigad (an antibiotic). Preventive drugs were given to the animals throughout their two-week confinement. One subcutaneous injection of anti-parasitic medicine. Avomec® at 0.5 ml/25 kg BW, one intramuscular injection of a long-acting oxytetracycline HCl at 1 ml/10 kg BW, one oral anti-stress medicine Vitalyte®, and one subcutaneous injection of the live PPR vaccination (1 ml at 102.5 TCID50 PPR virus) in the neck region. Three full meals were prepared with SS at inclusion levels of 0% (control), 15%, and 30% (Table 1). NRC [34]. When constructing meals to meet the needs of growing goats, regulations were observed. Buck youngsters were fed 5% of their body weight (based on dry matter [DM]) for 12 weeks (January to April) and then adjusted to body weight. The goats were then systematically and randomly assigned to one of the experimental diets. To ensure that some feed was left over, the amount of composite feed fed to the goats during the experiment was adjusted frequently to match new body weights. Every day, there were two feeding intervals: 8:00 and 16:00. The experimental animals had unrestricted access to clean water (*ad lib*).

Feed intake and body weight

To calculate feed intake, the entire weight of general feed provided the day before was subtracted from the weight of residual feed. The dry matter feed intake of the animal was multiplied by the dry matter content of the nutrients in the diets to calculate the nutrient intake [11, 35, 36, 37]. The individual initial body weight (BW) was measured at the beginning of the experiment, and the individual final BW was measured shortly before the goats were fed at the end of the study using a traditional small-ruminant weighing scale (UmaTech Scales) [38-40].

Table 1 Ingredient composition of the experimental diets.

Ingredient (kg)	Diet		
	T1 (control)	T2	T3
Yellow Corn	25.00	25.00	25.00
Corn bran	30.00	15.00	0.00
BSCS	0.00	15.00	30.00
GNC	17.00	17.00	17.00
Cowpea husk	25.00	25.00	25.00
Salt	0.50	0.50	0.50
Limestone	2.00	2.00	2.00
Premix	0.50	0.50	0.50
Total	100.00	100.00	100.00

GNC, groundnut cake; BSS, biodegraded sugarcane scrapings

Semen morphology and testicular morphometric evaluation

Standardized microscopic techniques were used to accurately examine sperm morphology and quantify the percentage of normal and defective spermatozoa. Semen samples were obtained and processed as smear slides, using standard washing procedures. Ninety-five (95) clean glass slides were prepared to evaluate sperm morphology [41]. After air-drying, the smears were stained with 7.5% Giemsa stain (Doles Laboratory), prepared by diluting the stock solution with distilled water. To ensure adequate structural distinction of sperm, the slides were immersed in the staining solution for 2 hours. Following that, they were removed, gently cleaned with distilled water, and allowed to air dry upright at room temperature. A light microscope was used to conduct a microscopic study under oil immersion (×1000 magnification). The percentages of morphologically normal spermatozoa and specific sperm abnormalities were estimated by examining at least 200 sperm cells per slide. Sperm cells were classified as normal or abnormal based on their morphology at the head, midpiece, and tail. Anomalies seen included midpiece droplets, disconnected heads, coiled tails, bending tails, and free tails. According to the concepts presented in [42] and later applied in caprine reproductive research [11, 22, 23], sperm morphology was classified using accepted morphological criteria, adapted for small ruminants. When the feeding trial concluded in the thirteenth week, the experimental bucks were humanely sedated and slaughtered in accordance with ethical guidelines for animal research. Following thorough dissection to uncover the reproductive tracts, the testes and epididymides were removed, freed of adherent connective tissues, and rinsed in physiological saline. A high-precision electronic balance (Mettler balance) was used to weigh the left and right testes separately, with findings recorded to the nearest 0.001 g [35]. Testicular morphometric characteristics were assessed to assess reproductive organ development and function. A digital vernier caliper was used to determine the length of the testis along its longitudinal axis. Similarly, the length of the epididymal segments' heads (caput), bodies (corpus), and tails (cauda) were measured independently [42]. The water displacement method, based on the well-known Archimedes' principle, was used to determine testicular volume. Each testis was immersed in a graduated cylinder containing a known volume of water, and the displacement volume was recorded as the testicular volume. A similar method was used to assess epididymal volume [43-45]. Because these characteristics are closely related to daily sperm production and overall reproductive capacity in male goats, determining and evaluating them may likely yield an accurate/precise estimate of spermatogenic activity and androgenic function [22-23]. Thus, investigating each of these parameters enabled a full assessment of the reproductive effects of BSS dietary inclusion.

Statistical analyses

The final data (results) were analyzed using SPSS (24.0) in a completely randomized design. To establish the significance of the mean difference at the $p < 0.05$ level, the Duncan multiple range test was used in the same application.

Results and Discussion

Dry matter and nutrient intake of experimental animals

The dry matter and nutrient intakes of the experimental animals are shown in Table 2. Intakes of dry matter, CP, EE, OM, and hemicellulose showed a similar trend, with T2 and diet T3 having the highest and lowest intakes, respectively ($p < 0.05$). CF consumption varied between T1 and T2, with T2 and T3 intakes significantly greater ($p < 0.05$) than T1 but comparable to each other ($p > 0.05$). The intake of non-fiber carbohydrate varied considerably among the three experimental groups ($p < 0.05$), with T1 having the highest and T3 the lowest. Similarly, ADF and cellulose intakes were highest, middle, and lowest in T3, T2, and T1, respectively ($p < 0.05$). NDF intake varied, with T1 and T3 similar ($p > 0.05$) but lower than T2 ($p < 0.05$).

The chemical composition, characteristics, and palatability of feeds are major factors influencing ruminant dry matter intake (DMI) [12]. According to Ososanya [46], feed intake is an important component of livestock feed utilization, determining the availability of energy and protein, and serving as a crucial performance parameter for small ruminants. Low-digestibility feeds are commonly thought to limit DMI due to their delayed passage through the digestive tract [47]. In a similar vein, [8, 9, 12] identified DMI as a major factor in ruminant feed utilization and a critical determinant of energy availability and performance in small ruminants. The presented feed intake result is associated with the research of [48]. who found that when treated agro-industrial byproducts (AIBPs) increased, DMI decreased. Cases of decreased feed intake when treated crop residues were fed to ruminants have been linked to the fill effect due to the high fiber content, a negative indicator of feed intake [9], according to [12, 49]. This could account for the goats on the T3 diet having the lowest intake. Because feed intake decreased when corn bran replacement with BSS was increased to 100%, it seems that replacement should not exceed 50%. Greater feed intake of the goats fed T2 than those fed T1 indicates improved palatability when 50% of corn bran was replaced with BSS.

The DMI and crude protein intake (CPI) followed a similar pattern. According to [50], CPI and DMI have a favorable correlation. The DMI and OM intakes showed similar trends. The energy content of the meal is determined by the organic matter [12]. Thus, even with a 50% replacement of corn bran, there appears to be sufficient energy availability for the bucks, as treatments 1 and 2 show no significant change. The trend in EE intake was consistent with that of DMI, CPI, and OMI, according to Van Soest and collaborators [51]. EE is defined as estimated crude fat in feed (diet); thus, high EE intake in T2 is related to the high ether extract content in the diet and the animals' improved performance as a result of extra stored energy, cell growth, repair, and lymph node activity, which aids in the fight against antibodies and general infections. The analogous relationship among DMI, CPI, OM consumption, and EE intake supports the previous submission [11]. The amount of nutrients consumed is determined by both DMI and the meal's nutritional

Table 2 Dry matter and nutrient intake of experimental animals.

Intake (g/day)	Treatments			
	T1	T2	T3	SEM
Dry matter	354.08^{b}	373.94^{a}	318.75^{c}	3.39
Crude protein	55.59^{b}	59.08^{a}	50.65^{c}	0.53
Ether extract	20.46^{b}	21.68^{a}	18.55^{c}	0.19
Crude fibre	45.39^{b}	57.96^{a}	57.66^{a}	0.47
Organic matter	331.98^{b}	343.88^{a}	291.12^{c}	3.16
Non-fibre carbohydrate	118.93^{a}	111.21^{b}	86.82^{c}	1.08
Neutral detergent fibre	136.99^{b}	151.89^{a}	135.79^{b}	1.34
Acid detergent fibre	74.18^{c}	86.38^{a}	80.45^{b}	0.74
Cellulose	64.05^{c}	74.37^{a}	66.26^{b}	0.64
Hemicellulose	62.81^{b}	65.51^{a}	55.33^{c}	0.59

Means with the different superscripts along the row are significantly ($p < 0.05$) different
T1: 0% biodegraded sugarcane scrapings; T2: 15% biodegraded sugarcane scrapings; T3: 30% biodegraded sugarcane scrapings.

Table 3 Testicular and epididymal morphometrics of experimental animals.

Parameter	T1	T2	T3	SEM
Right testis weight (g)	40.82^{b}	43.63^{a}	39.97^{b}	0.95
Left testis weight (g)	40.10^{b}	43.10^{a}	39.60^{b}	0.80
Right testis length (cm)	5.80^{b}	6.25^{a}	5.65^{b}	0.18
Left testis length (cm)	5.75^{b}	6.18^{a}	5.60^{b}	0.17
Right testis volume (cm^3)	42.40^{b}	46.10^{a}	41.50^{b}	1.95
Left testis volume (cm^3)	42.10^{b}	45.80^{a}	41.20^{b}	1.01
Epididymal head weight (g)	5.20^{b}	5.85^{a}	5.05^{b}	0.20
Epididymal head length (cm)	2.35^{b}	2.60^{a}	2.25^{b}	0.13
Epididymal volume (cm^3)	7.63^{b}	8.41^{a}	7.31^{b}	0.25

Means with the different superscripts along the row are significantly ($p < 0.05$) different
T1 (0% BSS), T2 (15% BSS) and T3 (30% BSS) connoting treatments one, two and three.

content. Although lower than the published consumption estimate of 107-126 g/day, the crude fiber intake results in this investigation followed the same pattern as those reported by Saleh [52]. Similarly, when goats were fed a full diet of sugarcane peels, their CF intake was lower than the levels reported by [53]. This could be due to microbial deterioration. Because sugar cane peels were fed without fermentation and had a high lignin bond content, Saleh and Maigandi [54] consumed more CF. Changes in the diet (fermented and unfermented SS), the breeds and ages of the goats used, the amount of feed provided, the level of BSS inclusion, and environmental (geographic) factors may all contribute to changes in the results. According to Van Soest et al. [51], NFC is a convenient energy source in feed. T1 consumes the most NFC due to its higher dietary concentrate and concentration of corn bran NFC compared to BSS NFC. Corn bran contains more soluble, or easily fermentable, carbohydrates than BSS, since maize is an energy-dense feedstuff and sugarcane scrapings are roughage. Because nutrient intake is a function of feed intake and nutrient composition, the intakes of cellulose, hemicellulose, NDF, and ADF either followed the feed-intake pattern or exhibited distinct compositional patterns across the diets [9, 12].

Testicular and Epididymal Morphometrics of experimental animals

Table 3 shows that dietary treatments significantly ($p < 0.05$) affected testicular and epididymal morphometric parameters. Bucks in T2 had significantly greater values across all examined indices than those in T1 and T3, which were statistically equivalent ($p > 0.05$). Notably, T3 had somewhat lower values than T1, indicating that greater BSS inclusion levels would not provide additional reproductive benefits and may thus marginally reduce the morphometric parameters. This illustrates that, while excessive participation does not improve physiological outcomes, moderate inclusion promotes reproductive development. The dietary inclusion of BSS influenced the testicular and epididymal morphometrics of experimental animals, with T2 providing considerably higher values than both T1 and T3. This pattern suggests a dose-dependent response, with T2 showing reproductive organ development and excessive inclusion potentially reducing morphometric traits without providing further benefits. In male goats, testicular weight, length, and volume are known indicators of spermatogenic activity and capacity [11, 41], representing seminiferous tubule mass and daily sperm production. As a result, the best values in T2 show that the small addition of BSS improves nutritional availability, which promotes seminiferous tubule growth and androgen production (synthesis). T3's somewhat lower testicular morphometrics than T1's could be a result of general effects associated with increased BSS inclusion. Fungal biodegradation improves protein content, digestibility, and mineral bioavailability [55–58]. However, high-inclusion diets containing excessive fiber or undegraded lignin residues may have inhibited nutrient utilization, thereby limiting reproductive growth. These findings were consistent with a previous study that determined the optimal inclusion levels of lignocellulosic by-products for ruminant performance [12, 59]. T2 (50% replacement of BSS with corn bran) had the highest epididymal morphometrics (head weight, length, and volume), indicating that T2 inclusion improved post-testicular sperm maturation and epididymal storage capacity. The epididymis regulates sperm motility, concentration, and fertilization potential [23, 60]. Morphometric stability between T1 and T3 indicates that epididymal functions are maintained across all treatment groups, supporting the biological safety of the test ingredient, BSS, in goats. Because of fungal fermentation, the observed patterns emphasize the importance of nutritional quality and nutrient bioavailability. White rot fungi (*Pleurotus ostreatus*) increase the availability of essential minerals, such as zinc and selenium, which are physiologically required for testicular steroidogenesis and spermatogenesis, while simultaneously decreasing fiber fractions (lignin linkages) and enhancing microbial protein [11, 61]. As a result, 50% replacement of BSS (T2) most likely promotes healthy endocrine function and the growth of reproductive tissue. This is similar to previous research on ruminant nutrition and production employing fungal-treated agro-industrial byproducts and crop residues [2, 8, 9, 11, 12].

Sperm morphology of experimental animals

Table 4 shows the result for morphology and that T2 had the largest proportion of normal sperm cells (86.12%), which was significantly higher than in the control/T1 (85.45%) and statistically equivalent with T3 (84.80%). In T2, sperm defects such as midpiece droplet, coiled tail, bent tail, detached head, and free tail were lowest, whereas T3 had the most. T2 had the lowest value for total sperm abnormalities (13.88%), whereas T3 had the greatest value (15.20%). This suggests that moderate BSS inclusion improves general sperm quality, most likely through enhanced nutritional availability and antioxidant protection from BSS. According to Ewuola [43], testicular generation of viable spermatogenic cells, as well as the reproductive system's ability to properly store and preserve spermatozoa, are the two primary characteristics that influence the selection of breeding males. In a similar vein, [62] emphasized the buck's morphometric and functional properties as reliable indicators of breeding and fertility indices. This is often due to the physiological relationship between fertilization ability, sperm storage capacity, and testicular efficiency [60]. Sperm morphology is essential to male fertility because a large proportion of normal spermatozoa is directly linked to

Table 4. Sperm morphology of experimental animals.

Parameter (%)	T1	T2	T3	SEM
Normal sperm cells	85.45^{b}	86.12^{a}	84.80^{b}	0.82
Midpiece droplet	2.18^{a}	2.05^{b}	2.40^{a}	0.11
Coiled tail	2.86^{a}	2.78^{b}	3.10^{a}	0.11
Bent tail	2.62^{a}	2.56^{b}	2.80^{a}	0.19
Detached head	1.95^{a}	1.88^{b}	2.10^{a}	0.10
Free tail	2.14^{a}	2.10^{b}	2.30^{a}	0.02
Total abnormalities	14.55^{a}	13.88^{b}	15.20^{a}	0.72

Means with the different superscripts along the row are significantly ($p < 0.05$) different
T1 (0% BSS), T2 (15% BSS) and T3 (30% BSS) connoting treatments one, two and three.

Table 5 Body and tail morphometrics of experimental animals.

Parameter	T1	T2	T3	SEM
Body weight (kg)	14.70^{b}	15.40^{a}	14.20^{c}	0.54
Body length (cm)	52.40^{b}	53.30^{a}	51.90^{c}	0.73
Tail weight (g)	156.80^{b}	163.60^{a}	153.90^{c}	4.92
Tail length (cm)	19.95^{b}	20.50^{a}	19.60^{c}	0.41

Means with the different superscripts along the row are significantly ($p < 0.05$) different
T1 (0% BSS), T2 (15% BSS) and T3 (30% BSS) connoting treatments one, two and three.

reproductive efficiency and fertilizing capacity [23]. In this study, sperm quality was affected by the inclusion of BSS. The experimental bucks in T2 had the highest percentage of normal sperm cells and the lowest percentage of abnormal sperm cells, as shown in the Table above. The increase in sperm morphology reported in T2 could be attributed to the improved nutritional and functional characteristics of BSS. Previous research has found that BSS increases the bioavailability of various micronutrients, including zinc and selenium, which are required for spermatogenesis and antioxidant defense [37]. Degenerative/Impaired spermatogenesis, oxidative stress, or inadequate epididymal maturation are usually associated with sperm abnormalities such as midpiece droplets, coiled tails, bending tails, detached heads, and free tails. Moderate BSS inclusion may have enhanced epididymal functional capacity, thereby reducing oxidative damage associated with sperm production and resulting in significantly lower rates of these abnormalities in T2. This conclusion is consistent with several reports that SSF feed components improved antioxidant status and scavenged ROS, thereby protecting sperm cellular membranes [23, 63].

Body and tail morphometrics of experimental animals

Table 5 presents the developmental and morphometric characteristics of Kano Brown bucks fed diets containing varying percentages of BSS. Dietary interventions had a substantial impact on body weight, body length, tail weight, and tail length ($p < 0.05$). T2 bucks had the highest values for all parameters, followed by T1. T3 bucks had the lowest values. Observed improvements with increasing BSS inclusion most likely imply that the test ingredient's nutritional availability and digestibility have improved. Solid-state fermentation (fungal biodegradation) degrades lignocellulosic linkages, thereby increasing protein content and, consequently, energy content and mineral fractions [2, 11, 12, 23]. This method may contribute to gradual increases in growth parameters while avoiding significant metabolic stress [64-69].

Conclusion

The study summarized the overall effects of replacing maize bran in the diets of developing (growing) Kano Brown bucks with BSS at 15% and 30% levels. It was marked as safe, nutritionally sufficient, and without negative impacts on sperm quality or reproductive organ development, as evidenced by the results presented. In addition, results for final body weights, length, tail parameters, testicular and epididymal morphometrics, and sperm morphology were all reported. The difference between the bucks fed BSS-inclusive diets and the control group was not significant. BSS inclusion appeared to have significantly increased the nutritional content (value) of this agro-industrial by-product, as evidenced by significant increases in body and tail measurements, as well as testicular and epididymal morphometric parameters, with higher BSS inclusion. Fungal treatment, in particular, most likely increased protein content, thereby improving subsequent digestibility and the bioavailability of important nutrients, thereby assisting in the maintenance of normal physiological growth and reproductive organ development. BSS supplementation had no detrimental effects on sperm parameters, thereby maintaining semen quality and reproductive potential. Subsequently supporting the use of BSS as a functional feed ingredient capable of meeting growing bucks' typical nutritional and reproductive needs.

Compliance with ethical standards

The Co-farms Green Aid Revolution's Animal Ethics and Conduct Board granted ethical approval under registration number 16499001/19/501/002. The approval acknowledges the current worldwide recommendations for sample collection in livestock research and complies with international requirements for conducting research on small ruminants.

Conflict of interest

The authors declare no conflicts of interest.

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