Haematology and serum biochemistry of West African Dwarf goats fed Pleurotus tuber-regium–treated cassava root sievate–based diets

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Abstract
The study aimed at determining the effect of Pleurotus tuber-regium–treated cassava root sievate–based diets on haematology and serum biochemistry of West African Dwarf (WAD) goats. Thirty-two WAD goats between 6 and 8 months old were randomly divided into four groups of eight goats each. The four experimental diets were formulated to contain 0, 20, 40 and 60% dietary levels of inclusion of Pleurotus tuber-regium–treated cassava root sievate, respectively. The groups were randomly assigned to the four experiment diets (T1, T2, T3 and T4) for 90 days in a completely randomized design. At the start of the experiment, packed cell volume (PCV) ranged from 24.90 to 29.49% and red blood cell (RBC) 9.42–10.44 × 1012/L while mean cell haemoglobin significantly (p < 0.05) ranged from 5.44 to 6.41 pg. At the end of the experiment, PCV and RBC showed significant differences (p < 0.05) and were better in T2. At the start of the experiment, cholesterol ranged from 2.15 to 2.29 mmol/l, creatinine from 75.72 to 80.32 μmol/l, urea from 16.39 to 16.72 mg/dl, total bilirubin from 0.25 to 0.28 μmol/l, total protein from 61.73 to 63.16 g/I, globulin from 29.08 to 29.59 g/I and aspartate aminotransferase (AST) from 68.62 to 71.06 U/L. At the end of the trial, cholesterol values were significantly (p < 0.05) higher in T1. Urea was significantly reduced (p < 0.05) with T1 showing significantly higher values than T3 and T4. Total protein, globulin and total bilirubin increased (p < 0.05) linearly from T1 to T4. AST was improved (p < 0.05) at the end of the study. The study revealed that the inclusion of Pleurotus tuber-regium-degraded cassava root sievate in the diets of West African Dwarf goats had no deleterious effects on the haematological and serum biochemical parameters of goats and could be included in goat diets up to 60%.

Keywords Goats · Solid-state fermentation · Biodegradation · Cassava root sievate · Blood parameters

Introduction
Protein is usually the most limiting nutrient in small ruminant feeding programmes focused on poor-quality tropical forages and agricultural wastes; thus, additional dietary protein may be needed to maintain an efficient rumen ecology that stimulates improved nutrient intake and general performance. The use of unconventional feedstuffs for improved livestock production was enthused by the increased demand for conventional feedstuffs among humans and feed millers, as well as deficient animal protein intake in the diets of citizenries of developing countries. Cassava waste or by-product is one such feedstuffs that has been successfully used in most developing countries to feed both ruminants and non-ruminants as an alternative to conventional feedstuff like maize. Cassava wastes or by-products have been fed to small ruminants with varying results (Anaeto et al. 2013; Jiwuba et al. 2018). Cassava root sievate is one of
such cassava wastes that have been added to the diets of both ruminants and non-ruminants to enhance performance. Jiwuba et al. (2018) reported high lignin content in cassava root sievate, indicating the need to improve nutritional value of this agricultural waste. White rot fungi have been widely used in the degrading of a variety of agricultural wastes in recent years. The ligninolytic enzymes found in white rot fungi are responsible for starting the depolymerization of lignin owing to their high oxidative activity and limited substrate specificity (Barde et al. 2014). Pleurotus tuber-regium is useful in the production of mycopharmaceuticals, as well as in the conversion of lignocellulosic biomass into more palatable animal feeds, human food (mushrooms) and bioremediation (Mshandete and Mgonja 2009). As a result, biodegradation of agricultural waste is a cost-effective and safe process in which agro-wastes such as cassava root sievate are digested in a controlled environment by mono or mixed cultures of microorganisms to improve the nutritional value and aesthetic value of these wastes. The use of Pleurotus tuber-regium to break the complex carbohydrate bonds formed during biodegradation can be used to improve the nutritional value of cassava root sievate and other numerous agricultural wastes, resulting in a higher inclusion of such feedstuff in livestock feeding program. On the other hand, Pleurotus mushroom farming is extremely important in Nigeria as it is utilized as a nutritional supplement with high culinary value. Its nutritional and medicinal properties are well documented (Galappaththi et al. 2021). The production of Pleurotus mushroom is currently high in recent year because of their higher biological efficiency, low cost of production and easy methods of cultivation, with the National Farmers Information Service (NAFIS) of Nigeria reported yearly production of 300 tons, which is far below 12,000 tons annual demand. (Ayanfunke 2019).

Blood indices are understood to be important pointers of the physiological stage farm animals, demonstrating the link between diet and health (Jiwuba et al. 2016). Nutrition, breed, sex, age and stress (Balkici et al. 2007) have all been found to have an impact on haematological and biochemical parameters and are thought to play crucial roles in the differences in haematological and biochemical indices recorded between tropical and temperate animals (Opara and Fagbemi 2009). Haematological and biochemical indices, according to Akhunombohge and Orheruata (2006), provide useful information on the performance capabilities of West African dwarf goats. There is a wide variation in haematological and biochemical indicators between goat breeds (Tambuwal et al. 2002). Therefore, developing a general metabolic baseline examination for goats could be difficult. These discrepancies have emphasized the necessity for suitable physiological baseline values for various goat breeds in the tropics, which could help in a realistic assessment of nutrition, management practices and disease diagnostics (Opara et al. 2010).

There have been a lot of researches and publications on the feeding values of cassava by-products; there has been little or no research on the haematology and serum biochemistry of West African Dwarf (WAD) goats fed Pleurotus tuber-regium–treated cassava root sievate. The objective of this research was to evaluate the effect of different quantities of Pleurotus tuber-regium–treated cassava root sievate on the haematology and serum biochemistry of WAD goats.

Materials and methods

This study was conducted at the Sheep and Goat unit, of Federal College of Agriculture, Ishiagu, Ivo L.G.A., Ebonyi State, Nigeria. The institution is situated approximately 3 km from Ishiagu main municipal. The institution is found at latitude 5.56° N and longitude 7.31° E, with about 1653 mm annual rainfall, relative humidity (RH) of about 80% and a prevalent temperature of 28.50° C. The cassava root sievate (CRS) variety TME419 used for this study was obtained from Akawa, Nneato, Umunneochi L.G.A., Abia State. The sievates were obtained after the cassava roots intended for fufu (a common stable food in Nigeria) production were peeled or not, rinsed clean, retted for 3–5 days to lower the HCN content and to soften the roots before sieving. After that, the retted cassava roots were sifted, the sievates (wastes) were harvested and were sun-dried for approximately 7 days to reduce the moistness of the sievates to around 10–15%. To minimize the particle size and increase surface area, the sundried sievates were milled, to create a better surface area for microbial activity.

The inoculation room was properly swept, scrubbed and disinfected with Izal in water (1 l Izal to 4 l of water). To destroy any remaining contaminants, the floor was mopped clean, and the doors were allowed to dry before being shut for 21 days. Following that, the milled cassava root sievates were thoroughly mixed with water at a ratio of 1.0 kg sievate to 1.0 l water to ensure complete wetting of the sievates. The Pleurotus tuber-regium (PTR) tubers were weighed, washed, divided into smaller pieces and immersed in water for 2 h before being removed and placed in white transparent buckets and covered for 3 days to allow the tubers to develop spores. To establish an airtight atmosphere, the ends of the polyethylene sheets were pulled together and sealed with masking tape. The inoculation room was then closed, and water was poured on the floor and some left in buckets. On the 45th day bioconversion, the mass of the composted CRS already colonized by mycelium of the fungi revealing whitish growths was removed from the inoculation room and sun-dried by spreading thinly on a drying surface to end the fungi growth and dry the materials. The materials were placed in sacks and kept in storage until they were needed.
The experimental diets represented as $T_1$, $T_2$, $T_3$, $T_4$ were formulated from non-treated cassava root sievate, brewers dried grain, palm kernel meal, soybean meal, bone meal, salt and premix. The Pleurotus tuber-regium–treated cassava root sievate (PTR-CRS) was included at the rate of 0, 20, 40 and 60% (Table 1).

Thirty-two WAD bucks of approximately 6–8 months of age and weighing approximately 5.26 kg were sourced from Nkwo, Achara, Uturu, Isuikwuato, L.G.A., Abia State, Nigeria. The goats were quarantined for 21 days before the experiment commenced. The goats were vaccinated against internal and external parasites with ivermectin (1 ml/10 kg body weight (injected subcutaneously) and albendazole (0.1 mg/kg BW given orally) before the experiment commenced. The goats were injected against Peste’ Petit de’ Ruminante’ (PPR) with PPR vaccine at a dosage of 1 ml per 10 kg of body weight. For a preliminary period of 21 days, each animal was fed a specified treatment diet based on 3.5% body weight in the morning and 1 kg of wilted chopped basal Panicum maximum. This was done to improve the appetite of the animals for the concentrate diet. According to the authorization and instructions of the Animal Ethics Committee, Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria, the experimental animals were acclimatized for 21 days prior to the start of the study.

The goats were randomly separated into four experimental groups, each with eight animals. The four experimental diets ($T_1$, $T_2$, $T_3$ and $T_4$) were allotted to the groups in a completely randomized design (CRD). The goats were kept separately in a well-ventilated concrete floored pens furnished with feeders and drinkers. For 90 days, each animal was fed a specific treatment diet in the morning (08:00 h). Feeding was based on 3.5% body weight per day, in addition to 1 kg wilted chopped Panicum maximum that was fed at 16:00 h. Fresh drinkable water was made available regularly.

On the first and last days of the feeding trial, blood samples (10 mL) were taken from each goat through the jugular vein. The blood samples were separated into two and were used to determine the serum biochemical and haematological parameters according to the methods of Dacie and Lewis (1991). The first group (5 mL) was collected in sterile bijou bottles with 1 mg/mL ethylene diamine tetraacetate (EDTA). This was utilized for the determination of the haematological parameters like packed cell volume (PCV), haemoglobin (Hb), red blood cell (RBC), white blood cell (WBC), mean cell volume (MCV), mean cell haemoglobin concentrations (MCHCs) and mean cell haemoglobin (MCH). The second group (5 ml) was collected in bottles that were devoid of anti-coagulants. Within 3 h of collection, the blood samples were allowed to clot at room temperature, and the samples were separated by centrifuging. This was utilized for the determination of the serum biochemical parameters such as cholesterol, glucose, creatinine, urea, total protein, globulin, albumin, total bilirubin, aspartate aminotransferase (AST) and alanine aminotransferase (ALT).

Triplicate sample of the Pleurotus tuber-regium–treated cassava root sievate–based diets were analyzed for crude protein (CP), ether extract (EE), dry matter (DM), crude fibre (CF), nitrogen-free extract (NFE), ash and organic matter (OM) as described by AOAC (2000). The fibre fractions such as acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined following the methods of Van Soest et al. (1991).

Gross energy was computed using the formula.

$$T = 5.72Z_1 + 9.50Z_2 + 4.79Z_3 + 4.03Z_4 \pm 0.9\%$$

where.

$T$ = Gross energy.

$Z_1$ = Crude protein.

$Z_2$ = Crude fat.

$Z_3$ = Crude fibre.

$Z_4$ = Nitrogen-free extract.

The silver titration method as described by Oboh et al. (2002) was used to determine the cyanide content.

The data collected in this study were analyzed using the analysis of variance (ANOVA) as outlined by SAS (2008). Significant means were separated using the Duncan multiple range test (Duncan 1955) at $p < 0.05$.

## Results

Table 2 shows the chemical content of the experimental diets. The treatment diets had significant ($p < 0.05$) effect on CP, ash, NFE, NDF, ADF and hydrogen cyanide (HCN), but had no effect ($p > 0.05$) on DM, CF, EE and gross energy.
(GE). With increasing levels of PTR-CRS in the diets, the CP of the treatment diets increased. \(T_3\) and \(T_4\) CP values, on the other hand, were significantly \((p < 0.05)\) higher than \(T_1\) and \(T_2\). Also, with increasing PTR-CRS in the diets, ash values for the treatment diets were improved \((p < 0.05)\). There was decreasing \((p < 0.05)\) trend in NDF and ADF with incremental levels of PTR-CRS in the diets. The haematology of West African Dwarf goats fed Pleurotus tuber-regium–treated cassava root sievate–based diets is shown in Table 3. At the beginning of the experiment, all the haematological parameters examined except mean cell haemoglobin were not significantly \((p > 0.05)\) influenced. Packed cell volume ranged from 24.90 to 29.49% at the start of the experiment, while Hb, RBC, MCV, MCHC and WBC ranged from 8.57 to 9.44 g/dL, from 9.35 to 10.49 \(\times\) 10\(^{12}\)/L, from 20.01 to 20.88 fl, from 29.03 to 31.22% and 5.98 \(\times\) 10\(^7\)/L respectively and were not significant \((p > 0.05)\). Mean cell haemoglobin ranged between \((p < 0.05)\) 5.44 and 6.41 pg at the start of the study. The results of all of the haematological indices studied improved at the end of the experiment. At the end of the experiment, PCV and RBC values were significantly improved \((p < 0.05)\). The blood biochemistry of West African Dwarf goats fed Pleurotus tuber-regium–treated cassava root sievate–based diets is shown in Table 4. All serum biochemical indices were not significantly different \((p > 0.05)\) at the commencement of the experiment. At the end of the experiment, cholesterol values increased significantly \((p < 0.05)\) compared with the values at the start of the experiment. However, the values at the end of the experiment showed significant \((p < 0.05)\) difference

| Parameters (%) | \(T_1\) (0%) | \(T_2\) (20%) | \(T_3\) (40%) | \(T_4\) (60%) | SEM |
|----------------|-------------|-------------|-------------|-------------|-----|
| Dry matter     | 91.33       | 91.90       | 91.55       | 91.84       | 0.83|
| Crude protein  | 9.28b       | 9.82b       | 14.12a      | 16.06a      | 1.11|
| Crude fibre    | 14.57       | 13.35       | 11.52       | 9.62        | 1.00|
| Ether extract  | 0.84        | 0.72        | 0.72        | 1.02        | 0.19|
| Ash            | 8.26c       | 12.17b      | 12.71ab     | 13.03a      | 0.73|
| Organic matter | 83.08       | 79.73       | 80.7        | 78.81       | 0.95|
| Nitrogen free extract | 58.39a     | 55.85ab     | 52.49b      | 52.12b      | 1.04|
| Gross Energy (kcal/g) | 3.66      | 3.51        | 3.54        | 3.59        | 0.77|
| Neutral detergent fibre | 55.57a     | 49.30b      | 34.44c      | 31.18c      | 3.84|
| Acid detergent fibre | 49.50a     | 39.15b      | 29.78c      | 21.91d      | 3.92|
| Hydrogen cyanide (mg/kg) | 2.25a      | 1.67ab      | 1.23ab      | 0.56c       | 0.27|

Means within the same row with different lowercase letters are significantly different \((p < 0.05)\).

| Parameters        | Normal range | \(T_1\) | \(T_2\) | \(T_3\) | \(T_4\) | SEM |
|-------------------|--------------|--------|--------|--------|--------|-----|
| Packed cell volume (%) | 22–38       | 29.31  | 29.49  | 24.90  | 26.90  | 1.22|
| Haemoglobin (g/dL) | 8.0–12.0    | 9.44   | 9.23   | 8.57   | 8.91   | 0.40|
| Red blood cell (\(\times\) 10 12/L) | 8.0–18.0  | 9.42   | 10.49  | 9.44   | 9.35   | 0.22|
| Mean cell volume (fl) | 16–25     | 20.07  | 20.01  | 20.39  | 20.88  | 0.62|
| Mean cell haemoglobin conc. (%) | 30.0–36.0 | 30.93  | 31.22  | 30.43  | 30.43  | 0.61|
| Mean cell haemoglobin (Pg) | 5.2–8.0     | 5.94ab | 5.44ab | 6.41a  | 5.47b  | 0.17|
| White blood cell (\(\times\) 109/L) | 4.0–13.0   | 5.98   | 5.98   | 5.54   | 5.87   | 0.11|

At the end of the experiment

| Parameters        | Normal range | \(T_1\) | \(T_2\) | \(T_3\) | \(T_4\) | SEM |
|-------------------|--------------|--------|--------|--------|--------|-----|
| Packed cell volume (%) | 22–38       | 30.74b | 35.68a | 29.11b | 29.24b | 1.27|
| Haemoglobin (g/dL) | 8.0–12.0    | 9.84   | 10.59  | 9.54   | 10.85  | 0.25|
| Red blood cell (\(\times\) 10 12/L) | 8.0–18.0   | 10.43b | 13.44a | 10.53b | 9.07b  | 0.60|
| Mean cell volume (fl) | 16–25      | 23.76  | 24.11  | 23.01  | 20.66  | 0.69|
| Mean cell haemoglobin conc. (%) | 30.0–36.0  | 32.14  | 32.66  | 32.35  | 32.61  | 0.68|
| Mean cell haemoglobin (Pg) | 5.2–8.0    | 6.55   | 7.14   | 7.10   | 6.57   | 0.32|
| White blood cell (\(\times\) 109/L) | 4.0–13.0  | 6.98   | 7.37   | 7.21   | 7.24   | 0.26|

Means within the same row with different lowercase letters are significantly different \((p < 0.05)\). Normal range according to Radostits et al. (2007)
with $T_1$ (0%) having significantly ($p < 0.05$) higher values in comparison to $T_2$, $T_3$ and $T_4$ (20%, 40% and 60%). Blood glucose slightly decreased ($p > 0.05$) from the values at the start of the experiment. $T_4$ creatinine value was significantly ($p < 0.05$) higher than $T_1$ and $T_2$. In comparison to $T_1$, $T_4$ produced significantly lower urea ($p < 0.05$) value. With increasing PTR-CRS dietary levels, total protein, globulin and total bilirubin levels increased significantly ($p < 0.05$). The treatment diets had no effect ($p > 0.05$) on albumin and alanine aminotransferase (ALT). Aspartate aminotransferase (AST) values showed significant ($p < 0.05$) increase across the dietary treatment.

Discussion

The crude protein value of all the diets were higher than the acceptable 7% CP for ruminant maintenance as advised by ARC (1980) and above 8% for ruminal function as proposed by Norton et al. (1994). The higher CP obtained in $T_3$ and $T_4$ diets could help to balance out the amino acid imbalances that may have occurred during protein degradation. This could be attributable to the fungi mycelial biomass during bioconversion. The variations in the NFE values could be attributed to the influence of graded levels of PTR-CRS in the diets. NFE contains starches as well as a small amount of hemicellulose and lignin (Khan et al. 2003). The decrease in NDF value was not too rapid as to pose a problem, since Lalman (2012) observed that ruminant diets should contain at least 20% NDF on a DM basis to maintain optimal roughage digestion. The values of neutral detergent fibre in the diets were tolerable to aid the rumen motility stimulation among the goats. The biological treatment nutritional superiority was shown by the reduction in ADF. Lalman (2012) reported in a previous study that diets with lower ADF values are of good nutritional value. In comparison to the control diet, the lower NDF and ADF values in PTR-CRS containing diets may indicate that Pleurotus tuber-regium solubilized and utilized the cell walls as carbon sources, altering the ratio of insoluble to soluble carbohydrates in the diets. The PTR-CRS in the diets may be responsible for the decrease in HCN levels. Padmaja (1995) and Aro (2008) attributed the reduction in cyanogenic glycosides during hydrolysis to the ability of the Pleurotus spp. to secrete amylase, xylanase and linamarase enzymes to form hydrolytic complex bound to the cyanide compound.

The PCV values reported herein are within the Daramola et al. (2005) reference range of 21 to 35% for clinically healthy WAD goats. The biologically active compounds in the treatment diets may have improved nutrition

| Parameters | Normal range | $T_1$ | $T_2$ | $T_3$ | $T_4$ | SEM |
|------------|--------------|-------|-------|-------|-------|-----|
| Cholesterol (mmol/l) | 2.07–3.37 | 2.27 | 2.29 | 2.30 | 2.15 | 0.07 |
| Glucose (mmol/l) | 2.78–4.16 | 3.12 | 3.02 | 3.11 | 3.00 | 0.08 |
| Creatinine (μmol/l) | 88.4–159 | 79.89 | 75.72 | 78.00 | 80.32 | 3.69 |
| Urea (mg/dl) | 10–20 | 16.48 | 16.39 | 16.56 | 16.72 | 0.15 |
| Total protein (g/l) | 64.0–70.0 | 62.60 | 62.00 | 63.16 | 61.73 | 0.52 |
| Globulin (g/l) | 27.0–41.0 | 29.08 | 29.08 | 29.57 | 29.59 | 0.32 |
| Albumin (g/l) | 27.0–39.0 | 33.52 | 33.84 | 33.91 | 32.14 | 0.30 |
| Total bilirubin (μmol/l) | 0–1.71 | 0.27 | 0.24 | 0.25 | 0.28 | 0.02 |
| AST (U/L) | 167–513 | 68.97 | 71.06 | 68.62 | 70.98 | 1.45 |
| ALT (U/L) | 6–19 | 28.51 | 28.5 | 29.21 | 28.35 | 0.90 |

Means within the same row with different lowercase letters are significantly different ($p < 0.05$). The normal range according to Aiello and Mays (1998) and Kaneko et al. (2008)
utilization or oxygen-carrying capacity of the blood, resulting in improved PCV at the end of the study. The Hb range reported herein was within the physiological ranges of 7–15 g/dl and 8–16 g/dl for clinically healthy WAD goats reported by Daramola et al. (2005) and Olaifa and Opara (2011), respectively, and 8.50–11.40 g/dl for WAD goats fed fungal-treated rice straw reported by Wuanor and Carew (2018). The results are lower than those reported by Barde et al. (2014) for WAD goats fed Pleurotus tuber-regium–treated cassava peel–based diets and 13.2 g/l by Taiwo and Ogunsanmi (2003) for clinically healthy WAD goats, but higher than those reported by Jiwuba et al. (2018) for WAD goats fed fufu sievate meal–based diets. All of the diets appeared to be capable of supporting high carrying capacity of oxygenated blood among the goats, owing to the relatively higher Hb concentration obtained in this investigation. Furthermore, the Hb concentration of WAD goats on the diets could indicate that the dietary proteins were of good quality. The RBC counts found in this investigation were within the physiological ranges reported by Daramola et al. (2005) and Olaifa and Opara (2011) for apparently healthy WAD goats, which were 9.2–13.5 g/l and 7–21 × 10^6/L, respectively. The within normal physiological range for apparently healthy WAD goats obtained in this research indicated that the diets supported good health status, and hence, the animals were unlikely to suffer from anaemia-related problems. The non-significant effects observed for MCV, MCH and MCHC are in agreement with the report of Wuanor and Carew (2018) for WAD goats fed fungal-treated rice straw. This implies that the nutritional quality of the diets was not compromised. The normal ranges for RBC differentials demonstrated the absence of anaemia among the experimental goats. The WBC counts fell within the normal physiological range of 6.8–20.1 × 10^3/μl reported by Daramola et al. (2005) for clinically health goats; hence, possibility of leucocytosis is ruled out. The increased WBC counts could be attributable in part to enhanced nutrition utilization in all the treatments. This suggested active immunity, which ensured good health condition among the goats. Ahamefule et al. (2005) linked high WBC counts to recent parasitism, the presence of foreign body or antigen in the circulating medium. WAD goats, on the other hand, appear to have a defence system that provides immediate and effective protection against any infectious organism, which could be the physiological base for the adaptation of this species in their ecological zone.

The cholesterol levels were within the ranges of 2.07–3.37 mmol/l and 1.7–3.5 mmol/l, suggested by Kaneko et al. (2008) and Aiello and Mays (1998) respectively for clinically healthy goats. Since high value of serum cholesterol may indicate heart-related disease, the findings may suggest that the goats were normal and not susceptible to cardiac diseases. Furthermore, goats in the treatment groups showed significantly decreased cholesterol levels; this may suggest that PTR-CRS reduced the cholesterol levels. Huang et al. (2014) previously reported the anti-hyperglycaemic and antioxidant effects of Pleurotus tuber-regium. The glucose levels varied from 2.86 to 3.12 mmol/L, which were within the physiological ranges of 2.7–4.2 mmol/L reported by Aiello and Mays (1998) and 2.78–4.16 mmol/l reported by Kaneko et al. (2008) for clinically healthy goats. This showed the ability of the diets to provide the goats sufficient energy required for improved performance. The result indicated that there was no catabolism or wastage of muscle, signifying that the goats never survived at the cost of their body reserves, since the creatinine values were within the reference range according to Kaneko et al. (2008). In animals, creatinine levels are directly related to muscle mass and renal function (Pruvlovic et al. 2012). With increasing levels of PTR-CRS in the diets, serum urea decreased, with animals on T1 and T2 having the highest values and those on T3 and T4 having the lowest. Eggum (1970) linked a high blood urea level to low protein quality in animals. This could indicate that the protein quality in T3 and T4 was higher, confirming Khan and Tania (2012)’s assertion that Pleurotus tuber-regium is high in proteins with essential amino acids. This may infer that the goats had properly functioning kidneys, since creatinine and urea are used as markers of renal function. The significantly progressive increase on total protein and globulin is similar to the findings of Barde et al. (2014) for WAD goats fed Pleurotus tuber-regium–treated cassava peel–based diets and Wuanor and Carew (2018) for WAD goats fed fungal-treated rice straw. The higher total protein and globulin values in the treatment groups suggested that PTR-CRS improved the dietary protein and immunity of the goats. Pleurotus tuber-regium has been previously reported to have medicinal, antioxidant, pharmacological and immunity-boosting attributes (Wong et al. 2011). The albumin concentrations were within the normal physiological ranges of 24–36 g/L and 27.0–39.0 g/L for clinically healthy goats, by Aiello and Mays (1998) and Kaneko et al. (2008), respectively. This indicated that the diets met the rumen microbial protein requirements. Jiwuba et al. (2017) reported total bilirubin values of 0.45–0.80 μmol/l for WAD goats, which are similar to the values obtained in this research. Since bilirubin is considered an index of liver function, the values reported herein fell within the range of 0–1.7 mol/l reported by Kaneko et al. (2008) for clinically healthy goats, suggesting that the diets were not harmful to the liver. The within-normal range for AST (66–230 U/L) and ALT (15–52 U/L) by Aiello and Mays (1998) for clinically healthy goats is indication of high quality of the diets and that there was no hepatocellular damage among the goats.
Conclusion

It is concluded from this study that *Pleurotus tuber-regium* degraded cassava root sievate can be included in the diets of goats up to 60% without deleterious effects on the haematological and serum biochemical parameters of West African Dwarf goats.

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Author contribution PCI — designed the study, wrote the protocol and wrote the first draft of the manuscript.

KI — reviewed the experimental design managed the analyses of the study and performed the statistical analysis.

LCI — sourced the white-rot fungi and carried out the inoculation of the cassava root sievate.

LEO, WA and SUI — sourced the experimental goats, performed the chemical and blood analyses and carried out the literature search.

UK and FOA — guidance and monitoring of experiment and critical revision on the initial draft and approval of the final manuscript.

All the authors read and approved the final manuscript.

Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval This paper followed all the guidelines for the care and use of the laboratory animal model of the Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria.

Consent for publication The authors have consent to publish the paper in Tropical Journal of Animal Health and Production at no free access (no publication fees to the authors).

Conflict of interest The authors declare no competing interests.

References

Ahamefule, F. O., Ibeawuchi, J. A. and Okoye, F. C. (2005). Blood biochemistry and haematology of West African Dwarf (WAD) bucks fed pigeon pea-cassava peel based diets. *Journal of Animal and Veterinary Advances*, 4 (12): 1016–1020.

Aiello, S. E. and Mays, A. (1998). The Merck veterinary manual. Whitehouse Station, NJ: Merck & Co., Inc. 8, 2187–2197.

Aikhuomobhogbe, P. U. and Otheruata, A. M. (2006). Haematological and blood biochemical indices in West African dwarf goats vaccinated against *Pestes des petit ruminants* (PPR). *African Journal of Biotechnology*, 5(9), 743–748.

Anaeto, M., Sawyerr A.F., Alli, T.R., Tayo, G.O., Adeyeye, J.A. and Olarimoye, A.O. (2013). Cassava leaf silage and cassava peel as dry season feed for West African dwarf sheep. *Global journal of science frontier research agriculture and veterinary sciences*, 13 (2): 1–5.

AOAC. (2000). Association of Official Analytical Chemists: Official Methods of Analysis. 6th Edition. Washington DC, USA.

ARC (1980). The nutrient requirement of ruminant livestock. CABi. Farnham Royal, U.K.

Aro, S.O. (2008). Improvement in the nutritive quality of cassava and its by-products through microbial fermentation. *African Journal of Biotechnology*, 7: 4789–4797.

Ayanfunke, T.S. (2019). Training Needs of Mushroom (Agaricus bisporus) Farmers in Oyo state, Nigeria. *Journal of Agricultural Extension*, 23(3): 95–106.

Balikci, E., Yildiz, A. and Gurdogan, F. (2007). Blood metabolite concentrations during pregnancy and post-partum in Akkaraman ewes. *Small Ruminant Research*, 67(2–3), 247–251.

Barde, R.E., Ayoade, J.A., Attah, S. and Musa, I.S. (2014). Effect of *Pleurotus tuber regium* treated cassava peel based diets on haematological and serum biochemical parameters of WAD bucks. *Production Agriculture and Technology Journal*, 10 (1): 135-143.

Dacie, J.V. and Lewis, S.M. (1991). Practical haematology. 8th edition. Longman group ltd. London. Pp 88–96.

Daramola, J. O., Adeloye, A. A. Fatoba, T. A and Soladoye, A. O. (2005). Haematological and Biochemical parameters of West African dwarf goats. *Livestock Research for Rural Development*, 17(8).

Duncan, D. B. (1955). Duncan, D. B. (1955). Multiple Range and Multiple F Tests. *Biometrics*, 11: 1–42.

Eggum, B.O. (1970). The protein quality of cassava leaves. *British Journal of Nutrition*, 24:761-768.

Galappaththi, M.C.A., Dauner, L., Madawala, S. and Karunanarathna, S.C. (2021). Nutritional and medicinal benefits of Oyster (*Pleurotus*) mushrooms: a review. Fungal *Biotec* 1(2): 65–87. https://doi.org/10.5943/FunBiotec1/2/5

Huang, H., Korivi, M., Yang, H., Huang, C., Chaing, Y. and Tsai, Y. (2014). Effect of *Pleurotus tuber-regium* polysaccharides supplementation on the progression of diabetes complications in obese-diabetic rats. *Chinese Journal of Physiology*, 57(4): 198-208. https://doi.org/10.4077/CJP.

Jiwuba, P.C., Ikwunze, K., Dauda, E and Ugwu, D.O. (2016). Haematological and serum biochemical Indices of growing rabbits fed diets containing varying levels of fufu sievate meal based diets with Panicum *miliaceum* leaf meal. *Biotechnology Journal International*, 15(2): 1-7. https://doi.org/10.9734/BBJ/2016/28095

Jiwuba, P.C., Ahamefule F.O., Ogboewue I.P. and Ikwunze K. (2017). Blood chemistry and haematology of West African Dwarf goats fed *Moringa oleifera* leaf meal (*MOLM*) in their diet. *Comparative Clinical Pathology*, 26(3), 621-624. https://doi.org/10.1007/s00580-017-2434-2

Jiwuba, P.C. Assam, E.M. and Inyang, E.C. (2018). Effects of feeding varying levels of fufu sievate meal based diets with Panicum maximum basal on the blood characteristics of West African dwarf goats. *Sustainability, Agriculture, Food and Environmental Research*, 6(1): 1-10. https://doi.org/10.7777/safer-V6N1-art1316

Kaneko, J.J., Harvey, J.W., Bruss, M. L. (2008). Clinical *biochemistry and biomedical sciences*. 6th edition. New York, Academic Press.

Khan, A. and Tania, M. (2012). Nutritional and Medicinal Importance of *Pleurotus* Mushrooms: An Overview. *Food reviews International*, 28(3):313-329.

Khan, M.A., Mahr-Un-Nisa and Sarwar, M. (2003). Techniques measuring digestibility for the nutritional evaluation of feeds. *International Journal of Agriculture and Biology*, 5(1):91-94

Lalman, D. (2012). Nutritive value of feeds for beef cattle. Oklahoma Cooperative Extension Fact Sheets.

Mshandete, A.M. and Mgonja J.R. (2009). Submerged liquid fermentation of some Tanzanian basidiomycetes for the production of mycelial biomass, exopolysaccharides and mycelium protein using...
wastes peels media. *Journal of Agricultural and Biological Science*, 4, 1-13.

Nehring, K., and Haenlein, G. F. W. (1973). Feed evaluation and ration calculation based on net energy. *Journal of Animal Science*, 36(5):949–964.

Norton, B.W.B., Lowry, C. and Sweeney, M.C. (1994). The nutritive value of Leucaena specie. Paper presented at Int’l. Workshop on Leucaena. R.D. Bogor, Indonesia. 20–29 January 1994.

Oboh, G., Akindahunsi, A.A. and Oshodi, A.A. (2002). Nutrient and anti-nutrient contents of *Aspergillus niger* fermented cassava products (flour and gari). *Journal of Food Composition and Analysis*, 15(5), 617-622.

Olaifa, A. K. and Opara, M. N. (2011). Haematological and biochemical parameters of West African Dwarf (WAD) bucks castrated by the burdizzo method. *Veterinary Archives*, 81, 743-750.

Opara, M.N., Udevi, N. and Okoli, I.C. (2010). Haematological parameters and blood chemistry of apparently healthy West African dwarf (WAD) goats in Owerri, southeastern Nigeria. *New York Science Journal*, 3(8): 68-72.

Opara, M.N. and Fagbemi, B.O. (2009). Dietary influences of feed types on the haematological indices of captive-reared grasscutters experimentally infected with Trypanosoma congolense. In: Proceedings of the 10th Biennial Conference of the Society for Tropical Veterinary Medicine, June 28-July 3, Lubeck, Germany, 63–67.

Padmaja, G. (1995). Cyanide detoxification in cassava for food and feed uses. *Critical Reviews in Food Science and Nutrition*, 35: 299-339.

Pruulovic, D., Kosarcic, S., Popovic, M., Dimitrijevic, D., Grubor, L.G. (2012). The influence of hydrated aluminosilicate on biochemical and haematological blood parameters, growth performance and carcass traits of pigs. *Journal of Animal and Veterinary Advances*, 11(1), 134–140.

Radostits, O.M., Gay, C.C., Hinchcliff, K.W., Constable, P.D. (2007). Veterinary Medicine E-Book: A textbook of the diseases of cattle, horses, sheep, pigs and goats. 10th ed. Saunders, Elsevier New York.

SAS (2008). Statistical Analysis System User’s Guide, Version 13 for Windows. Statistical Analysis Institute, Inc., SAS Camp Drive Cary, North Carolina U. S. A.

Taiwo, V.O. and Ogunsanmi, A.O. (2003). Haematology, plasma, whole blood and erythrocyte biochemical values of clinically healthy captive-reared grey duiker (*Sylvicapra grimmia*) and West African Dwarf sheep and goats Ibadan, Nigeria. *Israel Journal of Veterinary Medicine*, 58(2&3):57–61.

Tambuwal, F. M., Agale, B. M., and Bangana, A. (2002). Haematological and biochemical values of apparently healthy Red Sokoto goats. In Proceeding of 27th Annual Conference Nigerian Society of Animal Production (NSAP) (pp. 50–53).

Van Soest, P.J., Robertson, J.B. and Lewis, B.A. (1991). Methods of dietary fibre, neutral detergent and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, 74(10): 3583-3597. https://doi.org/10.3168/jds

Wong, K.H., Lai, C. K. M. and Cheung, P. C. K. (2011). Immunomodulatory activities of mushroom sclerotial polysaccharides,” *Food Hydrocolloids*, 25(2):150–158.

Wuanor, A. and Carew, S. N. (2018). Feed Efficiency and Blood Profiles of West African Dwarf Goats Fed *Pleurotus tuber-regium* Biodegraded Rice Straw and Maize Offal-Brewer Yeast Slurry Mixture. *Journal of Agriculture and Ecology Research International*, 14(1): 1-10.

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