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CARCASS CHARACTERISTICS, INTESTINAL MORPHOLOGY AND MICROBIOTA OF WEANER RABBITS AS INFLUENCED BY SEX AND FEED TYPES

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Abstract

A total of seventy-two (thirty-six males and thirty-six females) 6 weeks old weaner rabbits (Chinchilla X New Zealand white) with weight ranging from 790–830 grammes were used to investigate the effect of different feed types on carcass characteristics, intestinal morphology, and microbiota of weaner rabbits. The rabbits were allotted into 8 treatments after weight equalization based on sex and different dietary groups (100% mash, 100% pellet, 50% mash + 50% Sunflower leaf (*Tithonia diversifolia*) and 50% pellet + 50% Sunflower leaf) in a 2 x 4 factorial arrangement, with each treatment consisting of 9 rabbits; each treatment was further subdivided into 3 replicates and 3 rabbits per each replicate. The experiment lasted for 8 weeks. The data collected were analysed using a one-way analysis of variance.

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Results showed that live and carcass weights were highest in female rabbits fed 100% pellets (1846.50 ± 89.20 g) and lowest in rabbits fed 100% mash; dressing percentage, forelimbs, and hindlimbs were highest in rabbits fed 100 % mash. Gut morphology showed that duodenum weight (1.62 ± 0.16%) and length (114.47 ± 17.64 cm), caecum weight, caecum apical width, and basal width were highest ($p < 0.05$) in rabbits fed 50% pellet + 50% forage. Ileal villi height was highest ($p < 0.05$) in females offered 100% mash while males fed 100% mash had normal intestinal villi. *Proteus mirabilis and Enterobacter* were highest in rabbits fed a mixed diet, while *Escherichia coli* was highest in females fed 100% pellet. The study concluded that feeding 100% pellet yielded higher live weight, carcass weight and dressing percentage while those fed 100% mash had improved intestinal morphology.

Introduction

The rising demand for animal protein by the ever-increasing population in Africa has led to the exploration of healthier and cheaper meat options, such as rabbit, and this increase in meat production can be achieved through proper nutrition and inclusion of feed ingredients at required levels (ETIM and OGUIKE 2010). OLIVEIRA et al. (2008) reported that conventional feeding has been the most critical challenge of rabbit production, representing 70% of the overall production cost, and hence, made rabbit rearing relatively expensive, as there are no known customized commercial feeds for rabbits. Researchers such as PHIMMASAN et al. (2004) and HUE and PRESTON (2006) had carried out successful nutritional interventions, such as feeding rabbits solely on some forage species in an attempt to reduce feed cost in rabbit production. According to WAFAR et al. (2019), forages could serve as a potential source of nutrients for animals, since rabbits can utilize fibrous materials for the production of meat and can also thrive on forages such as sunflowers (*Tithonia diversifolia*) because of their enlarged caecum, sunflower is cost-effective with high protein content of about 18% (OLAYENI et al. 2006). SOGUNLE et al. (2014) stated that nutrient uptake can be affected by the form of feed presentation; therefore, feed presentation, such as mash, crumbs, and pellets are vital for effective utilization and a crucial meat yield factor. Hence, optimising rabbit production requires a comprehensive understanding of how diet influences growth performance, carcass traits, and organ development (HERNANDEZ et al. 2008). This is because feed composition is a critical determinant of carcass quality, organ health, and overall productivity, highlighting the need for alternative, cost-effective feed resources that are both nutritionally adequate and economically viable. Rabbitry in Nigeria, in its present state, depends mainly on poultry feeds. Very few or none of the feed mills produce rabbit feed pellets. KPODEKON et al. (2009) showed that pellet feed provides better performance for rabbits, and the use of pellets feed reduced fattening period for about 13 to 15 days while SAFWAT et al. (2014) reported improved feed conversion when pellets were restricted and supplemented with a variety of green forages. Rabbit is a monogastric herbivore whose digestive tract is adapted to process large amounts of fiber-rich feed. Microbial fermentation of the feed takes place in the caecum to ensure nutrient supply (HARCOURT-BROWN 2004). Hence, some basis of digestive anatomy and physiology govern and allow for a better understanding of its feeding behavior is proposed as fresh forages stimulate stomach growth, which accounted for subsequent higher feed intake capacity compared to rabbits fed only pellets; higher caecal volume was reported when fed diets containing a greater quantity of fiber (DOUGNON et al. 2012). The effects of diets have been an important source of change in carcass traits of rabbits (LAUDADIO et al. 2009); however, NICODEMUS et al. (2006) reported that increase in the dietary fiber source or particle size of rabbit diets does not always lead to modifications in slaughter yield. Carcass characteristics and meat quality are the fundamental aspects that guide research on the production of fattening rabbits, due to the relevance reached by this species to produce meat of good nutritional quality (DALLE ZOTTE 2002, DAL BOSCO et al. 2012). Carcass traits are influenced by the adult weight and the maturity of rabbits at the age of slaughter (PILES et al. 2000). According to WALTHALL et al. (2005), the structure of the gastrointestinal tract is affected by several factors, including diet, age, genetic determinants, and hormones secreted in the intestine and in the other organs during postnatal development. DOUGNON et al. (2012) stated that the size and function of the gastrointestinal organs, especially the caecum, are directly influenced by the diet, with high-fibre feeds promoting larger caecal sizes. At the same time, the form and function of the alimentary tract develop to meet the increased metabolic demands during the growth period. Thus, the structure and size of the gut should be adequate to the nutritional and energetic requirements of the animal (MIRGHELENI and GOLIAN 2009). This indicates the advantages resulting from morphometric studies that could provide criteria of animal condition. Sexing weaner rabbits allows farmers to tailor nutrition, management, and health programs to meet the specific needs of males and females. AYO-AJASA et al. (2022) also opined that sex is an important factor for consideration when selecting animals to be used in ethno botanical studies. There are often conflicting reports on the absence of sex dimorphism in experimental rabbits (LAXMI et al. 2009). Some studies (ORTIS-HERNANDEZ and RUBIO-LUZANO 2001, MURSHED et al. 2014) had reported that, unlike in most domestic livestock species, sex does not strongly influence growth and carcass characteristics in rabbits. Hence, this study investigated the effect of sex and feed types on carcass characteristics, intestinal morphology and microbiota of rabbits.

Materials And Methods

Experimental site

The experiment was carried out at the Rabbitry Unit of Teaching and Research Farms, Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria. The site is located in the rain forest vegetation zone of South-Western Nigeria on latitude 7°13’49.46’N, longitude 3°26’11.98E with an elevation of 415 feet and altitude of 76 m above the sea level (GOOGLE EARTH 2023). The climate is humid with a mean annual rainfall of 1.037 mm and mean temperature and humidity of 34.7°C and 83%, respectively. The liver and gastrointestinal tract histology were examined at College of Veterinary Medicine (COLVET) at the Department of Veterinary Physiology and Pharmacology, Federal University of Agriculture, Abeokuta.

Experimental animals and management

A total of seventy-two (thirty-six male and thirty-six female) Chinchilla X New Zealand White crossbred, six (6) weeks old weaner rabbits with weight ranging from 790–830 g were used in this 8-week feeding trial. The rabbits were randomly divided into eight experimental groups consisting of three replicates and three animals per replicate. The rabbits were housed in hutches; the hutches and equipment were thoroughly washed and disinfected prior to the commencement of the experiment. A good hygienic environment was maintained throughout the experiment, and all necessary medications were given. The rabbits were maintained on three experimental feeds which were mash, pellet and forage (sunflower leaves and stalk). They were fed as 100% mash, 100% pellet, 50% mash + 50% forage, 50% pellet + 50% forage. Each group of rabbits was offered one of the experimental diets. The mash was a commercial grower’s mash sourced and purchased from a reputable feed store; feed composition as provided by the manufacturer contains 16% CP, 7% CF, 5% Fat and oil, 1.6% Calcium, 0.5% Phosphorus, 0.75% Lysine, 0.36% Methionine, 0.3% Salt (NaCl), 2450 Kcal/kg Metabolisable Energy (Table 1). The pellets were prepared from the grower’s mash. The mesh size used in pelleting the mash was 4 mm; the feed mixture was added 4–6% of water which played a role of lubrication when granulating the feed. The heat (85–90 °C) also causes gelatinization of raw starch on the surface of the feed ingredients after which the feed was extruded from the outlet pelletizer. After pelletizing, it was sieved to remove powder and debris after which it was cooled down and then bagged. The forage (wild sunflower leaves and stalks) was cut fresh from the surrounding of the rabbit pen in the morning and left in the rabbit pen to wilt to reduce the moisture content before being fed to the rabbits in the evening. This study was a 2 x 4 factorial layout in a completely randomized design, and the factors were sex (buck and doe) and 4 different feed types as stated above.

Table 1

Nutrient composition of the commercial feed (as declared)

Ingredients	Mash	Pellet
Crude protein [%]	16.00	15.00
Fats/oil [%]	5.00	3.00
Crude fibre [%]	7.00	8.00
Calcium [%]	1.60	1.20
Available phosphorus [%]	0.50	0.35
Lysine [%]	0.75	0.80
Methionine [%]	0.36	0.25
Salt [%]	0.30	0.00
Available moisture	0.00	14.00
Energy [Kcal/kg ME]	2450	2650

Data Collection

Proximate analysis of wild sunflower (*Tithonia diversifolia*)

The proximate analysis of the sunflower forage was determined according to the methods of AOAC (2005) – Table 2. The moisture content of the sample was determined by oven-drying 220 grammes of wilted sunflower in hot air laboratory oven for 10–12 hours at 60 °C until a constant weight of 30 grammes was obtained. The dried samples (2 grammes) of sunflower were analysed for Crude protein using the Kjedahl method, which consist of the digestion of the forage sample, distillation of the digest, and titration of the distillate. The actual crude protein values of the sunflower samples were obtained by converting nitrogen (N %) content with a constant (6.25), and crude protein was obtained thus (6.25 · N %). Fat from the sunflower sample was extracted by the Soxhlet extraction method using petroleum ether (60/80) for 16–18h, where loss in sample (1 g dry sample weighed and wrapped in a filter paper) weight was calculated as the fat percentage. For ash content, dried sample (2 g) was ignited in a muffle furnace at 600 °C for 4–6h until the ash was formed and weighed.

Table 2

Proximate analysis of wild sunflower (*Tithonia diversifolia*)

Parameters	[%]
Dry matter	86.13
Crude protein	12.25
Crude fibre	12.5
Ether extract	7.5
Ash	18.75
Neutral detergent fibre (NDF)	54.78
Acid detergent fibre (ADF)	37.91
Acid detergent lignin (ADL)	13.97

Carcass evaluation

At the end of the 8th week of the experiment, three rabbits per treatment were selected for carcass studies. Feed was withdrawn for 12 hours from the rabbits so as to empty their gastro intestinal tract (GIT) and to reduce the variability in body weight due to intestinal content. Prior to slaughtering, the rabbits were weighed. The rabbits were stunned, bled, scald with fire and then eviscerated. The carcass weight and dressing percentage were determined and recorded:

$$\textit{Dressing percentage} = \textit{carcass weight} \cdot \textit{100 live weight}$$

The carcass was cut into retail parts (forelimb, hind limb, chest, neck, loin, back, head and tail) and then weighed with a sensitive electronic weighing scale. The weight of the liver, kidney, heart, lung and spleen were also taken. The primal cut-up parts and organs were expressed as a percentage of live weight.

Intestinal morphology

One (1) rabbit from each replicate, with body weights that was the average weights of each replicate were used for the microscopic study of intestinal morphology. The length of each intestinal segment was determined with a flexible tape on a glass surface to prevent inadvertent stretching. The gastrointestinal tracts of the rabbits used in carcass traits evaluation were removed and used for the microscopic study of intestinal villus morphology. The length of each intestinal segment was determined with a flexible tape on a glass surface to prevent inadvertent stretching. Thus, the length (±0.1 mm) of the duodenum (from the pyloric junction to the distal-most point of insertion of the duodenal mesentery), the length of the jejunum (from the distal-most point of insertion of the duodenal mesentery to the Meckel's diverticulum), and length of the ileum (from the Meckel's diverticulum to the ileocecal junction) were taken (SOGUNLE et al. 2014).

Intestinal microbiota

Swabs from slaughtered rabbits were taken from eviscerated organ; caecum to determine the microbial counts in the intestine (CHEESEBROUGH 2000). Total bacteria count (TBC) and individual bacterial count, which included; *Escherichia coli, Streptococcus faecalis, Staphylococcus aureus, Proteus mirabilis, Enterobacter and Pseudomonas* population and identification, were determined.

Statistical analysis

Data obtained were assessed using 2 x 4 factorial analysis of variance (ANOVA). Significant differences ($p < 0.05$) between the means were separated using Duncan-Multiple Range Test as contained in SAS (2010), and the interactions were tested as shown in the statistical model.

Experimental model

$$\mathrm{Y}_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk},$$

where:

Y_{ijk} – individual observation
μ – general mean
A_i – effect of Factor A (sex)
B_j – effect of Factor B (feed type)
$(AB)_{ij}$ – effect of interaction AB (feed type · sex)
εi ijk – experimental error

Results

Table 3 shows the carcass characteristics of sexed weaner rabbits fed different feed types. The results show that sex had no significant ($p > 0.05$) difference on all the carcass parameters evaluated, while feed types significantly ($p < 0.05$) influenced the live weight, dressing percentage, head, forelimb, and loin. The heaviest ($p < 0.05$) live and carcass weight (1744.75 g and 1209.60 g) were recorded in rabbits fed 100% pellets while others had comparative values. while a similar dressing percentage was observed in rabbits fed 100% M and 100% P (60.50 g and 62.16 g, respectively). Significantly ($p < 0.05$) highest head values (8.03% and 7.82%), were recorded in rabbits fed 100% mash and 50% mash, 50% forage, respectively, while rabbits fed 100% pellets recorded the least percentage (7.09%). Also, the highest forelimb (5.90%) was observed in rabbits fed 100% mash, similar and lowest percentages were observed from rabbits in other groups, while loin was significantly ($p < 0.05$) highest (10.17%) in rabbits fed 100% pellet. Rabbits offered 100% mash and 50% pellet, 50% forage had the highest ($p < 0.05$) value (0.26%) for heart, while rabbits fed 100% pellets recorded the lowest (0.22%). Spleen was highest ($P < 0.05$) in rabbits fed 50% pellet, 50% forage (0.07%), and rabbits fed 100% pellet had the lowest (0.03%).

The main effect of sex and feed type on the intestinal morphometry of weaner rabbits is presented in Table 4. The parameters that were significantly ($p < 0.05$) influenced by sex are ileum weight and colon length. Buck had the higher ileum weight (1.97%) while doe had a lower weight (1.03%). Doe was observed to have a longer ($p < 0.05$) colon (112.15 cm) than buck (93.04 cm). The parameters that were significantly ($p < 0.05$) influenced by feed type are live weight, duodenum weight and length, jejunum weight and length, ileum length, heart and spleen. Live weight and ileum length were significantly ($p < 0.05$) higher in rabbits fed 100% pellet (1744.80 g and 138.37 cm, respectively), while rabbits offered other feed types had lower values.

Highest ($p < 0.05$) duodenum weight (1.63%) and length (116.57 cm) were obtained from rabbits fed 50%pellet, 50% forage, while rabbits offered 100% mash, 100% pellets, and 50% mash: 50% forage had the least value. The jejunum weight was significantly ($p < 0.05$) highest in rabbits fed 100% mash, 50% mash, 50% forage, and 50% pellet: 50% forage, while the lowest was obtained in rabbits fed 100% pellets (0.89%). Rabbits offered 50% pellet, 50% forage had the highest jejunum length (110.15 cm), while rabbits fed 100% pellets had the lowest (64.74 cm). Jejunum length values recorded in 100% mash and 50% mash, 50% forage were comparable to rabbit of higher values.

Table 3

Main effect of sex and feed types on the carcass characteristics of weaner rabbits

Parameters	Sex		Feed types			
	buck	doe	[100% m]	[100% p]	[50% m, 50% f]	[50% p, 50 f]
Live weight [g]	1434.83±61.64	1550.79±73.71	1355.50±85.54^{b}	1744.75±66.46^{a}	1413.33±37.50^{b}	1457.67±110.46^{b}
Carcass weight [g]	912.25±86.13	1049.29±53.55	809.50±143.84^{b}	1209.60±40.82^{a}	955.70±37.00^{ab}	948.33±91.99^{ab}
Dressing percentage [%]	60.02±1.70	58.84±0.85	60.50±1.72^{a}	62.16±0.96^{a}	59.67±1.78^{ab}	55.38±0.31^{b}
Primal cut part [%LW]						
Neck	2.05±0.10	2.05±0.04	2.10±0.09	1.90±0.15	2.07±0.06	2.14±0.09
Head	7.81±0.22	7.38±0.10	8.03±0.32^{a}	7.09±0.12^{b}	7.82±0.22^{a}	7.46±0.17^{ab}
Fore limb	5.06±0.46	4.52±0.14	5.90±0.78^{a}	4.49±0.16^{b}	4.64±0.24^{b}	4.13±0.11^{b}
Hind limb	12.62±0.57	11.98±0.36	12.74±1.14	11.82±0.35	12.76±0.13	11.85±0.66
Back	11.98±1.04	10.99±0.53	12.05±1.69	12.43±0.46	11.17±1.25	10.31±1.04
Loin	8.20±0.59	8.08±0.30	7.50±0.23^{b}	10.17±0.59^{a}	7.61±0.29^{b}	7.28±0.54^{b}
Chest	20.02±0.58	21.28 ±0.42	20.76 ±1.11	21.08±0.64	21.12±0.64	19.63±0.51
Tail	0.14±0.02	0.15±0.02	0.15 ±0.02	0.17±0.02	0.11±0.02	0.14±0.03
Organs [%LW]						
Liver	3.17 ±0.15	2.89 ±0.12	2.94 ±0.20	3.08±0.21	2.95±0.12	3.16±0.28
Heart	0.24±0.01	0.24 ±0.01	0.26 ±0.02^{a}	0.22±0.01^{b}	0.24±0.02^{ab}	0.26±0.01^{a}
Kidney	0.78±0.06	0.61± 0.03	0.67±0.04	0.66± 0.06	0.71±0.05	0.74±0.13
Spleen	0.05±0.00	0.05±0.00	0.05±0.01^{ab}	0.03±0.00^{b}	0.06±0.01^{ab}	0.07±0.01^{a}
Lungs	0.50 ±0.03	0.53±0.03	0.47±0.02	0.48±0.02	0.59±0.06	0.53±0.05
Abdominal fat	0.16±0.07	0.20± 0.08	0.17±0.08	0.28±0.09	0.25±0.16	0.02±0.02

Explanations: ^{a,b} means in the same row with different superscripts differ significantly ($p < 0.05$);
m – mash; p – pellet; f – forage; LW– live weight

Table 4

Main effect of sex and feed type on the intestinal morphometry of weaner rabbits

Parameters	Sex		Feed types			
	buck	doe	[100% m]	[100% p]	[50%m, 50% f]	[50% p, 50% f]
Live weight [g]	1434.83 ± 61.64	1550.79 ± 73.71	1355.50 ± 85.54^{b}	1744.80 ± 66.46^{a}	1413.30 ± 37.50^{b}	1457.70 ± 110.46^{b}
Duodenum weight [%]	1.03 ± 0.13	1.16 ± 0.12	1.03 ± 0.18^{b}	0.73 ± 0.08^{b}	0.98 ± 0.07$^{\mathrm{b}}$	1.63 ± 0.11^{a}
Duodenum length [cm]	83.79 ± 8.89	70.39 ± 8.91	67.70 ± 4.82^{b}	64.51 ± 8.20^{b}	59.53 ± 6.53^{b}	116.57 ± 13.32^{a}
Jejunum weight [%]	1.50 ± 0.24	1.76 ± 0.20	1.90 ± 0.29^{a}	0.89 ± 0.07^{b}	1.93 ± 0.40^{a}	1.80 ± 0.21^{a}
Jejunum length [cm]	93.23 ± 11.04	92.80 ± 9.04	101.05 ± 11.98^{ab}	64.74 ± 5.80^{b}	96.12 ± 16.43^{ab}	110.15 ± 14.66^{a}
Ileum weight [%]	1.97 ± 0.20^{a}	1.03 ± 0.13^{b}	1.44 ± 0.41	1.80 ± 0.27	1.52 ± 0.20	1.24 ± 0.34
Ileum length [cm]	97.57 ± 17.81	90.90 ± 11.53	57.83 ± 15.96^{b}	138.37 ± 12.07^{a}	99.53 ± 16.20^{ab}	81.22 ± 25.15^{b}
Caecum [%]	8.63 ± 0.94	9.92 ± 0.54	10.24 ± 0.92	7.63 ± 1.13	8.89 ± 0.92	10.35 ± 1.24
Colon weight [%]	2.38 ± 0.14	2.64 ± 0.15	2.19 ± 0.04	2.71 ± 0.29	2.57 ± 0.24	2.56 ± 0.14
Colon length [cm]	93.04 ± 7.08$^{\mathrm{b}}$	112.15 ± 5.05^{a}	93.94 ± 2.11	106.22 ± 9.85	99.57 ± 16.00	110.65 ± 3.98

Explanations: ^{a,b} Means in the same row with different superscripts differ significantly ($p < 0.05$); m – mash; p – pellet; f – forage

Table 5 shows the main effects of sex and feed type on the intestinal morphology of weaner rabbit. The parameters that were significantly ($p < 0.05$) influenced by sex are duodenum apical width and lamina propria depth and caecum lamina propria depth, while others were not significantly ($p > 0.05$) influenced. In the duodenum, buck had highest values in the apical width and lamina propria depth (72.50 µm and 81.25 µm respectively) while the lowest was observed in doe (59.38 and 68.75 µm respectively). However, the caecum *lamina propria* depth was higher in doe (200.00 µm) and lowest in buck (121.88 µm). The parameters significantly ($p < 0.05$) influenced by feed type are villi height of duodenum, apical width, basal width and lamina propria depth of ileum, basal width, lamina propria depth of jejunum and apical width, basal width. Highest duodenum villi height (443.75 µm) was recorded in rabbits fed 50% mash, 50% forage while the lowest (300.00 µm) was observed in rabbit fed 100%pellet. In the ileum, the apical width was significantly ($p < 0.05$) higher (68.75 µm) in rabbits fed 100% mash and lowest in rabbit fed other feed types. Highest (106.25 µm) basal width were observed in rabbits fed 50% mash, 50% forage and 100% pellet (105.00 µm) while the least (87.50 µm) was observed in rabbit fed 50% pellet, 50% forage. Rabbits fed 100% mash had higher (106.25 µm) *lamina propria* depth and lowest in rabbits offered 100% pellet (81.25 µm). Jejunum had higher (131.25 µm) basal width in rabbits fed 50% pellet, 50% forage and lowest in rabbits fed other feed types. Highest (75.00 µm) lamina propria depth was recorded in rabbits fed 50% mash, 50% forage (118.75 µm) and lowest in rabbits fed 100% mash. Caecum, highest apical width and basal width (81.25 µm and 143.75 µm) were observed in rabbits fed 50% pellet, 50% forage while the least values were reported in other feed types.

The main effect of sex and feed type on the intestinal microbial count of weaner rabbits is represented in Table 6. None of the parameters examined were significantly ($p > 0.05$) influenced by sex. The parameters that were significantly ($p < 0.05$) influenced by feed type are *Escherichia coli, Proteus mirabilis and Enterobacter. Escherichia coli* had highest ($p < 0.05$) count ($0.65 \cdot 10^6$ cfu/ml) in rabbits fed 100% pellet and lowest ($0.18 \cdot 10^6$ cfu/ml) in rabbits fed 50% mash, 50% forage. Highest *Proteus mirabilis* was observed with counts ranging from ($0.15 \cdot 10^6$ cfu/ml) to the least in rabbit fed 100% and 50% mash, 50% forage ($0.05 \cdot 10^6$ cfu/ml). Highest *Enterobacter* count ($0.28 \cdot 10^6$ cfu/ml) was recorded in rabbits fed 50% mash, 50% forage and 50% pellet, 50% forage and lowest ($0.10 \cdot 10^6$ cfu/ml) in rabbits fed 100% pellet.

Table 5

Main effect of sex and feed type on the intestinal morphology of weaner rabbits

Parameter	Sex		Feed types			
	buck	doe	[100% m]	[100% p]	[50% m, 50% f]	[50% p, 50% f]
Duodenum morphometry						
Villus Height [µm]	384.38 ± 23.29	356.25 ± 40.84	400.00 ± 50.41^{ab}	300.00 ± 51.64^{b}	443.75 ± 29.89^{a}	337.50 ± 36.37^{ab}
Apical Width [µm]	59.38 ± 3.13^{b}	72.50 ± 2.36^{a}	62.50 ± 5.59	62.50 ± 4.56	70.00 ± 4.70	68.75 ± 4.27
Basal Width [µm]	101.25 ± 6.10	99.38 ± 8.50	106.25 ± 11.06	107.50 ± 9.64	92.50 ± 9.64	95.00 ± 11.78
Lamina Propria depth [µm]	68.75 ± 2.89^{b}	81.25 ± 4.49^{a}	68.75 ± 4.27	81.25 ± 11.06	75.00 ± 0.00	75.00 ± 0.00
Ileum morphometry						
Villus Height [µm]	421.88 ± 12.88	450.00 ± 0.22	468.75 ± 30.58	425.00 ± 2.91	437.50 ± 31.46	412.50 ± 8.54
Apical Width [µm]	56.25 ± 3.26	56.25 ± 2.89	68.75 ± 4 .27^{a}	50.00 ± 0.00^{b}	50.00 ± 0.00^{b}	56.25 ± 4.27^{b}
Basal Width [µm]	100.00 ± 5.10	99.38 ± 4.15	105.00 ± 7.44^{a}	100.00 ± 0.00^{ab}	106.25 ± 4.27^{a}	87.50 ± 8.54^{b}
Lamina Propria depth [µm]	96.88 ± 6.18	93.75 ± 5.65	106.25 ± 7.74^{a}	81.25 ± 4.27^{b}	93.75 ± 8.98^{ab}	100.00 ± 9.13^{ab}
Jejunum morphometry						
Villus Height [µm]	343.75 ± 18.50	365.63 ± 25.05	337.50 ± 31.46	325.00 ± 30.28	362.50 ± 30.79	393.75 ± 30.92
Apical Width [µm]	62.50 ± 3.44	59.38 ± 3.13	56.25 ± 4.27	56.25 ± 4.27	62.50 ± 4.56	68.75 ± 4.27
Basal Width [µm]	115.63 ± 7.86	103.13 ± 3.81	106.25 ± 7.74^{b}	93.75 ± 4.27^{b}	106.25 ± 4.27^{b}	131.25 ± 11.06^{a}
Lamina Propria depth [µm]	87.50 ± 9.23	100.0 0 ± 5.96	75.00 ± 7.22^{c}	81.25 ± 8.98^{bc}	118.75 ± 11.97^{a}	100.00 ± 7.22^{ab}
Caecum morphometry						
Villus Height [µm]	190.00 ± 12.00	196.875 ± 5.98	198.75 ± 6.51	181.25 ± 13.60	206.25 ± 10.08	187.50 ± 20.16
Apical Width [µm]	63.125 ± 5.69	62.50 ±3 .44	57.50 ± 7.01^{b}	62.50 ± 4.56^{b}	50.00 ± 0.00^{b}	81.25 ± 4.27^{a}
Basal Width [µm]	102.50 ± 11.39	110.00 ± 7.66	87.50 ± 9.46^{b}	106.25 ± 11.06^{b}	87.50 ± 4.56^{b}	143.75 ± 13.60^{a}
Lamina Propria depth [µm]	200.00 ± 30.43^{a}	121.88 ± 14.20^{b}	212.50 ± 53.81	137.50 ± 27.76	181.25 ± 35.32	112.50 ± 8.54

Explanations: ^{a,b,c} means in the same row with different superscripts differ significantly ($p < 0.05$); m – mash; p – pellet; f – forage

Table 6

Main effect of sex and feed type on the intestinal microbial count of rabbits

Parameter	Sex		Feed types			
	buck	doe	[100% m]	[100% p]	[50% m, 50% f]	[50% p, 50% f]
Total bacteria count [$\cdot 10^6$ cfu/ml]	1.41 ± 0.11	1.18 ± 0.16	1.10 ± 0.15	1.50 ± 0.27	1.18± 0.09	1.43 ± 0.25
Escherichia coli [$\cdot 10^6$ cfu/ml]	0.41 ± 0.07	0.45 ± 0.14	0.45 ± 0.10^{ab}	0.65 ± 0.22^{a}	0.18 ± 0.08^{b}	0.45 ± 0.15^{ab}
Streptococcus faecalis [$\cdot 10^6$ cfu/ml]	0.26 ± 0.06	0.18 ± 0.05	0.10 ± 0.04	0.20 ± 0.11	0.30 ± 0.07	0.30 ± 0.06
Staphylococcus aureus [$\cdot 10^6$ cfu/ml]	0.31 ± 0.08	0.21 ± 0.05	0.23 ± 0.09	0.33 ± 0.11	0.33 ± 0.10	0.18 ± 0.05
Proteus mirabilis [$\cdot 10^6$ cfu/ml]	0.13 ± 0.03	0.08 ± 0.02	0.05 ± 0.03^{b}	0.15 ± 0.02^{ab}	0.05 ± 0.03^{b}	0.15 ± 0.04^{a}
Enterobacter [$\cdot 10^6$ cfu/ml]	0.21 ± 0.05	0.21 ± 0.04	0.20 ± 0.07^{ab}	0.10 ± 0.07^{b}	0.28 ± 0.04^{a}	0.28 ± 0.04^{a}
Pseudomonas [$\cdot 10^6$ cfu/ml]	0.09 ± 0.02	0.05 ± 0.01	0.08 ± 0.03	0.08 ± 0.03	0.05 ± 0.02	0.075 ± 0.03

Explanations: ^{a,b} means in the same row with different superscripts differ significantly ($p < 0.05$); m – mash; p – pellet; f – forage

Discussion

Carcass characteristics is a fundamental aspect that guide research on the production of fattening rabbits, due to the relevance reached by this species to produce meat of good nutritional quality (Dalle Zotte 2002, Dal Bosco et al. 2012, Capra et al. 2013) with high reproductive and growing performance. This present investigation found that sex did not significantly affect any of the carcass parameters in weaner rabbits, whereas feed type had a significant influence ($p < 0.05$) on live weight, dressing percentage and proportions of head, forelimb and loin. Non-significant influence of sex on liveweight, head, fore limb, hindlimb and chest in this study complies with the result reported by Gbenge et al. (2022). The absence of sex differences in carcass traits aligns with previous work indicating that sexual dimorphism in rabbits may be minimal at the weaner stage, and that growth and carcass deposition are more strongly affected by diet and management rather than sex per se (Okanlawon et al. 2024). This suggests uniformity of muscle and fat deposition between male and female rabbits under controlled feeding conditions at this growth stage.

The superior performance of the pellet-fed rabbits (in terms of live weight, carcass weight and dressing %) likely reflects the benefits of pelleted feeds: improved nutrient uniformity, reduced selective feeding, better digestibility, and higher nutrient density compared with mash or forage-rich diets. Pelleting generally reduces feed wastage and increases intake and nutrient availability, thereby enhancing growth performance and carcass yield. Indeed, other studies have demonstrated that pelleted diets enhance growth rate and dressing yield in rabbits (Rahman et al. 2015). In addition, the relatively lower head and forelimb proportions and higher loin proportion in the pellet group may indicate more efficient partitioning of nutrients towards high-value cuts and muscle deposition rather than structural or skeletal parts. By contrast, the mash and forage-rich diets may have led to slower muscle growth or increased relative size of less economically important parts (head, forelimbs) due to lower growth efficiency. The result of the present study for fore limbs and hind limbs percentage values was in agreement with those reported by (Yalcin et al. 2006). Fanimo et al. (2003) reported that the shoulder, rack and loin are the most economically important portions of the carcass because they provide the greatest potions of edible meat for consumers.

Intestinal organ in an animal is used to assess the toxicity of feed ingested by the animal. The higher internal organ proportions (heart, spleen) in the forage-mixed diet of rabbits may reflect elevated metabolic demands or increased visceral organ development in response to higher fibre intake, as forage diets stimulate greater gastrointestinal and reticulo-endothelial system activity (ABUBAKAR et al. 2021). The variation in the size of the lungs among the rabbits might be attributed to the health status of the rabbits and not the nutrition (SOGUNLE et al. 2014). The percentage values of heart weight were consistent with those of YALCIN et al. (2006) that were obtained with New Zealand White rabbits; they observed that variation in the size of the heart could be caused by abnormal blood circulation as affected by dietary factors. The mean values of kidney percentage in this experiment were similar with the study of YALCIN et al. (2006). The breed, age or weight of the rabbits used in experiments might create the differences in the percentages of liver, kidney and heart. There were no significant differences in female and male for the weights and the percentages of these traits. The non-significant effect of feed type on liver, kidney, lungs, and abdominal fat and spleen is in agreement with the report of ATTIA et al. (2015), which stated that feeding regimes generally had no significant effect on the weights of internal organs in rabbits. Kidney and liver are actively involved in the metabolism of carbohydrates and protein in the diets (BAWA et al. 2007). The kidney might be enlarged, and this could probably be related to a kidney overload resulting from the excess of effluents or the possibility of the presence of an anti-nutrient in feed given. The non-significant difference observed in the liver weight and lung weight indicates that the physiological and anatomical functions of these organs were not affected by the various treatments, this further indicate that the forages may not have anti-nutritive factors or toxins at the levels that tampers with the normal physiological and anatomical functions of these organs in weaner rabbits. The fact that the kidney weights were not significant implies the safety of the combination of the concentrate and forages to the health of the rabbits.

Sex influence on ileum weight and colon length may be attributed to hormonal and physiological variations in gastrointestinal motility and tissue mass, as previously observed in growing rabbits (OKANLAWON et al. 2024). Feed type markedly influenced intestinal morphometric indices. Rabbits fed 100% pellets had the highest live weight and ileum length, suggesting improved nutrient assimilation capacity. The duodenum and jejunum lengths and weights were greatest in the 50% pellet + 50% forage group, indicating a compensatory enlargement of absorptive surfaces in response to moderate fibre levels. High fibre diets often stimulate gut hypertrophy and elongation to enhance digestive retention time and microbial fermentation (CHEEKE et al. 1983). Hence, gut morphometry adapts dynamically to diet structure: pelleted diets optimize efficiency via compact villi and high nutrient concentration, while fibrous diets expand gut length to compensate for reduced digestibility. Chemical digestion and a small amount of nutrient absorption take place in the duodenum while the main function of the jejunum is absorption of important nutrients such as sugars, fatty acids and amino acid; involuntary smooth muscle contractions that move nutrients through the digestive system (Peristalsis) takes place in the jejunum. Ileum communicates with the caecum of the large intestine through the ileocaecal valve, the caecum is enlarged and is about 60% of the GIT (LEBAS et al. 1996) and is the major site of microbial fermentation. Villi heights and crypt depth are the functional units of the small intestine that assumes the role of digestion and absorption of nutrients, the morphological alterations in the GIT affects the secretion and function of digestive enzymes, WANG et al. (2023). The lamina propria provides immune defense and forms barriers to protect internal tissues from external pathogenic micro-organism. This study showed a non-significant influence of sex on intestinal morphology and this was contrary to reports by AMERAH et al. (2007) who observed no significant effect of feed type and particle size on intestinal morphology of broilers.

The significant effect of feed type on villi height of duodenum, apical width, basal width and lamina propria depth of ileum, basal width and lamina propria depth of the jejunum and the apical width, basal width of the caecum is similar to the findings reported by SOGUNLE et al. 2014 who fed growing rabbits different feed types and particle sizes and obtained significant influences of feed type on the intestinal organ. This also agrees with the study of LODDI et al. (2003) who observed varying degrees of effect on intestinal villus morphology but was contrary to reports by TUFARELLI et al. (2010) that feeding of pellets of finely ground particle size to rabbits does not have any negative effect on intestinal or gut morphology. KEMP and KENNY (2003) also reported duodenal villus morphology of locally-adapted turkeys fed two forms (pellet and mash) of feed and reported that the processing of feed can affect the ileum and caecum microflora and growth. Rabbits that are fed mash had higher villi height; this result contradicted the works of AGUZEY et al. (2018) who reported that pelletized diet caused extension of the villus, enlargement of total luminal villus absorptive area and subsequently resulted in adequate digestive enzymes action and higher transport of nutrients at the villus surface.

Intestinal microbiota refers to the collection of microorganisms that live in peaceful coexistence with their hosts. Microbial enumeration revealed that feed type significantly influenced *Escherichia coli*, *Proteus mirabilis*, and *Enterobacter* counts. Pellet-fed rabbits showed the highest *E. coli* loads ($0.65 \cdot 10^6$ cfu/ml), whereas forage-mixed diets had the lowest. This aligns with evidence that finely processed, high-starch pelleted diets can reduce microbial diversity and favour facultative pathogens due to lower digesta pH and substrate uniformity (DHAKAL et al. 2025). In contrast, moderate forage inclusion supports a balanced microbial community and competitive exclusion of pathogens through enhanced fibre fermentation and volatile fatty acid production (RASPA et al. 2024). Numerous pathogens such as *staphylococcus, Streptococcus, Escherichia coli*, *Enterobacteriaceae* have recently contaminated the meat chains (MORALES et al. 2007). Presence of *Enterobacteriaceae* indicates inadequate hygiene and presence of pathogenic microorganisms. The safety of meat and shelf life of meat is limited by microbial growth, where a high initial contamination of meat reduces product shelf life. The difference in the bacteria count may be attributed to slaughtering process which may cause extensive contamination of muscle tissue with a vast range of micro-organisms. Some of these microorganisms come from the animal intestinal tract and others from the environment in contact with the animals before or during slaughter (KOUTSOUMANIS and SOFOS 2004).

Conclusion

This study concluded that feed type exerted a greater influence than sex on carcass characteristics, intestinal morphometry, histomorphology, and microbial balance of weaner rabbits. Pelleted diets improved live weight, dressing yield, and loin proportion through enhanced nutrient availability, but reduced villi height and microbial diversity.

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