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Effects of Housing and Feeding Types on Growth and Physiological Performance of Growing Rabbits (*Oryctolagus cuniculus*) in Humid Tropics

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Abstract | The study aimed to evaluate the impact of housing and feeding types on the growth and physiological response of growing rabbits. The study involved Ninety unsexed matured New Zealand White rabbits, which were randomly assigned to three housing systems (concrete pen with litter filled floor [H_1], concrete pen with soil filled floor [H_2], and battery cage [H_3]) and three feeding systems (forage only [F_1], concentrate feed only [F_2], and forage + concentrate [F_3]) in a 3x3 factorial completely randomized experimental design for ten weeks. The study found that the main effect of housing and feeding systems with their interaction had a significant ($p<0.05$) effect on measured growth and hematological parameters. Measured serum biochemical indices of rabbits were not significantly ($p>0.05$) affected by treatments. Rabbit carcass weight (kg) and dressing-out percentage (%) were significantly ($p<0.05$) affected by the main and interactive effect of housing with feeding systems. Overall, H_3 and F_3 had the best growth performance, carcass characteristics and physiological response ($p<0.05$) as compared to other treatment groups. The interaction effects revealed that the combination of H_3 x F_3 had the best performance ($p<0.05$) as compared to other groups. Rabbits on H_1 and F_1 had the lowest overall performance ($p<0.05$) based on measured parameters, no mortality was recorded in the study. In conclusion, both housing and feeding types are capable of influencing rabbit production. Feeding rabbits with a combination of forage with concentrate in a battery cage housing system is suitable for optimum rabbit production in humid tropics.

Keywords | Feeding systems, Pen types, Cage, Growth indices, Biochemical parameters, Rabbit

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INTRODUCTION

Over the years, farmed rabbit (*Oryctolagus cuniculus*) production has gained popularity and proven to be a viable means of increasing animal protein sources (Akinmoladun *et al*., 2018). Apart from the nutritional attributes of its meat (rich in protein, low in cholesterol and fat), the rabbit has a high growth rate, produces large litters with short generation intervals, and can subsist on forage, unlike other livestock (Prajapati *et al*., 2019).

In most developing countries, the high feed costs and scarcity of quality feed and fodders constitute a significant constraint to livestock production (Nworgu *et al*., 2000; Alabi *et al*., 2017). Being primarily herbivores and hindgut fermenters, rabbits could effectively utilize quality fodders exclusively or combined with concentrates (Bhatt *et al*., 2009). Studies evaluating rabbit management with forages and compounded concentrates/supplements have been well explored. However, rabbits reared solely on forages (Bamikole and Ezenwa, 1999) or compounded concentrates (Khuc and Preston, 2006) do not give optimum results in the tropics.

The type of housing environment adopted should provide a sufficient allowance for growing rabbits to stretch and move at all age intervals (Onbasilar *et al*., 2005). Rabbits can be reared in cages or pens (deep litter), either individually or in a grouped housing system, and each comes with its own merits and demerits. In addition to the restricted movement space that cages cause, studies have shown that housing rabbits in cages causes stress, reduces feed intake and weight gain, and increases the likelihood of aggressive lesions on the body (Szendro and Dalle-Zotte, 2011). On the other side, the pen floor gives the animal constant, direct contact with the floor (locomotive and resting behaviour) and, when adequately bedded, provides a warm lying area for rabbits, thereby minimizing the influence of environmental temperatures (Matics *et al*., 2014; Prajapati *et al*., 2019). Despite the advantage of deep litter, studies have shown that rabbits can consume litter materials, thus predisposing them to an increased risk of digestive diseases and mortality (Dal Bosco *et al*., 2002). Rabbits found to have consumed litter materials show reduced weight gain, body weight and dress-out percentage due to reduced feed consumption (Combes *et al*., 2010). Ayoola *et al*. (2020) affirmed that the improvement of reproductive patterns in rabbits should correspond to welfare concerning housing and feeding for profit maximization.

The effect of housing systems on rabbits' growth, welfare and reproductive characteristics have been well documented (Ndor *et al*., 2010; Krunt *et al*., 2020). There are factors in the blood whose levels are usually determined to assess the degree of well-being of animals as deviation in these factors is used to assess nutritional stress or other factors that predispose animals to stress (Ayoola *et al*., 2023). The commonest parameter for measuring these implications is through the blood serum biochemistry of the animals (Aro *et al*., 2013). Haematological studies are important because the blood is the major transport system of the body, and an evaluation of the haematological profile usually furnishes vital information on the body's response to injury of all forms, including toxic injury (Ihedioha *et al*., 2004). Moreover, the comparison of blood profile with nutrient intake might indicate the need for adjustment of certain nutrients upward or downward for rabbits (Rafiu *et al*., 2013).

Hypothetically, a combination of an appropriate housing and feeding system will significantly improve the productivity and welfare of rabbits. Experiments that assessed the combined effect of feeding and housing systems on rabbits are sparse. Hence, this study assesses rabbits' growth and health status under three housing and feeding systems.

MATERIALS AND METHODS

Study area and ethical clearance

The research was conducted at the Teaching and Research Farm, Bowen University, Iwo Osun State, Nigeria. The experimental site lies approximately on latitude 4.1770° E and longitude 7.6401° N with an average temperature of 28.4°C and average precipitation (rainfall) rate of 206.63mm. The methods/procedures used in this study were concomitant with those outlined in the Animals ARRIVE guidelines and were carried out by the U.K. Animals (Scientific Procedures) Act, 1986 and associated guidelines; EU Directive 2010/63/EU for animal experiments; or the National Institutes of Health guide for the care and use of laboratory animals (NIH Publications No. 8023, revised 1978). The study was conducted with the approval of the Bowen University Ethics Committee.

Experimental animals, design and management

Ninety (90) unsexed New Zealand White rabbits (average weight: 0.92±0.01 kg) of 60 days old were allotted to the three housing systems and three feeding systems in a 3x3 factorial experiment in a completely randomized design. The treatment groups were three housing systems (concrete pen with litter filled floor (H_1), concrete pen with soil filled floor (H_2) and battery cage (H_3) and three feeding systems (forage only (F_1), concentrate only (F_2), and forage+concentrate (F_3). Rabbits were fed *ad libitum* throughout the trial period that lasted 10 weeks, and the forage+concentrate combination was offered as a total mixed ration (concentrate in the morning, and forage at evening). The animals were housed in a nine (9) housing and diet combination groups (dietary forage (*Tridax procumbens*), compounded feed alone or both) with five (5) animals per treatment. Each treatment was replicated twice, and water was administered *ad libitum*. The dimension of each cage was 1.025x0.525 m, basic area 0.54 m^2 and five rabbits were housed per cage). The concrete pen with litter filled floor was constructed using concrete and spread with litter floor material of wood shaving at 5cm thickness. The concrete floor filled with soil was made of concrete and filled with sand at 30cm thickness. Each rabbit was provided (1.35 x 0.925) 1.2 m^2) of floor space and standard routine management throughout the experimental trial. The rabbits were acclimatized for one week in their respective treatment groups before the commencement of the trial. In this study, pens and cages were kept under the same micro-environment (Temperature 25.00±0.61°C and relative humidity 65.00±3.38%) where a continuous 16L: 8D lightning schedule was applied throughout the experiment. The simulated floor was stirred and disinfected every two weeks with antimicrobial/fungicide (Polidine (Iodophor), and the cages, feeder, and water trough were regularly cleaned. The litters and soil bedding was changed twice during the 10 weeks trial. The concentrate diet was formulated to satisfy the nutritional needs of growing rabbits. Table 1 lists the components and nutrient makeup of concentrate and forage diets.

Table 1: Ingredients, nutrient compositions of concentrate (g/kg) diets.

Ingredient	% Inclusions	Forage (*T. procumbens*)
Maize	49.3	-
Wheat offal	16.0	-
Groundnut cake	12.5	-
Soyabean meal	14.5	-
Oyster shell	1.0	-
Bone meal	2.0	-
Premix*	2.5	-
Salt	2.0	-
Methionine	0.1	-
Lysine	0.1	-
Total	100	-
Calculated values		
Metabolizable energy (Kcal/kg)	2800.5	-
Moisture	8.35	14.10
Crude protein (%)	20.1	16.01
Crude fibre (%)	4.98	10.52
Ether extract (%)	5.5	3.05
Ash	7.25	12.55
Nitrogen free extract	65.12	25.16

*Premix to provide the following per kg of feed: Vitamin A-500 IU, Vit. D3 - 1,200 mg, Vit. E - 11 mg, Vit. K3 - 2 mg, Riboflavin - 20 mg, Nicotinic acid -10 mg, Pantothenic acid - 7 mg, Cobalamin - 0.08 mg, Choline chloride - 900 mg, Folic acid - 1.5 mg, Biotin - 1.5 mg, Iron – 25 mg, Manganese - 80 mg, Copper - 2 mg, Zinc – 50 mg, Cobalt - 1.2 mg and Selenium - 0.1 mg.

Data collection

Growth performance

Over a ten-week trial period, the average daily weight gain (ADWG), average daily feed intake (ADFI), final body weight and feed conversion ratio (FCR) were measured, along with mortality.

Blood collection and analysis

Blood samples were taken from two randomly chosen rabbits from each replicate group at the end of the experiment (n = 36). Sterilized syringes and needles were used to draw around 5 ml of blood from the external ear vein into two clearly labelled tubes (with or without anticoagulants) and transported immediately with an ice pack container to the laboratory for analysis. Packed cell volume, white blood cell, red blood cell, and haemoglobin were evaluated as haematological parameters, while the serum biochemical indices including total serum protein, creatinine, aspartate aminotransferase, and alanine aminotransferase were evaluated following standard procedures (Schalm *et al*., 1975).

Carcass characteristic and internal organs analysis

On the 70th day of the experiment, 36 rabbits (all healthy rabbits: n=2/replicate for each treatment group of feed type and housing) were randomly picked for slaughtering and further analysis. They were fasted for six hours and slaughtered by cutting the carotid arteries and jugular veins after electrical stunning. The Slaughter and carcass dissection procedures were by the recommendation of the World Rabbit Science Association (Blasco and Ouhayoun 1996). Data on carcass weight, dressing-out percentage, liver, heart, lungs, kidney and spleen weight were collected.

Dressing-out percentage (DP)% = (carcass weight / live weight) x 100

Statistical analysis

For the factorial experiment in a completely randomized design for growth performance and haemato-biochemical variables with feeding and housing systems as the major influence, the data collected were subjected to analysis of variance using the general linear model procedure (PROC GLM) of SAS. Duncan's multiple range test of the same software was used to separate the difference in means. A significant difference was arrived at when $p<0.05$. The experimental model used was:

$$Y_{ijk} = \mu + H_i + F_j + (HF)_{ij} + e_{ijk}$$

Where Y_{ij} = individual observation; μ = population mean; H_i = effect of housing system (i = 1-3); F_j = effect of feeding system (j = 1-3); $(HF)_{ij}$ = interaction effect of housing and feeding system; e_{ijk} = expected error

RESULTS AND DISCUSSION

Results of the main and interaction effects between the housing and feeding systems are provided separately.

Table 2: Main effect of housing type on the growth performance of growing rabbit over 70 day's trial (n=90).

Parameters	H_1	H_2	H_3	SEM	P-value
IBW (kg)	0.94	0.93	0.90	0.52	0.175
FBW (kg)	1.47^{c}	1.90^{ab}	1.95^{a}	0.55	0.020
ABWG (kg)	0.53^{c}	0.97^{b}	1.05^{a}	0.36	0.029
AFI (kg)	6.04	6.67	6.64	0.11	0.144
FCR	4.10^{a}	3.51^{b}	3.41^{c}	0.06	0.033
Mortality (%)	0.00	0.00	0.00	0.00	0.00

^{abc} means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis. IBW: initial body weight; FBW: final body weight; ABW: average body weight gain; AFI: average feed intake; FCR: feed conversion ratio; H_1: pen with litter floor; H_2: pen with soil floor; H_3: battery cage system.

Table 2 displays how housing types affect rabbit growth performance. Each of the growth performance measured, including final body weight (FBW), average body weight gain (ABWG), and feed conversion ratio (FCR) were all affected significantly ($p<0.05$), except for the average feed intake (AFI). Battery cage housing type had the highest FBW and best FCR that is significantly higher ($p<0.05$) as compared to other treatments, however, the effect of housing type (H_2) concrete pen with soil filled floor on FBW was similar ($p<0.05$) to the battery cage housing type.

Table 3: Main effect of feeding systems on the growth performance of growing rabbits (n=90).

Parameters	F_1	F_2	F_3	SEM	P-value
IBW (kg)	0.98	0.97	0.99	0.09	0.172
FBW (kg)	1.05^{c}	1.88^{b}	2.07^{a}	0.05	0.001
ABWG (kg)	0.07^{c}	0.91^{ab}	1.08^{a}	0.08	0.001
AFI, kg	4.51^{c}	5.90^{b}	6.24^{a}	0.04	0.046
FCR	4.30^{a}	3.14^{b}	3.01^{b}	0.03	0.003
Mortality	0.00^{a}	0.00	0.00	0.00	

^{abc} means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis. IW: initial weight; FBW: final body weight; ABWG: average body weight gain; AFI: average feed intake; FCR: feed conversion ratio; F_1 – forage, F_2 –concentrate only, F_3 -forage with concentrate.

The effect of different feeding systems on growth performance of growing rabbits is shown in Table 3. Rabbits fed the forage-concentrate mixture (F_3) had the highest ($p<0.05$) average body weight gain (ABWG), FBW, AFI and best FCR. However, the effect of concentrate feed (F_2) alone on the ABWG of growing rabbits was similar ($p>0.05$) to that of F_3. The interaction effect of housing and feeding systems on the growth performance of growing rabbits is shown in Table 4. The interaction effects of housing and feeding systems were significant ($p<0.05$) for all the measured growth performance parameters. The combined impact of H_2xF_3 produced the highest ($p<0.05$) ABWG. The interaction effect of F_3 with all housing types gave the highest value ($p<0.05$) as compared to other combinations. However, the interaction effect on AFBW, AFI, and FCR saw that H_3xF_3 had the highest value and best FCR ($p<0.05$), respectively. Similarly, it was observed that the interaction effect of F_3 with all housing types gave the highest value ($p<0.05$) as compared to other combinations for all measured growth parameters.

Table 4: Interaction effect of housing and feeding systems on the growth performance of growing rabbit (n=90).

Parameters	Housing type	Feeding system	Interactions		SEM	P value
ABWG (kg)	H_1	F_1	H_1xF_1	0.56^{c}	0.07	0.038
		F_2	H_1xF_2	1.11^{b}		
		F_3	H_1xF_3	1.62^{a}		
	H_2	F_1	H_2xF_1	0.55^{c}		
		F_2	H_2xF_2	1.12^{b}		
		F_3	H_2xF_3	1.72^{a}		
	H_3	F_1	H_3xF_1	0.53^{c}		
		F_2	H_3xF_2	1.45^{b}		
		F_3	H_3xF_3	1.53^{a}		
AFBW (kg)	H_1	F_1	H_1xF_1	1.20^{c}	0.05	0.043
		F_2	H_1xF_2	1.67^{b}		
		F_3	H_1xF_3	1.75^{a}		
	H_2	F_1	H_2xF_1	1.44^{c}		
		F_2	H_2xF_2	1.81^{ab}		
		F_3	H_2xF_3	1.83^{a}		
	H_3	F_1	H_3xF_1	1.50^{c}		
		F_2	H_3xF_2	1.87^{b}		
		F_3	H_3xF_3	1.98^{a}		
AFI (kg)	H_1	F_1	H_1xF_1	4.13^{c}	0.03	0.041
		F_2	H_1xF_2	5.28^{b}		
		F_3	H_1xF_3	6.33^{a}		
	H_2	F_1	H_2xF_1	4.16^{c}		
		F_2	H_2xF_2	6.30^{ab}		
		F_3	H_2xF_3	6.28^{a}		
	H_3	F_1	H_3xF_1	4.11^{c}		
		F_2	H_3xF_2	6.31^{ab}		
		F_3	H_3xF_3	6.33^{a}		
FCR	H_1	F_1	H_1xF_1	4.04^{a}	0.02	0.026
		F_2	H_1xF_2	3.24^{b}		
		F_3	H_1xF_3	3.20^{bc}		
	H_2	F_1	H_2xF_1	4.01^{a}		
		F_2	H_2xF_2	3.25^{b}		
		F_3	H_2xF_3	3.21^{bc}		
	H_3	F_1	H_3xF_1	4.01^{a}		
		F_2	H_3xF_2	3.21^{bc}		
		F_3	H_3xF_3	3.19^{c}		

^{abc} means with similar superscripts down to the column are not significantly (P > 0.05) different. *; P<0.05. IW: initial weight; FW: final weight; ABW: average body weight; AFI: average feed intake; FCR: feed conversion ratio; F_1 – forage, F_2 –concentrate only, F_3 -forage with concentrate; H_1: pen with litter floor; H_2: pen with soil floor; H_3: battery cage system.

Table 5: Main effect of different feeding system on the blood indices of growing rabbit (n=36).

Parameters	F_1	F_2	F_3	SEM	p-value
Haematology					
WBC (x10⁹/µl)	10.05[a]	7.72[b]	7.51[b]	0.70	0.028
RBC (x10¹²/µl)	3.32[c]	4.41[b]	5.70[a]	0.42	0.042
Hb (g/dL)	11.16[c]	13.72[b]	15.14[a]	0.60	0.045
PCV (%)	38.01[c]	41.18[ab]	45.11[a]	1.38	0.041
Serum biochemical indices					
Tp (g/dL)	76.25	76.77	76.65	0.50	0.083
Creatinine (mg/dl)	0.85	0.71	0.91	4.50	0.238
ALT (U/L)	39.75	31.61	30.01	6.35	0.334
AST (U/L)	89.34	90.75	90.10	6.10	0.121

[ab] "Means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis". WBC = White blood cell, RBC = Red blood cell, Hb = Haemoglobin, PCV = Pack cell volume, Tp = Total protein, ALT= Alanine aminotransferase, AST = Aspartate aminotransferase", F_1 – forage, F_2 –concentrate only, F_3 -forage with concentrate".

Table 6: Main effect of different housing typeon the blood indices of growing rabbit (n=36).

Parameters	H_1	H_2	H_3	SEM	p-value
Haematology					
WBC (x10⁹/L)	10.79[a]	8.30[c]	9.88[ab]	0.70	0.002
RBC (x10¹²/L)	4.32[b]	5.41[a]	5.75[a]	0.42	0.041
Hb (g/dL)	11.16[c]	14.72[a]	13.44[a]	0.60	0.042
PCV (%)	37.1[c]	45.28[a]	42.41[ab]	1.38	0.037
Serum biochemical indices					
Tp (g/dL)	76.15	70.10	70.17	0.50	0.062
Creatinine (µmol/L)	1.85	1.71	1.72	4.50	0.073
ALT (IU/L)	39.75	38.61	38.9	6.35	0.061
AST (IU/L)	91.34	81.75	93.10	6.10	0.064

[abc] Means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis". WBC = White blood cell, RBC = Red blood cell, Hb = Haemoglobin, PCV = Pack cell volume, ALT= Alanine aminotransferase, AST = Aspartate aminotransferase, H_1: pen with litter floor; H_2: pen with soil floor; H_3: battery cage system.

The main effect of different feeding systems on the blood indices of growing rabbits is shown in Table 5. The combined feed type (F_3) promoted the highest ($p<0.05$) red blood cell count (RBC), haemoglobin (Hb) and packed cell volume (PCV) compared to F_2 and F_1. Feeding rabbits with forage alone produced the highest ($p<0.05$) WBC but the lowest ($p<0.05$) in other haematological parameters. However, the effect of the different feeding systems was not significant ($p>0.05$) on the measured serum biochemical indices. The main effect of different housing systems on the blood indices of growing rabbits is shown in Table 6. Concrete pen with litter filled floor (H_1) promoted the highest ($p<0.05$) WBC, which is not significant ($p>0.05$) from battery cage (H3). RBC, Hb and PCV were not significant ($p>0.05$) for H_2 and H_3 but were different ($p<0.05$) for H_1. In the same line, the effect of the different housing types was not significant ($p>0.05$) on the measured serum biochemical indices.

Table 7: The interaction effect of the housing and feeding systems on the haematological indices of growing rabbits (n=36).

Parameters	Housing type	Feeding system	Interactions		SEM	P value
WBC (x10⁹/L)	H_1	F_1	H_1xF_1	12.76[a]	0.70	0.022
		F_2	H_1xF_2	10.01[b]		
		F_3	H_1xF_3	8.62[c]		
	H_2	F_1	H_2xF_1	10.15[b]		
		F_2	H_2xF_2	9.72[bc]		
		F_3	H_2xF_3	7.05[c]		
	H_3	F_1	H_3xF_1	12.45[a]		
		F_2	H_3xF_2	10.05[b]		
		F_3	H_3xF_3	9.33[bc]		
RBC (x10¹²/L)	H_1	F_1	H_1xF_1	3.40	0.92	0.130
		F_2	H_1xF_2	4.03		
		F_3	H_1xF_3	4.53		
	H_2	F_1	H_2xF_1	4.36		
		F_2	H_2xF_2	5.01		
		F_3	H_2xF_3	5.85		
	H_3	F_1	H_3xF_1	3.75		
		F_2	H_3xF_2	4.61		
		F_3	H_3xF_3	4.88		
Hb (g/dL)	H_1	F_1	H_1xF_1	10.04	0.60	0.082
		F_2	H_1xF_2	12.24		
		F_3	H_1xF_3	12.20		
	H_2	F_1	H_2xF_1	10.91		
		F_2	H_2xF_2	13.75		
		F_3	H_2xF_3	12.49		
	H_3	F_1	H_3xF_1	10.02		
		F_2	H_3xF_2	12.02		
		F_3	H_3xF_3	13.28		
PCV (%)	H_1	F_1	H_1xF_1	42.04	1.40	0.111
		F_2	H_1xF_2	40.14		
		F_3	H_1xF_3	44.12		
	H_2	F_1	H_2xF_1	44.91		
		F_2	H_2xF_2	42.75		
		F_3	H_2xF_3	42.19		
	H_3	F_1	H_3xF_1	41.02		
		F_2	H_3xF_2	41.62		
		F_3	H_3xF_3	42.58		

[abc] means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis, IW: initial weight; FW: final weight; ABW: average body weight; AFI: average feed intake; FCR: feed conversion ratio; F_1 – forage, F_2 –concentrate only, F_3 -forage with concentrate; H_1: pen with litter floor; H_2: pen with soil floor; H_3: battery cage system.

Table 8: The interaction effect of the housing and feeding systems on the serological indices of growing rabbits (n=36).

Parameters	Housings	Feedings	Interactions		SEM	P value
Total serum protein (g/dL)	H_1	F_1	H_1xF_1	70.76	0.30	0.212
		F_2	H_1xF_2	73.01		
		F_3	H_1xF_3	71.62		
	H_2	F_1	H_2xF_1	75.15		
		F_2	H_2xF_2	75.72		
		F_3	H_2xF_3	76.05		
	H_3	F_1	H_3xF_1	71.09		
		F_2	H_3xF_2	72.45		
		F_3	H_3xF_3	73.33		
Creatinine (µmol/L)	H_1	F_1	H_1xF_1	1.40	0.65	0.080
		F_2	H_1xF_2	1.43		
		F_3	H_1xF_3	1.53		
	H_2	F_1	H_2xF_1	1.36		
		F_2	H_2xF_2	1.31		
		F_3	H_2xF_3	1.35		
	H_3	F_1	H_3xF_1	1.55		
		F_2	H_3xF_2	1.61		
		F_3	H_3xF_3	1.58		
ALT (IU/L)	H_1	F_1	H_1xF_1	30.04	0.70	0.111
		F_2	H_1xF_2	32.24		
		F_3	H_1xF_3	34.20		
	H_2	F_1	H_2xF_1	30.91		
		F_2	H_2xF_2	33.75		
		F_3	H_2xF_3	35.49		
	H_3	F_1	H_3xF_1	30.02		
		F_2	H_3xF_2	35.02		
		F_3	H_3xF_3	33.28		
AST (IU/L)	H_1	F_1	H_1xF_1	92.04	1.13	0.091
		F_2	H_1xF_2	90.14		
		F_3	H_1xF_3	94.12		
	H_2	F_1	H_2xF_1	90.91		
		F_2	H_2xF_2	92.75		
		F_3	H_2xF_3	96.19		
	H_3	F_1	H_3xF_1	91.02		
		F_2	H_3xF_2	98.62		
		F_3	H_3xF_3	96.58		

[abc] means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis; IW: initial weight; FW: final weight; ABW: average body weight; AFI: average feed intake; FCR: feed conversion ratio; F_1 – forage, F_2 –concentrate only, F_3 -forage with concentrate; H_1: pen with litter floor; H_2: pen with soil floor; H_3: battery cage system.

The interaction effect of housing and feeding systems on the haematological indices of growing rabbits is shown in Table 7. The interaction effects of housing and feeding systems were insignificant (p>0.05) on the RBC of experimental rabbits. However, the highest (p<0.05) values of WBC were recorded in the interactions of H_1xF_1, and H_3xF_1 as compared to others. The values recorded for Hb and PCV in the experimental rabbits were not significantly (p>0.05) different across the experimental treatments. The interaction effect of housing and feeding systems on serological indices of rabbits was not (p>0.05) significant as shown in Table 8.

The main effect of housing and feeding systems as presented in Tables 9 and 10 shows that carcass weight and dressing out percentage of rabbits are significantly (p<0.05) different across the treatments. Rabbits on H_3 and F_3 had the highest value (p<0.05) for both measured parameters, respectively. Other measured parameters were not (p>0.05) affected by the treatment. The interaction effect of housing x feeding systems on carcass weight and dressing out percentage were the only parameters that were significantly (p<0.05) affected as shown in Table 11. H_3 x F_3 and H_1 x F_1 had the highest and lowest values (p<0.05).

Table 9: Main effect of housing type on the carcass and relative internal organs (% slaughter weight) of growing rabbit at 70th day's trial (n =36).

Parameters	H_1	H_2	H_3	SEM	P-value
Carcass weight (kg)	0.93[c]	1.15[ab]	1.17[a]	0.42	0.045
Dressing-out percentage	50.47[c]	58.10[ab]	61.95[a]	3.55	0.030
Liver (g)	2.45	2.48	2.53	0.16	0.91
Heart (g)	0.22	0.24	0.26	0.01	0.34
Lung (g)	0.38	0.39	0.40	0.06	0.41
Kidney (g)	0.44	0.42	0.44	0.03	0.42
Spleen (g)	0.02	0.04	0.03	0.05	0.51

[abc] means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis. IBW: initial body weight; FBW: final body weight; ABW: average body weight gain; AFI: average feed intake; FCR: feed conversion ratio; H_1: pen with litter floor; H_2: pen with soil floor; H_3: battery cage system.

Table 10: Main effect of feeding systems on the carcass and relative internal organs (% slaughter weight) of growing rabbit at 70th day's trial (n =36).

Parameters	F_1	F_2	F_3	SEM	P-value
Carcass weight (kg)	0.72[b]	1.14[b]	1.24[a]	0.09	0.025
Dressing-out percentage (%)	48.05[c]	55.88[b]	62.07[a]	5.05	0.001
Liver (g)	2.75	2.68	2.73	0.18	0.91
Heart (g)	0.27	0.25	0.26	0.03	0.25
Lung (g)	0.40	0.36	0.40	0.04	0.51
Kidney (g)	0.52	0.45	0.54	0.02	0.35
Spleen (g)	0.05	0.02	0.05	0.01	0.31

[abc] means along the same row with similar superscripts are not significantly (P > 0.05) different using Duncan's test as post hoc analysis; IW: initial weight; FW: final weight; ABWG: average body weight gain; AFI: average feed intake; FCR: feed conversion ratio; F_1 – forage, F_2 –concentrate only, F_3 -forage with concentrate.

Table 11: The interaction effect of the housing and feeding systems on the carcass and relative internal organs (% slaughter weight) of growing rabbit at 70th day's trial (n =36).

Parameters	Housings	Feedings	Interactions		SEM	P value
Carcass weight (kg)	H_1	F_1	H_1xF_1	0.76^d	0.30	0.02
		F_2	H_1xF_2	0.98^c		
		F_3	H_1xF_3	1.10^{ab}		
	H_2	F_1	H_2xF_1	0.85^d		
		F_2	H_2xF_2	1.02^b		
		F_3	H_2xF_3	1.15^{ab}		
	H_3	F_1	H_3xF_1	0.92^c		
		F_2	H_3xF_2	1.17^b		
		F_3	H_3xF_3	1.23^a		
Dressing-percentage (%)	H_1	F_1	H_1xF_1	48.40^b	0.65	0.030
		F_2	H_1xF_2	50.03^{bc}		
		F_3	H_1xF_3	53.51^a		
	H_2	F_1	H_2xF_1	48.76^b		
		F_2	H_2xF_2	52.01^{bc}		
		F_3	H_2xF_3	55.05^a		
	H_3	F_1	H_3xF_1	49.85^c		
		F_2	H_3xF_2	52.61^{ab}		
		F_3	H_3xF_3	57.18^a		

[abc] means along the same row with similar superscripts are not significantly ($P > 0.05$) different using Duncan's test as post hoc analysis; IW: initial weight; FW: final weight; ABW: average body weight; AFI: average feed intake; FCR: feed conversion ratio; F_1 – forage, F_2 –concentrate only, F_3 -forage with concentrate; H_1: pen with litter floor; H_2: pen with soil floor; H_3: battery cage system.

Studies have indicated that rabbits housed in battery cages perform better in terms of growth than pen-housed rabbits, which usually perform worse (Szendro and Dalle-Zotte, 2011). However, some studies reported no change in live performance when rabbits were maintained in either pens or cages (Krunt *et al*., 2020; Matics *et al*., 2014). The housing system in this experiment affected the final body weight, average body weight and FCR. This study's findings regarding the impact of housing on growth performance were consistent with those of several other researches (Prajapati *et al*., 2019; Dal Bosco *et al*., 2002). A similar effect of non-significance on growing rabbits' feed intake in cages or pens has been reported (Szendro *et al*., 2015). However, Matics *et al*. (2014) averred a significantly lower average body weight gain and average final body weight for rabbits housed in pens with straw litter than in battery cages or elevated wired platforms. The authors attributed the depression in daily gain to a much-increased consumption of litter materials by the rabbits, as observed in the significantly lowered feed intake. Szendro and Dalle (2011), on the other hand, explained the slower growth seen in rabbits raised in pens as being caused by their higher level of physical activity, thus depleting the ingested energy. The continual energy loss from high locomotive activity that occurs when bunnies are confined in pens typically causes chronic stress, which lowers body weight gain (Szendro *et al*., 2009).

In this study, the varieties of feed groups adopted substantially impacted the growth performance of rabbits. The high crude fibre concentration in *T. procumbens* could make it less preferable to concentrate with a much lower crude fibre level (Odeh *et al*., 2022). Our report contrasts with other authors (Gidenne *et al*., 2010; Gomez-Conde *et al*., 2009), who reported improved digestive health and reduced mortality in growing rabbits fed forage with high fibre. The higher but similar feed intakes in the F_2 and F_3 rabbit groups indicate that they were more palatable than ordinary forage (F_1) due to their high crude protein content. This higher feed intake contributed to their much-increased final weight and average daily weight gain. A similar observation was reported by Iyeghe-Erakpotobor (2007) on growing rabbits fed with different concentrate and forage types. Compared to other feeding systems, the lowest FCR recorded for F_1 resulted from the lowest AFI and ABWG. This finding agrees with Odeh *et al*. (2022) and Hasanat *et al*. (2006), who reported increased daily weight gain from a rabbit-fed concentrate diet. Feeding forage alone would not sustain appropriate growth performance, according to Iyeghe-Erakpotobor *et al*. (2015). Rabbits can thrive by consuming forage diets. However, a mixed feeding regimen that includes both forages and concentrates improves performance (Arijeniwa *et al*., 2000). This study suggests that better growth performance can be achieved when rabbits are fed a combination of concentrate and forage (F_3). This was further bolstered by the significant interaction effect of housing and feeding types on the various growth performance parameters. The measured growth performance indices are at their best when feed type F3 is combined with either housing H_3 or H_2. Our current findings also align with Rahman *et al*. (2020) who reported rabbits as pseudo-ruminants, able to digest forages and concentrates. This result corroborated previous findings of Akinmoladun *et al*. (2018) and Nworgu *et al*. (2000), who found higher daily weight gain in rabbits on the dietary mixture (concentrate and forages) compared to those fed forages alone. However, other studies have reported higher weight gains in rabbits fed with concentrate alone compared to a dietary mixture (Christopher *et al*., 2023; Nworgu *et al*., 2000).

The assessment of haematological parameters provides valuable insights into the physiological status of animals and their response to various physiological situations, as noted by Esonu *et al*. (2006). As Daramola *et al*. (2005) noted, these metrics can also be used as a benchmark for comparison in situations involving nutrient deprivation, physiological changes, and animal health conditions. The

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significant effect of housing types on all the haematological indices of rabbits in this study contradicts what Szendro *et al.* (2015) reported, who observed no difference ($p>0.05$) between battery cage and deep litter on the haematology of growing rabbits. However, the mean values of WBC (7.51-10.05 x 109/L) for the main effects of feeding and housing types were close to the normal physiological range for rabbits (Wiley-Blackwell, 2011; Mitruka and Rawnsley, 1977). Hence, this suggests that the defence mechanisms of the rabbits were not compromised. The range of Hb (11.16-15.14 g/dl) and PCV (38.01-45.11 %) for the main effects in this study were within the reported range of 10-17.4g/dl or 9.0-21.3g/dl and 33.0-50.0% or 27-57% (Bennette and Hawkey, 1988) for Hb and PCV respectively. This normal range of PCV and Hb reflects that the rabbits were in good health and were not dehydrated or anaemic. The amount of protein that is readily available influences the production of serum protein and albumin (Qian *et al.*, 2022). The non-significant ($p>0.05$) housing and feeding type effect on serum protein could indicate that protein synthesis was not compromised. Although the serum biochemical indices were within the normal range (Hewitt *et al.*, 1989). Studies have demonstrated that the kind and amount of dietary protein affects the levels of creatinine and total protein (Qian *et al.*, 2022). Excess creatinine in the blood is typically caused by enhanced creatinine phosphate catabolism in specific illness states (such as muscle wasting) (Zsolt *et al.*, 2019).

As reported in Table 7, the significant interaction effect of housing and feeding types on WBC indicated that both factors are capable of interfering with the body defence mechanism of the treated animals. The measured WBC blood performance indices were at the highest when fed feed type F_1 was combined with either housing H_1 or H_3. This may imply that feeding rabbits 100% forage may decline the ability of rabbits to fight infection, while housing type on litter (H_1) and battery cage with mesh floor (H_3) could expose the rabbits to infection due to direct access to feaces and cage fatigue respectively (Togun *et al.*, 2007). The values of measured WBC are within the normal range for healthy rabbit (Wiley-Blackwell, 2011). Yet, the results of this study show that serum transaminases were within the normal range (Wiley-Blackwell, 2011; Mitruka and Rawnsely, 1977). Hence, the housing and feed systems support growing rabbit production without deleterious effects on their immune status.

The results for the main effect of housing and feeding type as presented in Tables 9 and 10, respectively show that both carcass weight and dressing percentage of rabbits were significantly affected ($p<0.05$). The significant interaction ($p<0.05$) effect was at the highest for both carcass weight and dressing percentage when H_3 and F_3 were combined and with other housing or feeding types. These findings are related to the significant difference in final body weight as earlier reported for main and interaction effects. These results corroborate those of (Dalle *et al.*, 2015; Szendro *et al.*, 2009). The no significant ($p>0.05$) effect observed in the main effect of housing and feeding type with their interaction on measured organ weights shows that the treatments do not have any negative effect on the weight of measured organ parameters.

CONCLUSIONS AND RECOMMENDATIONS

The findings indicated that the three housing systems could be used effectively for rabbit production based on the data recorded in these findings. The battery cage system had the highest average body weight gain and FCR. However, the concrete pen with the soil filled floor system may be considered a suitable alternative housing systems because it satisfies the specific requirement of rabbits and also allays the ethical concern related to animal welfare in modern livestock production. Feeding forages only to growing rabbits or concentrate only as their main diet should be done cautiously due to disrupting the gastrointestinal tracts. On the other hand, a feeding system of concentrate or a combination of forage and concentrate yielded good results.

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NOVELTY STATEMENT

The study's originality focuses on the interaction effect of housing and feeding types on physiological performance of growing rabbits.

AUTHOR'S CONTRIBUTION

AM and SK: Conceptualization, methodology, software. SK, AM and AF: Data curation, writing, original draft preparation. AM and OA: Visualization, investigation. LT: Supervision. OA and FT: Software, validation. AM, AF and SK: Writing- reviewing and editing.

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All the information and results used to complete the

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Conflict of interest

The authors have declared no conflict of interest.

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