

PERFORMANCE, HAEMATO-BIOCHEMICAL AND REPRODUCTIVE POTENTIAL INDICES OF NEW ZEALAND WHITE AND DUTCH BELTED RABBIT BUCKS FED DIETS CONTAINING MONOSODIUM GLUTAMATE

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Abstract: The study aimed to assess the growth performance, haematology, serum biochemistry, gonadal and extragonadal sperm reserves of two breeds of rabbit bucks fed dietary monosodium glutamate (MSG) at varying inclusion levels (0.00, 0.25, 0.50 and 0.75 g/kg diet). A total of 320 sexually mature New Zealand White Bucks and Dutch Belted Bucks aged 8 to 10 mo with average weight ranging from 1.34 to 1.96 kg were used for the study, which lasted 8 wk. The bucks were weighed and distributed to the four treatment diets. Each treatment was replicated 10 times with four bucks per replicate in a 2×4 factorial experiment. At the end of the feeding trial, 2 bucks per replicate were euthanised. Blood samples were collected from the jugular veins for haematological and serum analyses and their reproductive tracts were dissected. The testes and epididymides were carefully sampled, weighed and processed. The results showed that the bucks fed the diet containing 0.25 g MSG/kg had the best ($P<0.05$) feed conversion ratio and daily weight gain, daily sperm production and sperm production efficiency. The inclusions of up to 0.75 g MSG/kg diet did not compromise the bucks' health status, performance and reproductive potential, irrespective of their breeds. However, optimum performance and sperm production were recorded at 0.25 g MSG/kg diet. This study suggests that dietary MSG at 0.25 g/kg in diet can significantly improve rabbit feed palatability, thereby bringing about optimum growth performance, sperm production, and efficiency without causing any physiological imbalance in the bucks.

Key Words: bucks, daily sperm production, sperm efficiency, blood profile, monosodium glutamate, rabbit.

INTRODUCTION

In recent times, there has been a consistent decline in the animal protein intake of most citizens of developing countries, especially those of sub-Saharan Africa. In Nigeria, for instance, only 8.6 g of animal protein is consumed, compared to the 35 g animal protein per person per day recommended by Food and Agriculture Organization (Adetunji and Adepoju, 2011; FAO, 2014). This has, today, resulted in a malnourished population, especially among the rural people that live on less than a dollar per day. The level of animal protein consumption was reported as being directly linked to the general wellbeing and health of the population (Olarotimi, 2016). These individuals are at risk of several deficiency syndromes, as a lot of carbohydrates and fibres are taken daily, with little or no protein intake to balance the diet.

Meeting the animal protein intake of the teeming population from developing countries should be a constant concern for animal scientists from the region. Rabbits may be a significant protein supplier in this region if

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the potential is well harnessed. Rabbits are good at utilising and converting non-conventional feed resources, especially forages, to meat. These non-conventional feed resources are abundant and could be easily accessed at no cost in these regions. Their growth rate is high and comparable only to that of broiler chickens, apart from the fact that the meat is relatively cheaper and comparatively lower in cholesterol than meats from other animals such as pork, beef, mutton and chevon, which are also more expensive (Olarotimi *et al.*, 2015).

However, most of the available and nutritious agro waste products and forages that could be used to feed rabbits have poor palatability (Olarotimi, 2020). Therefore, the addition of feed additives to enhance palatability and acceptability will be a welcomed development. Enhancing feed palatability, acceptability and digestibility would lead to improving growth, health and reproductive performance. Monosodium glutamate (MSG) is widely regarded as a flavour enhancer. It has been severally used in human nutrition for enhanced food palatability. Previously, there have been reports of improved performance in animals fed MSG. Gbore *et al.* (2016) highlighted increased weight gain, improved feed intake and feed conversion ratio in rabbit does orally supplemented with 1 to 2 mg per kg body weight of 40% aqueous solution. Olateju *et al.* (2019) likewise reported an increased weight gain in broiler chickens fed dietary MSG at 0.25 to 0.50 g/kg diet. The toxicity of MSG had been reported in some quarters (Eweka and Adjene, 2007; Igwebuike *et al.*, 2011), but it may be due to the overuse of this additive, as there has not been a consensus agreement on labelling MSG as unsafe (Olarotimi *et al.*, 2021). To ascertain the inclusion level where dietary MSG could be toxic to rabbit, determination of haemato-biochemical indices will help unearth the possibility of any physiological compromise of organs. Haematological indices such as red blood cell (RBC), packed cell volume (PCV), serum proteins and glucose are directly affected by dietary influences (Ewuola and Egbunike, 2008). This study, therefore, aimed to evaluate the growth performance, haematology, serum biochemistry, daily sperm production and efficiency of rabbit bucks fed diets with varying inclusions of MSG, under the hypothesis that high inclusion of MSG in rabbit bucks diets may offset their normal physiological functions.

MATERIALS AND METHODS

Experimental site

The study was carried out at the Rabbit Section of the Teaching and Research Farm of the Federal University of Technology Akure, Nigeria, from July to October 2020. The geographical coordinates of the location are between 7°17' North and 5°9' East (Mapzoom, 2020) with the atmospheric temperature ranging from 28°C to 31°C and mean annual relative humidity of about 80% (Ajibefun, 2011). The experiment was conducted as approved by the research ethics and guidelines of the Animal Production and Health Department of the institution (FUTA/APH/15/4750).

Experimental animals, diets and design

A total of three hundred and twenty (320) mature rabbit bucks aged 8 to 10 mo with an average initial weight of 1.34 kg were used for the study. Two breeds of rabbit bucks consisting of 160 New Zealand White Bucks (NZWB) and 160 Dutch Belted Bucks (DBB) were used for the experiment. An experimental basal rabbit grower diet was compounded (Table 1). The bucks were housed in metallic cages covered with wire mesh in a well-ventilated pen. Water and experimental diets were supplied *ad libitum*. The pen was routinely cleaned daily for 56 d (8 wk) of the experiment. The basal diet was portioned into 4 equal parts designated diets A, B, C and D containing 0.00, 0.25, 0.50 and 0.75 g MSG/kg diet, respectively. The different diets were pelleted to 6 mm diameter. The two breeds of rabbit bucks were distributed randomly to the four diets in a 2×4 factorial experiment. Forty (40) bucks were allotted to each treatment and were replicated 10 times with 4 bucks per replicate. At the end of each week, the weights of the bucks and feed leftovers were captured and recorded to determine the average daily weight gain (ADWG), average daily feed intake (ADFI) and the feed conversion ratio (FCR) of the two breeds of bucks.

Blood and organ sampling

On the last day of the experiment, 20 bucks/treatment (2 buck/replicate) were randomly selected and fasted overnight before being euthanised. Blood samples for serum analyses were centrifuged for 10 min at 3000 rpm to obtain

clean supernatant serum. The serum samples collected were kept frozen at -20°C until the determination of serum, enzymes, metabolites, glucose and proteins. The reproductive tracts of the selected bucks were carefully harvested. The testes were separated and the adhering connective tissues and fats removed. The left and right testes were weighed separately using a highly sensitive weighing balance in the laboratory, and their weights were recorded. The volumes of the testes were measured volumetrically using Archimedes' principle of water displacement in a measuring cylinder as described by Olarotimi *et al.* (2015), and the result was recorded. The testes densities were calculated from the testicular weights and volumes and expressed as g/mL (Olarotimi *et al.*, 2015).

Testis density = Testis weight (g) / Testis volume (mL)

Serum protein, metabolite and enzyme analyses

The serum total protein (TP) was determined by the biuret method. Globulin (GLB) was determined by bromocresol green method as described by Tietz (1995) and albumin (ALB) was calculated as the difference between the TP and ALB. Creatinine, bilirubin, and urea were estimated by deproteinisation and Urease-Berhelot colorimetric methods using a commercial kit (Randox Laboratories Ltd, U.K). The serum enzymes: alanine transaminase (ALT), aspartate transaminase (AST) and alkaline phosphatase (ALP) were obtained using auto analysing test kits from Randox Laboratories, Crumlin, UK. The results were expressed as mg/dL.

Estimation of daily sperm production (DSP) and daily sperm efficiency (SPE)

A sample of each testis was sectioned and weighed. The samples were homogenised separately with a pair of sharp scissors in 0.9% NaCl (normal/physiological saline) at the rate of 5 mL/g testis. The testicular homogenate sample was stored overnight at 4°C to let the spermatozoa ooze out of the organ (Amao and Akanbi, 2017). The suspensions were mixed and filtered through a double layer of sterile gauze into clean glass test tubes, and the filtrate was diluted with distilled water to a 1:10 ratio (Amao and Akanbi, 2017). Some drops of the homogenate were introduced into an improved Neubauer haemocytometer counting chamber. All the elongated spermatids and mature sperm cells in the four diagonal and the centre squares of the haemocytometer were counted in each diluted homogenate.

The testicular sperm reserve (TSR), which is the concentration of the sperm cells per gram of testis parenchyma, was calculated as described by Olarotimi and Adu (2020a). Therefore, the daily sperm production (DSP) for each buck was calculated by dividing the TSR by the time divisor for rabbit. The time divisor was obtained by multiplying the fraction of the cycle of seminiferous epithelium occupied by these cells by the duration of a cycle. A time divisor of 3.43 proposed by Amann (1970) was used.

DSP = Testicular Sperm Reserve (TSR) / Time divisor (3.43)

The efficiency of sperm production also known as daily sperm production per gram (DSP/g) parenchyma (testis) was estimated as: DSP/g = [Paired TSR/g] / [Time divisor (3.43)].

Table 1: Ingredient composition of the basal rabbit diet.

Ingredients (kg)	
Maize	39.00
Soybean meal	4.50
Groundnut cake	4.20
Brewer dried grain	41.80
Wheat offal	7.60
Bone meal	2.10
Limestone	0.33
Salt	0.20
Lysine	0.01
Methionine	0.01
Premix ¹	0.25
Total	100.00
Calculated nutrients	
ME (kcal/kg) ²	2540
Crude protein (%)	16.08
Calcium (%)	1.01
Phosphorus (%)	0.46
Lysine (%)	0.75
Methionine (%)	0.32
Crude fibre (%)	15.56

¹Composition of premix: 2.5 kg of premix contains: Vit. A (10000000 iu), Vit. D3 (2500000 iu), Vit. E (12000 iu), Vit. B1 (2000 mg), Niacin (15000 mg), Vit. B6 (1500 mg), Vit. B12 (10 mg), Vit. K3 (2000 mg), Biotin (20 mg), Folic Acid (600 mg), Pantothenic Acid (7000 mg), Chlorine Chloride (150000 mg), Manganese (80000 mg), Iron (40000 mg), Copper (10 mg), Zinc (60000 mg), Selenium (150 mg), Iodine (1000 mg), Magnesium (100 mg), Ethoxyquin (500 g), BHT (700 g).

²Calculated as ME (kcal/kg) = $[37 \times \text{CP}(\%) + 81.8 \times \text{EE}(\%) + 35.5 \times \text{NFE}(\%)] \times 0.88 = (37 \times 16.08) + (81.8 \times 5.70) + (35.5 \times 51.42) \times 0.88 = 2540$ kcal/kg (Pauzenga, 1985).

Statistical Analysis

All data collected were subjected to two way analyses of variance with the following model: $Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk}$ in a completely randomised design using General Linear Models procedure of GraphPad Prism, software version 6.01 (2012), where: Y_{ijk} = an observed value in the i^{th} treatment in the j^{th} breed difference of the k^{th} individual. μ : overall mean, α_i : treatment effects, β_j : breed effects, $(\alpha\beta)_{ij}$: interaction of treatment and breed, and ϵ_{ijk} : random error means. Significant differences ($\alpha=0.05$) between the means were separated using Duncan's Multiple Range Test option of the same software.

RESULTS

Performance

The results of the performance of two breeds of rabbit bucks fed diets with different levels of MSG are shown in Table 2. There were significant ($P<0.05$) breed differences in the daily weight gain (DWG) and daily feed intake (DFI) of the two breeds of bucks used in this experiment. It was observed that the DBB recorded significantly ($P<0.05$) higher values for these two performance parameters when compared with the NZWB. However, there was no significant ($P>0.05$) breed effect on the FCR of the two breeds of bucks used in the present study. For the treatment effects, the varying inclusions of MSG in the bucks' diets significantly ($P<0.05$) increased DWG among the treated bucks compared with the bucks on the control diet. However, the bucks on diet B (Basal+0.25 g MSG/kg) presented the higher significant ($P<0.05$) weight gain when compared with bucks fed other inclusions of MSG. Increasing the inclusion of MSG from 0.25 to 0.50 and 0.75 g MSG/kg diet did not, however, result in any significant ($P>0.05$) increase in weight gain. Furthermore, the DFI among the bucks fed diet containing 0.75 g MSG/kg was significantly ($P<0.05$) higher than that in bucks on other diets. There was a statistical similarity ($P>0.05$) between the DFI of the bucks fed 0.50 g MSG/kg diet and the bucks on the control diet. The bucks on the diet containing 0.25 g MSG/kg had the best ($P<0.05$) FCR compared with bucks on other diets. The rabbit bucks' performance indicators such as DWG and DFI followed the same trend as influenced by the interaction between breeds and treatments. For example, the DWG and DFI among the NZWB fed 0.25 g MSG/kg diet and the control were statistically ($P<0.05$) similar, while those fed 0.50 and 0.75 g MSG/kg diet were significantly ($P<0.05$) higher when compared with those on the diets containing 0.00 to 0.25 g MSG/kg. The interaction between breeds and treatments did not significantly improve performance in the DBB fed 0.75 g MSG/kg, as the bucks on this diet recorded significantly lower DWG and DFI compared to those fed diets containing 0.00 to 0.50 g MSG/kg. However, the best FCR, in the interaction between breeds and treatments, were recorded among the bucks fed 0.50 g MSG/kg diet for the two breeds of bucks.

Haematology and serum biochemistry

The haematological effects of the varying inclusions of MSG on the two breeds of rabbit bucks are shown in Table 3. The different haematological indices studied in the present experiment showed no significant breed effects ($P>0.05$). The same assertion could have held for the treatment effects, but for the PCV a significant ($P<0.05$) decrease was observed among the bucks fed the diet containing 0.75 g MSG/kg when compared to those on the control diet and those fed the diet B. The PCV values of the bucks fed 0.75 g MSG/kg diet were intermediate. Also, the interaction between breeds and treatments did not influence ($P>0.05$) the haematological parameters, except for the PCV, where bucks fed diet containing 0.75 g MSG/kg recorded the least significant ($P<0.05$) values when compared with DBB on the control diet.

The effects of varying inclusions of MSG on the serum biochemical components of the two breeds of rabbit bucks are shown in Table 4. The breeds of the rabbit bucks did not significantly ($P>0.05$) affect their serum biochemical components. However, varying inclusions of MSG significantly affected some of the serum biochemical parameters. For example, serum proteins, such as albumin and globulin, were significantly ($P<0.05$) influenced. The inclusion of MSG at 0.75 g MSG/kg in diet resulted in a significant ($P<0.05$) increase in serum albumin, cholesterol and urea. In contrast, a significant ($P<0.05$) reduction in serum globulin was observed compared to the control. The interaction

Table 2: Performance of two breeds of rabbit bucks fed different levels of MSG for 56 d.

Breeds	Treatment (g/kg)	IBW (g)	FBW (g)	DWG (g/d)	DFI (g/d)	FCR
NZWB		1375	1837	8.25 ^a	31.66 ^a	3.84
DBB		1358	1872	9.19 ^b	32.95 ^b	3.59
SEM		23	26	0.39	0.27	0.19
	A	1365	1789 ^a	7.57 ^a	32.10 ^a	4.24 ^c
	B	1370	1947 ^c	10.30 ^c	33.03 ^b	3.21 ^a
	C	1375	1856 ^b	8.60 ^b	32.66 ^a	3.80 ^b
	D	1370	1873 ^b	8.99 ^b	34.20 ^c	3.80 ^b
	SEM	23	26	0.38	0.25	0.14
Breed x Treatment						
NZWB	A	1360	1705 ^a	6.15 ^a	30.00 ^a	4.87 ^c
NZWB	B	1367	1760 ^a	7.03 ^a	29.56 ^a	4.20 ^b
NZWB	C	1380	1960 ^b	10.36 ^b	33.06 ^b	3.19 ^a
NZWB	D	1393	1924 ^b	9.47 ^b	34.01 ^b	3.59 ^b
DBB	A	1370	1873 ^b	8.99 ^b	34.20 ^b	3.80 ^b
DBB	B	1344	1893 ^b	9.80 ^b	33.29 ^b	3.40 ^b
DBB	C	1360	1934 ^b	10.24 ^b	33.00 ^b	3.22 ^a
DBB	D	1356	1788 ^a	7.73 ^a	31.30 ^a	4.05 ^c
SEM		23	26	0.31	0.28	0.17
P-values						
Breeds (B)		0.12	0.71	0.01	0.04	0.10
Treatments (T)		0.16	0.04	0.04	0.02	0.01
B×T		0.21	0.04	0.01	0.01	0.02

Means in a column (within variable) without common superscripts are significantly ($P < 0.05$) different. IBW: initial body weights, FBW: final body weights, DWG: daily weight gain, DFI: daily feed intake, FCR: feed conversion ratio, NZWB: New Zealand White Bucks, DBB: Dutch Belted Bucks, A=Control, B=Basal+0.25 g MSG/kg, C=Basal+0.50 g MSG/kg, D=Basal+0.75 g MSG/kg. MSG: Monosodium glutamate, SEM: standard error of the mean.

between breeds and treatments did not significantly ($P > 0.05$) influence the serum biochemical indices except the serum globulin, where a significant effect was recorded.

Testicular and epididymal parameters

The effects of varying inclusions of MSG on the testicular weights, volumes and densities of the two breeds of rabbit bucks are shown in Table 5. The effects of breeds, treatments and their interaction ($P > 0.05$) on the studied parameters were not significant. In the same vein, there were no noticeable ($P > 0.05$) breed effects on the epididymal sperm reserves (Table 6). All the parameters such as caput, corpus and cauda right and left epididymal sperm reserves, as well as paired sperm reserves, were similar ($P > 0.05$) statistically as far as breed effect was concerned. However, treatment effects were pronounced ($P < 0.05$) in the sperm reserves of the caput, corpus and total right and left epididymides, respectively, as well as paired epididymal sperm reserves. It was, however, observed that bucks fed 0.25 g MSG/kg diet recorded significantly ($P < 0.05$) higher sperm reserves where treatment effects were recorded. The interaction of the breeds and treatments did not affect ($P > 0.05$) any of the epididymal sperm reserves. The testicular sperm reserves (TSR), daily sperm production (DSP) and sperm production efficiency (SPE) are shown in Table 7. From the result, it was clear that the breed did not influence ($P > 0.05$) the TSR, DSP and SPE of the bucks. The effects of the treatments were not significantly ($P > 0.05$) felt on the studied parameters, except the DSP and SPE, where bucks fed diets containing 0.25 g MSG/kg diet recorded significantly ($P < 0.05$) higher DSP and SPE.

Table 3: Haematology of two breeds of rabbit bucks fed different levels of MSG for 56 d.

Breeds	Treatment (g/kg)	PCV (%)	Hb (g/dL)	RBC ($\times 10^9/\text{mm}^3$)	MCV (fL)	MCH (pg)	MCHC (g/dL)	MONO (%)	LYM (%)	HETERO (%)	BASO (%)	EOSINO (%)
NZWB		34.44	12.24	5.45	65.23	21.07	22.90	8.02	48.24	38.73	3.33	2.38
DBB		36.32	11.92	5.46	65.64	21.72	22.29	7.86	47.45	38.63	3.83	2.23
SEM		1.38	1.02	1.48	1.89	0.87	0.84	0.59	1.19	1.19	0.39	0.35
	A	36.53 ^b	12.03	5.38	65.17	22.10	22.72	7.99	49.04	37.78	3.42	1.77
	B	37.22 ^b	11.83	5.31	64.68	20.75	22.17	8.02	47.91	38.52	3.93	1.65
	C	35.65 ^{ab}	12.51	5.55	65.03	21.52	23.20	8.02	47.60	38.63	3.83	1.95
	D	32.92 ^a	11.93	5.58	66.85	21.17	22.31	7.73	46.89	39.78	3.17	2.43
	SEM	1.89	1.12	1.87	2.11	0.82	0.89	0.61	1.23	1.18	0.41	0.37
Breed×Treatment												
NZWB	A	37.80 ^{ab}	11.83	5.53	63.83	20.67	23.50	7.37	50.00	38.37	3.13	1.13
NZWB	B	36.11 ^{ab}	12.47	5.35	67.74	21.23	21.81	8.15	48.48	38.27	2.73	2.37
NZWB	C	36.03 ^{ab}	12.90	5.53	65.57	21.37	23.93	8.07	46.33	39.83	3.87	1.93
NZWB	D	32.80 ^a	11.75	5.44	63.80	21.08	22.37	8.53	48.16	38.47	3.63	1.27
DBB	A	41.27 ^b	12.23	5.24	66.52	23.53	21.93	8.62	48.08	37.22	3.70	2.40
DBB	B	36.13 ^{ab}	11.42	5.85	66.00	21.14	22.84	7.32	45.28	41.34	3.60	2.50
DBB	C	35.27 ^{ab}	12.13	5.57	64.50	21.67	22.47	7.97	48.86	37.47	3.73	1.97
DBB	D	32.60 ^a	11.91	5.18	65.57	20.5	21.97	7.53	47.64	38.53	4.27	2.03
SEM		1.47	1.07	1.57	2.12	0.97	0.94	0.55	1.28	1.11	0.36	0.32
P-values												
Breeds		0.09	0.29	0.19	0.16	0.31	0.27	0.16	0.20	0.23	0.72	0.81
Treatments		0.03	0.41	0.48	0.08	0.17	0.10	0.17	0.09	0.33	0.11	0.15
B×T		0.02	0.20	0.07	0.55	0.75	0.57	0.11	0.70	0.89	0.84	0.90

Means in a column (within variable) without common superscripts are significantly ($P < 0.05$) different. PCV: packed cell volume, RBC: red blood cell, Hb: haemoglobin, LYM: lymphocyte, MONO: monocytes, BASO: basophils, HETERO: heterophils, EOSINO: eosinophils, MCHC: mean corpuscular haemoglobin concentration, MCH: mean corpuscular haemoglobin, MCV: mean corpuscular volume, IBW: initial body weights, FBW: final body weights, DWG: daily weight gain, DFI: daily feed intake, FCR: feed conversion ratio, NZWB: New Zealand White Bucks, DBB: Dutch Belted Bucks, A=Control, B=Basal+0.25 g MSG/kg, C=Basal+0.50 g MSG/kg, D=Basal+0.75 g MSG/kg. MSG: Monosodium glutamate, SEM: standard error of the mean.

The interaction of breeds and treatment, however, played no significant ($P > 0.05$) role in influencing the reproductive potential of the experimental bucks.

DISCUSSION

Parameters such as weight gain, feed conversion ratio and feed intake are reliable indicators often used to assess the performance of animals and subsequent productivity of any animal production technique. Adopting the use of feed flavour additives to enhance the palatability and acceptability of non-conventional feed resources, achieving higher productivity in rabbit production without compromising the health status of the animals, could be a welcomed development. The breed differences observed in the DWG and DFI of the two breeds of bucks could be due to their genetic lineage variation. The New Zealand and Dutch belted breeds of rabbits were products of cross-breeding programmes over some time. This involved breeding rabbits with diverse genetic makeup to arrive at a strain with desirable heritable characters of values. The New Zealand rabbit, for instance, is the result of a cross between Belgian hares and Flemish giants (Raising-Rabbits, 2021), while the Dutch breed descended from the Brabancon breed (Lafeber, 2021). The significantly higher feed intake observed among the bucks fed 0.75 g MSG/kg diet (mainly in NZW bucks) was indicative of the palatability enhancement of MSG in rabbit diets. This was in agreement with Khadiga *et al.* (2009), who also observed an increased total feed intake in chicks fed 1% MSG. Gbore *et al.* (2016)

Table 4: Serum biochemical components of two breeds of adult rabbit bucks fed different levels of MSG for 56 d.

Breeds	Treatment (g/kg)	TP (g/dL)	ALB (g/dL)	GLB (g/dL)	CHOL (mg/dL)	Urea (mg/dL)	ALT (U/L)	AST (U/L)	CRT (mg/dL)	Glucose (g/dL)
NZWB		6.83	3.36	3.47	28.99	13.87	52.18	61.05	0.99	123.0
DBB		6.81	3.46	3.41	26.75	14.33	52.41	60.99	1.03	122.2
SEM		0.12	0.17	0.25	2.01	1.1	1.19	0.91	0.06	8.0
	A	6.93	3.25 ^a	3.81 ^b	26.03 ^a	14.80 ^{ab}	51.95	61.31	1.01	124.1
	B	6.81	3.28 ^a	3.53 ^{ab}	27.88 ^a	13.80 ^a	53.12	60.65	1.01	123.3
	C	6.62	3.29 ^a	3.31 ^{ab}	25.42 ^a	11.73 ^a	51.63	61.25	0.98	125.7
	D	6.93	3.82 ^b	3.11 ^a	32.15 ^b	16.07 ^b	52.51	60.88	1.03	120.3
	SEM	0.22	0.23	0.24	2.91	1.18	1.21	0.84	0.11	8.0
Breed×Treatment										
NZWB	A	6.67	3.21	3.46 ^b	27.21	15.17	52.93	61.27	0.96	119.0
NZWB	B	7.21	3.06	4.14 ^b	26.47	13.13	51.72	59.97	1.09	121.3
NZWB	C	6.37	3.27	3.09 ^{ab}	27.13	11.55	51.17	61.87	0.83	121.6
NZWB	D	7.07	3.89	3.18 ^{ab}	35.17	15.63	52.93	61.10	1.06	121.3
DBB	A	7.21	3.32	4.15 ^b	24.87	14.43	50.97	61.33	1.07	120.0
DBB	B	6.40	3.49	2.91 ^a	29.34	14.47	54.51	61.33	0.92	119.3
DBB	C	6.83	3.31	3.52 ^b	23.71	11.92	52.11	60.63	1.13	120.1
DBB	D	6.80	3.75	3.05 ^{ab}	29.13	16.51	52.07	60.67	1.01	119.3
SEM		0.24	0.19	0.23	2.92	1.13	1.17	0.73	0.09	7.6
P-values										
Breeds		0.34	0.52	0.41	0.67	0.12	0.08	0.31	0.06	0.11
Treatments		0.09	0.01	0.03	0.02	0.01	0.22	0.14	0.22	0.94
B×T		0.11	0.17	0.01	0.23	0.58	0.32	0.09	0.09	0.54

Means in a column (within variable) without common superscripts are significantly ($P<0.05$) different. TP: total protein, ALB: albumin, GLB: globulin, CHOL: cholesterol, ALT: alanine aminotransferase, AST: aspartate aminotransferase, CRT: creatinine, NZWB: New Zealand White Bucks, DBB: Dutch Belted Bucks, A=Control, B=Basal+0.25 g MSG/kg, C=Basal+0.50 g MSG/kg, D=Basal+0.75 g MSG/kg. MSG: Monosodium glutamate, SEM: standard error of the mean.

also reported increasing feed intake in response to an increased level of MSG used among female rabbits. The mechanism whereby MSG enhances the palatability of feeds, influences appetite positively and induces weight gain has been linked with stimulation of the orosensory receptors (Moore, 2003). However, the significantly higher DWG and better FCR observed among the bucks fed 0.25 g MSG/kg diet, with lower feed intake, when compared to bucks fed 0.75 g MSG, with higher feed intake, could be a result of the oxidative stress impact caused by high inclusion rate of MSG in the diets (Kondoh and Torii, 2008). The interaction of the breeds and treatment revealed that supplementing NZWB and DBB diets with 0.50 g MSG would bring about a better FCR.

Haematological indices are indicators and biomarkers used to assess the physiological influence of dietary treatments on experimental animals. It has been established that the blood parameters directly affected by dietary influences include RBC, PCV, serum proteins and glucose (Ewuola and Egbunike, 2008). From the present study, it was clear that the inclusion rate of MSG used was not hazardous to the wellbeing of the bucks. This was a result of the non-significant influence of varying inclusions of MSG on each of the parameters except the PCV, where a significant effect was observed. The PCV were still within the range of haematological reference values for normal rabbit bucks (33.10-47.70) as reported by Özkan *et al.* (2012). This was contrary to that reported by Gbore *et al.* (2016), who observed reduced PCV and Hb values (lower than reference values) among rabbits orally administered 4 mg MSG/kg body weight. This variation could result from different factors such as route of MSG administration, stress, blood collection methods and environmental conditions. The result of this study further showed that the immune status of the bucks was not altered by varying inclusions of dietary MSG. This was in line with the findings of Oyetunji (2013), who reported no influence on the haematological and biochemical parameters of Wistar rats

Table 5: Testicular characteristics of two breeds of adult rabbit bucks fed different levels of MSG for 56 d.

Breeds	Treatment (g/kg)	LTW (g)	RTW (g)	PTW (g)	LTV (mL)	RTV (mL)	PTV (mL)	LTD (g/mL)	RTD (g/mL)	PTD (g/mL)
NZWB		2.21	1.98	4.19	1.09	1.07	2.17	2.03	1.85	1.93
DBB		2.19	1.95	4.15	1.08	1.07	2.16	2.03	1.82	1.92
SEM		0.10	0.11	0.12	0.06	0.07	0.09	1.90	2.91	3.01
	A	2.11	1.80	3.91	1.11	1.05	2.21	1.91	1.64	1.77
	B	2.23	2.06	4.29	1.04	1.03	2.09	2.14	2.00	2.05
	C	2.39	2.17	4.57	1.09	1.07	2.18	2.19	2.03	2.11
	D	2.07	1.83	3.9	1.1	1.08	2.18	1.88	1.69	1.79
	SEM	0.13	0.16	0.39	0.08	0.02	0.05	0.14	0.18	0.16
Breed×Treatment										
NZWB	A	2.13	1.81	3.93	1.14	1.11	2.25	1.87	1.63	1.75
NZWB	B	2.33	2.17	4.52	1.03	1.01	2.05	2.26	2.15	2.23
NZWB	C	2.31	2.03	4.34	1.12	1.09	2.23	2.06	1.86	1.95
NZWB	D	2.09	1.99	3.99	1.08	1.07	2.15	1.94	1.78	1.86
DBB	A	2.11	1.78	3.88	1.08	1.08	2.17	1.94	1.65	1.79
DBB	B	2.14	1.95	4.09	1.06	1.04	2.12	2.02	1.88	1.93
DBB	C	2.48	2.32	4.79	1.07	1.05	2.12	2.32	2.21	2.26
DBB	D	2.05	1.77	3.82	1.12	1.09	2.21	1.83	1.62	1.73
SEM		0.12	0.13	0.24	0.05	0.04	0.07	2.4	3.25	3.43
P-values										
Breeds		0.28	0.52	0.18	0.06	0.08	0.13	0.46	0.10	0.15
Treatments		0.07	0.14	0.83	0.19	0.21	0.49	0.17	0.13	0.91
B×T		0.11	0.30	0.15	0.35	0.51	0.09	0.22	0.56	0.44

LTW: left testis weight, RTW: right testis weight, PTW: paired testes weight, LTV: left testis volume, RTV: right testis volume, PTV: paired testes volume, LTD: left testis density, RTD: right testis density, PTD: paired testes density NZW: New Zealand White, DBB: Dutch Belted Bucks, A=Control, B=Basal+0.25 g MSG/kg, C=Basal+0.50 g MSG/kg, D=Basal+0.75 g MSG/kg. MSG: Monosodium glutamate, SEM: standard error of the mean.

supplemented with 5 to 15 mg MSG/kg body weight. The non-significant white blood count differentials reported in this research suggested that the varying inclusions of MSG as used in this study did not obstruct the normal physiological functions of the bucks' immune system to protect against infections.

The serum biochemical components help provide baseline information about the functionality and health status of the body organs. Though significant treatment effects were observed in the serum albumin, globulin, cholesterol and urea in this study, they were found to be within the range of reference values for normal rabbit bucks, as previously reported by several studies (Elmas *et al.*, 2006; Melillo, 2007; Özkan *et al.*, 2012). Elevated serum glucose levels in rabbits, for instance, were linked with stress factors (Melillo, 2007). Therefore, the non-significant effects of varying inclusions of MSG on the glucose levels in this study could be due to the fact that the quantity of MSG employed might not be sufficient enough to impose nutrition-induced stress on rabbit bucks. The liver is the site of blood protein synthesis. Any impairment of hepatic function will be indicated in the disturbance of protein synthesis. The fact that the serum proteins were within the normal range for rabbit bucks (Özkan *et al.*, 2012) indicated that the amount of MSG used in this study did not negatively affect the normal liver protein synthesis. However, the increasing levels of albumin in response to the increasing inclusion level of MSG was indicative that higher inclusion levels of MSG might disrupt the normal function of the liver as far as protein synthesis is concerned. The high level of serum enzymes (aminotransferases) in the bloodstream suggests hepatocellular damage. Therefore, the quantity of MSG used in this study did not affect the liver negatively. The non-significant differences observed in alanine aminotransferase (ALT), and aspartate aminotransferase (AST) under the breed, treatment and their interaction in this study is an indicator that there were no significant alterations in liver functions. Therefore, the present investigation revealed no

Table 6: Epididymal sperm reserves of two breeds of adult rabbit bucks fed different levels of MSG for 56 d.

Breeds	Treatment (g/kg)	LESRC1 (x10 ⁷)	LESRC2 (x10 ⁷)	LESRC3 (x10 ⁷)	TLESR (x10 ⁷)	RESRC1 (x10 ⁷)	RESRC2 (x10 ⁷)	RESRC3 (x10 ⁷)	TRESR (x10 ⁷)	PESR (x10 ⁷)
NZWB		2.11	3.67	2.74	8.52	1.94	3.54	2.45	7.93	16.45
DBB		2.14	3.61	2.64	8.39	1.91	3.39	2.39	7.69	16.08
SEM		1.01	0.09	0.17	0.21	0.07	0.14	0.08	0.04	0.52
	A	2.07 ^a	3.45 ^a	2.48	8.00 ^a	1.84 ^{ab}	3.27 ^a	2.24	7.35 ^a	15.35 ^a
	B	2.20 ^b	3.82 ^b	2.78	8.89 ^b	2.05 ^c	3.98 ^b	2.52	8.65 ^b	17.54 ^b
	C	2.14 ^{ab}	3.70 ^{ab}	2.82	8.66 ^{ab}	1.99 ^{bc}	3.66 ^b	2.52	8.17 ^b	16.83 ^{ab}
	D	1.99 ^a	3.58 ^{ab}	2.68	8.25 ^a	1.80 ^a	3.35 ^a	2.45	7.55 ^{ab}	15.81 ^{as}
	SEM	0.06	0.15	0.11	0.16	0.03	0.09	0.17	0.13	0.10
Breed×Treatment										
NZWB	A	1.94	3.47	2.47	7.88	1.78	3.32	2.21	7.39	15.18
NZWB	B	2.37	4.01	2.99	9.37	2.15	3.74	2.72	8.59	17.96
NZWB	C	2.11	3.59	2.75	8.45	2.23	3.72	2.44	8.16	16.61
NZWB	D	2.01	3.68	2.76	8.37	1.82	3.39	2.48	7.69	16.06
DBB	A	2.27	3.43	2.49	8.12	1.99	3.22	2.28	7.48	15.52
DBB	B	2.22	3.63	2.57	8.42	1.95	3.43	2.33	7.71	16.13
DBB	C	2.17	3.82	2.89	8.88	1.99	3.59	2.61	8.19	17.07
DBB	D	1.96	3.56	2.65	8.12	1.78	3.35	2.32	7.49	15.52
SEM		0.07	0.12	0.16	0.14	0.06	0.09	0.12	0.47	0.31
P-values										
Breeds		0.51	0.07	0.31	0.26	0.11	0.72	0.83	0.10	0.34
Treatments		0.01	0.01	0.15	0.03	0.01	0.02	0.41	0.04	0.01
B×T		0.09	0.27	0.62	0.53	0.06	0.90	0.19	0.33	0.45

Means in a column (within variable) without common superscripts are significantly ($P < 0.05$) different. LESRC1: left epididymal sperm reserve caput, LESRC2: left epididymal sperm reserve corpus, LESRC3: left epididymal sperm reserve cauda, TLESR: total left epididymal sperm reserve, RESRC1: right epididymal sperm reserve caput, RESRC2: right epididymal sperm reserve corpus, RESRC3: right epididymal sperm reserve cauda, TRESR: total right epididymal sperm reserve, PESR: paired epididymal sperm reserve, NZWB: New Zealand White Bucks, DBB: Dutch Belted Bucks, A=Control, B=Basal+0.25 g MSG/kg, C=Basal+0.50 g MSG/kg, D=Basal+0.75 g MSG/kg. MSG: Monosodium glutamate, SEM: standard error of the mean.

sign of hepatocellular damage induced by varying inclusions of MSG on the bucks fed the experimental diets. This result contradicted the findings of Inuwa *et al.* (2011), who reported hepatocellular damage in Wistar rats treated with 200 to 400 mg MSG/kg body weight and the reported significant elevation in the serum aminotransferases in male albino rats fed a high dose of monosodium glutamate consumption (Egbonu *et al.*, 2009). An elevation in the concentrations of serum creatinine and urea is also indicative of a decline in renal filtration ability. From our results, it was clear that the kidneys of the bucks fed varying inclusions of MSG were unaffected, as indicated by the non-significant difference in creatinine and urea being within the reference values (Özkan *et al.*, 2012).

The non-significant breed, treatment and interaction effects on the testicular weights, volumes and densities observed in this study showed that inclusion of MSG up to 0.75 g/kg diet would not compromise the testicular integrity of the bucks. Our result agreed with Olarotimi *et al.* (2020), who reported no adverse effect on the gross testicular weights, volumes and densities of cocks fed MSG inclusion up to 0.75 g/kg diet. However, they observed a significant increase in the testicular densities when MSG inclusion level above 0.75 g/kg diet was fed to the bucks. This is instructive that grading up the inclusion level of the bucks' diets above 0.75 g/kg diet MSG may predispose them to be oligozoospermic or present increased abnormal sperm morphology. Reduction in daily sperm production in MSG-treated animals has been explained as being caused by reduction in testicular weight, seminiferous tubular diameter, epithelium and testicular seminiferous height (Fernandes *et al.*, 2012). Therefore, the daily sperm production tendency in the experimental bucks might not be hampered due to the morphological integrity of the testes that has not been compromised by the varying inclusion levels of MSG. There were no breed and interaction effects on the epididymal sperm reserves of the studied bucks. However, the significant treatment effects (increases) noted in the

Table 7: Testicular sperm reserves, sperm production and efficiency of two breeds of adult rabbit bucks fed different levels of MSG for 56 d.

Breeds	Treatment (g/kg)	RTSR/g T ($\times 10^9$)	LTSR/g T ($\times 10^9$)	PTSR/g T ($\times 10^9$)	RTSR/T ($\times 10^9$)	LTSR/T ($\times 10^9$)	PTSR/T ($\times 10^9$)	DSP ($\times 10^9$)	SPE ($\times 10^9$)
NZW		1.52	1.63	3.15	2.59	2.72	5.32	1.55	0.92
DBB		1.39	1.52	2.91	2.33	2.51	4.85	1.41	0.85
SEM		0.07	0.09	0.06	0.04	0.09	0.08	0.06	0.03
	A	1.38	1.56	2.94	2.45	2.63	5.07	1.48 ^{ab}	0.86 ^a
	B	1.55	1.62	3.17	2.50	2.62	5.13	1.58 ^b	0.92 ^b
	C	1.46	1.53	2.98	2.50	2.59	5.11	1.50 ^{ab}	0.87 ^a
	D	1.43	1.59	3.02	2.41	2.64	5.05	1.47 ^a	0.88 ^a
	SEM	0.19	0.15	0.09	0.18	0.16	0.11	0.08	0.13
Breed×Treatment									
NZW	A	1.42	1.53	2.95	2.56	2.71	5.26	1.53	0.86
NZW	B	1.69	1.76	3.45	2.71	2.74	5.45	1.59	1.01
NZW	C	1.42	1.47	2.89	2.45	2.55	5.03	1.47	0.84
NZW	D	1.53	1.77	3.30	2.65	2.89	5.54	1.62	0.96
DBB	A	1.35	1.58	2.93	2.33	2.54	4.88	1.42	0.85
DBB	B	1.40	1.48	2.88	2.28	2.49	4.81	1.40	0.84
DBB	C	1.49	1.59	3.08	2.56	2.62	5.18	1.51	0.90
DBB	D	1.32	1.42	2.74	2.16	2.39	4.55	1.33	0.80
SEM		0.42	0.09	0.91	0.11	0.08	0.18	0.38	0.09
P-values									
Breeds		0.16	0.87	0.45	0.02	0.01	0.01	0.09	0.11
Treatments		0.08	0.09	0.11	0.24	0.13	0.32	0.02	0.03
B×T		0.23	0.12	0.63	0.18	0.22	0.19	0.16	0.42

Means in a column (within variable) without common superscripts are significantly ($P < 0.05$) different. RTSR/g T: right testicular sperm reserve per gram testis, LTSR/g T: left testicular sperm reserve per gram testis, PTSR/g T: paired testicular sperm reserve per gram testis, RTSR/T: right testicular sperm reserve per testis, LTSR/T: left testicular sperm reserve per testis, PTSR/T: paired testicular sperm reserve per testis, DSP: daily sperm production, SPE: Sperm production efficiency, NZWB: New Zealand White Bucks, DBB: Dutch Belted Bucks, A=Control, B=Basal+0.25 g MSG/kg, C=Basal+0.50 g MSG/kg, D=Basal+0.75 g MSG/kg. MSG: Monosodium glutamate, SEM: standard error of the mean.

left caput and corpus, right caput and corpus, total left and right as well as paired epididymal sperm reserves of the bucks fed 0.25 g MSG/kg diet indicated that sperm storage tendency is better enhanced at 0.25 g/kg MSG. Though the inclusion of 0.50 and 0.75 g MSG/kg diet did not significantly hamper the ability of the epididymis in sperm storage, there may be distortion in the function of this organ if inclusion above 0.75 g/kg MSG is used. Our results partially agreed with a previous study that reported that epididymal sperm reserve was enhanced when bucks were fed MSG diets up to 0.50 g. However, a decrease in epididymal sperm reserve was observed at 0.75 and above (Olarotimi and Adu, 2020b). Considering a reduction in epididymal sperm reserve, especially at 0.75 g/kg MSG, it is indicative that increasing levels of MSG above this could intercept the normal process of spermatogenesis and thereby adversely affect the bucks' reproduction potential. The experimental bucks' daily sperm production and sperm production efficiency followed the same trend as observed in the epididymal sperm reserve, as they were better enhanced at 0.25 g MSG/kg diet. Though the DSP and SPE recorded among the bucks on the diet containing 0.75 g MSG/kg diet was not significantly different from the means recorded among those on the control diet; any further increase in MSG inclusion could have a detrimental effect on normal spermatogenesis process in the bucks. This is because increasing MSG inclusion had been explained as causing degeneration of Sertoli cells that provide nourishment for the growth and survival of sperm cells within the seminiferous tubules (Olarotimi and Adu, 2020a).

The results of the present study may be limited. One of the limitations of this study is that the effectiveness of MSG on reproductive parameters has not been fully proven, since it would be necessary to carry out an experiment using the semen of these males to inseminate rabbits and study fertility and prolificacy. Moreover, further research is required to assess the impact of dietary MSG on rabbit bucks fed treated diets from the postnatal to adult stage.

CONCLUSION

Though supplementation of bucks' diets with MSG up to 0.75 g/kg did not have negative effects on the health status as shown by the blood profile, performance and reproductive potential, the optimum performance and reproductive potential as shown by the epididymal sperm reserve, daily sperm production and sperm production efficiency were enhanced at 0.25 g MSG/kg diet inclusion level. Rabbit farmers could therefore enhance the palatability of the non-conventional feed resources in rabbit feed production for optimum feed utilisation by including 0.25 g MSG/kg diet, without conferring any adverse effects on the performance, health status and reproductive potential of the bucks irrespective of the breeds of bucks involved.

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