BF-1583
[1-6]

RESEARCH ARTICLE

Indian Journal of Animal Research

Modulating the Growth Curve in Broiler Chicken through Varying Balanced Protein Regimen (All Step-up, Designed to Get Compensatory Responses)

B. Rashid[1], T.N. Pasha[1], Saima[1], A. Mahmud[2]

10.18805/IJAR.BF-1583

ABSTRACT

Background: Compensatory growth is a well-established characteristic even in broiler chicken having very short grow-out cycle. Feeding manipulations that take advantages of compensatory growth after a period of nutrient restriction might be beneficial to poultry industry.

Methods: In total, 1400 one-day-old straight run broiler chicks (Hubbard) were allocated to 8 experimental treatments, replicated 7 times with 25 chicks in each, in a completely randomized design. The 3 isocaloric corn soybean meal experimental diets; a high BP (HBP) with 1.2% standardized ileal digestible lysine (SID Lys), a medium BP (MBP) with 1.1% SID Lys and a low BP (LBP) 1.0% SID Lys, were offered in starter, grower and finisher phases, as HML (conventional) and LHH, MHH, LMM, MMH, LLM, LLH and LMH as all steps-up.

Result: Greater (P<0.05) BW and BWG were observed in HML groups during all phases. The MMH group had greater FI (P<0.05) during grower and finisher phases. The HML group had better FCR (*P*<0.05) during starter and grower phases. The LMM group had heavier (P<0.05) abdominal fat pad, whereas, MHH and HML groups had greater (P<0.05) dressed carcass, breast meat, drumstick and thigh yield. The MHH and HML groups, similarly, had higher (P<0.05) spleen, thymus, bursa weights, greater antibody titers against NDV and IBDV and total protein concentration. The LLH group had greater (P<0.05) blood glucose, urea and total cholesterol concentrations. It is, therefore, recommended that HBP (1.2% SID Lys) should be gradually step down to LBP (1.10% SID Lys) for efficient and sustainable production of broiler chicken.

Key words: Balanced protein, Broiler chicken, Compensatory growth, Phase feeding, SID lysine.

INTRODUCTION

The modern broiler chicken has greater growth rates, better FCR and rapid metabolic rates boosting their sensitivity to nutritional disorders including sudden death syndrome, myopathies and ascites (Ebeid *et al.,* 2022). Quantitative and qualitative feed restriction programs are used to modulate the growth curve and metabolic rates to alleviate the incidence of metabolic disorders and decrease the cost of production (Sahraei, 2014; Aziz *et al.,* 2021). The qualitative feed restriction may involve the modification of diet composition in particularly protein, energy and/ or fiber (Sahraei, 2014).

Compensatory growth is a well-established characteristic in most farm animals, even in broiler chicken having very short grow-out cycle. Compensatory growth refers to the period of rapid growth, relative to age, exhibited by mammals and birds after a period of nutritional restriction. Feed restriction provides opportunity to take advantage of compensatory growth (Gobane *et al.,* 2021). The tendency of broilers to show compensatory growth suggested an opportunity to modulate the dietary concentration of balanced protein during different phases to optimize overall performance (Aftab, 2012). It has been observed that male broilers fed low protein diet in first phase reimbursed their lower initial body weight (Eits *et al.,* 2003). These findings strongly suggested that protein concentrations in grower and finisher diets should be optimized simultaneously. Therefore, the current trial was planned to evaluate the performance of broilers by modulating growth curve through varying BP regimen under conventional all step-up phase feeding designed to get compensatory growth.

[1]Department of Animal Nutrition, Faculty of Animal Production and Technology, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan.

[2]Department of Poultry Production, Faculty of Animal Production and Technology, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan.

Corresponding Author: B. Rashid, Department of Animal Nutrition, Faculty of Animal Production and Technology, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan.
Email: drbabar2007@gmail.com

How to cite this article: Rashid, B., Pasha, T.N., Saima, and Mahmud, A. (2022). Modulating the Growth Curve in Broiler Chicken through Varying Balanced Protein Regimen (All Step-up, Designed to Get Compensatory Responses). Indian Journal of Animal Research. doi: 10.18805/IJAR.BF-1583.

Submitted: 05-09-2022 **Accepted:** 23-12-2022 **Online:** 24-01-2023

MATERIALS AND METHODS

The trial was executed at Department of Animal Nutrition, University of Veterinary and Animal Sciences, Lahore

Pakistan for 35 days. In total, 1400 one-day-old straight run broilers (Hubbard) were allocated to eight experimental treatments, replicated 7 times with 25 broilers each, in a completely randomized design. The three isocaloric corn soybean meal experimental diets (Table 1); a high BP (HBP) with 1.2% standardized Ileal digestible lysine (SID Lys), a medium BP (MBP) with 1.1% SID Lys and a low BP (LBP) 1.0% SID Lys, were offered in starter (1-10 days), grower (11-25 days) and finisher (26-35 days) phases, as HML (conventional, HBP for 1-10d, MBP for 11-25d and LBP for 26-35 days), LHH (LBP for 1-10d and HBP for 11-35d), MHH (MBP for 1-10d and HBP for 11-35d), LMM (LBP for 1-10d and MBP for 11-35d), MMH (MBP for 1- 25d and HBP for 26-35d), LLM (LBP for 1-25d and MBP for 26-35d), LLH (LBP for 1-25d and HBP for 26-35d) and LMH (LBP for 1-10d, MBP for 11-25d and HBP for 26-35d) as all step-up phase feeding to get compensatory growth. The birds were reared in an environmentally controlled house and offered *ad-libitum* feed and water throughout the experimental period. The birds were immunized against Newcastle disease virus (NDV) (Ceva-Phylaxia, Budapest, Hungry) in drinking water on day 2nd, 14th and 28th of age and on day 2nd and 14th against infectious bursal disease virus (IBDV) (Lohman Animal Health GmbH, Cuxhaven, Germany). The recommended management conditions were followed as per guidelines of Hubbard broiler management guide (2009).

The composition of the dietary treatments was evaluated (AOAC, 2016). The data regarding growth performance including body weight (BW), body weight gain (BWG), feed intake (FI) and FCR were measured at the end of each phase. At the 35th day of trial, three broiler chicken from each pen were arbitrarily selected and 5 ml blood was collected by puncturing wing vein, serum harvested and was used to determine the concentration of glucose, cholesterol (mg/dl) and antibody titers against NDV and IBDV by procedures described by Waqas *et al.* (2019). The total protein (g/dl) (Biuret Method cat # 157004) and urea (mg/dl) were also measured (Berthelot Method cat # 10505). The selected birds were slaughtered by Halal method and carcasses were processed to determine weights of dressed carcass, breast meat, abdominal fat, thigh and drumstick and immune organs including thymus, spleen and bursa of fabricius (Raju *et al.,* 2022). The values were expressed as percentage of live BW. The breast samples were used to determine proximate composition including DM, CP, ether extract and crude ash with the procedure described by Gnanaraj *et al.* (2020).

Data were analyzed using one way analysis of variance (ANOVA) technique in a completely randomized design (Steel *et al.,* 1997) in SAS (version 9.1; SAS Inst. Inc., Cary, NC). Means were declared statistically significant at P<0.05 and compared using Duncan multiple range (DMR) test (Duncan, 1955).

RESULTS AND DISCUSSION

Growth performance

Table 2 represents the influence of experimental diets on growth performance of broilers. Greater (P<0.05) BW and BWG were observed in HML group during the starter, grower and finisher phases. The BWG, however, was not influenced by the dietary treatments in finisher phase. The MMH group had greater FI (P<0.05), at par with LLM and LLH groups during the grower phase. The MMH group, similarly, had higher (P<0.05) FI during the finisher phase. The FI, however, was not influenced during starter phase. The HML group had better (P<0.05) FCR during the starter phase. During grower phase, moreover, the HML group had better FCR (P<0.05) at par with the LHH LMH LMM and MHH groups. These results are in agreement with the results reported by Faluyi *et al.* (2015). These later authors reported

Table 1: Dietary ingredients and nutrient composition of the experimental diets (% as fed basis).

Ingredients %	Treatments HBP	MBP	LBP
Maize	56.2	59.8	63.4
Rice broken	5.0	5.0	5.0
Soybean meal (45 %)	31.3	24.1	20.0
Canola meal (35 %)	1.0	4.6	6.3
Corn gluten meal (55 %)	2.0	2.0	1.0
Poultry byproduct meal	2.0	2.0	2.0
Bone ash	1.1	1.1	1.1
Marble chips	0.3	0.2	0.2
Lysine sulphate 70%	0.4	0.4	0.4
DL-methionine	0.2	0.1	0.1
L-threonine	0.07	0.06	0.05
Premix[1]	0.2	0.2	0.8
Salt	0.3	0.3	0.3
Phyzyme (10000 FTU) gm/ton	50.0	50.0	50.0
Analyzed nutrient composition (%)			
CP	23.0	21.0	19.0
Ether Extract	3.1	3.1	3.2
Crude Fibre	3.3	3.8	3.5
Calcium	0.8	0.8	0.8
Av. Phosphorous	0.42	0.42	0.42
Calculated nutrient composition (% until and unless otherwise mentioned)			
ME (Kcal/kg)	2800	2800	2800
D. Lys	1.20	1.10	1.00
D. M+C	0.86	0.79	0.72
D. Thr	0.80	0.74	0.67
D. Tryp	0.21	0.19	0.17
D. Val	0.92	0.85	0.79
D. Isoleu	0.86	0.77	0.70
D. Arg	1.30	1.16	1.06

[1]Premix composition (per kg of diet): 12,000 IE retinol, 2,400 IE cholecalciferol, 50 mg dl-a-tocopherol, 1.5 mg menadione, 2.0 thiamine, 7.5 mg riboflavin, 3.5 mg pyridoxine, 20 mcg cyanocobalamins, 35 mg niacin, 12 mg D- Pantothenic acid, 460 mg choline chloride, 1.0 mg folic acid, 0.2 mg biotin, 80 mg iron, 12 mg copper,85 mg manganese, 60 mg zinc, 0.8 mg iodine, 0.1 mg selenium, 125 mg anti-oxidant mixture.

that the broiler chicken fed higher (1.14%) Lys had BW and BWG compared with control group. In contrast to these results it has been reported that supplemental Lys (110 and 120% of strain recommendations) did not influence the growth performance in broiler chicken (Sigolo *et al.,* 2019). These results are in agreement to the previous work reported by Jalal and Zakaria (2012) but incongruent to the work done by Pinheiro *et al.* (2004). The groups fed MBP and HBP after LBP and MBP diets had slightly improved BWG that is in agreement to findings of Camacho *et al.* (2004). These later authors reported that BWG was not completely recovered in broiler chicken fed LBP diets in first phase. Due to low density diets bird FI was higher which resulted in poor FCR. It was principally because of the fact that for first phase, LBP diet was utilized by the birds to sustain their BW resulting in slow growth. This leads to a higher feed: gain ratio (Saleh *et al.* 2005).

Carcass characteristics and composition

The influences of the dietary treatments on the carcass characteristics and composition are presented in Table 3. The MHH and HML groups had higher ($P<0.05$) dressed carcass, breast meat and drumstick yield. The LMM group, however, had heavier ($P<0.05$) abdominal fat pads. The HML and MHH group had greater ($P<0.05$) relative weights of thigh. The greater relative weights of thigh may be attributed to the higher BW in these groups since the relative weight was calculated as % of the BW. These results are incongruent the previous studies (Jalal and Zakaria, 2012). The dressing percentage was significantly decreased by feeding of LBP in first phase. Quantitative breast, leg quarters and wing yield were significantly lower. The greater ($P<0.05$) relative weights of spleen, thymus and bursa of Fabricius were recorded in MHH and HML groups. These results are in line with those reported by Sigolo *et al.* (2019). These later authors stated that Lys supplementation (110% of strain recommendations) increased the relative weight of bursa of Fabricius in broilers. Mulyantini (2014) similarly, reported that broiler chicken fed greater Lys levels had higher weights of thymus and bursa of Fabricius. Ghoreyshi *et al.* (2019), similarly reported that the broiler chicken fed greater Lys levels (130% of NRC recommendations) had higher spleen weight, whereas, the weights of thymus and bursa of Fabricius remained unaffected by the experimental diets. The dietary treatments did not affect ($P>0.05$) carcass composition in the broilers.

Serum metabolites and antibody titers

The impacts of the dietary treatments on the serum metabolites and antibody titers in the broiler chicken are presented in Table 4. The greater ($P<0.05$) blood glucose and urea concentration were recorded in LLH group. The LLH group, moreover, had elevated ($P<0.05$) total cholesterol concentration. The HML and MHH groups, however, had higher ($P<0.05$) total protein concentration. Sigolo *et al.* (2019) reported that broiler chicken fed greater Lys (110 and 120% of strain recommendations) had higher blood glucose levels, whereas the cholesterol level was not influenced by the Lys supplementation. These results are in

Table 2: Effects of the varying balanced protein regimen (all steps-up) on growth performance in the broiler chicken[1] at different phases of the experiment.

Parameters	Treatments[2]									
	HML	LHH	MHH	LMM	MMH	LLM	LLH	LMH	SEM	P-value
BW, g										
Starter	290.6^{a}	274.2^{c}	284.3^{ab}	280.1^{bc}	285.5^{ab}	275.8^{bc}	279.8^{bc}	281.0^{abc}	3.1	<0.001
Grower	1186.4^{a}	1122.8^{bc}	1165.8^{ab}	1147.4^{abc}	1164.7^{ab}	1102.3^{c}	1135.5^{abc}	1158.9^{ab}	16.9	<0.001
Finisher	1859.0^{a}	1752.1^{b}	1824.4^{ab}	1784.2^{ab}	1844.4^{ab}	1745.7^{b}	1785.9^{ab}	1796.6^{ab}	31.8	0.006
BW gain, g										
Starter	249.6^{a}	233.2^{c}	243.3^{ab}	239.1^{bc}	244.5^{ab}	234.8^{bc}	238.8^{bc}	240.0^{abc}	3.15	<0.001
Grower	901.8^{a}	848.5^{bc}	881.5^{ab}	867.3^{abc}	870.2^{ab}	826.5^{c}	855.7^{abc}	877.9^{ab}	15.7	<0.001
Finisher	672.6	629.3	658.6	636.7	657.7	643.4	650.4	637.6	24.9	NS
F intake, g										
Starter	277.1	282.5	272.8	274.2	272.5	282.5	278.4	278.4	3.8	NS
Grower	1201.4^{b}	1126.4^{c}	1183.1^{bc}	1151.8^{bc}	1342.5^{a}	1284.5^{a}	1312.9^{a}	1164.1^{bc}	22.4	<0.001
Finisher	1390.5^{a}	1288.9^{de}	1353.2^{bc}	1337.7^{c}	1345.6^{bc}	1278.8^{e}	1301.6^{d}	1360.0^{b}	35.6	0.037
FCR, g/g										
Starter	1.11^{a}	1.21^{e}	1.12^{ab}	1.15^{bc}	1.12^{ab}	1.20^{de}	1.17^{cd}	1.16^{c}	0.01	<0.001
Grower	1.33^{a}	1.33^{a}	1.34^{a}	1.33^{a}	1.49^{b}	1.55^{c}	1.54^{c}	1.33^{a}	0.01	<0.001
Finisher	2.05	2.05	2.06	2.10	2.06	1.99	2.00	2.15	0.08	NS

$^{a-e}$Values in a row without a common superscript differ significantly ($P<0.05$).

[1]Each value represents the mean of 7 replicates (25 birds per replicate).

[2]HML; High, Medium, Low, LHH; Low High-High, MHH; Medium High-High, LMM; Low, Medium-Medium, MMH; Medium-Medium, High, LLM; Low-Low, Medium, LLH; Low-Low, High, LMH; Low, Medium, High

consistent to the previous work done by Boostani *et al.* (2010). Chronic stress due to feeding of LBP diets in first phase leads to increased plasma corticosterone concentrations. The variations in corticosterone excretion are because of the metabolic effect of low density feed (De Jong *et al.,* 2002). Corticosterone is involved in the regulation of glucose, urea and cholesterol level in blood. The greater levels of serum glucose in restricted-fed birds can be due to improved nutrients absorption and FCR. Hypoglycemia during restriction can be stopped by glucose production *via* gluconeogenesis (Boostani *et al.,* 2010). These results are in disagreement to Rezaei and Hajati (2010) who had reported non-significant effect on protein with LBP or HBP in any growing phase.

The greater (P<0.05) antibody titers against NDV and IBDV were observed in MHH and HML groups. These findings are in line with those reported by Faluyi *et al*. (2015). These later authors stated that the broiler chicken fed greater Lys (1.13%) had better antibody titers against NDV. Ghoreyshi *et al.* (2019) similarly reported that broiler chicken fed greater Lys levels had higher immune response against NDV and IBDV. A HBP diet promotes the development of immunological organs (Attia *et al.,* 2017). Antibodies are proteins, therefore, any deficiency of Lys, particularly during the growth of chickens, results in poor immune competence since it affects the magnitude of immune response (Kidd, 2004).

The economics of the feeding of the various balanced protein regimes (all step up) in the broiler chicken is

Table 3: Effects of varying balanced protein regimen (all steps-up) on carcass characteristics and composition in the broilers chicken1.

Parameters (% of BW)	Treatments2 HML	LHH	MHH	LMM	MMH	LLM	LLH	LMH	SEM	P-Value
Dressed carcass	71.4a	69.9ab	73.05a	66.2b	69.3ab	69.5ab	69.9ab	61.7c	0.70	<0.001
Breast meat	29.4a	28.2sb	29.1a	27.2bc	29.9ab	27.6bc	27.4bc	27.5bc	0.21	<0.001
Abdominal fat	1.7abc	1.9abc	1.8abc	2.0a	1.3d	1.9ab	1.6bcd	1.5cd	0.04	<0.001
Drumstick	12.1a	11.9ab	12.4a	11.0c	11.6bc	11.4bc	11.6bc	11.4bc	0.08	<0.001
Thigh	12.8a	12.5bc	12.9a	12.6bc	12.6bc	12.4c	12.4c	12.4c	0.04	<0.001
Spleen	0.13a	0.11bc	0.14a	0.10bc	0.09c	0.11bc	0.11bc	0.12ab	0.03	<0.001
Thymus	0.27b	0.25bc	0.29a	0.27b	0.25cd	0.25cd	0.29a	0.27b	0.02	<0.001
Bursa	0.18a	0.17abc	0.18a	0.17abc	0.16cd	0.16cd	0.17abc	0.17bcd	0.02	<0.001
Carcass composition (%)										
Moisture	71.3	71.4	71.7	71.3	71.4	70.9	71.1	71.1	0.18	NS
Crude Protein	19.0	19.4	19.8	19.6	19.9	19.7	19.6	19.8	0.11	NS
Crude Ash	1.4	1.5	1.4	1.6	1.4	1.4	1.5	1.5	0.03	NS
Ether Extract	3.4	3.5	3.5	3.4	3.5	3.4	3.2	3.3	0.04	NS

a-dValues in a row without a common superscript differ significantly (P<0.05).

1Each value represents the mean of 7 replicates (3 birds per replicate).

2HML; High, Medium, Low, LHH; Low High-High, MHH; Medium High-High, LMM; Low, Medium-Medium, MMH; Medium-Medium, High, LLM; Low-Low, Medium, LLH; Low-Low, High, LMH; Low, Medium, High.

Table 4: Effects of varying balanced protein regimen (all steps-up) on the selected blood metabolites and antibody titers in the broilers chicken[1].

Treatments[2]	Parameters: Glucose (mg/dl)	Total cholesterol (mg/dl)	Urea (mg/dl)	Total protein (g/dl)	NDV titer	IBDV titer
HML	179.0^{b}	154.1^{b}	21.7^{c}	111.9^{ab}	6.7^{a}	4839.1^{a}
LHH	181.1^{ab}	163.9^{b}	24.4a^{b}	105.5^{b}	6.4^{d}	4087.6^{e}
MHH	177.6^{b}	149.2^{b}	24.1^{abc}	108.6^{ab}	6.7^{a}	4822.4^{a}
LMM	191.9^{ab}	153.9^{b}	23.3^{abc}	103.5^{b}	6.1^{e}	4522.7^{c}
MMH	189.5^{ab}	156.3^{b}	23.1^{abc}	102.9^{b}	6.6^{b}	4849.1^{a}
LLM	191.9^{ab}	153.9^{b}	23.3^{abc}	103.5^{b}	6.1^{e}	4522.7^{c}
LLH	199.5^{a}	178.3^{a}	25.2^{a}	103.9^{b}	6.5^{c}	3780.6^{f}
LMH	194.2^{ab}	160.1^{b}	22.1^{bc}	103.4^{b}	5.9^{g}	4465.6^{d}
SEM	2.37	1.81	0.3	1.07	0.04	9.8
P-Value	<0.001	0.002	0.010	0.002	<0.001	<0.001

$^{a\text{-}g}$Values in a column without a common superscript differ significantly (P<0.05).

[1]Each value represents the mean of 7 replicates (3 birds per replicate).

[2]HML; High, Medium, Low, LHH; Low High-High, MHH; Medium High-High, LMM; Low, Medium-Medium, MMH; Medium-Medium, High, LLM; Low-Low, Medium, LLH; Low-Low, High, LMH; Low, Medium, High.

Table 5: Effects of varying balanced protein regimen (all steps-up) on the economics in the broilers chicken[1].

Parameters	Treatments[2]							
	HML	LHH	MHH	LMM	MMH	LLM	LLH	LMH
Total feed cost (PKR)	319.0	325.0	340.0	310.0	346.0	313.0	337.0	327.0
Day old chick cost (PKR)	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Misc. cost/bird (PKR)	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Total cost/bird (PKR)	389.0	395.0	410.0	385.0	416.0	383.0	407.0	397.0
Avg. weight/bird (kg)	1.86	1.75	1.82	1.78	1.84	1.74	1.79	1.79
Sale price/kg (PKR)	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
Revenue/bird (PKR)	446.2	420.5	437.8	428.2	442.6	418.8	428.6	431.3
Profit/bird (PKR)	57.16	25.48	27.76	43.16	26.56	35.8	21.64	34.28
Profit/kg (PKR)	30.75	14.54	15.22	24.19	14.4	20.52	12.12	19.08
Profit/kg (%)	7.90	3.68	3.71	6.28	3.46	5.3	2.9	4.80

[1]The economic impacts of dietary treatments are average value per broiler chicken.

[2]HML; High, Medium, Low, LHH; Low High-High, MHH; Medium High-High, LMM; Low, Medium-Medium, MMH; Medium-Medium, High, LLM; Low-Low, Medium, LLH; Low-Low, High, LMH; Low, Medium, High.

presented in Table 5. The broiler chicken fed HML diets had greater % profit per kg of the live weight sold among the experimental groups.

Conclusion

In conclusion, the broiler chicken fed HML diets had better growth performance and carcass traits. Moreover, the groups fed HML diets had better immunity and greater profit/ kg of the live weight sold. It is, therefore, recommended that HBP (1.20% SID Lys) should be step down to LBP (1.0% SID Lys) gradually as HML (Starter 1.2%, grower 1.1% and finisher 1.0% SID Lys) for efficient and sustainable production of broiler chicken.

Conflict of interest: None.

References

Acres, A. (2009). Broiler Management Guide. Aviagen Limited: Midlothian, UK, 1-59.

Aftab, U. (2012). Dietary amino acid optima: An economic appraisal. Journal of Applied Poultry Research. 21(4): 738-743.

AOAC. (2016). Official Methods of Analysis. Association of Official Analytical Chemists, 20th Edn, Washington, DC.

Attia, Y.A., Abd-Elhamid, E.A.E., Mustafa, M., Al-Harthi, M.A., Muhammad, M. (2017). Response of slow-growing chickens to feed restriction and effects on growth performance, blood constituents and immune markers. Revista Mexicana de Ciencias Pecuarias. 8(2): 175-184.

Aziz, N.H., Saeed, R.B., Akram, S.A. and Kirkuki, S.M.S. (2021). Effect of feeding frequency on productive broiler performance. Journal of Animal and Poultry Production. 12(2): 91-94.

Boostani, A., Ashayerizadeh, A., Mahmoodian, F.H. and Kamalzadeh, A. (2010). Comparison of the effects of several feed restriction periods to control ascites on performance, carcass characteristics and hematological indices of broiler chickens. Revista Brasileira de Ciência Avícola. 12(3): 170-177.

Camacho, M.A., Suarez, M.E., Herrera, J.G., Cuca , J.M. and Carcia-Bojalil, C.M. (2004). Effect of age of feed restriction and microelement supplementation to control ascites on production and carcass characteristics of broilers. Poultry Science. 83: 526-532.

Duncan, D.B. (1955). Multiple ranges and multiple F-tests. Biometrics. 11(1): 1-42.

Ebeid, T.A., Tùmová, E., Al-Homidan, I.H., Ketta, M. and Chodová, D. (2022). Recent advances in the role of feed restriction in poultry productivity: Part I-performance, gut development, microbiota and immune response. World's Poultry Science Journal. 1-18.

Eits, R.M., Kwakkel, R.P., Verstegen, M.W.A. and Emmans, G.C. (2003). Responses of broiler chickens to dietary protein: Effects of early life protein nutrition on later responses. British Poultry Science. 44: 398-409.

Faluyi, O., Agbede, J. and Adebayo, I. (2015). Growth performance and immunological response to newcastle disease vaccinations of broiler chickens fed lysine supplemented diets. Journal of Veterinary Medicine and Animal Health. 7: 77-84.

Ghoreyshi, S.M., Omri, B., Chalghoumi, R., Bouyeh, M., Seidavi, A., Dadashbeiki, M., Lucarini, M., Durazzo, A., Hoven, R.V.D., Santini, A. (2019). Effects of dietary supplementation of l-carnitine and excess lysine-methionine on growth performance, carcass characteristics and immunity markers of broiler chicken. Animals. 9(6): 362. doi: 10.3390/ani9060362.

Gnanaraj, P.T., Sundaram, A.S., Rajkumar, K. and Babu, R.N. (2020). Proximate composition and meat quality of three indian native chicken breeds. Indian Journal of Animal Research. 54: 1584-1589.

Gobane, Z., Goni, S., Chikwanda, D. and Zhou, L. (2021). The effect of quantitative feed restriction duration on growth performance and carcass characteristics of broiler chickens. Open Journal of Animal Sciences. 11: 635-645.

Jalal, M.A.R. and Zakaria, H. (2012). The Effect of quantitative feed restriction during the starter period on compensatory growth and carcass characteristics of broiler chickens. Pakistan Journal of Nutrition. 11(9): 719. DOI: 10.4236/ojas.2021. 114043.

Jong, D.I., Voorst, S.V., Ehlhardt, D. and Blokhuis, H. (2002). Effects of restricted feeding on physiological stress parameters in growing broiler breeders. British Poultry Science. 43: 157-168.

Kidd, M.T. (2004). Nutritional modulation of immune function in broilers. Poultry Science. 83(4): 650-657.

Mulyantini, N.G. (2014). The antibody and organ immune responses of broiler starter Fed diets with graded levels of digestible lysine. Media Peternakan. 37(1): 57-57.

Pinheiro, D.F., Cruz, V.C., Sartori, J.R. and Paulino, M.L.V. (2004). Effect of early feed restriction and enzyme supplementation on digestive enzyme activities in broilers. Poultry Science. 83: 1544-1550.

Raju, M.V.L.N., Rama, S.V. and Prakash, B. (2022). Performance, serum biochemical profile, slaughter characteristics and nutrient retention of vanaraja chicks fed rice-based distillers dried grains with solubles in diet. Indian Journal of Animal Research. 56(2): 1182-186.

Rezaei, M. and Hajati, H. (2010). Effect of diet dilution at early age on performance, carcass characteristics and blood parameters of broiler chicks. Italian Journal of Animal Science. 9(1): 19. https://doi.org/10.4081/ijas.2010.e19.

Sahraei, M. (2014). Effects of feed restriction on metabolic disorders in broiler chickens: A review. Biotechnology in Animal Husbandry. 30(1): 1-3.

Saleh. E.A., Watkins, S.E., Waldroup, A.L. and Waldroup, P.W. (2005). Effects of early quantitative feed restriction on live performance and carcass composition of male broilers grown for further processing. Journal of Applied Poultry Research. 14(1): 87-93.

Sigolo, S., Deldar, E., Seidavi, A., Bouyeh, M., Gallo, A. and Prandini, A. (2019). Effects of dietary surpluses of methionine and lysine on growth performance, blood serum parameters, immune responses and carcass traits of broilers. Journal of Applied Animal Research. 47: 146-153.

Steel, R.G.D., Torrie, J.H., Dickie, D.A. (1997). Principles and Procedures of Statistics. A Biometric Approach, 3rd Ed. McGraw-Hill, Book Publishing Company, Toronto, Canada.

Waqas, M., Mehmood, S., Mahmud, A., Hussain, J., Ahmad, S., Khan, M.T., Rehman, A., Zia, M.W. and Shaheen, M.S. (2019). Effect of yeast based mannan oligosaccharide (Actigen™) supplementation on growth, carcass characteristics and physiological response in broiler chickens. Indian Journal of Animal Research. 53(11): 1475-9.