BF-1543
[1-5]

RESEARCH ARTICLE

Indian Journal of Animal Research

Modulating the Growth Curve in Broiler Chicken Through Varying Balanced Protein Regimen (Conventional All Step-down)

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

10.18805/IJAR.BF-1543

ABSTRACT

Background: Selecting the appropriate amino acid levels according to age of modern broiler chicken is critical since proteins are costly. This study, therefore, evaluated the performance of the broiler chicken by modulating growth curve through varying balanced protein (BP) regimen under conventional all step-down phase feeding.

Methods: In total, 1750 one-day-old straight run broiler chicks (Hubbard) were randomly allocated to 10 treatments, replicated 7 times with 25 broilers. The 3 diets; a high BP (HBP) with 1.2% standardized Ileal digestible lysine (SIDLys), a medium BP (MBP) with 1.1% SIDLys and a low BP (LBP) with 1.0% SIDLys, were offered in starter, grower and finisher phases as HHH, MMM, LLL, HHM, HHL, MML, HHM, MML, HLL and HML.

Result: Higher (*P*<0.05) average BW and BWG were observed in HMM group in starter period. The greater (*P*<0.05) FI, however, was observed in HHH and in MLL groups in grower and finisher phases. The HMM group had better (*P*<0.05) FCR in all phases. The HHH group had greater (*P*<0.05) dressed carcass weight, breast yield, drum stick and thigh weights. The HHH group, moreover, had heavier (*P*<0.05) abdominal fat, thigh, spleen, thymus and bursa of Fabricius. The HHH group, similarly, had higher (*P*<0.05) serum glucose, cholesterol, urea concentrations and antibody titers against NDV and IBDV. In conclusion, 1.2% SIDLys in the HBP diets improved growth performance, carcass characteristics, blood metabolites and immunity in the broiler chicken.

Key words: Balanced protein, Broiler chicken, Growth performance, Phase feeding, SID lysine.

INTRODUCTION

In comparison with a random bred broiler chicken strain from 1957, the growth rate has been increased 4 folds and FCR has been reduced to half at 42 day of age in modern broiler chicken (Zuidhof *et al.,* 2014). The breeding companies develop new strains, approximately every 5 years with the updated nutritional requirements (Brown *et al.,* 2022). The nutrient requirements of broiler chicken change with age; hence rebalancing the diets, in demand to meet the changing nutrient requirements of broiler chickens according to their age are inevitable (Taheri *et al.,* 2020).

Feed costs about 70% of commercial broiler chicken production. Selecting the appropriate level of dietary amino acids, therefore, may be of critical economic decision since protein (amino acids) are costly nutrients per unit feed (Maharjan *et al.,* 2021). Globally, digestible amino acids and ratios to lysine (Lys) are used extensively in formulating poultry diets. The digestible Lys level in diet for each stage of production is critical in setting the minimums for the other essential digestible amino acids in the ideal protein concept as a balanced protein (Kidd and Tillman, 2016). Utilizing the correct amount of balanced dietary AA for poultry is, therefore, a high priority issue due to its significant impact on broiler chicken growth and meat yield.

In phase-feeding (PF) strategy levels of dietary amino acids (AA) are reduced gradually over time in order to decrease feed cost linked with excess dietary AA supply (Emmert and Baker, 1997). Reduced protein contents, however, during starter phase had negative effects on production performance. It is critical to optimize the requirements of AA at different time periods in broiler chicken for efficient protein utilization as ever increasing protein ingredient prices urge the needs of optimum balanced protein (BP) concept to fulfill bird's requirements avoiding under formulation or over formulation. Since over formulation is costly and under-formulation may result in suboptimal growth and meat production leading to less economic returns. Knowledge of the period in a broiler chicken's life when amino acid needs are greatest is critical so that amino acid requirements patterns may be adjusted in an efficient manner. The present study was, therefore, designed to evaluate the performance of the broiler chicken by modulating growth curve through varying BP regimen under conventional all step-down phase feeding.

[1]Department of Animal Nutrition, University of Veterinary and Animal Sciences, Lahore 5400, Pakistan.
[2]Department of Poultry Production, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan.

Corresponding Author: B. Rashid, Department of Animal Nutrition, University of Veterinary and Animal Sciences, Lahore 5400, 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 (Conventional All Step-down). Indian Journal of Animal Research. DOI: 10.18805/IJAR.BF-1543.

Submitted: 19-05-2022 **Accepted:** 22-08-2022 **Online:** 05-09-2022

METERIALS AND METHODS

This trial was carried out according to the guidelines of Animal Care and Use Committee, University of Veterinary and Animal Sciences, Lahore, Pakistan. In total, 1750 one-day-old straight run broiler chicks (Hubbard) were allocated to 10 experimental treatments, replicated 7 times with 25 birds each, in a completely randomized design. Three isocaloric 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 HHH (HBP for 1-35d), MMM (MBP for 1-35d), LLL (LBP for 1-35d), HHM (HBP for 1-25d and MBP for 26-35d), HHL (HBP for 1-25d and LBP for 26-35d), MML, (MBP for 1-25d and LBP for 26-35d), HMM (HBP for 1-10d and MBP for 26-35d), MLL (MBP for 1-10d and LBP for 26-35d), HLL (HBP for 1-10d and LBP for 26-35d) and HML (HBP for 1-10d, MBP for 11-25d and LBP for 25-35d under conventional all step-down phase feeding. The birds were reared in environmentally controlled house using rice husk as a bedding material and offered ad-libitum feed and water throughout the trial. The birds were immunized against Newcastle disease virus (NDV) (Ceva-Phylaxia, Budapest, Hungry) in drinking water at day 2^{nd}, 14^{th} and 28^{th} day of age. The chicks were vaccinated on day 2^{nd} and 14^{th} against infectious bursal disease virus (IBDV) (Lohman Animal Health GmbH, Cuxhaven, Germany). The recommended management conditions were followed as per guidelines of Hubbard broiler chicken management guide.

The data of growth performance including body weight (BW), body weight gain (BWG), feed intake (FI) and FCR were collected at the end of each phase. The nutrient compositions of the experimental diets were analyzed with the procedure described by Hussain *et al.* (2020). At the 35^{th} day of experiment, three birds from each pen were selected randomly and 5 ml blood was collected by puncturing wing vein, serum harvested that 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 (Rajkumar *et al.,* 2021). 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 analysis of variance (ANOVA) technique in a completely randomized design (Steel *et al.,* 1997) using PROC GLM in SAS software (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

The impacts of the dietary treatments on growth performance are presented in Table 2. During starter phase, higher ($P<0.05$) average BW and BWG were observed in the HMM group. The average BW and BWG, however, were not influenced ($P>0.05$) by the dietary treatments in the grower and finisher phases. The FI was not affected ($P>0.05$) by the dietary treatments in the starter phase. The greater

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 nutrients (% until and otherwise mentioned)			
ME (Kcal/kg)	2800	2800	2800
D. Lys	1.20	1.10	1.0
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 mg 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.

(*P*<0.05) FI, however, was observed in HHH and MLL groups in the grower and finisher phases, respectively. The HMM group had better (*P*<0.05) FCR in the starter, grower and finisher phases. These results are validated by the previous work in broiler chicken (Zarghi *et al.,* 2020). The improved BWG in the broiler chicken fed HBP diets may partially be due to a higher FI resulting in more nutrients and fulfilling the energy needs (Nasr and Kheiri, 2011). Amino acids are major regulators of growth and protein metabolism. The broiler chicken fed diets deficient in Lys had reduced growth performance, protein accretion and breast muscle development (Tesseraud *et al.,* 2009). It has been reported that increasing Lys (0.95 to 1.36%) improves FCR in broiler chicken (Tran *et al.,* 2021).

Carcass characteristics and composition

The impacts of the dietary treatments on the carcass characteristics and composition are presented in Table 3. The higher (*P*<0.05) dressed weight was observed in HHM and HMM groups. The HHH group had heavier (*P*<0.05) breast and abdominal fat pad. The HHH group, likewise, had a higher (*P*<0.05) drumstick weight at par with HLL, HMM, MML and MMM groups. The HHH group had a greater (*P*<0.05) thigh weight at par with HHL and HMM groups. The HHH group had heavier (*P*<0.05) spleens, thymus and bursa of Fabricius. Meat production is the interaction of growth and feed efficiency. An adequate dietary level of limiting AA is needed to support optimum growth and carcass yield of fast growing broiler chicken (Handique *et al.,* 2019). The diets with high Lys may affect carcass characteristics since Lys is an essential AA in protein synthesis. The results regarding carcass characteristics are in line with previous findings by Zarghi *et al.* (2020). These later authors reported that the increasing dig Lys levels (0.88, 0.94, 1.00, 1.06 and 1.12% dig Lys) in broiler chicken diets enhanced carcass and breast meat yield, whereas the abdominal fat was reduced.

The chemical composition of carcass including moisture, CP, crude and ether extract contents in the meat samples was not influenced (*P*>0.05) by the dietary treatments (Table 3).

Serum metabolites and antibody titers

The effects of the dietary treatments on the serum metabolites and antibody titers are presented in Table 4. The HHH group had higher (*P*<0.05) serum glucose, total cholesterol and urea concentrations. In agreement to current findings, it was reported that blood glucose was influenced by the supplementation of Lys above the recommended levels since it acts as a precursor of L-carnitine that has a glucogenic effect (Arslan, 2006). In contrast to the present findings, it was reported that cholesterol concentration was not influenced by Lys levels (Zhang *et al.,* 2021). The greater total cholesterol concentration in the HBP fed group may be due to the availability of cholesterol in feed or synthesized in the body. The increase in cholesterol concentration in circulating blood could be due to endogenous synthesis of cholesterol in birds. The current blood urea findings are in contrast to those reported by Gong *et al.* (2005). The blood urea may be increased due to increasing CP levels in the diets.

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

Parameters	Treatments[2]										SEM	*P*-Value
	HHH	HHL	HHM	HLL	HML	HMM	LLL	MLL	MML	MMM		
BW, (g)												
Starter	279.9^{abc}	280.1^{abc}	288.1^{ab}	287.7^{ab}	290.41^{ab}	294.10^{a}	269.0^{c}	287.9^{ab}	269.3^{c}	276.1^{bc}	4.7	<0.001
Grower	1168.2	1171.9	1156.26	1121.2	1143.46	1149.50	1125.9	1120.7	1136.9	1143.8	24.8	NS
Finisher	1794.5	1812.5	1786.8	1781.9	1811.30	1807.18	1798.0	1755.8	1757.4	1794.4	40.3	NS
BW Gain, (g)												
Starter	238.9^{abc}	239.1^{abc}	247.1^{ab}	246.7^{ab}	249.4^{ab}	253.1^{a}	228.0^{c}	246.9^{ab}	228.3^{c}	235.1^{bc}	4.7	<0.001
Grower	888.3	891.8	868.2	833.5	853.0	855.4	857.0	832.8	867.5	867.6	24.1	NS
Finisher	626.3	640.6	630.5	660.6	667.8	657.7	672.0	635.1	620.5	650.7	32.8	NS
FI, (g)												
Starter	296.2	285.6	288.1	290.5	296.5	298.9	287.5	292.3	292.2	287.9	7.2	NS
Grower	1488.2^{a}	1470.4^{ab}	1442.4^{abc}	1341.0^{bc}	1331.3^{bc}	1304.1^{c}	1445.0^{ab}	1354.6^{abc}	1465.0^{ab}	1445.4^{ab}	42.5	<0.001
Finisher	1460.9^{bcd}	1349.2^{cde}	1276.1^{de}	1298.8^{de}	1333.1^{cde}	1142.1^{e}	1282.9^{de}	1758.4^{a}	1613.4^{abc}	1651.0^{ab}	88.5	<0.001
FCR, (g/g)												
Starter	1.24^{ab}	1.20^{a}	1.16^{a}	1.18^{a}	1.19^{a}	1.18^{a}	1.26^{b}	1.18^{a}	1.28^{b}	1.23^{ab}	0.03	0.003
Grower	1.66^{b}	1.65^{ab}	1.66^{b}	1.61^{ab}	1.61^{ab}	1.56^{a}	1.68^{b}	1.63^{ab}	1.69^{b}	1.67^{b}	0.04	0.004
Finisher	2.34^{abc}	2.14^{bcd}	2.02^{cd}	1.97^{cd}	2.00^{cd}	1.74^{a}	1.91^{cd}	2.77^{c}	2.65^{ab}	2.55^{ab}	0.16	<0.001

$^{a-e}$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]HHH: High, High, High; HHL: High-High, Low; HHM: High-High, Medium; HLL: High, Low-Low; HML: High, Medium, Low; HMM: High, Medium-Medium; LLL: Low, Low, Low; MLL: Medium, Low-Low; MML: Medium-Medium, Low; MMM: Medium, Medium, Medium.

Table 3: Effects of varying balanced protein regimen (conventional all step down) on carcass characteristics and composition in the broilers chicken[1].

Parameters (% of BW)	Treatments[2]										SEM	*P*-Value
	HHH	HHL	HHM	HLL	HML	HMM	LLL	MLL	MML	MMM		
Dressed carcass	72.1^{a}	64.1^{c}	64.3^{c}	62.1^{d}	66.4^{b}	68.2^{b}	59.9^{e}	60.5^{e}	60.5^{e}	63.0^{cd}	0.28	<0.001
Breast meat	19.4^{a}	17.9^{b}	17.4^{b}	17.6^{b}	17.5^{b}	17.8^{b}	16.1^{c}	17.9^{b}	17.9^{b}	17.3^{b}	0.10	<0.001
Abdominal fat	2.1^{a}	1.5^{cd}	1.7^{bc}	1.3^{d}	1.6^{bcd}	1.5^{cd}	1.9^{ab}	1.7^{bc}	1.5^{cd}	1.4^{d}	0.03	<0.001
Drumstick	9.5^{a}	8.9^{a}	8.7^{b}	8.5^{bc}	8.6^{bc}	9.2^{a}	8.1^{c}	8.6^{bc}	9.3^{a}	9.2^{a}	0.05	<0.001
Thigh	11.3^{a}	11.2^{a}	10.9^{ab}	11.0^{ab}	10.2^{c}	11.3^{a}	9.2^{d}	10.1^{c}	10.6^{bc}	10.9^{ab}	0.07	<0.001
Spleen	0.12^{a}	0.11^{b}	0.11^{b}	0.08^{d}	0.07^{de}	0.11^{b}	0.08^{de}	0.08^{de}	0.06^{e}	0.1^{c}	0.01	<0.001
Thymus	0.15^{a}	0.10^{b}	0.09^{bc}	0.05^{cd}	0.05^{cd}	0.10^{b}	0.06^{c}	0.14^{ab}	0.15^{a}	0.13^{b}	0.02	<0.001
Bursa	0.13^{a}	0.11^{b}	0.12^{a}	0.10^{bc}	0.06^{d}	0.11^{b}	0.06^{d}	0.10^{bc}	0.08^{cd}	0.09^{bc}	0.01	<0.001
Carcass composition (%)												
Moisture	59.4	60.3	61.1	60.1	60.3	61.8	61.4	63.7	60.1	59.9	0.46	NS
Crude protein	15.6	15.5	15.7	15.7	15.1	15.7	16.3	15.5	16.0	15.5	0.15	NS
Crude ash	2.8	2.6	2.8	2.6	2.5	2.4	2.7	2.4	2.5	2.7	0.4	NS
Ether extract	15.1	16.4	14.1	14.6	14.3	13.4	13.4	12.3	14.1	14.9	0.39	NS

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

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

2HHH: High, High, High; HHL: High-High, Low; HHM: High-High, Medium; HLL: High, Low-Low; HML: High, Medium, Low; HMM: High, Medium-Medium; LLL: Low, Low, Low; MLL: Medium, Low-Low; MML: Medium-Medium, Low; MMM: Medium, Medium, Medium.

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

	Parameters					
Treatments[2]	Glucose (mg/dl)	Total cholesterol (mg/dl)	Urea (mg/dl)	Total protein (g/dl)	NDV titer	IBDV titer
HHH	219.8^{a}	180.7^{a}	28.5^{a}	101.0	2.3^{a}	4849.1^{a}
HML	184.6^{bc}	162.4^{bc}	24.8^{bc}	104.4	2.1^{ab}	4693.1^{b}
HHM	177.4^{c}	148.1^{c}	23.9^{bc}	108.7	2.1^{ab}	4087.6^{d}
HLL	181.2^{bc}	148.1^{c}	22.5^{bc}	101.9	1.4^{d}	3464.6^{h}
HML	178.7^{bc}	153.2^{c}	22.1^{c}	110.5	1.4^{d}	3780.6^{e}
HMM	190.5^{bc}	154.7^{c}	23.7^{b}	102.6	2.1^{ab}	4622.6^{b}
LLL	198.9^{b}	156.9^{bc}	24.6^{bc}	103.9	0.6^{f}	3526.4^{f}
MLL	154.1^{d}	153.1^{c}	25.5^{b}	113.1	2.0^{b}	4122.1^{d}
MML	192.8^{bc}	172.2^{ab}	21.8^{c}	101.7	1.0^{e}	4165.6^{d}
MMM	191.5^{bc}	155.5^{c}	23.2^{bc}	103.5	1.7^{c}	4522.4^{c}
SEM	2.4	1.83	0.33	1.03	0.04	9.8
P-Value	<0.001	<0.001	<0.001	NS	<0.001	<0.001

$^{a-h}$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]HHH: High, High, High; HHL: High-High, Low; HHM: High-High, Medium; HLL: High, Low-Low; HML: High, Medium, Low; HMM: High, Medium-Medium; LLL: Low, Low, Low; MLL: Medium, Low-Low; MML: Medium-Medium, Low; MMM: Medium, Medium, Medium.

The greater (*P*<0.05) antibody titers against NDV and IBDV were observed in HHH group. It has been reported that feeding of high density diets leads to greater development of immune organs (Attia *et al.,* 2017). The greater weights of bursa of Fabricius in HHH groups in the current study might be the possible explanation of greater antibody titers since the bursa of Fabricius is the primary lymphoid organ responsible for the formation and conservation of the B cells in birds (Jankowski *et al.,* 2014).

CONCLUSION

In conclusion, 1.2% SID Lys in the HBP diets improved the growth performance, carcass characteristics, selected blood metabolites and immunity in the broiler chickens. However, the nutrient density and phase feeding had no effects on carcass chemical composition.

Conflict of interest: None.

REFERENCES

Arslan, C. (2006). L-carnitine and its use as a feed additive in poultry feeding: A review. Revista de Medicina Veterinaria. 157(3): 134-142.

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.

Brown, A., Lee, J., Adhikari, R., Haydon, K., Wamsley, K. (2022). Determining the optimum digestible isoleucine to lysine ratio for Ross 708 × Ross YP male broilers from 0 to 18 d of age. Journal of Applied Poultry Research. 31(1): 100217.

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

Emmert, J.L. and Baker, D.H. (1997). Use of the ideal protein concept for precision formulation of amino acid levels in broiler diets. Journal of Applied Poultry Research. 6: 462-470.

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.

Gong, L.M., Lai, C.H., Qiao, S.Y., Li, D., Ma, Y.X., Liu, Y.L. (2005). Growth performance, carcass characteristics, nutrient digestibility and serum biochemical parameters of broilers fed low-protein diets supplemented with various ratios of threonine to lysine. Asian Australian Journal of Animal Science. 18(8): 1164-1261.

Hussain, M., Mahmud, A., Hussain, J., Qaisrani, S.N., Mehmood, S., Ahmad, S. and Rehman, A.U. (2020). Effect of dietary amino acid regimens on growth performance and body conformation and immune responses in Aseel chicken. Indian Journal of Animal Research. 54(1): 53-58.

Handique, B., Yengkhom, R., Maurya, L.K. (2019). Lysine and methionine supplementation in commercial broiler chicken: A review. Journal of Entomology and Zoology Studies. 7(3): 193-196.

Jankowski, J., Kubińska, M., Zduńczyk, Z. (2014). Nutritional and immunomodulatory function of methionine in poultry diets - a review. Annals of Animal Science. 14: 17-32.

Kidd, M., Tillman, P. (2016). Key principles concerning dietary amino acid responses in broilers. Animal Feed Science and Technology. 221: 314-322.

Maharjan, P., Martinez, D., Weil, J., Suesuttajit, N., Umberson, C., Mullenix, G., Hilton, K., Beitia, A., Coon, C. (2021). Physiological growth trend of current meat broilers and dietary protein and energy management approaches for sustainable broiler production. Animal. 100284.

Nasr, J. and Kheiri, F. (2011). Increasing amino acids density improves broiler live weight. International. Journal of Poultry Science. 10(7): 523-526.

Rajkumar, U., Prince, L.L.L., Haunshi, S., Paswan, C. and Muthukumar, M.P. (2021). Evaluation of growth, carcass and meat quality of a two-way cross developed for rural poultry farming. Indian Journal of Animal Research. 55: 498-502.

Ravindran, V. (2012). Advances and future directions in poultry nutrition: An overview. Korean Journal of Poultry Science. 39: 53-62.

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.

Taheri, H., Mansouri, A., Ghaderi, O. (2020). Comparison of multi-step phase-feeding programs (eight or thirteen steps) with a commercial three-step feeding program for broiler chickens. Poultry Science. 8: 9-15.

Tesseraud, S., Bouvarel, I., Collin, A., Audouin, E., Crochet, S., Seiliez, I., Leterrier, C. (2009). Daily variations in dietary lysine content alter the expression of genes related to proteolysis in chicken pectoralis major muscle. The Journal of Nutrition. 139: 38-43.

Tran, D.H., Schonewille, J.T., Pukkung, C., Khempaka, S. (2021). Growth performance and accretion of selected amino acids in response to three levels of dietary lysine fed to fast- and slow-growing broilers. Poultry Science. 100: 100998.

Waqas, M., Mehmood, S., Mahmud, A., Hussain, J., Ahmad, S., Khan, M.T., Rehman, A., Zia, M.W. 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.

Zarghi, H., Golian, A., Nikbakhtzade, M. (2020). Effect of dietary digestible lysine level on growth performance, blood metabolites and meat quality of broilers 23-38 days of age. Journal of Animal Physiology and Animal Nutrition. 104(1): 156-65.

Zhang, J., Wang, W., Wang, Y., Hu, H., Yu, B., Zhou, Z., Guo, J., Gu, Y., Cai, Z., Xin, G. (2021). Modulation of broiler plasma metabolic spectrum by the addition of lysine residue to the diet. Journal of Animal Physiology and Animal Nutrition. 00: 1-14.

Zuidhof, M.J., Schneider, B.L., Carney, V.L., Korver, D.R., Robinson, F.E. (2014). Growth, efficiency and yield of commercial broilers from 1957, 1978 and 2005. Poultry Science. 93: 2970-2982.