RESEARCH ARTICLE Asian Journal of Dairy and Food Research, Volume 42 Issue 3: 326-331 (September 2023)

Effect of Dietary Supplementation of L-Valine on Growth, Immunocompetence Traits, Carcass Quality and Meat Composition of Turkey Poults

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10.18805/ajdfr.DR-1600

ABSTRACT

Background: Valine is an important amino acid and its deficiency may result in reduced growth and immunity. However, studies in turkeys are limited. Hence a study was conducted to assess the effect of supplemental L-valine (L-val) on growth performance, immunocompetence traits, carcass quality and meat composition of turkey poults.

Methods: Day old turkey poults (n=96) were distributed into four dietary treatment groups: T_1-basal diet, T_2-T_1+0.04% L-val, T_3- T_1+0.08% L-val, T_4- T_1+0.12% L-val, having three replicates of 8 birds each.

Result: No significance difference observed in average weekly body weight (BW), body weight gain (BWG) and feed conversion ratio (FCR) of birds throughout experimental period except at 7th week where T_2 and T_3 poults had a significantly higher (P<0.05) BW, BWG and significantly better (P<0.05) FCR. HA titre was significantly higher (P<0.05) in T_3. Per cent breast weight was significantly higher (P<0.05) in T_3. Percent crude protein level in breast muscle of turkey poults was significantly higher (P<0.05) in T_3. Thus, supplementation of L-val @ 0.08% in turkey poults resulted in significantly better humoral immune response, higher percent breast yield and higher percent crude protein in breast meat.

Key words: Body weight, FCR, Immunity, L-Valine, Turkey poults.

INTRODUCTION

Turkey is a rapidly growing bird and requires more energy, protein, vitamins and minerals than chicken. The poultry industry has already been dealing with fluctuating spikes in the price of various feed ingredients. When the cost of protein-rich feed ingredients goes up, the reduction of dietary crude protein *via* the use of commercially available amino acids becomes an effective formulation strategy that can reduce diet costs, maintain broiler performance and not interfere with feed milling throughput. An effort to decrease production costs can be accomplished via supplementation with L-lysine, DL-methionine, L-threonine and L-valine. Reduction of dietary protein level and use of synthetic amino acids are often suggested to reduce the feed cost and also to contain the environmental pollution of nitrogen.

Valine is 4th amino acid in corn and soybean meal-based diets (Baker *et al*., 2002; Corzo *et al*., 2007, 2009; Rostagno *et al*., 2011). Valine deficiency in broilers may result in reduced growth performance, carcass quality and immune response (Kumar *et al*., 2015; Nascimento *et al*., 2016; Kaplan and Yildiz, 2017) respectively. Studies have been conducted on dietary supplementation of L-valine in broilers performance (Corzo *et al*., 2007; Azzam *et al.,* 2015) but such studies are lacking in turkeys. Hence, the present study was designed with the objective to study the effect of supplementation of L-valine on growth performance, immunocompetence traits, carcass quality and meat composition of turkey poults.

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How to cite this article: Singh, V.K., Shukla, P.K., Bhattacharyya, A., Vaswani, S., Yadav, B. and Sharma, A. (2023). Effect of Dietary Supplementation of L-Valine on Growth, Immunocompetence traits, Carcass Quality and Meat Composition of Turkey Poults. Asian Journal of Dairy and Food Research. 42(3): 326-331. doi: 10.18805/ajdfr.DR-1600.

Submitted: 06-11-2020 **Accepted:** 14-06-2023 **Online:** 19-07-2023

MATERIALS AND METHODS

The present experiment was conducted at the Department of Poultry Science, College of Veterinary Science and Animal

Husbandry, DUVASU, Mathura after due approval of the IAEC on 96-day-old turkey poults. Feed prepared as per NRC, (1994) was procured from CARI, Izatnagar.

Experimental design

Ninety-six-day old straight run turkey poults were randomly distributed into four dietary treatments comprising three replicates and eight poults in each replicate. The feed was offered *ad lib* in different experimental groups. The birds were housed in deep litter system. Water was offered *ad lib*. The dietary treatments during the experimental period of 8 weeks were as follows:

T_1: Control basal diet as per breed requirement with no addition of L-valine.
T_2: Basal diet + 0.04% L-valine.
T_3: Basal diet + 0.08% L-valine.
T_4: Basal diet + 0.12% L-valine.

Nutrient composition

The composition of the basal diet (Turkey Starter) has been depicted in Table 1 and the amino acid composition of the basal diet has been portrayed in Table 2. The nutrient chemical composition of the experimental feed is given in Table 3.

Body weight and feed conversion ratio

Weekly body weight and replicate wise feed consumption was recorded. Thereafter, phase wise (0-4 weeks, 4-8 weeks and 0-8 weeks) body weight gain and phase wise feed conversion ratio were calculated at the end of the experiment.

Antibody response to goat red blood cells (GRBC)

The microtitre plate haemagglutination procedure as described by (Siegel and Gross, 1980) with slight modifications was followed to measure total HA antibody titres in turkey poults on day zero and day 5th post injection with 1 ml of 1% (V/V) of GRBC suspension.

Immunization and harvesting of immune serum

1 ml of 1% (V/V) of GRBC suspension was injected to 8 poults of each treatment group. About 3 ml of blood on 0 and 5th day post immunization (dpi) were collected from wing vein. The blood was endorsed to clot in an incubator having temperature of 37°C for 1 hour. The blood was endorsed to retract after detaching it from sides of its container and left at 4°C. Centrifugation of blood was carried out at 2000 rpm for 5-10 minutes as it facilitated rapid collection of serum. The antibody titre was determined by HA methods (Vander Zijpp, 1983; Siegel and Gross, 1980). Antibodies were determined by means of a mercaptoethanol (ME) HA test as per the method described by Martin *et al*. (1989) with slight modification.

Carcass quality traits

At the time of slaughter, 16 birds were taken at 8 weeks of age for studying various slaughter traits *viz*. pre-slaughter fasting shrinkage in live weight (%), dressing (%) and total ready-to-cook yield (%).

Proximate composition of breast (*pectoralis major*) muscle of turkey poults

At 8 weeks of age, 4 birds from each treatment group (2 male and 2 female) were sacrificed and there after fresh samples of breast (*pectoralis major*) was processed and analysed for moisture, crude protein (CP), ether extract (EE), total ash, calcium and phosphorous (AOAC, 1990).

Statistical analysis

The data pertaining to various parameters were analyzed statistically as per the standard procedure (Snedecor and Cochran, 1989) and difference between the treatment means were obtained by using Duncan multiple range test (Duncan, 1955).

RESULTS AND DISCUSSION

Weekly body weight and body weight gain

The weekly body weight (BW) and weekly body weight gain (BWG) of turkey poults from 0-8 weeks have been presented in Table 4 and 5 respectively. Data on BW and BWG changes indicated that there was no significant difference in average weekly BW and BWG of birds throughout experimental period except at 7th week. T_2 and T_3 group birds had significantly higher ($P<0.05$) BW and BWG compared to the other two treatment groups at 7th weeks of age. Baker *et al.* (1996) noted that there was increase in BWG of chicken with increasing levels of digestible valine and the BWG was highest with supplementation of 1.06% digestible valine. Alves *et al.* (2017) reported that BW in meat-type quails

Table 1: Composition of basal diet (Turkey starter).

Feed ingredients	Starter (0-8 wks)
Gross composition (kg/100 kg)	
Maize	42.52
Soya bean meal	43.75
Fish meal	8.0
Animal fat	2.25
Dicalcium phosphate	2.0
Limestone powder	1.0
Mineral mixture 1	0.1
Vitamin mixture 2	0.025
Choline chloride (60%)	0.16
Salt	0.1
Methionine	0.1
Chemical composition (%)	
Crude protein	28.31
Metabolizable energy (K cal/kg)	2843.84
Calcium	1.65
Phosphorous (Total)	0.9

1. Each gram contains: Copper-15 mg, Iron-250 mg, Iodine-6 mg, Manganese-300 mg and Zinc-300 mg.
2. Each gram contains: Vitamins A-82,500 IU, B_2 -50 mg, D_3-12,000 IU, K-10 mg. B_1- 8 mg, B_6 -16 mg, B_{12}-80 mg, E-80 mg, niacin-120 mg, calcium pantothenate-80 mg.

was highest when the digestible Val: Lys ratio was 0.80 followed by 0.85. In the present study, the valine percent in T_2 and T_3 was 1.21 and 1.25 and the digestible Val: Lys ratio in T_2 and T_3 as determined by digestibility coefficients was 0.82 and 0.85 and the body weight in T_2 followed by T_3 was apparently higher compared to the other treatment groups throughout the experiment.

Corzo *et al.* (2007) noted that broilers were more sensitive to L-valine supplementation pertaining to BWG better in the valine supplemented group. In the present study too, BWG was comparatively higher in all the valine supplemented groups compared to the control group during the entire growth phase. Tavernari *et al.* (2013) observed that BWG was highest in broilers when the digestible Val: Lys ratio was 0.81. Similarly, Alves *et al.* (2017) reported that BWG in meat-type quails was highest when the digestible Val: Lys ratio was 0.80 followed by 0.85. The digestible Val: Lys ratio in T_2 and T_3 were 0.82 and 0.85 in the present study.

Table 2: Amino acid composition of basal diet (Turkey starter).

Amino acids	Amount (%)
Lysine	1.56
Methionine	0.52
Cystine	0.44
Arginine	1.96
Threonine	1.06
Tryptophan	0.38
Isoleucine	1.22
Leucine	2.38
Phenyalanine	1.42
Valine	1.36
Histidine	0.78
Glycine	0.96

Weekly feed conversion ratio and phase-wise feed conversion ratio

The weekly and phase-wise feed conversion ratio (FCR) of turkey poults are presented in Table 6 and 7, respectively. Results indicated that there was no significant difference in FCR of birds during the entire experimental period except at 7th week and FCR was significantly better ($P<0.05$) in T_2 and T_3 as compared to T_1 and T_4 group. Results indicated that there was no significant difference in FCR of birds during 0-4 weeks and during 4-8 weeks of age. However, when FCR was calculated during 0-8 weeks of age, significantly better ($P<0.05$) FCR was observed in T_2 and T_3 than T_1 and FCR of T_4 group was comparable to that of T_1, T_2 and T_3. Corzo *et al.* (2007) noted that broilers were more sensitive to L-valine supplementation pertaining to FCR as FCR was better in valine supplemented group. Similarly, in the present study, FCR was comparatively better in all the valine supplemented groups compared to the control during different phases of growth. Alves *et al.* (2017) reported that

Table 3: Chemical composition of Turkey starter feed.

Category	Dry matter %	Total ash %	Ether extract %	Ca%	P %	Protein %
Turkey starter feed	89.20	8.26	2.48	2.08	1.28	28

Table 4: Effect of L-valine supplementation on the average weekly body weight (g) of Turkey poults during 0-8 weeks of age.

Treatment	Day old	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week
T_1	46.67	86.42	144.25	215.00	310.58	423.46	579.67	734.92^a	929.00
T_2	46.67	88.17	149.00	221.75	327.00	441.83	593.75	791.58^b	1026.75
T_3	46.83	87.25	147.67	217.75	335.83	446.04	594.67	788.08^b	1022.67
T_4	46.83	89.58	148.17	218.92	313.42	421.50	578.92	740.75^a	944.75
Pooled SEM	0.06	0.58	1.51	2.47	4.48	4.81	4.26	9.35	18.05
Sig. level	NS	NS	NS	NS	NS	NS	NS	P<0.05	NS

Means bearing different superscripts within a column differ significantly ($P<0.05$).

NS: Not significant ($P>0.05$); SEM: Standard error of means.

Table 5: Effect of L-valine supplementation on the average weekly body weight gain (g) of Turkey poults during 0-8 weeks of age.

Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week
T_1	39.75	57.83	70.75	95.58	112.88	156.21	157.25^a	194.08
T_2	41.50	60.83	72.75	105.25	114.83	151.92	197.83^b	235.17
T_3	40.42	60.42	70.08	118.08	110.21	148.63	193.42^b	234.58
T_4	42.75	58.58	70.75	94.50	108.08	157.42	161.83^a	204.00
Pooled SEM	0.58	1.45	1.29	3.98	1.69	1.83	6.24	10.44
Sig. level	NS	NS	NS	NS	NS	NS	P<0.01	NS

Means bearing different superscripts within a column differ significantly ($P<0.01$).

NS: Not significant ($P>0.05$); SEM: Standard error of means.

Table 6: Effect of L-valine supplementation on the weekly feed conversion ratio of Turkey poults during 0-8 weeks of age.

Treatment	1st week	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week
T_1	2.10	2.44	2.44	2.81	2.90	2.85	2.79^b	2.80
T_2	2.00	2.33	2.42	2.60	2.87	2.91	2.39^a	2.42
T_3	2.05	2.36	2.59	2.31	2.93	2.95	2.45^a	2.48
T_4	1.99	2.41	2.44	2.90	2.96	2.81	2.82^b	2.72
Pooled SEM	0.03	0.05	0.05	0.10	0.04	0.04	0.07	0.09
Sig. level	NS	NS	NS	NS	NS	NS	P<0.05	NS

Means bearing different superscripts within a column differ significantly (P<0.05).
NS: Not significant (P>0.05); SEM: Standard error of means.

Table 7: Effect of L-valine supplementation on feed conversion ratio of Turkey poults at different phases of growth during 0-8 weeks of age.

Treatment	0 to 4 weeks	4 to 8 weeks	0 to 8 weeks
T_1	2.52	2.83	2.74^b
T_2	2.40	2.58	2.53^a
T_3	2.34	2.64	2.54^a
T_4	2.51	2.81	2.72^{ab}
Pooled SEM	0.03	0.05	0.04
Sig. level	NS	NS	P<0.05

Means bearing different superscripts within a column differ significantly (P<0.05). NS: Not significant (P>0.05); SEM: Standard error of means.

Table 8: Effect of L-valine supplementation on the humoral immune response [antibody titre (log 2) values] to 1% GRBC in Turkey poults at 8 weeks of age.

Treatment	HA	IgG	IgM
T_1	6.25^a	2.38	3.87
T_2	6.37^a	2.50	3.88
T_3	8.00^b	3.00	5.00
T_4	7.38^{ab}	2.50	4.88
Pooled SEM	0.26	0.11	0.21
Sig level	P<0.05	NS	NS

Means bearing different superscripts within a column differ significantly (P<0.05).
NS: Not significant (P>0.05); SEM: Standard error of means.

FCR in meat type quails was better when digestible Val: Lys ratio was 0.80 followed by 0.85. In the present study, the Val: Lys ratio in T_2 and T_3 was 0.82 and 0.85. Further, the FCR in T_2 followed by T_3 was better compared to the other treatment groups during the entire growth phase. The better FCR in valine supplemented groups compared to the control group may be due to better amino acid balance resulted in better protein accretion in the body.

Humoral immune response

Data on humoral immune response revealed that HA titre was significantly higher (P<0.05) in T_3 as compared to T_1 and T_2 treatment groups and numerically higher than T_4 treatment groups (Table 8). Similarly, IgG response was better in T_3 group as compared to the other treatment groups 8 weeks of age. In addition, HA, IgG and IgM titre values in 0.04%, 0.08% and 0.12% L-valine supplemented groups were apparently higher than the control group. This agrees with the results obtained by Daware *et al*. (2018) who noted that dietary supplementation of L-valine @ 0.01, 0.04, 0.08 and 0.12% in broilers resulted in higher ND titres compared to control. In the same experiment, it was also observed that 0.08% dietary valine supplementation elicited significantly higher ND titre compared to control. Branched chain amino acids (BCAA) including valine, isoleucine and leucine have the greatest potential to modulate immune responses among the amino acids in broilers (Konashi *et al.,* 2000) and play critical role in regulation of immunity against diseases in humans and in animals (Nie *et al*., 2018).

Carcass quality traits

Results pertaining to the yield of cut-up-parts of the carcass at 8 weeks of age have been expressed as a percent yield of the eviscerated weight of the carcass in Table 9. Breast percent was significantly higher (P<0.05) in the T_3 as compared to T_1 and T_2 and numerically higher than the T_4 group. Statistical analysis of the data revealed there was no significant difference observed in other cut-up-parts among the different treatment groups. The present findings are similar to Daware *et al*. (2018) who also reported that dietary supplementation of L-valine in broiler diet did not affect eviscerated yield but supplementation of 0.04, 0.08 and 0.12% L-valine in broilers significantly improved (p<0.05) breast yield in broilers at the end of sixth week of age. Similar to present findings, there was significantly higher breast yield and breast meat weight by dietary valine supplementation in broiler diet (Nascimento *et al.,* 2016).

Chemical composition of breast (*Pectoralis major*) muscle

Results pertaining to yield of proximate analysis of breast muscle of the carcass at 8th week of age are presented in Table 10. Per cent crude protein level in breast muscle of turkey poults were significantly higher (P<0.05) in T_3 as compared to T_1 and numerically higher than T_2 and T_4 treatment groups. These results may be because serum concentration of triiodothyronine (T_3) increased signiûcantly on L-valine supplementation compared to the control group (Azzam *et al*., 2015; Carew *et al.,* 1998). Thyroid hormones are recognised as the key metabolic hormones of the body,

Table 9: Effect of L-valine supplementation on the cut up-parts of Turkey poults at 8 weeks of age (% dressed weight).

Treatment	Breast %	Back %	Neck %	Wing %	Drumstick %	Thigh %
T_1	26.52[a]	21.56	5.78	13.19	15.58	16.49
T_2	27.18[a]	22.40	6.00	13.03	15.81	15.74
T_3	29.22[b]	21.02	5.64	12.81	15.18	15.94
T_4	27.87[ab]	22.13	5.43	13.39	15.37	15.55
Pooled SEM	0.33	0.42	0.17	0.14	0.11	0.21
Sig level	P<0.01	NS	NS	NS	NS	NS

Means bearing different superscripts within a column differ significantly (P<0.05).

NS: Not significant (P>0.05); SEM: Standard error of means.

Table 10: Effect of L-valine supplementation on chemical composition of breast muscle (*pectoralis major*) of Turkey poults at 8 weeks of age.

Treatment	Moisture %	DM %	CP %	EE %	Total ash %	Ca (mg/100 g)	P (mg/100 g)
T_1	74.18	23.31	20.22[a]	0.70	1.40	3.20	240.03
T_2	73.14	26.86	22.00[ab]	0.73	1.38	3.25	240.45
T_3	73.46	26.54	23.62[b]	0.70	1.38	3.24	241.83
T_4	73.41	26.59	22.44[ab]	0.75	1.42	3.24	242.30
Pooled SEM	0.19	0.71	0.46	0.03	0.03	0.05	0.78
Sig level	NS	NS	P<0.05	NS	NS	NS	NS

Means bearing different superscripts within a column differ significantly (P<0.05).

NS: Not significant (P>0.05); SEM: Standard error of means.

with triiodothyronine (T_3) being the most functionally active form. The serum concentration of thyroid hormones is associated with protein synthesis and energy production (Hornick *et al*., 2000; Smith *et al.,* 2002).

CONCLUSION

The present study indicated that dietary supplementation of L-valine @ 0.04% and 0.08% resulted in better growth performance. The present study also showed that dietary supplementation of L-valine @ 0.08% leads to better humoral immune response, an increase in per cent breast yield and percent crude protein level in breast meat.

ACKNOWLEDGEMENT

The authors are thankful to Vice Chancellor, DUVASU, Mathura for providing the necessary facilities for carrying out this study.

Conflict of interet: None.

REFERENCES

Alves, W.J., Viana, G.S., Barreto, S.L.T., Muniz, J.C.L., Hannas, M.I., Silva, A.D., Arnaut, P.R., Barros, V.R.M.S. (2017). Optimum digestible valine to lysine ratio for meat type quails from 15 to 35 days of age. Brazilian Journal of Poultry Science. 19: 185-190.

AOAC, (1990). Official Method of Analysis. 15th Edn. Association of Official Analytical Chemist Washington. D.C. 2004.

Azzam, M.M.M., Donga, X.Y., Dai, Z., Zou, X.T. (2015). Effect of excess dietary L-valine on laying hen performance, egg quality, serum free amino acids, immune function and antioxidant enzyme activity. British Poultry Science. 56: 72-78.

Baker, D.H., Batal, A.B., Parr, T.M., Augspurger, N.R., Parsons, C.M. (2002). Ideal ratio (relative to lysine) of tryptophan, threonine, isoleucine and valine for chicks during the second and third weeks post hatch. Poultry Science. 81: 485-494.

Baker, D.H., Fernandez, S.R., Parsons, C.M., Edwards III, H.M., Emmert, J.L., Webel, D.M. (1996). Maintenance requirement for valine and efficiency of its use above maintenance for accretion of whole body valine and protein in young chicks. The Journal of Nutrition. 126: 1844-1851.

Carew, L.B., Evarts, K.G., Alster, F.A. (1998). Growth, feed intake and plasma thyroid hormone levels in chicks fed dietary excesses of essential amino acids. Poultry Science. 77: 295-298.

Corzo, A., Kidd, M.T., Dozier, W.A., Vieira, S.L. (2007). Marginality and needs of dietary valine for broilers fed certain all-vegetable diets. The Journal of Applied Poultry Research. 16: 546-554.

Corzo, A., Loar, II, R.E., Kidd, M.T. (2009). Limitations of dietary isoleucine and valine in broiler chick diets. Poultry Science. 88: 1934-1938.

Daware, A.G., Lonkar, V.D., Ranade, A.S., Patodkar, V.R., Mote, C.S., Bhalerao, S.M., Doiphode, A.Y. (2018). Effect of dietary supplementation of L-valine on carcass characteristics, immunity and serum biochemicals of broilers. International Journal of Agriculture Sciences. 18: 7150-7155.

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

Hornick, J.L., Van Eenaeme, C., Gérard, O., Dufrasne, I., Istasse, L. (2000). Mechanisms of reduced and compensatory growth. Domestic Animal Endocrinology. 19: 121-132.

Kaplan, M. and Yildiz, G. (2017). The effects of dietary supplementation levels of valine on performance and immune system of broiler chickens. Journal of Agricultural and Crop Research. 5: 25-31.

Konashi, S., Takahashi, K., Akiba, Y. (2000). Effects of dietary essential amino acid deficiencies on immunological variables in broiler chickens. British Journal Nutrition. 83: 449-456.

Kumar, B.C., Gloridoss, R.G., Singh, K.C., Prabhu, T.M., Siddaramanna, Suresh, B.N., Manegar. (2015). Impact of second line limiting amino acids deficiency in broilers fed low protein diets with rapeseed meal and de-oiled rice bran. Veterinary World. 8: 350-357.

Martin, A., Gross, W.B., Siegel, P.B. (1989). IgG and IgM responses in high and low antibody selected lines of chickens. The Journal of Heredity. 80: 249-252.

Nascimento, G.R., Murakami, A.E., Ospina-Rojas, I.C., Diaz-Vargas, M., Picoli, K.P., Garcia, R.G. (2016). Digestible valine requirements in low-protein diets for broilers chicks. Brazilian Journal of Poultry Science. 81(3): 381-386.

Nie, C., He, T., Zhang, W., Zhang, G., Ma, X. (2018). Branched chain amino acids: Beyond nutrition metabolism. International Journal of Molecular Science. 19: 954. doi: 10.3390/ijms19040954.

NRC, (1994). Nutrient Requirements of Poultry. 9th Revised Edition National Academy Press, Washington, DC.

Rostagno, H.S., Albino, L.F.T., Donzele, J.L., Gomes, P.C., Oliveira, R.F.M., Lopes, D.C., Ferreira, A.S., Barreto, S.L.T. (2011). Brazilian Tables for Poultry and Swine-composition of Feed Stuffs and Nutritional Requirements. 3rd ed. Viçosa, MG, Brasil.

Siegel, P.B. and Gross, W.B. (1980). Production and persistency of antibodies in chickens to sheep erythrocytes. 1. Directional selection. Poultry Science. 59: 1-5.

Smith, J.W., Evans, A.T., Costall, B., Smythe, J.W. (2002). Thyroid hormones, brain function and cognition: A brief review. Neuroscience and Biobehavioral Reviews. 26: 45-60.

Snedecor, G.W. and Cochran, W.G. (1989). Statistical Methods, 8th ed. Iowa State University Press, IA.

Tavernari, F.C., Lelis, G.R., Vieira, R.A., Rostagno, H.S., Albino, L.F.T., Oliveira N.A.R. (2013). Valine needs in starting and growing Cobb (500) broilers. Poultry Science. 92: 151-157.

Van der zijpp, A.J. (1983). The effect of genetic origin, source of antigen and dose of antigen on the immune response of cockerels. Poultry Science. 62: 205-211. doi: 10.3382/ps.0620205.