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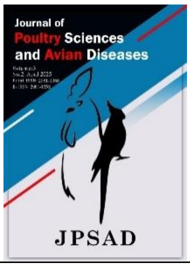

Effect of different dietary levels of energy and sulfur-containing amino acids, lysine, and threonine levels on productive and economic performance and carcass characteristics of broiler chickens

Mohammad Golzadeh[1], Shahriar Maghsoudlou[1*], Ashour Mohammad Gharebash[1], Javad Bayat Koohsar[1]

[1] Department of Animal Sciences , Faculty of Agriculture and Natural Resources, Gonbad Kavous University, Gonbad Kavous, Iran

*** Corresponding author email address**: maghsoudloushahriar@yahoo.com

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A B S T R A C T

An experiment was conducted to investigate the effect of different energy levels and the concentration of methionine, lysine and threonine amino acids on production and economic performance of broiler chickens with the number of 180 Arbor-acres strain broiler chickens in a 3×2 factorial arrangement (2 levels of metabolizable energy, high: 2950, 3000 and 3050 and low: 2850, 2900 and 2950 for starter, grower and finisher phases, respectively × 3 different levels of amino acids methionine, lysine and threonine: the recommended level for Arbor-acres, 15% more and 15% less than that) and three repetitions in a completely randomized design. The results showed that using a higher level of dietary energy caused a significant increase in feed intake and weight gain in the entire growth period ($p<0.05$). Although the use of different levels of amino acids did not have a significant effect on feed consumption ($p>0.05$), body weight was significantly affected by the concentration of amino acids in the diet ($p<0.05$). The main effects of energy and amino acids on food conversion ratio (FCR) were not significant at 1-42 days of age ($p>0.05$). Higher energy levels and higher concentrations of amino acids in the feed caused a significant increase in feed cost ($p<0.05$). However, different energy levels did not significantly affect birds' monetary returns ($p>0.05$). Different concentrations of amino acids showed a significant effect on the monetary returns of broiler chickens ($p< 0.05$), so the monetary returns of chickens fed with the amino acid recommended by Arbor-acres and 15 percent less than that, was higher than the other group (15% more than recommended level). Other results showed that an increase in dietary energy level resulted in an increase in thigh percentage, and an increase in the density of amino acids resulted in an increase in breast percentage. The interaction effects between dietary energy and amino acids were insignificant on any of the traits ($p>0.05$). The results of this experiment showed that the increased dietary energy and amino acid levels increased the live production performance and percentages of thigh and breast but did not significantly affect the food conversion ratio and did not improve the monetary returns of broiler chickens.

Keywords: *broiler, dietary energy level, methionine, lysine, threonine, carcass characteristics, economic performance*

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1 Introduction

Choosing the energy level is the first step in feed formulation and the basis for choosing the concentration of other nutrients in the diet. By reducing the energy level of the diet to an amount lower than the requirement of broilers, the growth and the amount of fat storage are reduced. As the energy level increases, the feed conversion ratio to weight gain (FCR) improves, although due to the high energy rations being relatively more expensive, the most economical state is achieved with rations with an average energy level (1). Adding synthetic amino acids such as lysine and methionine to the diet at high levels can stimulate protein synthesis and affect the FCR. In the research conducted, the amount of lysine required for a suitable FCR was reported higher than the amount recommended by the National Research Council, (2). Researchers found that broiler chickens' growth and body composition in different periods of growth can be regulated by changing the diet's content of energy, crude protein, and amino acids (3). Therefore, choosing the appropriate level of energy, protein, and amino acids in the diet in each growth phase has a very important role in improving broiler chickens' performance and economic performances and will improve the growth and composition of the carcass in order to satisfy consumers. Hosseinpour et al. (2012), by studying the effect of different levels of threonine (90, 100, 110, and 120% of the recommendation of Ross 308) on the carcass characteristics of broiler chickens in the initial period and growth, reported that providing a sufficient amount of threonine at the optimal level (up to 110 recommended percentage of Ross) improved the carcass traits of broiler chickens in the initial stages and growth, especially in diets containing low levels of protein (4). Waldrop et al. (1990) reported that the amount of dietary amino acids significantly affected abdominal fat in males and females, and abdominal fat decreased with an increase in the percentage of dietary amino acids (5). The improvement of the FCR due to the consumption of diets with a high density of nutrients was confirmed in the studies of researchers (6, 7). Adding synthetic amino acids such as lysine, methionine, and threonine to the diet at higher levels can stimulate protein synthesis and, to some extent, affect the food conversion factor. Some researchers reported that the lysine needed for a proper FCR was higher than the recommended amount for weight gain (8). Chickens fed a diet with a low level of synthetic amino acids consumed more feed to meet their needs, which resulted in increased carcass fat, decreased feed efficiency, and increased feces and litter nitrogen (9). The aim of this research is to investigate the effect of different levels of energy and concentrations of amino acids methionine, lysine, and threonine in the diet on production performance (feed consumption, live weight, FCR, economic traits (feed cost, feed cost to gain and monetary returns) and carcass characteristics (edible carcass, breast and thigh percentages, and abdominal fat percent) of broiler chickens.

2 Materials and methods

This experiment was carried out in the poultry research unit of Gonbad Kavous University. A number of 180 Arbor Acres commercial strain chickens (both sexes) were raised in the floor pens, and the experimental diets were fed ad-libitum in the starter (1 to 10 days), grower (11 to 24 days), and finisher (25-42 days) phases. This research was carried out as a 2×3 factorial arrangement in a completely randomized design (CRD) with 18 experimental units (6 treatments and 3 replications and 10 chicken pieces in each replication). The experimental treatments include two different levels of energy: higher, 2950, 3000, and 3050 and lower, 2850, 2900, and 2950 kcal/kg in the starter, grower, and finisher phases, respectively) × three different dietary levels of amino acids methionine+cysteine, lysine, and threonine: levels recommended by the Arbor-acres commercial strain, 15% higher and 15% lower than those recommended by the Arbor-acres recommended levels). During the experiment, feed consumption and live weight were measured for the whole growth period, and FCR was calculated. At the end of the breeding period, at the age of 42 days, one piece of bird from each replicate with a weight similar to the average weight of the treatment was selected, and after weighing and numbering, were killed, and carcass components were measured. The data obtained from the carcass analysis as a percentage of live weight was calculated and statistically analyzed. The rations were formulated by UFFDA computer ration software according to the recommendation of Arbor-acres incorporation. Nutrient specifications of rations and chemical analysis of diets and different growing phases (starter, grower, and finisher) are given in the tables 1-3. The obtained data were prepared and processed in Excel software and statistically analyzed in the SAS software with the GLM procedure (10). Mean comparisons were done using the Least Significant Difference (LSD) test at an error level of 5 percent.

Table 1. Feed ingredients and nutrients used in experimental diets in the starter phase (1 to 10 days)

Feed ingredients	Treatments					
	1	2	3	4	5	6
Corn	39.66	39.94	34.15	38.06	39.34	36.82
Wheat	20	20	20	20	20	20
Corn gluten	4.74	3.87	1	1	1	1
Soybean meal	26.25	26.25	34.2	32.19	30.69	33.66
soy oil	2	2	4.12	1.59	1.18	1.98
Wheat bran	2	2	2	2	2	2
Limestone	1.38	1.37	1.36	1.36	1.36	1.36
Di-calcium phosphate	1.80	1.80	1.73	1.75	1.76	1.73
Salt	0.44	0.44	0.44	0.44	0.44	0.44
D-L methionine	0.37	0.56	0.22	0.39	0.58	0.22
L-lysine	0.50	0.75	0.10	0.37	0.65	0.11
L-threonine	0.19	0.34	-	0.17	0.33	0.001
vitamin supplement	0.25	0.25	0.25	0.25	0.25	0.25
mineral supplement	0.25	0.25	0.25	0.25	0.25	0.25
Enzyme	0.03	0.03	0.03	0.03	0.03	0.03
Vitamin D3	0.05	0.05	0.05	0.05	0.05	0.05
Anti-coccidiosis	0.05	0.05	0.05	0.05	0.05	0.05
Total	100	100	100	100	100	100
Calculated nutrient composition of treatments						
Metabolizable energy (Kcal/Kg)	2950	2950	2950	2850	2850	2850
Crude protein (%)	21.45	21.45	21.45	21.45	21.45	21.45
Lysine (%)	1.39	1.60	1.19	1.39	1.60	1.19
Methionine + Cysteine (%)	1.04	1.22	0.89	1.04	1.20	0.89
Threonine (%)	0.92	1.05	0.78	0.92	1.05	0.78
price (Rials/Kg)	10395	11024	9678	9900	1055	9267

Treatments include:

1. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine recommended by Arbor-Acers. 2. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine 10% higher than recommended by Arbor Acers, 3. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine are 10% lower than the recommended Arbor Acres level. 4. Energy levels 2850, 2900, and 2950 and levels of amino acids lysine, methionine, and threonine recommended by Arbor Acres. 5. Energy levels 2850, 2900, and 2950 and amino acid levels of lysine, methionine, and threonine are 10% higher than recommended by Arbor-Acers. 6. Energy levels 2850, 2900, and 2950 and amino acid levels of lysine, methionine, and threonine 10% below the recommended level of Arbor Acres.

Each kilogram of vitamin supplement includes vitamin A: 3600000 international units, vitamin D3: 2,000,000 international units, vitamin E: 7,200 international units, vitamin K3: 2,000 mg, vitamin B1: 1,800 mg, vitamin B2: 6,600 mg, vitamin B3: 1000 mg, vitamin B6: 300 mg, vitamin B9: 1000 mg, vitamin B12: 15 mg, biotin: 100 mg, choline chloride: 500,000 mg.

Each kilogram of mineral supplement includes manganese oxide: 100000 mg, iron sulfate: 50000 mg, copper sulfate: 10000 mg, selenium: 2000 mg, calcium iodate: 1000 mg, zinc oxide: 9000

Table 2. Feed ingredients and nutrients used in experimental diets in the grower phase (11 to 24 days)

Feed ingredients	Treatments					
	1	2	3	4	5	6
Corn	43.87	44.11	40.27	42.80	48.96	42.79
Wheat	20	20	20	20	20	20
Corn gluten	4.52	3.76	1.13	1	1	1
Soybean meal	23.17	23.17	30.32	28.85	22.28	30.01

soy oil	2	2	3.50	1.10	1.00	1.42
Wheat bran	2	2	2	2	2	2
Limestone	1.15	1.14	1.13	1.13	1.10	1.14
Di-calcium phosphate	1.51	1.51	1.46	1.46	1.36	1.45
Salt	0.42	0.42	0.42	0.42	0.42	0.42
D-L methionine	0.25	0.42	0.13	0.28	0.39	0.13
L-lysine	0.35	0.57	-	0.23	0.42	0.003
L-threonine	0.10	0.25	-	0.08	0.20	-
vitamin supplement	0.25	0.25	0.25	0.25	0.25	0.25
mineral supplement	0.25	0.25	0.25	0.25	0.25	0.25
Enzyme	0.03	0.03	0.03	0.03	0.03	0.03
Vitamin D3	0.05	0.05	0.05	0.05	0.05	0.05
Anti-coccidiosis	0.05	0.05	0.05	0.05	0.05	0.05
Total	100	100	100	100	100	100
Calculated nutrient composition of treatments						
Metabolizable energy (Kcal/Kg)	3000	3000	3000	2900	2900	2900
Crude protein (%)	20	20	20	20	20	20
Lysine (%)	1.18	1.36	1	1.18	1.36	1
Methionine + Cysteine (%)	0.9	1.04	0.77	0.9	1.04	0.77
Threonine (%)	0.79	0.91	0.67	0.79	0.91	0.67
price (Rials/Kg)	9814	10373	9223	9285	9887	8963

Treatments include:

1. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine recommended by Arbor-Acers. 2. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine 10% higher than recommended by Arbor Acers, 3. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine are 10% lower than the recommended Arbor Acres level. 4. Energy levels 2850, 2900, and 2950 and levels of amino acids lysine, methionine, and threonine recommended by Arbor Acres. 5. Energy levels 2850, 2900, and 2950 and amino acid levels of lysine, methionine, and threonine are 10% higher than recommended by Arbor-Acers. 6. Energy levels 2850, 2900, and 2950 and amino acid levels of lysine, methionine, and threonine 10% below the recommended level of Arbor Acres.

Each kilogram of vitamin supplement includes vitamin A: 3600000 international units, vitamin D3: 2,000,000 international units, vitamin E: 7,200 international units, vitamin K3: 2,000 mg, vitamin B1: 1,800 mg, vitamin B2: 6,600 mg, vitamin B3: 1000 mg, vitamin B6: 300 mg, vitamin B9: 1000 mg, vitamin B12: 15 mg, biotin: 100 mg, choline chloride: 500,000 mg.

Each kilogram of mineral supplement includes: manganese oxide: 100000 mg, iron sulfate: 50000 mg, copper sulfate: 10000 mg, selenium: 2000 mg, calcium iodate: 1000 mg, zinc oxide: 9000. Each kilogram of vitamin supplement includes: vitamin A: 3600000 international units, vitamin D3: 2,000,000 international units, vitamin E: 7,200 international units, vitamin K3: 2,000 mg, vitamin B1: 1,800 mg, vitamin B2: 6,600 mg, vitamin B3: 1000 mg, vitamin B6: 300 mg, vitamin B9: 1000 mg, vitamin B12: 15 mg, biotin: 100 mg, choline chloride: 500,000 mg.

Each kilogram of mineral supplement contains 100000 mg of manganese oxide, 50000 mg of iron sulfate, 10000 mg of copper sulfate, 2000 mg of selenium, 1000 mg of calcium iodate, and 9000 mg of zinc oxide.

Table 3. Feed ingredients and nutrients used in experimental diets in the finisher phase (25 to 42 days)

Feed ingredients	Treatments					
	1	2	3	4	5	6
Corn	48.98	49.18	48.77	48.32	48.96	47.43
Wheat	20	20	20	20	20	20
Corn gluten	3.91	3.27	4.55	1	1	1

Soybean meal	18.91	18.91	18.90	23.4	22.28	24.45
soy oil	2	2	2	1.20	1	1.49
Wheat bran	2	2	2	2	2.24	2
Limestone	1.12	1.12	1.12	1.11	1.11	1.11
Di-calcium phosphate	1.39	1.39	1.39	1.35	1.36	1.34
Salt	0.42	0.42	0.42	0.42	0.42	0.42
D-L methionine	0.23	0.37	0.08	0.25	0.39	0.11
L-lysine	0.32	0.49	0.14	0.22	0.42	.0016
L-threonine	0.095	0.21	-	0.08	0.20	-
vitamin supplement	0.25	0.25	0.25	0.25	0.25	0.25
mineral supplement	0.25	0.25	0.25	0.25	0.25	0.25
Enzyme	0.03	0.03	0.03	0.03	0.03	0.03
Vitamin D3	0.05	0.05	0.05	0.05	0.05	0.05
Anti-coccidiosis	0.05	0.05	0.05	0.05	0.05	0.05
Total	100	100	100	100	100	100
Calculated nutrient composition of treatments						
Metabolizable energy (Kcal/Kg)	3050	3050	3050	2950	2950	2950
Crude protein (%)	18.11	18.11	18.11	18.11	18.11	18.11
Lysine (%)	1.04	1.19	0.88	1.04	1.19	0.88
Methionine + Cysteine (%)	0.82	0.94	0.70	0.82	0.94	0.70
Threonine (%)	0.71	0.81	0.63	0.71	0.81	0.63
price (Rials/Kg)	9517	9989	9062	9043	9537	8600

Treatments include:

1. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine recommended by Arbor-Acers. 2. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine 10% higher than recommended by Arbor Acers, 3. Energy levels 2950, 3000, and 3050 and amino acid levels of lysine, methionine, and threonine are 10% lower than the recommended Arbor Acres level. 4. Energy levels 2850, 2900, and 2950 and levels of amino acids lysine, methionine, and threonine recommended by Arbor Acres. 5. Energy levels 2850, 2900, and 2950 and amino acid levels of lysine, methionine, and threonine are 10% higher than recommended by Arbor-Acers. 6. Energy levels 2850, 2900, and 2950 and amino acid levels of lysine, methionine, and threonine 10% below the recommended level of Arbor Acres.

Each kilogram of vitamin supplement includes vitamin A: 3600000 international units, vitamin D3: 2,000,000 international units, vitamin E: 7,200 international units, vitamin K3: 2,000 mg, vitamin B1: 1,800 mg, vitamin B2: 6,600 mg, vitamin B3: 1000 mg, vitamin B6: 300 mg, vitamin B9: 1000 mg, vitamin B12: 15 mg, biotin: 100 mg, choline chloride: 500,000 mg.

Each kilogram of mineral supplement contains 100000 mg of manganese oxide, 50000 mg of iron sulfate, 10000 mg of copper sulfate, 2000 mg of selenium, 1000 mg of calcium iodate, and 9000 mg of zinc oxide.

3 Results and Discussion

The effects of different energy levels and density of amino acids (methionine, lysine, and threonine) on broilers' production and economic performances are shown in Table 4. The results showed that by using higher dietary energy levels, chickens consumed more feed than those using lower dietary energy levels. These results were in agreement with the results of Araujo et al. (2005), who reported that diets containing different levels of energy and lysine in the feeding of broiler chickens in the finisher period did not have an inverse relationship with the energy level of the diet and the birds fed with high energy final diet had higher energy consumption (11). These results were consistent with those of Hill and Dansky (1954), who reported that the energy intake of broilers increased significantly as the energy level of the diet increased (12). However, this finding was contrary to the opinion of Leeson et al. (1996) and Waldrop et al. (1990), who fed broilers with different levels of metabolizable energy in the finisher period and found a significant decrease in feed consumption by an increase in dietary energy level (5, 7). These researchers reported that broilers have the ability to control the amount of feed intake according to the energy level of the diet, and birds with lower feed intake have reduced fat accumulation in the carcass. The effect of different levels of amino acids did not show a significant effect on feed consumption ($p>0.05$). These results follow the results of Jariyahatthakij et al. (2018), which showed that dietary treatments for low protein diets and methionine supplementation did not significantly affect broiler chickens' feed consumption (13). The interaction effects of dietary energy and amino acid levels on feed consumption were insignificant (p>0.05). Higher energy levels compared to lower levels showed a significant difference in live weight at the whole growth period (p<0.05), so the treatments that consumed more energy diets had higher live weights than those with low energy diets. These results were not in agreement with the opinion of Cheng et al. (1997), who, in an experiment, reported the effect of different levels of metabolizable energy and crude protein levels in feeding Arbor-acres and Ross mixed strain broiler that the level of metabolizable energy of the ration did not have a significant effect on body weight of broilers (14). It also contradicts the opinion of Araujo et al. (2005), who investigated the effect of different levels of energy and lysine in the final ratio on the performance of broiler chickens and reported that different levels of energy in the finisher phase did not have a significant effect on the final weight gain. In accordance with the present results, Zamani et al. (2010), by studying the effect of different levels of energy and protein in the final ratio on the production performance of broiler chickens, reported that with the increase in the energy level of the ration, the body weight improved significantly.

The use of different levels of amino acids caused a significant difference in the body weight of chickens. The treatments consumed diets with 15% lower amino acid levels than recommended and showed lower body weight (p<0.05) than other treatments. The results showed that the highest body weight was associated with the recommended treatments and the lowest weight was associated with treatments that were 15% less than those recommended by the recommendations. These results were similar to the opinion of Nasr and Kheiri (2011), who reported that additional lysine at the level of 120% of NRC in starter and grower diets optimized body weight gain in the Arian broiler, whereas reductions in lysine level reduced growth and live weight (15). The interaction effects between energy and amino acids were not significant on feed conversion ratio (p>0.05). The effect of different energy levels and concentration levels of amino acids lysine, methionine+cysteine, and threonine on feed conversion ratio FCR was insignificant (p>0.05). The data shows that using a higher level of energy and recommended amino acids during the whole growth period improved the FCR, but this improvement was very small and not at a significant level (p>0.05). These results were in conflict with the opinion of Holsheimer and Vierkamp (1992), who investigated the effect of different levels of metabolizable energy, crude protein, and lysine in feeding broilers and reported that with increasing dietary energy levels, the feed conversion ratio significantly improved (16). It was also in agreement with the opinion of Araujo et al. (2005), who, during an experiment, investigated the effect of different levels of energy and lysine on the performance of broiler chickens and reported that different levels of energy had a significant effect on the feed conversion ratio (11). FCR improved with the increase in the energy level of the diet. These results also agree with the experiment of Shahriari et al. (2013), which showed that the main effects of protein, methionine, and threonine levels in the diet had no significant effect on the food conversion ratio (17).

3.1 *The cost of feed*

The information related to the effect of different dietary treatments on the cost of consumed feed is shown in Table 4. The results of the experiment showed that the use of different dietary energy levels caused a significant increase in feed cost (p<0.05). So, the treatments containing higher energy levels had higher feed costs at 42 days than those fed with lower energy levels. These results are in agreement with Idowu et al. (2003), who reported that in the response of broiler chickens in the finisher phase to diets containing different levels of metabolizable energy and crude protein, the cost per kilogram of the diet increased with the increase in energy density and protein level. The use of different levels of amino acids on the cost of feed consumption was also significant (p<0.05). The results showed that the treatments with 15% higher amino acids than the recommended amino acid level of Arbor-acers had a higher feed cost than those with 15% lower than the recommended level. In general, the highest cost of feed consumption was related to treatments containing 15% higher amino acids recommended by Arbor-racers, and the lowest cost of feed consumption was related to treatments containing 15% lower amino acids relative to those recommended by this incorporation. The interaction effects between energy and amino acids were insignificant on the feed consumed cost (p>0.05).

3.2 *The cost of feed consumed to weight gain*

The information related to the effect of the experimental diets on the feed cost to weight gain is reported in Table 5. The results showed that the use of different dietary energy levels on feed cost to gain was insignificant (p>0.05). The use of higher dietary energy levels caused a significant increase in the cost of feed consumption to weight gain at 42 days of age ($p<0.05$). These results were in contrast with the results of Idowu et al. (2003) et al., who, in an experiment, investigated the response of broiler chickens in the finisher phase to diets containing different levels of metabolizable energy and reported that the cost per kilogram increased with the increase of energy and protein density, while the nutritional cost per unit of weight gain decreased with the increase of energy and protein density in the ration (18). These researchers attributed this to the improvement (reduction) of the food conversion factor by consuming diets containing higher energy and protein levels. The use of different levels of amino acids at the age of 42 days, caused a significant increase (p<0.05) in the cost of feed consumed to weight gain at all levels, so that the treatments containing 15% higher than Arbor-acres recommendation have a higher cost than Arbor-acres recommendation and this ration also has a higher cost of feed to weight gain than 15% lower than Arbor-acres recommendation. These results are in agreement with the results of Kidd (2000), who stated that, since the essential amino acid threonine is one of the important components in growth, its amount should be determined precisely in the formulation of broiler feed because the amounts The addition of this amino acid increases the cost of feed (19). The interaction effects between energy and amino acids were insignificant in any level of the cost of consumed feed to weight gain (p>0.05).

3.3 *Monetary Returns*

The information related to the effect of treatment on monetary returns (Rials/chicken) is reported in Table 4. The interaction effect between energy and amino acids was not significant in any of the levels on the monetary returns ($p>0.05$). The results showed that different energy levels did not cause a significant difference in the monetary returns of broilers (p>0.05). However, the use of a higher energy level at these ages numerically increased monetary returns compared to lower energy levels, which was not significant. This result can be in line with the results of Maghsoudlou and Golian (2010) who, by examining the effect of different energy levels and the time of replacing starter and grower feed rations on the performance of broiler chickens weighing more than 2 kg reported that using a lower level of energy (2800 kcal/kg of feed) and earlier replacement of starter to grower feed rations may be more economically beneficial for broilers (20). Jariyahatthakij et al (2018) Also reported that supplementing Met in the Low-CP diet during the grower period and subsequently feeding with a control diet improved the feed and protein conversion ratios and reduced the production cost of broiler chickens with regard to fat deposition compared to the control diet (13). However, these results contradict the opinion of Zamani et al. (2010), who, by studying the effect of different levels of energy and protein in the finisher diet on the production performance of broilers, reported that the use of a higher level of energy (3300 kcal/kg) and a higher level of protein (10% higher than NRC's recommendation) in the finisher ration improves the production performance and economic efficiency of Ross308—broiler chickens (21). The use of different concentrations of amino acids at the age of 42 days caused a significant difference in monetary returns (p<0.05), so the use of the recommended amino acids level for Arbor-acres strain resulted in higher monetary returns per chicken compared with 15% higher than that. Generally, the lowest monetary returns belonged to 15% higher amino acid levels than the Arbor-acres recommendation. These results conflicted with the results of Ghahri and Gaikani (2010), who, by studying the effect of different levels of protein and lysine on the performance of Ross308 chickens, concluded that the gross profit increased with the increase of the protein level and with the increase of the lysine level up to 1% gross profit increased and beyond that level decreased (22).

Table 4. The average effect of different levels of a sulfur-containing amino acid (methionine + cysteine), lysine, and threonine in the diet on the performance of broiler chickens during the whole growth period (1-42 days)

Treatments	Production and Economic traits					
	Feed intake (g)	Body weight (g)	FCR	Feed cost (Rials/bird)	Feed cost/gain (Rials/g)	Monetary returns (Rials/bird)
Dietary Metabolizable Energy Level						
HE	4437.1 [a]	2498.7 [a]	1.808	42807 [a]	17426 [a]	34329
LE	4230.1 [b]	2359.0 [b]	1.826	38836 [b]	16765 [b]	33567

SEM	199.79	126.3	0.064	1925	63.25	318.1
p value	0.009	0.006	0.43	0.0001	0.009	0.48
Amino Acid Level						
Arbor Acres (AA1)	4434.3	2502.8 [a]	1.803	41695 [a]	16946 [b]	35590 [a]
15 (AA2) %+	4346.1	2438.2 [ab]	1.815	43120 [a]	17991 [a]	31971.3 [b]
15 (AA3) %-	4221.1	2345.5 [b]	1.835	37650 [b]	16350 [c]	34292 [ab]
SEM	245.1	154.9	0.079	2362	77.60	390.2
p value	0.066	0.03	0.50	0.0001	0.0001	0.04
Interaction effect of Dietary metabolizable energy× Amino acid level						
HE×AA_1	4513.0	2549.7	1.803	43520	17380.0	35360
HE×AA_2	4494.4	2536.3	1.803	45573	18280.0	32860
HE ×AA_3	4303.9	2410.0	1.820	39330	16620.0	34797
LE ×AA_1	4355.5	2456.0	1.803	39870	16513.3	35827
LE ×AA_2	4197.7	2340.0	1.826	49667	17703.3	31987
LE ×AA_3	4138.3	2281.0	1.850	35970	16080.0	33787
SEM	354.3	223.8	0.115	3414	112.1	563.9
p value	0.644	0.61	0.84	0.59	0.79	0.69

HE: Indicates higher energy levels. LE: Indicates lower energy. A1: indicates the recommended amino acid levels of methionine, lysine, and threonine of Arbor-acres. A2 indicates that the amino acid levels of methionine, lysine, and threonine are 15% higher than recommended by Arbor-Acrees. A3 indicates that the amino acid levels of methionine, lysine, and threonine are 15% lower than recommended by Arbor Acres.

Numbers within each column without a common letter indicate significant treatment differences ($p<0.05$).

3.4 Carcass characteristics

The results related to the effect of different dietary treatments on carcass characteristics as the percentage of live weight at the time of slaughter are reported in Table 5. The interaction effects between energy and amino acids were insignificant on all carcass traits ($p>0.05$). Different energy levels increased the weight of thighs in treatments that consumed higher than lower energy levels, which was significant ($p<0.05$). However, different dietary energy levels did not significantly affect edible carcass percentages of breast and abdominal fat ($p>0.05$). These results were in agreement with the report of Nawaz et al. (2006), who evaluated the effect of different energy levels in Hubbard broilers and cited that dietary treatments had no significant effect on carcass weight (23). Moran and Etches (1983) also reported similar results (24). These results were in agreement with the results of Zamani et al (2010) who, by studying the effect of different levels of energy and protein in the finisher diet on the production performance of broiler chickens, reported that the main interaction effects of dietary energy and protein on the percentage of edible carcasses, breast and abdominal fat percentage were not significant. The use of different levels of amino acids on edible carcasses, abdominal fat, and thighs was insignificant ($p>0.05$). However, the lower level of amino acids caused an increase in abdominal fat percentage, which was not significant. Different levels of amino acids in the breast weight were significant ($p<0.05$), so diets containing the recommended amino acids of Arbor-acres and 15% more than that had a higher breast weight than those group fed with 15% lower amino acid level than Arbor-acres recommended level. These results were in the same direction as the results of Ghahri and Gaikani (2010), who, by studying the effect of different levels of protein and lysine on the performance of Ross chickens, concluded that the breast percentage was not affected by protein and the interaction between protein and lysine (22). However, the level of lysine had a significant effect on the breast percentage, so with the increase in the lysine content of the diet from 0.8% to 1.1%, the breast increased from 20.27 to 23%. Protein and lysine and their interactions did not significantly affect thigh percentage. Kidd et al. (1997) also showed that increasing threonine in the diet improves breast meat production (25). Nejad Sajadi et al (2008) reported that increasing the level of methionine causes an increase in breast percentage (26). Ahiwe et al. (2018) also reported similar results (1).

Table 5. The average effect of different levels of sulfur-containing amino acids, lysine, and threonine in the diet on the performance of broiler chickens

Treatments	42 days			
	Edible carcass%	Breast %	Thighs %	Abdominal Fat%
Dietary Metabolizable Energy Level				
HE	73.94	24.31	20.93[a]	1.92
LE	74.23	25.74	19.82[b]	2.03
SEM	1.86	2.00	1.46	0.52
p value	0.65	0.05	0.04	0.53
Amino Acid Level				
Arbor Acres (AA1)	74.68	25.73 [a]	20.07	1.86
15 (AA2) %+	73.97	26.47 [a]	20.11	1.93
15 (AA3) %-	73.62	22.85 [b]	20.95	21.14
SEM	2.28	2.43	1.79	0.64
p value	0.39	0.002	0.29	0.40
Interaction effect of Dietary metabolizable energy× Amino acid level				
HE×AA_1	74.37	24.88	20.56	1.606
HE×AA_2	73.93	25.65	20.6	2.093
HE ×AA_3	73.53	22.38	21.62	2.053
LE ×AA_1	75.00	26.57	19.58	2.086
LE ×AA_2	74.00	27.28	19.61	1.776
LE ×AA_3	73.70	23.32	20.27	2.230
SEM	3.30	3.55	2.6	0.92
p value	0.92	0.88	0.94	0.22

HE: Indicates higher energy levels. LE: Indicates lower energy. A1: indicates the recommended amino acid levels of methionine, lysine, and threonine of Arbor-acres. A2 indicates that the amino acid levels of methionine, lysine, and threonine are 15% higher than recommended by Arbor-Acrees. A3 indicates that the amino acid levels of methionine, lysine, and threonine are 15% lower than recommended by Arbor Acres.
Numbers within each column without a common letter indicate significant treatment differences ($p<0.05$).

4 Conclusion

The results of this experiment showed that although increasing the energy level of the diet by one hundred kilocalories per kilogram in the whole growth period produced more live weight, it did not significantly affect the feed conversion ratio of chickens. Increasing the energy level of the ration did not have a significant effect on the carcass characteristics. A 15% increase in the level of three dietary limiting amino acids (methionine+cysteine, lysine, and threonine) did not significantly affect the weight gain of chickens. However, a 15% decrease caused a decrease in live weight performance. Increasing or decreasing the level of these three amino acids did not significantly affect the feed conversion ratio, nor did it significantly affect the carcass characteristics**.** The other results of this experiment showed that the cost of feed to weight gain increased by higher energy levels, and the lower energy diet produced cheaper meat per kilogram. Monetary returns, which are closely related to the profitability of poultry farming, were not significantly affected by dietary energy levels. The highest cost of feed per kilogram of weight gain was related to the treatment of 15% increase of limiting amino acids in the diet, and the lowest cost of feed per kilogram of weight gain was in diets with 15% less dietary amino acids concentration. Decreasing the level of amino acids in the diet did not significantly negatively affect monetary returns, but its 15% increase caused a decrease in the monetary returns. There was no significant interaction effect between the energy level of the diet and the levels of three amino acids limiting the diet (methionine, lysine, and threonine) for production, carcass quality, and economic traits. In general, for the production of more than 2 kg broilers, rations containing lower levels of energy and lower levels of limiting amino acids had the highest monetary returns and the lowest cost of feed consumed for weight gain. Using lower energy levels and amino acids than Arbor-acres recommended can benefit poultry breeders, depending on market conditions.

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Conflict of Interest

The authors declared no conflicts of interest.

Author Contributions

All authors contributed to the original idea and study design.

Data Availability Statement

The datasets generated during and analyzed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Ethical Considerations

There were no ethical considerations in this research.

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