Influence of Dietary Lysine Levels and Arginine:Lysine Ratios on Performance of Broilers Exposed to Heat or Cold Stress During the Period of Three to Six Weeks of Age[1]

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ABSTRACT Four trials of identical experimental design were conducted to determine the effects of temperature, dietary Lys level, and dietary Arg:Lys ratios on performance and carcass yield of male broilers. Birds of a commercial strain were grown from 21 to 42 d of age in wire-floored finishing batteries placed in environmental chambers. The chambers were programmed to provide either a constant thermoneutral temperature (21.1 C), a constant cold temperature (15.5 C), or a cycling hot diurnal temperature (25.5 to 33.3 C). Within each environment there was a factorial arrangement of three Lys levels (1.0, 1.1, and 1.2%) with four Arg:Lys ratios (1.1:1, 1.2:1, 1.3:1, and 1.4:1).

Environmental temperature significantly influenced virtually every characteristic examined. Hot cyclic temperatures reduced weight gain, feed intake, and breast meat yield, and increased feed conversion, dressing percentage, leg quarter yield, and abdominal fat content. The cold environment promoted increased feed intake and mortality. Ascites and cardiomyopathy were the leading causes of death under cold exposure and thermoneutral conditions, whereas complications arising from heat exposure were the main cause of death under hot cyclic conditions. Levels of Lys affected leg quarter yield and abdominal fat content over all environments but increased breast meat yield only under cold conditions. Increasing Arg:Lys ratios improved feed conversion and dressing percentage and reduced abdominal fat content; it could not be determined whether these responses were consistent with Arg *per se* or were due to a nonspecific N response. As increasing Lys levels or Arg:Lys ratios did not improve weight gain, increase breast meat yield, or attenuate adverse effects due to heat or cold exposure, it is concluded that the levels of Lys and Arg suggested for 21 to 42 d by the NRC are adequate for birds of this age under the environmental conditions encountered.

(*Key words*: lysine, arginine, broiler, carcass, temperature)

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INTRODUCTION

The effects of environmental temperature on growth, feed intake, and carcass quality of broiler chickens are well known (Leeson, 1986). Growth rate and feed consumption decrease when environmental temperature increases (Dale and Fuller, 1980; Suk and Washburn, 1995), and exposure to low temperature results in increased feed consumption per unit of body weight (May *et al.*, 1972). However, the overall effect of temperature on metabolism is more complex than is often suggested, as many responses are cubic rather than linear, as reported by Hurwitz *et al.* (1980). Cahaner *et al.* (1995) reported that nutritional requirements are affected by ambient temperature and by genotype. The combination of high ambient temperature and high protein diet depressed the growth rate and meat yield of commercial fast-growing broilers but not those of lean broilers. Smith (1993 a,b) reported that environmental temperature affects breast yield and nutrient content of some broiler carcass parts.

Papers dealing with nutrient requirements for broilers during the growing and finishing period are sparse. Several reports have addressed the question of Lys requirements for growth, body composition, and component yield (Summers *et al.*, 1988; Hickling *et al.*, 1990; Moran *et al.*, 1990; Acar *et al.*, 1991; Bilgili *et al.*, 1992; Han and Baker, 1994) and Lys requirements in warm temperature (March and Biely, 1972; May *et al.*, 1972; McNaughton *et al.*, 1978; McNaughton and Reece, 1984). It has recently been postulated that larger Arg:Lys ratios ameliorate effects of heat in growing broilers (Brake *et al.*, 1994). The objectives of the present study were to examine the response of male broilers to various levels of Lys and to different Arg:Lys ratios under heat or cold

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exposure, and under thermoneutral conditions during the period of 3 to 6 wk of age.

MATERIALS AND METHODS

Birds and Housing

Male birds of a commercial strain (Ross × Ross) were fed a common starter diet[4] that met the nutritional requirements of the broiler (NRC, 1994) and grown to 3 wk of age in electrically heated battery brooders. At 3 wk of age, birds were transferred to environmental chambers. Six chambers (2.43 × 3.58 × 2.43 m) in the University of Arkansas Poultry Environmental Research Unit were utilized. A wire-floored finishing battery with 12 compartments (0.47 m^2) was placed in each chamber. Six birds were randomly assigned to each compartment of the battery brooders to attain approximately equal beginning weights. Incandescent lighting was provided 23 h daily; feed and water were provided for *ad libitum* consumption.

Control of the environment was achieved by a continuous flow of temperature- and moisture-controlled air. Two chambers were programmed for a thermoneutral environment with a constant temperature of 21.1 C and 50% relative humidity, two were programmed to provide a cold environment with 15.5 C and 60% relative humidity, and two were programmed to provide a cycling hot diurnal temperature. In the hot environment, temperature ranged from 25.5 to 33.3 C. Maximum temperatures were present from 1200 to 1600 h with the peak at 1400 h. Minimum temperatures were present from 2400 to 0400 h with the nadir at 0200 h. Relative humidity was maintained constant at 45%.

Diets and Treatments

A basal diet containing corn, soybean meal, and corn gluten meal as intact protein sources was utilized (Table 1). These ingredients are all considered to have high amino acid digestibility (NRC, 1994). Formulation was based on actual crude protein and amino acid assays of the feed ingredients used in this study. The basal diet was formulated to provide a minimum of 110% of the NRC (1994) recommended amino acid levels for all essential amino acids except Lys and Arg. Supplemental Thr was used to help reduce levels of excess amino acids. The diet was calculated to provide NRC (1994) minimum levels of 1.0% Lys and 1.1% Arg, thus giving an Arg:Lys ratio of 1.1:1.

A 3 × 4 factorial arrangement of treatments was employed with three Lys levels (1.0, 1.1, 1.2%) and four Arg:Lys ratios (1.1:1, 1.2:1, 1.3:1, 1.4:1) in all combinations.

[4]This diet contained 60.43% yellow corn, 27.22% dehulled soybean meal, 5.0% poultry by-product meal, 3.49% poultry oil, 0.97% limestone, 1.50% dicalcium phosphate, 0.23% DL-Met, 0.12% L-Lys HCl, 0.44% salt, 0.50% vitamin premix, and 0.10% trace mineral mix. It was calculated to contain 3,135 ME kcal/kg, 21.3% CP, 0.57% Met, 0.93% TSAA, 1.21% Lys, and 1.37% Arg.

TABLE 1. Composition and nutrient content of basal diet

Ingredient	Content	
	(g/kg)	
Yellow corn	633.34	
Soybean meal, dehulled	215.40	
Poultry oil	32.22	
Corn gluten meal	68.37	
Salt	3.29	
Limestone	14.27	
Dicalcium phosphate	13.13	
DL methionine	1.25	
Lysine HCl	1.63	
Threonine	1.10	
Vitamin premix[1]	5.00	
Trace mineral mix[2]	1.00	
Variable[3]	10.00	
Total	1,000.00	
Nutrient	Calculated	Analyzed[4]
ME, kcal/kg	3,200	
CP, %	19.74	19.92
Ca, %	0.90	
P, total, %	0.59	
P, nonphytate, %	0.35	
Met, %	0.46	0.48
Lys, %	1.00	1.02
Trp, %	0.22	
Thr, %	0.81	0.83
Ile, %	0.80	0.86
His, %	0.49	0.46
Val, %	0.90	0.88
Leu, %	2.08	2.12
Arg, %	1.10	1.13
Phe, %	1.00	0.96
Gly, %	0.74	0.84
Ser, %	0.92	0.99
Met + Cys, %	0.79	0.82
Gly + Ser, %	1.66	1.83
Phe + Tyr, %	1.82	1.96

[1]Provides per kilogram of diet: vitamin A, 7,709 IU; cholecalciferol, 2,202 IU; vitamin E, 11 IU; vitamin B_{12}, 0.13 mg; riboflavin, 6 mg; niacin, 38 mg; pantothenic acid, 10 mg; choline, 495 mg; vitamin K, 1.5 mg; folic acid, 0.8 mg; thiamin, 0.55 mg; pyridoxine, 1.1 mg; d-biotin, 0.055 mg; ethoxyquin, 125 mg; Se, 0.1 mg.

[2]Provides per kilogram of diet: Mn ($MnSO_4 \cdot H_2O$), 100 mg; Zn ($ZnSO_4 \cdot 7H_2O$), 100 mg; Fe ($FeSO_4 \cdot 7H_2O$), 50 mg; Cu ($CuSO_4 \cdot 5H_2O$), 10 mg; I [$Ca(IO_3)_2 \cdot H_2O$], 1 mg.

[3]Consists of variable amounts of Lys HCl, Arg free base, and cornstarch.

[4]Analysis conducted by Degussa Corp., Allendale, NJ 07401.

Aliquots of a common basal diet were supplemented with appropriate amounts of Lys HCl, Arg free base, and cornstarch to provide necessary levels of these two amino acids. Diets were pelleted with steam using a 4-mm die. The basal diet was analyzed for crude protein content and for all amino acids (Llames and Fontaine, 1994); test diets were analyzed for supplemental Lys (NFIA, 1991) and for total Lys and Arg (Llames and Fontaine, 1994). Analyzed values were in good agreement with calculated values (Table 2).

Each of the 12 diets was assigned to one pen of six chicks in each environmental chamber per trial. Thus, in each trial two pens of chicks per diet were exposed to each of the three environmental conditions. Four consecutive trials were conducted, with the diets assigned to a different battery tier in each trial. Thus, a total of eight

TABLE 2. Total and supplemental amino acid assays of mixed feeds

	Percentage lysine			Percentage arginine	
Diet	Calculated	Total[1]	Added[2]	Calculated	Total[1]
1	1.00	1.02	0.12	1.10	1.13
2	1.00	1.01	0.13	1.20	1.19
3	1.00	1.02	0.11	1.30	1.32
4	1.00	0.98	0.14	1.40	1.38
5	1.10	1.08	0.20	1.21	1.20
6	1.10	1.11	0.23	1.32	1.33
7	1.10	1.09	0.21	1.43	1.41
8	1.10	1.12	0.20	1.54	1.53
9	1.20	1.18	0.30	1.32	1.29
10	1.20	1.21	0.31	1.44	1.37
11	1.20	1.22	0.34	1.56	1.51
12	1.20	1.19	0.31	1.68	1.69

[1]Performed by method of Llames and Fonotaine, 1994.

[2]Performed as described by NFIA (1991).

pens of chicks per diet were exposed to each to the three environmental conditions over the entire course of the study.

Measurements

At 21 d the birds were group weighed by pen, placed on the test diets, and exposed to their respective environments. At 42 d the test was terminated and birds group weighed by pen. Feed consumption during the test period was determined. Samples of birds (two birds per pen nearest the pen mean weight) were processed in each trial in a pilot processing laboratory to determine dressing percentage, abdominal fat content, and breast meat yield as described by Izat *et al.* (1990). Any bird that died during the study was weighed and submitted to necropsy by a qualified poultry diagnostician to determine cause of death. Weight of the dead birds was used to adjust feed conversion.

Statistical Analysis

Data were subjected to the analysis of variance using the PROC MIX procedure of the SAS Institute (1988). The data were analyzed as a split-split plot design with experiment as the main plot and temperatures as the split plot. Lysine levels and Arg:Lys ratios constituted the split-split plot. Response to Lys levels and Arg:Lys ratios were further subjected to regression analysis using PROC REG to determine appropriate linear, quadratic (Lys level, Arg: Lys ratio), or cubic (Arg:Lys ratio) response functions. For all measurements, pen means represented the experimental unit. Covariance analysis was used on body weight gain utilizing 21-d body weight as the covariate. All percentage data were subjected to arc sine transformation prior to analysis. Mortality data were analyzed by chi-square. When significant differences among or between treatment means were found, means were separated using repeated *t* tests using probabilities generated by the LS means option.

TABLE 3. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on 21- to 42-d weight gain[1] of male broilers (mean of four trials)

		Temperature[2]			
Lys	Arg:Lys ratio	Cold	Hot	Neutral	Mean
(%)		(g)			
1.0	. . .	1,641	1,385	1,707	1,578
1.1	. . .	1,680	1,397	1,688	1,588
1.2	. . .	1,648	1,354	1,788	1,563
. . .	1.1	1,640	1,375	1,698	1,571
. . .	1.2	1,645	1,369	1,699	1,571
. . .	1.3	1,663	1,403	1,730	1,599
. . .	1.4	1,678	1,367	1,650	1,565
. . .	. . .	1,656[b]	1,378[c]	1,694[a]	
Source of variation				SEM	Probability
Temperature (Temp)				12.051	0.0001
Lysine (Lys)				12.051	0.4336
Linear					0.5110
Quadratic					0.2646
Arg:Lys				13.915	0.3086
Linear					0.9783
Quadratic					0.2798
Cubic					0.1201
Temp × Lys				20.411	0.6618
Temp × Arg:Lys				24.102	0.5105
Lys × Arg:Lys				24.102	0.8314
Temp × Lys × Arg:Lys				41.746	0.4592

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Mean 21-d weight of 681 g. Body weight at 21 d used as covariate.

[2]Cold = 15.5 C; Hot = cyclic 25.5 to 33.3 C; Neutral = 21.1 C.

TABLE 4. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on 21- to 42-d feed consumption of male broiler chickens (mean of four trials)

Lys	Arg:Lys ratio	Temperature[1] Cold	Hot	Neutral	Mean
(%)		(g)			
1.0	. . .	3,167	2,694	3,074	2,978
1.1	. . .	3,154	2,690	3,006	2,950
1.2	. . .	3,153	2,617	2,982	2,917
. . .	1.1	3,178	2,676	3,017	2,957
. . .	1.2	3,119	2,679	3,053	2,950
. . .	1.3	3,196	2,684	3,048	2,976
. . .	1.4	3,139	2,629	2,965	2,911
. . .	. . .	3,158[a]	2,667[c]	3,021[b]	
Source of variation				SEM	Probability
Temperature (Temp)				17.975	0.0001
Lysine (Lys)				17.975	0.2058
Linear					0.0762
Quadratic					0.9195
Arg:Lys				21.042	0.1420
Linear					0.1091
Quadratic					0.2989
Cubic					0.1772
Temp × Lys				31.133	0.5979
Temp × ArgLys				35.950	0.8491
Lys × ArgLys				35.950	0.7673
Temp × Lys × ArgLys				62.267	0.5375

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Cold = 15.5 C; Hot = cyclic 25.5 to 33.3 C; Neutral = 21.1 C.

TABLE 5. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on 21- to 42-d feed conversion of male broilers chickens (mean of four trials)

Lys	Arg:Lys ratio	Temperature[1] Cold	Hot	Neutral	Mean
(%)		(g feed:g gain)			
1.0	. . .	1.922	1.950	1.803	1.891
1.1	. . .	1.891	1.930	1.785	1.869
1.2	. . .	1.919	1.927	1.767	1.871
. . .	1.1	1.952	1.955	1.779	1.895
. . .	1.2	1.899	1.961	1.800	1.887
. . .	1.3	1.910	1.916	1.762	1.863
. . .	1.4	1.882	1.912	1.797	1.864
. . .	. . .	1.911[a]	1.936[a]	1.785[b]	
Source of variation				SEM	Probability
Temperature (Temp)				0.009	0.0001
Lysine (Lys)				0.009	0.3120
Linear					0.3018
Quadratic					0.2629
Arg:Lys ratio				0.011	0.0360
Linear					0.0095
Quadratic					0.3878
Cubic					0.3046
Temp × Lys				0.016	0.6104
Temp × Arg:Lys				0.018	0.2823
Lys × Arg:Lys				0.018	0.4712
Temp × Lys × Arg:Lys				0.032	0.7543

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Cold = 15.5 C; Hot = cyclic 25.5 to 33.3 C; Neutral = 21.1 C.

TABLE 6. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on 21- to 42-d mortality of male broiler chickens (mean of four trials)

Lys	Arg:Lys ratio	Temperature[1] Cold	Hot	Neutral	Mean
(%)		(%)			
1.0	. . .	8.85	7.29	5.73	7.29
1.1	. . .	11.46	9.38	6.25	9.03
1.2	. . .	12.50	3.13	6.77	7.47
. . .	1.1	9.72	6.94	6.94	7.87
. . .	1.2	9.03	6.25	5.56	6.94
. . .	1.3	13.19	6.94	6.94	9.03
. . .	1.4	11.81	6.25	5.56	7.87
. . .	. . .	10.94[a]	6.60[b]	6.25[b]	
Source of variation				SEM	Probability
Temperature (Temp)				1.133	0.0057
Lysine (Lys)				1.133	0.7924
Linear					0.8463
Quadratic					0.5152
Arg:Lys				1.308	0.6381
Linear					0.7664
Quadratic					0.9444
Cubic					0.2072
Temp × Lys				1.866	0.3509
Temp × Arg:Lys				2.266	0.9807
Lys × Arg:Lys				2.226	0.6363
Temp × Lys × Arg:Lys				3.772	0.5631

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Cold = 15.5 C; Hot = cyclic 25.5 to 33.3 C; Neutral = 21.1 C.

RESULTS

Body Weight Gain

Environmental conditions significantly ($P \leq 0.05$) affected body weight gain (Table 3). Birds grown under hot cyclic temperatures had significantly reduced gains compared to those grown under cold or thermoneutral conditions; birds grown under cold conditions had significantly lower weights than those grown under thermoneutral conditions. However, body weight gains were not significantly ($P \leq 0.05$) influenced by Lys level, Arg:Lys ratio, or any interaction among temperature, Lys level, or Arg:Lys ratio.

Feed Consumption

Feed consumption was significantly ($P \leq 0.05$) reduced in hot cyclic temperature and increased in cold temperatures as compared to thermoneutral conditions (Table 4). There were no significant ($P \leq 0.05$) effects of Lys level, Arg:Lys ratio, or any interaction among temperature, Lys level, or Arg:Lys ratio on feed consumption.

Feed Conversion

Feed conversion (grams of feed per gram of gain) was significantly ($P \leq 0.05$) higher in cold and hot cyclic temperatures than in thermoneutral conditions (Table 5). There was no significant ($P \leq 0.05$) effect of dietary Lys

TABLE 7. Cause of death of broilers fed different Lys levels, Arg:Lys ratios, and maintained under different environmental temperatures (mean of four trials)

Cause	Temperature[1] Cold	Hot	Neutral	Lysine 1.0%	1.1%	1.2%	Arg:Lys ratio 1.1	1.2	1.3	1.4	Total
	(% of total mortality)[2]										
Unknown	6.9	11.1	8.3	9.7	13.9	2.8	4.2	5.5	8.4	8.4	26.5
Ascites	23.6	0.0	9.7	16.7	5.5	11.1	5.5	12.5	8.4	7.0	33.4
Airsaculitis	0.0	1.4	0.0	0.0	1.4	0.0	1.4	0.0	0.0	0.0	1.4
Heat prostration	0.0	11.1	0.0	2.8	2.8	5.5	4.2	0.0	1.4	5.5	11.1
Septicemia	2.8	0.0	0.0	0.0	1.4	1.4	1.4	0.0	1.4	0.0	2.8
Cardiomyopathy	12.5	0.0	4.2	4.2	4.2	8.3	1.4	2.8	6.9	5.5	16.6
Pneumonia	1.4	4.2	2.8	2.8	4.2	1.4	5.5	1.4	1.4	0.0	8.3
Total	47.2	27.8	25.0	36.2	33.4	30.5	23.6	22.2	27.9	26.4	

[1]Cold = 15.5 C; Hot = cyclic 25.5 to 33.3 C; Neutral = 21.1 C.

[2]May not total 100 due to rounding.

TABLE 8. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on dressing percentage[1] of male broiler chickens (mean of four trials)

Lys	Arg:Lys ratio	Temperature[2] Cold	Hot	Neutral	Mean
(%)		(%)			
1.0	. . .	66.61	68.69	67.32	67.54
1.1	. . .	66.67	68.32	66.93	67.31
1.2	. . .	66.62	68.13	66.78	67.18
. . .	1.1	66.10	68.69	66.61	67.13
. . .	1.2	66.47	68.21	67.14	67.27
. . .	1.3	67.12	68.08	67.03	67.41
. . .	1.4	66.86	68.57	67.28	67.57
. . .	. . .	66.64[b]	68.38[a]	67.01[b]	
Source of variation				SEM	Probability
Temperature (Temp)				0.132	0.0001
Lysine (Lys)				0.135	0.2278
Linear					0.0956
Quadratic					0.6728
Arg:Lys				0.155	0.1801
Linear					0.0282
Quadratic					0.8098
Cubic					0.9729
Temp × Lys				0.229	0.6855
Temp × Arg:Lys				0.265	0.1148
Lys × Arg:Lys				0.265	0.2643
Temp × Lys × Arg:Lys				0.459	0.5752

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Chilled carcass weight without giblets or abdominal fat as a percentage of fasted carcass weight prior to slaughter.

[2]Cold = 15.5 C; Hot = cyclic 25.5 to 33.3 C; Neutral = 21.1 C.

levels on feed conversion or any interaction of Lys level and environmental temperature. Increasing the Arg:Lys ratio resulted in a significant ($P \leq 0.05$) linear improvement in feed conversion. This improvement was rather constant across all environmental temperatures with no indication of an interaction of environmental temperature and Arg:Lys ratio or between Lys level and Arg:Lys ratio.

Mortality

Mortality was significantly ($P \leq 0.05$) influenced only by environmental temperature (Table 6). Birds exposed to the cold temperature had higher mortality than those maintained in thermoneutral or hot cyclic temperatures. There were no indications that dietary Lys level, Arg:Lys ratio, or any interaction among Lys level, Arg:Lys ratio, or environmental temperature significantly influenced mortality during the study. Leading causes of mortality included ascites and cardiomyopathy under cold exposure and thermoneutral conditions and complications arising from heat prostration[5] in hot cyclic conditions (Table 7). Levels of Lys or Arg:Lys ratios did not appear to influence cause of mortality.

[5]Birds diagnosed as dying from heat prostration exhibit a generalized hyperemia of tissues. Lungs usually show severe hyperemia and may be edematous. Other tissues such as the muscles, heart, and kidney may also have severe congestion with absence of lesions consistent with an infectious process or disease.

Dressing Percentage

Birds grown under hot cyclic conditions had significantly ($P \leq 0.05$) higher dressing percentage than those grown under cold or thermoneutral conditions (Table 8). There was no effect of Lys level on dressing percentage; however, there was a significant ($P \leq 0.05$) linear improvement in dressing percentage as the Arg:Lys ratio increased. There were no interactions of environment with the dietary factors.

Breast Meat Yield

Breast meat yield, expressed as percentage of the carcass, was significantly ($P \leq 0.05$) lower for birds grown under hot cyclic temperatures than for those grown under cold or thermoneutral conditions; birds grown under cold conditions had higher breast meat yields as a percentage of the carcass than those grown under thermoneutral conditions (Table 9). Overall, dietary Lys levels did not influence breast meat yield; however, there was a significant ($P \leq 0.05$) interaction of dietary Lys and environmental temperature. Increasing the dietary Lys level to 1.2% under cold environmental temperatures resulted in improved breast meat yield compared to yields of birds fed diets with 1.0 or 1.1% Lys; this improvement was not observed under hot or thermoneutral conditions. Increasing Arg:Lys ratios had no significant ($P \leq 0.05$) effect on breast meat yield under any of the environmental temperatures.

TABLE 9. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on breast meat yield[1] of male broilers (mean of four trials)

Lys	Arg:Lys ratio	Temperature[2] Cold	Hot	Neutral	Mean
(%)		(%)			
1.0	. . .	25.18[b]	22.62[c]	25.00[b]	24.27
1.1	. . .	25.17[b]	22.64[c]	25.29[b]	24.37
1.2	. . .	26.12[a]	23.00[c]	24.66[b]	24.59
. . .	1.1	25.13	22.50	24.80	24.15
. . .	1.2	25.68	22.65	24.61	24.31
. . .	1.3	25.47	23.07	25.36	24.63
. . .	1.4	25.67	22.79	25.16	24.54
. . .	. . .	25.49[a]	22.76[c]	24.98[b]	
Source of variation				SEM	Probability
Temperature (Temp)				0.136	0.0001
Lysine (Lys)				0.136	0.1759
Linear					0.0866
Quadratic					0.4620
Arg:Lys ratio				0.157	0.2472
Linear					0.1012
Quadratic					0.5553
Cubic					0.3023
Temp × Lys				0.232	0.0191
Temp × Arg:Lys				0.268	0.7406
Lys × Arg:Lys				0.966	0.0802
Temp × Lys × Arg:Lys				0.464	0.7835

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Breast meat weight (*Pectoralis major* and *Pectoralis minor*) as a percentage of chilled carcass weight without giblets or abdominal fat.

[2]Cold = 15.5 C; Hot = cyclic 25 to 33.3 C; Neutral = 21.1 C.

Leg Quarter Yield

Leg quarter yields were significantly ($P \leq 0.05$) influenced by environmental temperature (Table 10). Leg quarter yields, expressed as a percentage of the carcass, were greater under hot cyclic temperatures than under cold or thermoneutral conditions. As breast meat yield was depressed under hot cyclic temperatures, there was a concomitant increase in percentage leg quarter yield. There was a significant ($P \leq 0.05$) difference in leg quarter yield among the birds fed the different levels of Lys; however, this followed a quadratic trend by decreasing and then increasing as Lys level increased. There were no significant ($P \leq 0.05$) effects of Arg:Lys ratio or any interaction among temperature, Lys level, or Arg:Lys ratios on percentage leg quarters.

Abdominal Fat Content

Abdominal fat content, expressed as percentage of the carcass, was significantly ($P \leq 0.05$) affected by environmental temperature (Table 11). Birds grown under the hot cyclic environment had a greater percentage of abdominal fat and those grown in the cold environment had a lower percentage of abdominal fat than those grown under thermoneutral conditions. Abdominal fat content was significantly ($P \leq 0.05$) reduced in a linear manner by increasing dietary Lys or by increasing the Arg:Lys ratio.

DISCUSSION

The inverse relationship of growth rate with environmental temperature agrees with other studies (Dale and Fuller, 1980; Hurwitz *et al.*, 1980; Cahaner *et al.* 1995; Suk and Washburn, 1995). The absence of a growth response to higher Lys levels in different environments agrees with Han and Baker (1993), who suggested that heat-stressed male broilers (37 C) did not appear to require a higher Lys level than those reared at 24 C. It has been reported (McNaughton *et al.* 1978) that higher dietary Lys levels were required to maximize weight of 4-wk-old broilers reared under cold temperature (15.6 C) than those reared at warm temperature (29.4 C). March and Biely (1972) reported that when dietary Lys level was suboptimal, feed consumption and growth rate were depressed when temperature was increased or when the ME of the diet was increased.

The reduction in feed consumption and improvement in feed conversion associated with increased Lys level or increased Arg:Lys ratios may have been a true response to these amino acids, as amino acid requirements for feed conversion have been shown to be greater than required for body weight gain (Thomas *et al.*, 1977). However, a number of reports have demonstrated improvements in feed conversion in response to addition of nonspecific nitrogen sources such as feather meal or glutamic acid (Cabel *et al.*, 1987, 1988; Cabel and Waldroup, 1991).

TABLE 10. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on leg quarter yield[1] of male broiler chickens (mean of four trials)

Lys	Arg:Lys ratio	Temperature[2] Cold	Hot	Neutral	Mean
(%)		(%)			
1.0	. . .	33.51	34.78	35.53	33.94[a]
1.1	. . .	33.08	34.60	33.16	33.62[b]
1.2	. . .	33.14	35.00	33.83	33.99[a]
. . .	1.1	33.36	34.82	33.38	33.85
. . .	1.2	33.11	34.81	33.56	33.83
. . .	1.3	33.44	34.84	33.23	33.84
. . .	1.4	33.08	34.70	33.85	33.88
. . .	. . .	33.24[b]	34.79[a]	33.51[b]	
Source of variation				SEM	Probability
Temperature (Temp)				0.936	0.0001
Lysine (Lys)				0.093	0.0261
Linear					0.8344
Quadratic					0.0072
Arg:Lys ratio				0.107	0.9725
Linear					0.7243
Quadratic					0.8425
Cubic					0.8006
Temp × Lys				0.158	0.2002
Temp × Arg:Lys				0.183	0.1183
Lys × Arg:Lys				0.190	0.2201
Temp × Lys × Arg:Lys				0.317	0.7100

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Thigh and drumstick weight as a percentage of chilled carcass weight without giblets or abdominal fat.

[2]Cold = 15.5 C; Hot = cyclic 25 to 33.3 C; Neutral = 21.1 C.

The increase in abdominal fat at hot cyclic temperatures agrees with El-Husseiny and Creger (1980), who reported that abdominal fat in broilers reared at 32 C was 1.54% greater than those grown at 22 C. In a study by Suk and Washburn (1995), no differences were found in abdominal fat of broilers reared at 26.7 C and 21.1 C. The reduction in abdominal fat associated with increased Lys levels or Arg:Lys ratios may be a true response to these amino acids or a reflection of the increase in overall CP *per se*, as has been observed by a number of researchers (Summers *et al*., 1965; Griffiths *et al*., 1977; Cabel *et al*., 1987, 1988; Cabel and Waldroup, 1991).

Smith (1993a) reared broilers from 23 to 49 d of age at either 23.9 C constant temperature or 23.9 to 35 C cycling high temperature. Whole carcass weight for birds at 23.9 C were greater than from those in the high temperature, but there were no differences in dressing percentage. As in the present study, lower breast yield was found for birds exposed to heat.

Total breast meat yield represents 30% of all meat and 50% of edible protein (Summers *et al*., 1988) and breast muscles are increasing in weight during the 6- to 9-wk period at least five times greater than thigh and drumstick muscles (Halvorson and Jacobson, 1970). It has been suggested that Lys adequacy is crucial to breast meat yield in broilers even though body weight is unaffected (Moran *et al*., 1990). Several studies have reported increased breast meat yield with higher levels of Lys than required for growth (Moran and Bilgili, 1990; Hickling *et al*., 1990; Acar *et al*., 1991; Bilgili *et al*., 1992). However, it appears that breast growth is strongly related to broiler growth, whether due to improved genetics, feeding, or age of the birds (Fisher, 1993). In the present study, heat-exposed, and consequently growth-depressed, birds presented lower breast meat yield than those reared under thermoneutral environment. In the present study, no consistent improvements in breast meat yield were observed from increasing the Lys content in hot or thermoneutral environments, indicating that the Lys level suggested by the NRC (1994) is satisfactory for supporting maximum live performance and breast meat yield for birds grown to 6 wk under these environmental conditions. Recent work by Han and Baker (1994) projecting total Lys needs from digestible Lys requirements also confirms this level for optimizing feed conversion and breast meat yield of birds 3 to 6 wk of age.

Little research has been conducted on Arg requirements of broilers past the age of 21 to 28 d of age. Requirements suggested by the NRC (1994) are based primarily upon computer modeling (Hurwitz *et al*., 1978) and were reduced considerably from the previous edition (NRC, 1984). No consistent response to increased Arg:Lys ratios were observed in this study, indicating that the Arg level suggested by NRC (1994) is adequate for birds of this age. Brake *et al*. (1994) suggested that a greater Arg intake allows the broiler chicken to either

TABLE 11. Effect of dietary Lys levels, Arg:Lys ratios, and environmental temperature on abdominal fat content[1] of male broiler chickens (mean of four trials)

Lys	Arg:Lys ratio	Temperature[2] Cold	Hot	Neutral	Mean
(%)		(%)			
1.0	. . .	2.18	2.83	2.50	2.51[a]
1.1	. . .	2.01	2.83	2.39	2.41[ab]
1.2	. . .	1.95	2.65	2.27	2.29[b]
. . .	1.1	2.09	2.92	2.44	2.48
. . .	1.2	2.03	2.85	2.51	2.46
. . .	1.3	2.12	2.65	2.36	2.38
. . .	1.4	1.95	2.66	2.24	2.29
. . .	. . .	2.05[c]	2.77[a]	2.39[b]	
Source of variation				SEM	Probability
Temperature (Temp)				0.530	0.0001
Lysine (Lys)				0.053	0.0226
Linear					0.0063
Quadratic					0.7260
Arg:Lys				0.060	0.0649
Linear					0.0064
Quadratic					0.7822
Cubic					0.7770
Temp × Lys				0.090	0.9571
Temp × Arg:Lys				0.103	0.7986
Lys × Arg:Lys				0.103	0.1495
Temp × Lys × Arg:Lys				0.180	0.3820

[a–c]Means with no common superscript differ significantly ($P \leq 0.05$).

[1]Weight of abdominal fat as a percentage of chilled carcass weight without giblets or abdominal fat.

[2]Cold = 15.5 C; Hot = cyclic 25.5 to 33.3 C; Neutral = 21.1 C.

mobilize breast muscle for gluconeogenesis during stress or simply not deposit such muscle in the first place. This theory was not confirmed in the present study, as there was no effect of Arg:Lys ratio or interaction of Arg:Lys and environmental temperature on breast meat yield. It has recently been suggested (Wideman *et al.*, 1995) that 1% supplemental L-Arg added to the diet of broilers exposed to cool environmental temperature (10 to 15 C) attenuated the effects of pulmonary hypertension syndrome (ascites) in broilers in the absence of any improvement in growth rate or feed conversion; lower levels of 0.25 and 0.50% supplemental L-Arg were not effective. In contrast, the additional Arg used in the present study to increase Arg:Lys ratios (a maximum of 0.57%) had no effect on incidence of mortality from ascites in any environment.

It would appear from the results of the present study that the requirements for Lys (1.0%) and Arg (1.1%) suggested by NRC (1994) were sufficiently adequate to support maximum body weight gain and feed conversion for broilers grown 3 to 6 wk of age under the different environmental temperatures encountered. Breast meat yield under cold conditions was improved by increasing Lys but not under hot cyclic or thermoneutral conditions.

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