Increasing Amino Acid Density Improves Live Performance and Carcass Yields of Commercial Broilers[1,2]

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Primary Audience: Nutritionists, Researchers, Feed Manufacturers

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SUMMARY

It has been a tendency for broiler integrators in the US to reduce dietary nutrient density to lower overall input costs of broiler production. Dietary nutrient density is routinely scrutinized because feed represents over half of the live production costs. Numerous nutritionists and researchers from the supplier side of poultry production are arguing that the reduced dietary nutrient density regimen currently employed by some integrators is not an effective means of increasing profitability, especially when producing large, high-yield broilers for markets geared toward saleable white meat. This research evaluates nutrient density in various phases throughout life in Ross 508 male and female broilers to better understand the impact of reduced dietary nutrient density, mimicking the reduced dietary cost scenarios used by some broiler integrators.

Diets were provided to broilers in 4 phases from 1 to 14, 15 to 28, 29 to 35, and 36 to 49 d of age, in which treatments of high (H), medium (M), and low (L) amino acid densities were used. The combinations of nutrient density and feeding phases resulted in treatments of 1) HHHH, 2) HHML, 3) HHLL, 4) HMML, 5) HMLL, 6) HLLL, 7) MMMM, and 8) LLLL. Male broilers were more sensitive to amino acid density reductions than females. Reduction of nutrient density in the early feeds was detrimental for most parameters tested. High nutrient density throughout life (HHHH) optimized breast meat yield, whereas reductions in nutrient density reduced growth and breast meat yield and increased corrected feed conversion and leaf fat.

Integrators feeding slow-maturing, high-yield broilers with low and moderate nutrient dense diets may produce broilers with suboptimal growth and breast meat yield, although moderate diets may result in good feed conversion.

Key words: broiler, nutrient density, protein, amino acid, breast yield

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DESCRIPTION OF PROBLEM

Increasing some essential amino acids and dietary protein above levels considered adequate [1] has been shown to increase breast meat yield [2]. Hence, dietary amino acid levels should match a bird's need for maintenance and skeletal muscle accretion to effectively accrete white meat. The period in a bird's life in which dietary amino acid levels should be optimized is critical because amino acid needs, relative to other nutrients, represent a large portion of diet cost. Thus, dietary formulations containing high amino acid levels may result in greater economic return if implemented during periods when bird feed intake is relatively low and growth rate is high. The concept of early nutrition to impact growth in later periods is not new. For example, Fisher et al. [3] and Fisher and Ashley [4] demonstrated that feeding birds excess protein and amino acids early in life builds body protein reserves that could be used later in life. Further, Skinner et al. [5] demonstrated that amino acid levels could be reduced without any detrimental impact on broiler BW 3 to 5 d before slaughter. Therefore, feeding amino acids above recommended levels [1] in the beginning periods of life and marginally reducing amino acids below levels considered adequate [1] in the later periods may provide a mechanism for nutritionists to decrease feed cost relative to live BW.

Lysine levels needed to optimize protein accretion in young chicks have been shown to be higher than that of BW [6]. Additional research [7, 8] has demonstrated that dietary lysine in the starter feed impacts breast meat accretion of mature broilers. Holsheimer and Ruesink [7] determined that lysine needs of chicks from 1 to 14 d impacts breast meat accretion. Feeding chicks (1 to 18 d) low dietary lysine decreased breast meat accretion at 50 d [8]. Moreover, feeding the former chicks adequate to high dietary lysine (19 to 49 d) to compensate for deficient lysine in the starter period did not overcome the detrimental impact of low dietary starter lysine on breast meat accretion [8].

Because amino acid nutrition in broilers is critical to optimize white meat yield, we conducted an experiment to evaluate phase feeding of amino acid density. Early amino acid nutrition appears to be of particular importance, and Lys has been implicated as a critical amino acid to positively affect breast meat yield. Therefore, our experiment focused primarily on lysine in the early feeding periods as the key component of amino acid density.

MATERIALS AND METHODS

Diets and Dietary Treatments

Broilers were fed least-cost formulated diets primarily composed of corn, soybean meal, and poultry meal from 1 to 49 d. These protein-contributing ingredients were purchased and acquired at the research feed mill prior to blending experimental diets so that amino acid analysis could be performed. Amino acid levels obtained by acid hydrolysis analysis were used in least-cost formulation [9]. Least-cost formulated diets were mixed in a 1-ton horizontal mixer and steam pelleted. Composite samples of diets were taken for each mix from all treatments and analyzed for amino acids [9] and CP [10] (Tables 1 to 4). Diets were fed to broilers in 4 phases from 1 to 14, 15 to 28, 29 to 35, and 36 to 49 d of age (Tables 1 to 4).

The dietary treatments reflect nutrient regimens used by poultry integrators in the US. Treatment diets represented high (H), medium (M), and low (L) amino acid densities that were implemented from 1 to 49 d of age. Hence, the H, M, and L treatments corresponded aggressive, average, and low nutrient levels, respectively, known to be fed to broilers by some integrators. Different combinations of amino acid densities were fed during the 4 feed phases to derive 8 dietary treatments. Dietary treatments for the 4 periods were 1) HHHH, 2) HHML, 3) HHLL, 4) HMML, 5) HMLL, 6) HLLL, 7) MMMM, and 8) LLLL. Dietary treatments were created by imposing TSAA, Lys, and CP minimums. Treatments differed most in the minimum level of dietary Lys. Dietary Met and Lys supplements were allowed to enter formulation. Although dietary amino acid minimums varied, dietary treatments were equal in ME, Ca, available P, Na, and choline. The first feed (1 to 14 d) was fed in crumbled form, and subsequent feeds were fed as pellets.

TABLE 1. Starter diets from 0 to 14 d of age

Ingredient	High		Medium		Low	
Corn	59.58		62.70		65.75	
Soybean meal	29.78		27.16		24.55	
Poultry meal	5.00		5.00		5.00	
Poultry fat	2.36		1.91		1.47	
Dicalcium P	1.33		1.35		1.37	
Limestone	0.96		0.96		0.97	
NaCl	0.46		0.46		0.46	
DL-Met	0.19		0.17		0.15	
L-Lys HCl	0.12		0.10		0.10	
Minerals[A]	0.10		0.06		0.05	
Vitamins[B]	0.05		0.05		0.05	
Sacox 60[C]	0.05		0.05		0.05	
Choline Cl	0.02		0.03		0.03	
Composition	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
CP, %	22.50	23.35	21.50	21.32	20.50	20.37
Lys, %	1.37	1.38	1.25	1.22	1.15	1.13
TSAA, %	0.99	0.95	0.94	0.90	0.89	0.82
Thr, %	0.87	0.84	0.83	0.76	0.79	0.72
Ile, %	0.96	0.97	0.91	0.89	0.86	0.86
Val, %	1.08	1.10	1.03	1.02	0.98	1.01
Trp, %	0.27	0.29	0.25	0.27	0.24	0.23
Arg, %	1.51	1.53	1.43	1.39	1.35	1.32
Gly + Ser, %	2.11	2.00	2.02	1.81	1.93	1.75
ME, kcal/kg	3,086		3,086		3,086	
Ca, %	0.94		0.94		0.94	
P, % available	0.47		0.47		0.47	
Na, %	0.22		0.22		0.22	
Choline, mg/kg	1,550		1,550		1,550	

[A] The mineral premix supplied per kilogram of diet: manganese, 112 mg; zinc, 112 mg; magnesium, 27 mg; iron, 60 mg; copper, 10 mg; iodine, 2.6 mg; calcium, 23.5 mg.

[B] The vitamin premix supplied per kilogram of diet: retinyl acetate, 2,654 μg; cholecalciferol, 110 μg; DL-α-tocopherol acetate, 9.9 mg; menadione, 1.5 mg; B_{12}, 0.01 mg; folic acid, 0.8 μg; D-pantothenic acid, 12.1 mg; riboflavin, 7.2 mg; niacin, 44.1 mg; thiamin, 2.2 mg; D-biotin, 0.2 mg; pyridoxine, 3.3 mg.

[C] Sacox 60 was used for the prevention of coccidiosis and provided 60 g of salinomycin sodium activity per ton of feed.

Birds, Housing, and Gender Treatments

Ross × Ross 508 broilers were obtained from a commercial hatchery, feather sexed, and vaccinated for Newcastle disease virus and infectious bronchitis virus via spray cabinet. All birds received an in ovo vaccination for Marek's virus during the transfer from the incubator to the hatcher. Male and female broilers (1,440) were placed in floor pens (96) separately (15 birds/pen), resulting in gender being a treatment. Each floor pen measured 15 ft^2 and was equipped with 1 pan feeder, nipple drinkers (5 nipples/pen), and previously used pine shavings. Feed trays containing approximately 1 lb of crumbled feed were placed in pens on d 0 and were removed when all feed was consumed. Feed and water were available to the birds ad libitum. Birds received 23L:1D throughout the rearing period. The facility was closed-sided, which allowed light intensity to be decreased with time to mimic current industry practices.

Measurements

Pen weights and feed consumption were obtained at 14, 28, 35, and 49 d of age. Mortality was collected twice daily and weighed. Feed conversion was corrected in all periods except the starter because little mortality occurred in this period. Mortality age and the average pen weight for the periods were used to create equations to estimate feed intake for corrected feed conversion. Processing measurements were collected on d 35 from 5 birds per pen and d

TABLE 2. Grower diets fed from 15 to 28 d of age

Ingredient	High		Medium		Low	
Corn		62.43		68.17		71.21
Soybean meal		27.21		22.05		19.45
Poultry meal		5.00		5.00		5.00
Poultry fat		2.61		1.88		1.45
Dicalcium P		1.08		1.12		1.14
Limestone		0.85		0.87		0.87
NaCl		0.46		0.46		0.46
DL-Met		0.13		0.15		0.14
L-Lys HCl		—		0.06		0.03
Minerals[A]		0.10		0.10		0.10
Vitamins[B]		0.05		0.05		0.05
Sacox 60[C]		0.05		0.05		0.05
Choline Cl		0.03		0.04		0.05
Composition	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
CP, %	21.50	21.77	19.50	19.77	18.50	18.91
Lys, %	1.20	1.19	1.10	1.10	1.00	1.03
TSAA, %	0.90	0.85	0.87	0.85	0.83	0.83
Thr, %	0.83	0.79	0.75	0.74	0.71	0.69
Ile, %	0.91	0.89	0.81	0.77	0.76	0.76
Val, %	1.03	1.04	0.93	0.93	0.88	0.92
Trp, %	0.25	0.26	0.22	0.23	0.20	0.23
Arg, %	1.43	1.40	1.26	1.27	1.18	1.22
Gly + Ser, %	2.02	1.87	1.84	1.79	1.75	1.72
ME, kcal/kg	3,141		3,142		3,141	
Ca, %	0.84		0.84		0.84	
P, % available	0.42		0.42		0.42	
Na, %	0.22		0.22		0.22	
Choline, mg/kg	1,500		1,500		1,500	

[A] The mineral premix supplied per kg of diet: manganese, 112 mg; zinc, 112 mg; magnesium, 27 mg; iron, 60 mg; copper, 10 mg; iodine, 2.6 mg; calcium, 23.5 mg.

[B] The vitamin premix supplied per kilogram of diet: retinyl acetate, 2,654 μg; cholecalciferol, 110 μg; DL-α-tocopherol acetate, 9.9 mg; menadione, 1.5 mg; B_{12}, 0.01 mg; folic acid, 0.8 μg; D-pantothenic acid, 12.1 mg; riboflavin, 7.2 mg; niacin, 44.1 mg; thiamin, 2.2 mg; D-biotin, 0.2 mg; pyridoxine, 3.3 mg.

[C] Sacox 60 was used for the prevention of coccidiosis and provided 60 g of salinomycin sodium activity per ton of feed.

49 from all remaining birds per pen. Birds were weighed and cooped 12 h before processing. Processing was manual and live BW, carcass weight, and abdominal fat were obtained and recorded. Birds were chilled by air in a cooler for 2 h and then manually deboned. Carcass measurements obtained after chilling included bone-in and skin-on wings, thighs, and drums and boneless-skinless breast muscles (pectoralis major and pectoralis minor).

Statistical Analyses

Data were analyzed by growout period as a randomized complete block design with a factorial array of dietary nutrient density treatments by gender. Nutrient density treatment regimens resulted in the following factorial arrays of diet × gender: 0 to 14 d, 3 × 2; 0 to 28 d, 5 × 2; 0 to 35 d, 8 × 2; 0 to 49 d, 8 × 2. Pen was the experimental unit for all analysis. All data were analyzed by the GLM procedure of SAS software [11]. Significant ($P < 0.05$) interaction effects were separated using the least squares means option of SAS. When main effect means were found, they were separated with the least significant difference option of SAS [11] with an α of 0.05.

RESULTS AND DISCUSSION

The average calculated increases in major nutrients (CP, Lys, TSAA, and Thr) between H vs. M and H vs. L in the starter period (Table 1) were 5.2 and 12.3%, respectively. In comparison, the average analyzed differences between H vs. M and H vs. L for the former

TABLE 3. Finisher diets fed from 29 to 35 d of age

Ingredient		High		Medium		Low
Corn		70.20		73.34		76.40
Soybean meal		19.62		17.00		14.39
Poultry meal		5.00		5.00		5.00
Poultry fat		2.39		1.93		1.50
Dicalcium P		1.03		1.05		1.07
Limestone		0.83		0.84		0.84
NaCl		0.46		0.46		0.46
DL-Met		0.11		0.10		0.09
L-Lys HCl		0.12		0.04		—
Minerals[A]		0.10		0.10		0.10
Vitamins[B]		0.05		0.05		0.05
Sacox 60[C]		0.05		0.05		0.05
Choline Cl		0.04		0.04		0.05
Composition	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
CP, %	18.50	19.24	17.5	18.50	16.50	17.51
Lys, %	1.08	1.11	0.94	0.98	0.83	0.85
TSAA, %	0.80	0.77	0.76	0.74	0.72	0.69
Thr, %	0.71	0.71	0.67	0.67	0.63	0.63
Ile, %	0.76	0.75	0.71	0.69	0.65	0.64
Val, %	0.88	0.88	0.83	0.84	0.77	0.78
Trp, %	0.21	NA	0.18	NA	0.17	NA
Arg, %	1.181	1.21	1.10	1.13	1.02	1.04
Gly + Ser, %	1.76	1.74	1.67	1.65	1.57	1.55
ME, kcal/kg	3,197		3,197		3,197	
Ca, %	0.80		0.80		0.80	
P, % available	0.40		0.40		0.40	
Na, %	0.22		0.22		0.22	
Choline, mg/kg	1,400		1,400		1,400	

[A] The mineral premix supplied per kilogram of diet: manganese, 112 mg; zinc, 112 mg; magnesium, 27 mg; iron, 60 mg; copper, 10 mg; iodine, 2.6 mg; calcium, 23.5 mg.

[B] The vitamin premix supplied per kg of diet: retinyl acetate, 2,654 μg; cholecalciferol, 110 μg; DL-α-tocopherol acetate, 9.9 mg; menadione, 1.5 mg; B_{12}, 0.01 mg; folic acid, 0.8 μg; D-pantothenic acid, 12.1 mg; riboflavin, 7.2 mg; niacin, 44.1 mg; thiamin, 2.2 mg; D-biotin, 0.2 mg; pyridoxine, 3.3 mg.

[C] Sacox 60 was used for the prevention of coccidiosis and provided 60 g of salinomycin sodium activity per ton of feed.

major nutrients in the starter period were 9.7 and 17.3%, respectively. Although the percentage of difference in the analyzed nutrient reduction from H to L did not agree numerically with that calculated, the analyzed results of amino acids and CP indicated that all diets were blended properly to create the variations in nutrient density desired (Tables 1 to 4).

Diet by gender interactions for the 0-to-28-d period occurred for BW and corrected feed conversion (Table 5). Male broilers had the highest ($P < 0.05$) BW when fed HH in comparison with all other dietary treatments. However, female broilers fed HH, HM, or MM had better ($P < 0.05$) BW than LL. Male and female broilers fed the HH treatment diet had better ($P < 0.05$) corrected feed conversion than male and female broilers fed any other amino acid density regimen.

Diet by gender interactions also occurred for 35 d BW and 0 to 49 d corrected feed conversion (Table 6). Male broilers fed HHH, HHM, HHL, or HMM had equal ($P > 0.05$) 35 d BW. However, male broilers fed H as the first 2 feeds (HHH, HHM, and HHL) had better ($P > 0.05$) d 35 BW than male broilers fed HML, HLL, LLL, and all female broilers regardless of diet type. Male and female broilers fed the LLL dietary treatment had poorer d 35 BW than any other treatment regardless of gender. Corrected feed conversion (0 to 49 d) differed from 0 to 35 d BW in that male broilers fed M treatments throughout life (MMMM) had equal ($P > 0.05$) corrected feed conversion

TABLE 4. Withdrawal diets fed from 36 to 49 d

Ingredient		High		Medium		Low
Corn		72.91		76.03		79.17
Soybean meal		17.07		14.45		11.83
Poultry meal		5.00		5.00		5.00
Poultry fat		2.44		1.99		1.53
Dicalcium P		0.89		0.91		0.92
Limestone		0.77		0.77		0.78
NaCl		0.46		0.46		0.46
DL-Met		0.12		0.11		0.09
L-Lys HCl		0.15		0.08		0.01
Minerals[A]		0.07		0.07		0.07
Vitamins[B]		0.05		0.05		0.05
Sacox 60[C]		0.05		0.05		0.05
Choline Cl		0.02		0.03		0.04
Composition	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
CP, %	17.50	18.30	16.50	17.27	15.50	16.40
Lys, %	1.03	1.06	0.90	0.90	0.77	0.79
TSAA, %	0.78	0.74	0.74	0.71	0.70	0.66
Thr, %	0.67	0.67	0.63	0.61	0.59	0.58
Ile, %	0.71	0.69	0.66	0.64	0.60	0.59
Val, %	0.83	0.82	0.78	0.80	0.73	0.74
Trp, %	0.19	NA	0.17	NA	0.16	NA
Arg, %	1.10	1.11	1.02	1.0	0.94	0.96
Gly + Ser, %	1.67	1.61	1.58	1.53	1.49	1.52
ME, kcal/kg	3,230		3,230		3,229	
Ca, %	0.74		0.74		0.74	
P, % available	0.37		0.37		0.37	
Na, %	0.22		0.22		0.22	
Choline, mg/kg	1,250		1,250		1,250	

[A] The mineral premix supplied per kilogram of diet: manganese, 112 mg; zinc, 112 mg; magnesium, 27 mg; iron, 60 mg; copper, 10 mg; iodine, 2.6 mg; calcium, 23.5 mg.

[B] The vitamin premix supplied per kg of diet: retinyl acetate, 2,654 μg; cholecalciferol, 110 μg; D-α-tocopherol acetate, 9.9 mg; menadione, 1.5 mg; B_{12}, 0.01 mg; folic acid, 0.8 μg; D-pantothenic acid, 12.1 mg; riboflavin, 7.2 mg; niacin, 44.1 mg; thiamin, 2.2 mg; D-biotin, 0.2 mg; pyridoxine, 3.3 mg.

[C] Sacox 60 was used for the prevention of coccidiosis and provided 60 g of salinomycin sodium activity per ton of feed.

when compared with male broilers fed HHHH, HHML, and HHLL. Opposite of BW, female and male broilers fed HHHH had equal ($P > 0.05$) corrected feed conversion, but male broilers fed LLLL had poorer ($P < 0.05$) corrected feed conversion than female broilers fed LLLL.

TABLE 5. Diet amino acid density by gender interactions on 0 to 28 d live performance in Ross 508 broilers

	Dietary treatment[A]				
Gender	HH	HM	HL	MM	LL
BW (kg)					
Male	1.260^{a}	1.210^{b}	1.126^{c}	1.069^{d}	0.969^{e}
Female	1.132^{c}	1.122^{c}	1.063^{d}	1.104^{cd}	0.968^{e}
Corrected feed conversion (kg/kg)					
Male	1.473^{f}	1.539^{e}	1.644^{bc}	1.614^{cd}	1.758^{a}
Female	1.495^{f}	1.545^{e}	1.581^{de}	1.554^{e}	1.675^{b}

[a–f] Means within an individual parameter without common superscripts differ ($P < 0.05$).

[A] H = high amino acid density; M = medium amino acid density; L = low amino acid density. The first letter indicates dietary treatments fed from 1 to 14 d; the second letter indicates dietary treatment fed from 15 to 28 d.

TABLE 6. Diet amino acid density by gender interaction in Ross 508 broilers^{A}

	Dietary treatments for 0 to 35 d, BW (kg)							
Gender	HHH	HHM	HHL	HML	HMM	HLL	MMM	LLL
Male	1.833^{a}	1.822^{a}	1.797^{a}	1.707^{bc}	1.754^{ab}	1.615^{d}	1.521^{ef}	1.402^{g}
Female	1.642^{cd}	1.588^{de}	1.576^{def}	1.572^{def}	1.575^{def}	1.499^{f}	1.618^{d}	1.367^{g}
	Dietary treatments for 0 to 49 d, corrected feed conversion (kg/kg)							
	HHHH	HHML	HHLL	HMLL	HMML	HLLL	MMMM	LLLL
Male	1.839^{g}	1.890^{fg}	1.948^{efg}	2.038^{cde}	1.991^{def}	2.111^{bcd}	1.970^{defg}	2.434^{a}
Female	1.979^{defg}	2.083^{bcde}	2.025^{cdef}	2.111^{bcd}	2.227^{b}	2.138^{bc}	2.036^{cdef}	2.227^{b}

$^{a–g}$Means within an individual parameter without common superscripts differ ($P < 0.05$).
^{A}H = high amino acid density; M = medium amino acid density; L = low amino acid density. The first letter indicates dietary treatment fed from 1 to 14 d; the second letter indicates dietary treatment fed from 15 to 28 d; the third letter indicates dietary treatment from 29 to 35 d; the fourth letter indicates dietary treatment from 36 to 49 d.

The interactive results illustrate the heightened responsiveness of male vs. female broilers to increasing dietary density due to more whole body protein and less whole body fat. Moreover, male broilers needed the H grower regimen, in addition to being fed H in the starter period, to result in optimal growth. Hence, reduction of nutrient density to MMMM in male broilers resulted in good corrected feed conversion but not growth as compared with HHHH.

Gender differences did not occur for any parameter measured in the 0-to-14-d period (Table 7). Males had heavier ($P < 0.05$) BW than females at 28 d, and this response was maintained at 35 and 49 d (Tables 8 to 10). Overall corrected feed conversion was not affected by gender. Males had improved ($P < 0.05$) corrected feed conversion of 8 points in the 0-to-35-d period (Table 9). Carcass yields from broiler genders for 35 d indicate that all yields measured, except breast, were higher ($P < 0.05$) in female broilers (Table 11). At 49 d, however, percentage fat and breast were higher ($P < 0.05$) in females, whereas males had greater ($P < 0.05$) drumstick and thigh yields (Table 12). Although yields of female carcass parts were greater, the proportion of carcass fat also was greater, substantiating the previously

TABLE 7. Impact of diet amino acid density and gender on 0 to 14 d live performance of Ross 508 male and female broilers

Treatment^{A} and gender	BW (kg)	Corrected FCR^{B} (kg/kg)	Mortality (%)
H	0.384^{a}	1.167^{c}	1.02
M	0.353^{b}	1.205^{b}	0.56
L	0.336^{c}	1.278^{a}	0.56
Male	0.376	1.183	0.83
Female	0.373	1.188	0.97
SEM	0.006	0.011	0.94
CV	4.93	2.85	317.07
	Probability		
Source of variation			
Treatment	0.001	0.001	0.791
Gender	0.384	0.631	0.940
Treatment × gender	0.122	0.997	0.632

$^{a–c}$Means within a column without common superscripts differ ($P < 0.05$).
^{A}H = high amino acid density; M = medium amino acid density; L = low amino acid density.
^{B}Feed conversion ratio.

TABLE 8. Impact of diet amino acid density and gender on live performance (from d 0 to 28) of Ross 508 male and female broilers

Treatment[A] and gender	BW (kg)	Corrected FCR[B] (kg/kg)	Mortality (%)
HH	1.196^{a}	1.484^{d}	3.15
HM	1.166^{a}	1.542^{c}	1.94
HL	1.095^{b}	1.613^{b}	1.11
MM	.087^{b}	1.584^{b}	1.67
LL	0.968^{c}	1.716^{a}	1.67
Male	1.175^{a}	1.564	2.22
Female	1.093^{b}	1.548	2.22
SEM	0.017	0.016	1.278
CV	4.38	2.96	164.66
	Probability		
Source of variation			
Treatment	0.001	0.001	0.399
Gender	0.001	0.098	1.000
Treatment × gender	0.002	0.001	0.399

[a–c] Means within a column without common superscripts differ ($P < 0.05$).

[A] H = high amino acid density; M = medium amino acid density; L = low amino acid density. The first letter indicates dietary treatment fed from 1 to 14 d; the second letter indicates dietary treatment fed from 15 to 28 d.

[B] Feed conversion ratio.

TABLE 9. Impact of diet amino acid density and gender on 0 to 35 d live performance of Ross 508 male and female broilers

Treatment and gender[A]	BW (kg)	Corrected FCR[B] (kg/kg)	Mortality (%)
HHH	1.738^{a}	1.613^{c}	3.33
HHM	1.705^{ab}	1.626^{c}	6.00
HHL	1.686^{abc}	1.654^{bc}	5.00
HMM	1.664^{bc}	1.665^{bc}	2.42
HML	1.639^{c}	1.687^{bc}	3.33
HLL	1.557^{d}	1.743^{b}	1.67
MMM	1.570^{d}	1.734^{b}	3.33
LLL	1.385^{e}	1.899^{a}	1.82
Male	1.693^{a}	1.665^{b}	3.26
Female	1.542^{b}	1.740^{a}	3.40
SEM	0.021	0.033	1.696
CV	4.57	6.75	121.29
	Probability		
Source of variation			
Treatment	0.001	0.001	0.195
Gender	0.001	0.002	0.917
Treatment × gender	0.022	0.899	0.297

[a–d] Means within a column without common superscripts differ ($P < 0.05$).

[A] H = high amino acid density; M = medium amino acid density; L = low amino acid density. The first letter indicates dietary treatment fed from 1 to 14 d; the second letter indicates dietary treatment fed from 15 to 28 d; the third letter indicates dietary treatment fed from 29 to 35 d.

[B] Feed conversion ratio.

TABLE 10. Impact of diet amino acid density and gender on 0 to 49 d live performance of Ross 508 male and female broilers

Treatment[A] and gender	BW (kg)	Connected FCR (kg/kg)	Mortality (%)
HHHH	2.738^{a}	1.909^{d}	3.89
HHML	2.605^{bc}	1.987^{cd}	4.24
HHLL	2.635^{ab}	1.986^{cd}	5.00
HMML	2.500^{cd}	1.997^{cd}	3.70
HMLL	2.469^{d}	2.075^{bc}	4.01
HLLL	2.419^{d}	2.125^{b}	3.33
MMMM	2.449^{d}	2.003^{cd}	3.33
LLLL	2.131^{e}	2.330^{a}	2.42
Male	2.644^{a}	2.030	3.97
Female	2.342^{b}	2.075	3.97
SEM	0.058	0.052	2.083
CV	5.72	6.22	129.75
		Probability	
Source of variation			
Treatment	0.001	0.001	0.950
Gender	0.001	0.073	0.646
Treatment × gender	0.066	0.019	0.444

[a–d]Means within a column without common superscripts differ ($P < 0.05$).

[A]H = high amino acid density; M = medium amino acid density; L = low amino acid density. The first letter indicates dietary treatment fed from 1 to 14 d; the second letter indicates dietary treatment fed from 15 to 28 d; the third letter indicates dietary treatment fed from 29 to 35 d; the fourth letter indicates dietary treatment fed from 36 to 49 d.

noted reduced response of female broilers to dietary nutrient density. These yield differences observed, coupled with the differences in gender nutrient responses (Tables 5 and 6), point to the benefits of separate gender rearing of commercial broilers if gender-specific diets are implemented.

Broiler BW (28 d) was better ($P < 0.05$) in birds fed HH and HM over birds fed HL, MM, or LL, indicating the importance of high nutrient density in the starter and grower diets to optimize BW (Table 8). Further, birds fed HH had better ($P < 0.05$) corrected feed conversion than birds fed all other dietary treatments. In the 0-to-35-d period (Table 9), birds fed HHH had the best 35 d BW with birds fed HHM and HHL being statistically equal ($P < 0.05$), again indicating the importance of feeding high nutrient density early in life. The 0-to-35-d corrected feed conversion response was best ($P < 0.05$) in birds fed HHH and HHM vs. birds fed HLL, MMM, and LLL with the treatment groups of HHL, HMM, and HML being intermediate. Final live performance results (0 to 49 d, Table 10) demonstrate that the best ($P < 0.05$) BW occurred when birds were fed HHHH and HHLL over birds fed HMML, HMLL, HLLL, MMMM, and LLLL with HHML being intermediate. Increased ($P < 0.05$) final corrected feed conversion was noted in birds fed HMLL, HLLL, and LLLL over birds fed HHHH. Differences in mortality (Tables 7 to 10) did not occur.

Carcass yield at d 35 was best ($P < 0.05$) when birds were fed HHH, HHM, HML, and HMM vs. birds fed HLL and LLL (Table 11). Breast meat yield was increased ($P < 0.05$) in birds fed HHH and HHM compared with birds in all other treatments except HMM. However, wing yield was lower ($P < 0.05$) in birds fed HHH than in birds fed HHL, HLL, LLL, or MMM. Birds fed LLL had the highest ($P < 0.05$) thigh and drumstick yields. Amino acid density clearly reduced leaf fat as HHH, HHL, and HHM had lower ($P < 0.05$) percentages of leaf fat proportions than HLL, HML, HMM, and LLL. For dark meat yields of birds fed the low-density diets (LLL), the proportion of these yields corresponding to fat was not determined. In the carcass measurements on d 49 (Table 12), high nutrient density was not as critical for carcass yield as breast meat yield.

TABLE 11. Impact of diet amino acid density and gender on 35 d carcass measurements of Ross 508 male and female broilers

	Percentage of live BW at d 35					
Treatment and gender[A]	Carcass	Abdominal fat	Total breast[B]	Wings	Drumsticks	Thighs
	(%)					
HHH	67.33^{a}	1.75^{bc}	19.36^{a}	7.83^{b}	9.51^{ab}	18.99^{bc}
HHL	66.54^{bc}	1.72^{bc}	18.21^{cd}	8.00^{a}	9.54^{ab}	18.96^{c}
HHM	67.38^{a}	1.61^{c}	19.02^{ab}	7.94^{ab}	9.49^{b}	18.93^{c}
HLL	66.07^{cd}	2.11^{a}	17.20^{e}	8.03^{a}	9.60^{ab}	19.35^{a}
HML	67.02^{ab}	2.02^{a}	18.38^{cd}	7.97^{ab}	9.55^{ab}	19.30^{ab}
HMM	66.97^{ab}	1.95^{a}	18.67^{bc}	7.94^{ab}	9.40^{b}	19.26^{abc}
LLL	65.79^{d}	2.11^{a}	16.12^{f}	8.02^{a}	9.78^{a}	19.45^{a}
MMM	66.59^{b}	1.91^{ab}	17.91^{d}	8.03^{a}	9.63^{ab}	19.21^{abc}
Male	66.52^{b}	1.83^{b}	18.00	7.92^{b}	9.28^{b}	18.91^{b}
Female	66.89^{a}	1.97^{a}	18.17	8.02^{a}	9.85^{a}	19.45^{a}
SEM	0.252	0.100	0.262	0.081	0.132	0.167
CV	0.922	12.765	3.466	2.401	3.266	2.094
	Probability					
Source of variation						
Treatment	0.001	0.001	0.001	0.215	0.222	0.008
Gender	0.004	0.006	0.187	0.024	0.001	0.001
Treatment × gender	0.262	0.136	0.575	0.535	0.907	0.670

[a–f] Means within a column without common superscripts differ ($P < 0.05$).

[A] H = high amino acid density; M = medium amino acid density; L = low amino acid density. The first letter indicates dietary treatment fed from 1 to 14 d; the second letter indicates dietary treatment fed from 15 to 28 d; the third letter indicates dietary treatment fed from 29 to 35 d; the fourth letter indicates dietary treatment fed from 36 to 49 d.

[B] Total breast represents combined pectoralis major and pectoralis minor.

Hence, the best ($P < 0.05$) breast meat yield occurred in birds fed HHHH compared with all other broilers, whereas the best ($P < 0.05$) carcass yield was obtained in birds fed HHHH, HHML, HHLL, HMLL, and MMMM compared with birds fed HLLL and LLLL. Birds fed low-density diets as the last 3 feeds (LLLL and HLLL) or as the last 2 feeds when proceeded by an M (HMLL), had higher ($P < 0.05$) percentages of leaf fat than birds fed HHHH, HHML, and MMMM. Drumstick yields did not differ ($P < 0.05$) among treatments, and thigh and wing yields followed a similar pattern ($P < 0.05$) as the 35 d results.

Early Lys nutrition (starter period) improves breast meat yield of broilers [7, 8]. However, Kidd and Fancher [12] fed graduations of dietary Lys from deficient up to 1.43% total of diet to 1 to 18 d Ross 508 broilers and processed birds at d 41 or 42 after they had received common diets from 19 d to slaughter. Breast meat yield was only affected in one experiment and indicated that birds fed 1.32% Lys in the starting period had more ($P < 0.05$) breast meat yield (6.7%) than birds fed 0.99% total Lys. In the present experiment, increased starter nutrient density (HLLL vs. LLLL) also positively ($P < 0.05$) affected breast meat and resulted in 4.5% more breast meat yield at 49 d. Future research should address the impact of amino acid density (primarily Lys) in the starting period to impact breast meat yield in the finishing periods in various broiler genotypes.

This research demonstrates the practicality of past research [3, 4] indicating the importance of early nutrition as final BW was best in the birds fed H in the starter and grower periods. Hence, final BW and breast meat yield of the Ross 508 broilers responded positively to amino acid density throughout life, but it was more critical early in life (up to 28 d). Future research should address amino acid regimens in the final periods that provide the most limiting amino acid minimums (TSAA, Lys, and Thr) in adequacy while marginally reducing ex-

TABLE 12. Impact of diet amino acid density and gender on 49 d carcass measurements of Ross 508 male and female broilers

Treatment and gender^{A}	Carcass	Abdominal fat	Total breast^{B}	Wings	Drumsticks	Thighs
	Percentage of live BW at d 49					
	(%)					
HHHH	70.18^{a}	2.32^{d}	20.48^{a}	7.76^{b}	9.19	20.08^{b}
HHML	70.17^{a}	2.56^{c}	19.40^{b}	8.00^{a}	9.21	20.41^{ab}
HHLL	70.11^{a}	2.71^{abc}	19.64^{b}	7.84^{ab}	9.33	20.54^{a}
HMML	69.49^{bc}	2.61^{bc}	19.08^{b}	7.97^{a}	9.34	20.46^{ab}
HMLL	69.66^{ab}	2.82^{ab}	19.29^{b}	7.86^{ab}	9.36	20.39^{ab}
HLLL	69.03^{cd}	2.84^{ab}	18.31^{c}	7.95^{a}	9.39	20.43^{ab}
MMMM	69.76^{ab}	2.52^{cd}	19.41^{b}	7.96^{a}	9.21	20.37^{ab}
LLLL	68.49^{d}	2.87^{a}	17.52^{d}	7.99^{a}	9.38	20.56^{a}
Male	69.51	2.48^{b}	18.73^{b}	7.91	9.71^{a}	20.55^{a}
Female	69.70	2.83^{a}	19.51^{a}	7.92	8.90^{b}	20.27^{b}
SEM	0.306	0.112	0.320	0.093	0.122	0.205
CV	1.068	10.25	4.070	2.844	3.188	2.446
	Probability					
Source of variation						
Treatment	0.001	0.001	0.001	0.156	0.642	0.379
Gender	0.269	0.001	0.001	0.790	0.001	0.012
Treatment × gender	0.958	0.465	0.262	0.408	0.221	0.669

[a–d] Means within a column without common superscripts differ ($P < 0.05$).

[A] H = high amino acid density; M = medium amino acid density; L = low amino acid density. The first letter indicates dietary treatment fed from 1 to 14 d; the second letter indicates dietary treatment fed from 15 to 28 d; the third letter indicates dietary treatment fed from 29 to 35 d.

[B] Total breast represents combined pectoralis major and pectoralis minor.

cesses of the less limiting amino acids to reduce diet costs. Economic analyses of these data are warranted in terms of live performance and total white meat accreted. Indeed, optimizing amino acid nutrition early in life when feed intake is low seems economically advantageous.

CONCLUSIONS AND APPLICATIONS

1. Male broilers responded to increased dietary amino acid density at a greater rate than female broilers, indicating the potential importance of separate gender rearing of broilers provided that gender specific diets are implemented.
2. Feeding broilers moderate amino acid density (industry average amino acid minimums) resulted in good corrected feed conversion, but higher amino acid density diets were needed to optimize final broiler weight and breast meat yield.
3. Broiler nutritionists feeding high yield genotypes for maximum saleable white meat should consider feeding aggressive CP (0 to 14 d, 23.4%; 15 to 28 d, 21.8%) and amino acids levels (primarily Lys: 0 to 14 d, 1.38% total; 15 to 28 d, 1.19% total) early in the bird's life (up to d 28) to improve live body weight and breast meat yield.

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