Methionine and Cystine Requirements of Slow- and Fast-Feathering Broiler Males from Three to Six Weeks of Age

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ABSTRACT Two experiments were conducted to first determine Met then Cys needs of broilers from 3 to 6 wk of age and whether differences existed between slow-feathering (Ross × 308) and fast-feathering (Ross × 3F8) males. A corn-soybean meal diet (20.0% CP; 3,150 kcal ME/kg) with graded levels of Met or Cys was offered. The first experiment had dietary Met levels of 0.32, 0.38, 0.44, and 0.50% with surfeit Cys (0.40%). Broilers from both feathering strains responded similarly to supplemental Met. Although body weight was not responsive, F/G improved through to the highest level of dietary Met (linear, $P < 0.05$). Chilled carcass weight increased with Met (linear, $P < 0.05$) paralleling F/G; however, no differences were detected in the amount of associated abdominal fat. Breast fillet yield increased with Met to maximize at 0.48% (quadratic, $P \leq 0.009$). In a satellite study using the same birds in cages and feeds, N retention at d 29 maximized at 0.46% Met (quadratic, $P < 0.05$). The second experiment had Cys at 0.32, 0.34, 0.38, and 0.46% with Met fixed at a submarginal level of 0.38%. Increasing dietary Cys had no effect on live performance of slow-feathering birds, whereas weight gain of fast-feathering birds achieved maximum at 0.36% Cys (cubic; $P < 0.05$) with F/G responding similarly. Chilled carcass (cubic, $P < 0.002$) and breast fillet weights (cubic, $P < 0.001$) of fast-feathering birds also increased with Cys to maximize at 0.36%, and the amount of abdominal fat was not influenced by feathering or Cys supplementation. Separate measurement of N retention at d 31 failed to detect a difference in protein utilization attributable to feathering, but an optimum was achieved at 0.40% Cys with both broiler sources. Overall results suggest that the Met requirement for broiler males between 3 and 6 wk of age was independent of feathering and approximated 0.46% (95% of the level of maximal response). Cystine requirements once corrected for submarginal Met status indicated a greater demand by fast- than slow-feathering male broilers corresponding to 0.42 and 0.37%, respectively.

(*Key words*: amino acid requirement, broiler, cystine, methionine)

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INTRODUCTION

The TSAA requirements of broiler chickens between 3 and 6 wk of age as recommended by NRC (1994) is less than observed by Jensen et al. (1989) and Mendonca and Jensen (1989) to optimize live performance and minimize fat deposition. Furthermore, levels to maximize breast meat yield appear to be greater than requirements to optimize growth and minimize fatness (Hickling, et al., 1990; Jeroch and Pack, 1995; Schutte and Pack, 1995a,b; Huyghebaert and Pack, 1996). Expressing Met and Cys together as TSAA not only contributes to the inconsistency of their requirements as such but also restricts effective use of feedstuffs high in Cys. Nonequivalence in the conversion of Met to Cys (Creek, 1968) and oxidation of Cys when excessive contribute to these discrepancies and emphasize the need for accurate measurement of individual requirements. Studies assessing the proportion of TSAA as Cys (Cys replacement value) are scarce and variable. Cystine replacement values for broilers from 3 to 6 wk of age were reported to be 52% by Baker et al. (1996) as compared to 43% by Wheeler and Latshaw (1981) and 47% recommended by the NRC (1994).

Broiler chickens divert about 10% of their dietary protein needs through the first 6 wk to feather formation (Stilborn et al., 1994; Hancock et al., 1995), a process that is particularly high in Cys (Fisher et al., 1981; Stilborn et al., 1997). Engler and coworkers (1985) observed that male broilers having a slow-feathering genotype (K/k^+) require less Cys through the first 3 wk of age than their fast-feathering (k^+/k^+) counterpart. This difference in Cys need is likely to persist beyond 3 wk of age given the 15% advantage in relative feather weight with the k^+/k^+

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Abbreviation Key: F/G = ; SAA = sulfur amino acids.

bird at 48 d of age (Ajang et al., 1993). Once formed, nutrients in feathers are not available for other purposes; whereas, breast muscle may see its accretion rate reduced in support of continued keratin formation, should nutrient supply be limited (Smith, 1994; Wylie et al., 2001). Thus, a deficiency of Cys would be more likely to reduce breast meat recovery with further processing than decrease the extent of feathering.

The present experimentation examined the male broiler's individual requirements for Met and Cys between 3 and 6 wk of age while comparing slow and fast feathering as their only genetic difference. The resulting requirement values were not only based on an optimization of live performance but considered carcass quality characteristics as well.

MATERIALS AND METHODS

Birds

Two experiments were conducted with male broilers having slow (Ross × Ross 308) and fast (Ross × Ross 3F8) feathering. Chicks were commercially hatched from eggs that came from breeder flocks of varying and unknown age. Immunizations for Newcastle disease, infectious bronchitis disease, and Marek's disease were done at the hatchery, and vaccination for infectious bursal disease followed at 2 wk of age. Each experiment was initiated with 1,440 chicks that were randomized into 32 floor pens, respective of feathering, in an open-sided house having thermostatically heating, curtains, and cross ventilation. Feed and water were provided ad libitum, and lighting was continuous. The Auburn University Institutional Animal Care and Use Committee approved experimentation. Broilers that died were gross necropsied and categorized as being attributable to sudden death syndrome, ascites, leg problems, or unknown reasons. Females were included in mortality upon removal from the respective pens. Feed conversion was corrected for mortality on a bird-day basis.

Live Production Experimentation

From 0 to 3 wk of age, all birds were fed a nutritionally complete corn-soybean meal diet that had been steam pelleted and crumbled (Table 1). Birds placed in each pen at 1 d of age (45/pen) were reduced in number with the initiation of formal experimentation at 3 wk of age (25/pen; 0.17 m^2/bird). Diets provided from 3 to 6 wk were a corn-soybean meal basal that nutritionally exceeded NRC (1994) recommendations except for Met and Cys. The first experiment was designed to determine the Met requirement per se; thus, L-Cys was added to assure a total in excess to expected requirement. Four experimental diets were prepared with progressive additions of 0.06% DL-Met resulting in totals ranging from 0.32 to 0.50%. The second experiment determined Cys requirements and had DL-Met added to the basal diet at a submarginal amount relative to its previously determined requirement. Four experimental diets were prepared with three exponential additions of L-Cys resulting in totals of 0.32, 0.34, 0.38, and 0.46%. The "true" Cys requirement was obtained by using the ratio with Met at the submarginal level and corrected to the actual measured requirement of Met for 3 to 6 wk of age.

TABLE 1. Composition of common feed offered from 0 to 3 wk and sulfur amino acid-deficient basal diet used in experimentation from 3 to 6 wk (% as fed)

Ingredient	0 to 3 Weeks	Basal
Ground yellow corn	57.11	63.15
Soybean meal (48% CP)	35.56	29.75
Poultry fat	2.95	3.34
Dicalcium phosphate (21.5% P; 18.5% Ca)	1.79	1.34
Limestone	1.35	1.38
Salt	0.45	0.32
Trace-mineral premix[1]	0.25	0.25
Vitamin premix[2]	0.25	0.25
L-Lysine HCl	–	0.09
DL-Methionine	0.15	–
L-Cystine	0.10	–
Coccidiostat[3]	0.05	0.05
Calculated analysis		
ME/kg (kcal)	3,050.0	3,150.0
Crude protein	22.0	20.0
Lysine	1.25	1.15
Threonine	0.89	0.79
Methionine	0.50	0.32
Cystine	0.45	0.32

[1]Supplied per kilogram of diet: vitamin A, 7,500 IU; vitamin D_3, 2,500 IU; vitamin E, 10 IU; vitamin B_{12}, 0.02 mg; vitamin K, 2 mg; riboflavin, 5.5 mg; niacin, 37 mg; D-pantothenic acid, 13 mg; choline, 500 mg; folic acid, 0.5 mg; pyridoxine, 2.2 mg; thiamine, 1 mg; biotin, 0.1 mg.

[2]Supplied per kilogram of diet: selenium, 0.15 mg; manganese, 66 mg; zinc, 55 mg; iron, 55 mg, copper, 6 mg; iodine, 1.0 mg.

[3]Bio-cox 60, Roche Vitamins, Inc., Parsipanny, NJ.

At the end of live production in both experiments, birds were placed in transportation coops and held approximately 12 h until slaughter. On-line processing simulated commercial automated procedures and involved a 9-min kill line followed by a 7-min evisceration line. Resulting warm carcasses were chilled in static slush ice for approximately 4 h. The depot fat was removed from the abdominal cavity, and selected major defects central to carcass quality were enumerated based on their location and type (United States Department of Agriculture, 1989). The front half of all chilled carcasses were held on flaked ice until the subsequent day, and then each one was deboned on stationary cones by experienced personnel to obtain boneless skinless fillets (pectoralis major) and tenders (pectoralis minor).

N Balance

Broilers randomly removed at 3 wk of age to decrease pen population preceding each live production experiment were used in separate N balance studies with the same diets varying in Met and Cys. These birds were randomly placed in raised wire cages of Petersime[2] grow-

[3]Petersime Incubator Co., Gettysburg, OH.

TABLE 2. Analyses of experimental diets fed from 3 to 6 wk of age that had Met content progressively increase from a deficient level while Cys was maintained constant and exceeded its requirement (% as is)[1]

	Methionine, %			
Nutrient	0.32	0.38	0.44	0.50
Dry matter	87.9	88.2	88.0	87.7
Crude protein	20.3	20.2	20.4	20.0
Amino acid				
Methionine	0.34	0.41	0.43	0.49
Cystine	0.43	0.43	0.42	0.42
Lysine	1.10	1.10	1.15	1.09
Arginine	1.29	1.27	1.29	1.26
Threonine	0.73	0.76	0.73	0.73
Valine	0.93	0.93	0.94	0.93
Isoleucine	0.81	0.82	0.82	0.82

[1]Duplicate analyses were performed courtesy of Degussa-Hülls Corporation-Applied Technology Group, Allendale, NJ.

ing batteries (4 birds per cage; 9 replicate cages/feathering strain) that were located in a separate building having similar temperature, humidity, and lighting as birds concurrently being reared on the floor. Accessibility to water and feed were provided ad libitum; however, the starter feed was continued until 2 d before excreta collection when the test diets having varying levels of either Met or Cys were provided. Birds from experiment 1 received the Met feeds at 26 d of age followed by a 30-h excreta collection starting at 28 d, whereas the experimental Cys feeds (experiment 2) were first available at 28 d of age with excreta collection starting at 30 d of age.

Excreta were collected on aluminum foil that lined the trays of each cage whereupon the total was frozen for subsequent lyophilization. Each freeze-dried collection was homogenized in a blender then subsampled for measurement of N content.[3] Separate N measurements on the feeds were used to calculate N balance.

Statistical Analysis

Data from each experiment were subject to analysis of variance using a randomized complete block design followed by regression analysis using general linear procedures (SAS Institute, 1990). Model main effects corresponded to the level of each sulfur amino acid (SAA) and feathering strain, along with the interaction of SAA level with feathering strain, and block. Block related to pen location during experimentation. Experimental observations were adjusted using body weight at 3 wk of age as a covariate in the model. Regression equations derived from the polynomial having the most significant probability and best fit were used to estimate requirement levels for each SAA. The requirement was defined as 95% of the level at maximum response.

RESULTS AND DISCUSSION

Common feed provided through the first 3 wk of live production satisfied NRC (1994) nutrient recommendations, prior to determining the subsequent needs of Met and Cys from 3 to 6 wk of age (Table 1). Measurement of the requirement for Met per se not only necessitated that the experimental feed be deficient but Cys content exceed need in order to avoid its de novo formation. Ohta and Ishibashi (1994) reported that increasing Cys concentration above required levels with Met-adequate diets did not affect broiler performance or influence absolute requirement for Met. Analyses of experimental feeds verified the anticipated levels and progression of Met, whereas Cys was consistently adequate (Table 2).

In experiment 1, slow-feathering males had greater initial and 3-wk weights (Table 3) than the fast-feathering males as well as at the end of experimentation (Table 4). Given that both sources of broilers were commercially obtained and of unknown background, such differences are likely due to egg weight, breeder age, and terms of incubation rather than genetic potential. However, a growth advantage has previously been observed with slow-feathering males compared to fast-feathering males when chicks originate from female parents of similar age, and this difference continues through to 8 wk of age (Lowe and Merkley, 1986; Dozier et al., 2000).

Although body weight was not affected, equivalent improvements in feed conversion were obvious with each progressive level of Met. The slow- and fast-feathering males used in present experimentation appeared to have similar Met needs; otherwise a divergence in their apparent use of feed would be expected to occur. Extent of feathering could alter energy needs for thermoregulation (Wang, 2000) as well as amino acid utilization for synthesis of other tissues (Ajang et al., 1993; Pesti et al., 1996; Dozier et al., 2000). A favorably high environmental temperature together with a low Met concentration in feather protein (Stilborn et al., 1997) and high dietary Cys would explain the absence of a differential in dietary Met needs between slow- and fast-feathering males.

Improvement in feed conversion was continuous through to the highest level of Met provided; thus, a requirement could not be defined in terms of live performance. Presumably, Met beyond 0.50% would not further improve feed conversion in light of recent reports by Schutte and Pack (1995a,b) that similar levels of supple-

[3]Degussa-Hülls Corp., Feed Technology Group, Allendale, NJ.

TABLE 3. Live performance of slow- and fast-feathering broiler males given common feed from 0 to 3 wk of age (experiment 1) that preceded access to feeds having progressively increasing Met content from a deficient level while Cys was constant and exceeded its requirement[1]

Feathering	Initial BW (g)	3-week BW (g)	BW gain (g)	F/G[2]	Mortality (%)
Slow	43.4	786	743	1.42	1.3
Fast	40.6	771	731	1.37	3.7
SEM	0.21	5.1	5.1	0.02	0.51
P <	***	*	NS	NS	*

[1]Values represent least square means of 16 pens each with 45 chicks at day of age. Average temperature and humidity with standard deviation through the entire period were 27 ± 3°C and 70 ± 10% RH, respectively.

[2]Feed conversion was corrected for mortality.

NS$P > 0.10$; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

mental Met were necessary to optimize feed efficiency and breast meat yield using broilers through similar ages.

Alteration in the recovery of depot fat removed from the abdominal cavity and amount of resulting chilled carcass that could be attributed to broiler feathering or dietary Met could not be statistically supported (Table 5). Although Met per se can alter abdominal fat deposition by influencing key lipogenic/lipolytic enzymes (Takahashi and Akiba, 1995), adequacy of total SAA has been shown to be considerably more influential (Jensen et al., 1989; Mendonca and Jensen, 1989; Moran, 1994; Jeroch and Pack, 1995; Schutte and Pack, 1995a). Absence of a response by abdominal fat to Met supplementation in present experimentation was likely due a less pronounced SAA limitation that occurred with the supplementation and adequacy of Cys.

Differences in the extent of feathering attributable to sex-linked genes with commercial male broilers are known to persist beyond 6 wk of age (Lowe and Merkley, 1986; Ajang et al., 1993). Consequently, assessing the incidence of major carcass defects in present experimentation was an attempt to indirectly measure potential differences in surface protection from overlying feathers. The relative incidence between slow- and fast-feathering birds was similar for all defects evaluated (grand means ± SEM: broken wings, 2.4 ± 0.53%; bruised wings, 25.1 ± 1.26%; bruised drumsticks, 1.7 ± 0.42%; broken breast clavicle, 6.5 ± 0.82%; bruised back, 25.6 ± 1.72%; back skin tear, 1.1 ± 0.41%; back skin scratch, 7.6 ± 0.88%; grade "A", 48.5 ± 1.71%), except for wing bone joint dislocations which was greater with slow- than fast-feathering broilers (2.5 vs. 0.8%, SEM = 0.56, $P < 0.05$). Dietary Met content did not influence any defect examined ($P > 0.05$).

Deboning the front half of these carcasses measured the amount of skinless boneless breast meat (Table 6). Fillets were dominant in this respect, and amounts minimally altered between slow- and fast-feathered males compared to the effect of Met. Fillet yield maximized at a level approximating 0.48% Met based on the associated regression equation ($Y = -43.7 + 978.0\ X - 1{,}028.1\ X^2$).

TABLE 4. Live performance of slow- and fast-feathering male broilers given feeds of progressively increasing Met content from 3 to 6 wk of age while Cys level was constant and exceeded its requirement

				Mortality[3]		
Contrast	BW (g)	Gain (g)	F/G[2]	% Total	% SDS	% ASC
Feathering	**	**	NS	NS	NS	NS
Slow	2,790	2,012	1.73	2.8	0.9	0.3
Fast	2,728	1,949	1.72	1.7	1.3	0.02
SEM	12.3	12.3	0.01	0.87	0.56	0.19
% Methionine[1]	NS	NS	*	NS	NS	NS
0.32	2,728	1,949	1.75	1.6	1.0	–
0.38	2,758	1,979	1.73	0.4	0.2	0.02
0.44	2,778	1,999	1.71	2.9	0.8	0.6
0.50	2,772	1,994	1.70	4.1	2.3	0.02
SEM	17.4	17.4	0.01	1.24	0.79	0.27
Polynomial						
Linear	*	*	*	–	–	–
Quadratic	NS	NS	NS	–	–	–
Cubic	NS	NS	NS	–	–	–
r^2	0.71	0.61	0.55	–	–	–
Interaction	NS	NS	NS	NS	NS	NS

[1]All values represent the least square means of eight pens, each with 25 birds at 3 wk of age and the start of experimentation. The average temperature and relative humidity with their standard deviations through the entire period were 23 ± 3°C and 72 ± 14% RH, respectively.

[2]Feed conversion was corrected for mortality.

[3]Total mortality, sudden death syndrome (SDS), and ascites (ASC) percentages were transformed to the arcsine √ for ANOVA, whereas SEM values were estimates based on actual percentages.

NS$P > 0.10$; *$P < 0.05$; **$P < 0.01$.

TABLE 5. Whole carcass yield of slow- and fast-feathering broiler males at 6 wk of age after receiving feeds having progressively increasing Met from a deficient level at 3 wk while Cys was constant and exceeded its requirement

	Abdominal fat[2]		Carcass without abdominal fat[3]	
Contrast	Weight (g)	Carcass (%)	Weight (g)	Carcass (%)
Feathering	NS	NS	0.06	NS
Slow	43	2.28	1,833	65.8
Fast	41	2.24	1,804	66.1
SEM	0.61	0.03	9.6	0.13
% Methionine[1]	NS	NS	0.08	NS
0.32	43	2.31	1,795	65.8
0.38	42	2.27	1,806	65.7
0.44	42	2.27	1,837	66.1
0.50	41	2.17	1,838	66.2
SEM	0.86	0.04	13.6	0.19
Polynomial				
Linear	NS	*	**	0.08
Quadratic	NS	NS	NS	NS
Cubic	NS	NS	NS	NS
r^2	0.25	0.29	0.68	0.41
Interaction	NS	NS	NS	NS

[1]All values represent least square means of ca. 22 carcasses from each of eight pens.

[2]Abdominal fat expressed on an absolute basis and relative to the chilled carcass.

[3]Carcass without neck and giblets after 4 h of slush-ice chilling and removal of abdominal fat expressed on an absolute basis and relative to the full-fed live bird.

$^{NS}P > 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$.

Methionine supplementation to satisfy TSAA need has been previously observed to improve breast meat yield with broilers of similar age (Hickling et al., 1990; Schutte and Pack, 1995 a,b; Huyghebaert and Pack, 1996), with optimization occurring at levels exceeding those required for maximum growth performance. The acute response of breast meat compared to weight gain when Met is first limiting can be explained in terms of growth uncomplicated by fat deposition based on modeling equations of Gous et al. (1999).

The same test diets were used to measure N balance utilizing caged males between 28 and 29 d of age (Table 7). Percentage N retention relates dietary protein consumed used for growth per se. During this 1-d interval, N retention by slow- and fast-feathering males was similar, and adding Met improved retention for both groups up to 0.46% ($Y = 24.3 + 174.4\ X - 188.4\ X^2$).

Results from both studies indicate that a dietary level of Met per se approximating 0.46% (95% of maximum response) is sufficient to optimize carcass quality of broiler males between 3 and 6 wk of age, regardless of feathering. Maximization of live performance has usually been achieved with less Met. Although the present value approximating 0.50% is significantly higher than the

TABLE 6. Breast meat yield from chilled carcasses of 6-wk-old slow- and fast-feathering broiler males after receiving feeds from 3 wk with Met progressively increased from a deficient level while Cys was constant and exceeded its requirement

	Fillets		Tenders	
Contrast	Weight (g)	Carcass (%)	Weight (g)	Carcass (%)
Feathering	NS	0.06	*	NS
Slow	417	22.7	84	4.6
Fast	415	23.0	82	4.6
SEM	2.76	0.09	0.53	0.02
% Methionine[1]	***	***	*	NS
0.32	401	22.3	82	4.5
0.38	415	23.0	83	4.6
0.44	425	23.1	84	4.6
0.50	424	23.1	85	4.6
SEM	3.91	0.13	0.75	0.03
Polynomial				
Linear	***	***	**	NS
Quadratic	0.06	**	NS	NS
Cubic	NS	NS	NS	NS
r^2	0.73	0.64	0.64	0.37
Interaction	NS	NS	NS	NS

[1]All values represent least square means of eight pens, each providing front halves from ca. 22 carcasses.

$^{NS}P > 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

TABLE 7. Nitrogen balance of 29-d-old slow- and fast-feathering male broilers receiving feeds progressively increased in Met from a deficient level while Cys was constant and exceeded its requirement for a 30-h collection period

	Nitrogen		
Contrast	Consumption (mg)	Excreted (mg)	Retention (%)
Feathering	***	***	NS
Slow	5,273	1,893	64.1
Fast	4,696	1,651	64.8
SEM	48.4	28.1	0.44
% Methionine[1]	NS	***	***
0.32	5,057	1,948	61.6
0.38	4,979	1,733	65.2
0.44	5,025	1,752	65.2
0.50	4,876	1,655	66.1
SEM	68.4	39.7	0.62
Polynomial			
Linear	NS	***	***
Quadratic	NS	NS	*
Cubic	NS	0.052	NS
r^2	0.55	0.54	0.40
Interaction	NS	NS	NS

[1]All values represent least square means of measurements on 18 battery cages each having four birds.

$^{NS}P > 0.10$; $^{*}P < 0.05$; $^{***}P < 0.001$.

0.38% recommended by NRC (1994), it is in agreement with 0.46% Met estimated by Thomas et al. (1992). Comparing present results with other studies in which determining TSAA needs was the objective might not be valid because few could ascertain actual Met need (Wheeler and Latshaw, 1981; Baker et al., 1996), recommendations that were based on live performance and in accordance with NRC (1994).

Measurement of actual Cys need not only necessitates that it be deficient but that the level of accompanying Met be at its actual or slightly below the requirement as well (Baker, 1986; 1987). In experiment 2, Met was purposely made submarginal to the previously determined requirement (0.38 vs. 0.46%), and Cys was progressively supplemented. Analyses of the experimental feeds verified these expectations (Table 8). The same starter feed that had been used in the first experiment was offered to all birds through the first 3 wk. An advantage in body weight for slow-feathering males over fast-feathering males was again apparent at the start and 3 wk of age (Table 9), although not during the 3-to-6-wk period when response to Cys supplementation was being measured (2,574 vs. 2,627 g for slow- and fast-feathering broilers, respectively; $P < 0.01$). Increasing dietary Cys improved body weight gain; however, this advantage was only apparent with fast-feathering males (Table 10). In this respect, weight gain maximized at 0.36% Cys then proceeded to decrease. A cubic regression equation provided the best fit to the data ($Y = -33{,}515.6 + 268{,}325\,X - 688{,}765.2\,X^2 + 584{,}384.3\,X^3$) while describing the response to the transition of Cys being first limiting to that of Met. Featherston and Rogler (1978) and Sell et al. (1980) reported a similar change with chicks when Met became limiting as Cys exceeded requirements.

TABLE 8. Analyses of experimental feeds having Cys progressively increase from a deficient level while Met was maintained submarginal to its requirement (% as is)[1]

	Cystine (%)			
Nutrient	0.32	0.34	0.38	0.46
Dry matter	88.9	88.6	88.3	88.4
Crude protein	19.8	19.9	19.8	19.7
Amino acid				
Cystine	0.32	0.33	0.38	0.45
Methionine	0.38	0.37	0.36	0.38
Lysine	1.08	1.04	1.07	1.10
Arginine	1.25	1.18	1.20	1.33
Threonine	0.72	0.70	0.71	0.76
Valine	0.91	0.90	0.92	0.90
Isoleucine	0.81	0.81	0.81	0.83

[1]Representative samples were analyzed in duplicate courtesy of Degussa-Hülls Corporation, Applied Technology Group; Allendale, NJ.

The amount of depot fat removed from the abdominal cavity after processing was similar, regardless of feathering and Cys level, whereas the resulting amounts of chilled carcass followed the same pattern of treatment effects as live weights (Table 11). Similar to present results, Bunchasak et al. (1998) found no response in fat deposition in broilers fed increasing levels of Cys in a Met-adequate diet. The improvement in chilled carcass weights from supplementing Cys with fast-feathering males optimized at 0.35% in parallel to levels needed for live weight (Table 12).

Feather development is speculated to change with dietary Cys and be needed in excess of requirements for growth (Moran, 1981; Pesti et al., 1996, reported as SAA). This exaggerated need relates to the extremely high Cys concentration in feather protein (Stilborn et al., 1997) as compared to other body tissues (Kirchgessner et al., 1988). As in the previous experiment, incidence of carcass defects was used to indirectly reveal potential differences in feather cover. Although major carcass defects were observed (grand mean ± SEM: wing dislocation, 0.9 ± 0.29%; broken wing, 2.9 ± 0.80%; bruised wing, 32.7 ± 1.43%; bruised drumstick, 1.0 ± 0.34%; broken breast clavicle, 3.7 ± 0.56%; back bruise, 23.6 ± 1.55%; back skin tear, 7.1 ± 0.31%; back skin scratch, 5.8 ± 0.96%; total grade "A", 45.6 ± 1.57%), no differences in the incidence of defects could be established ($P > 0.05$) for feathering or dietary Cys level.

Skinless boneless breast meats obtained by deboning provide a measure of treatment effects on a low fat muscle apart from all other tissues (Table 13). A significant advantage in the amount of fillets and tenders was observed with the fast-feathering males compared to slow-feathering males (400 vs. 380 g and 83 vs. 81 g, respectively) even though live weights at 1 d of age and start of Cys experimentation were to the converse. Breast meat from the fast feathering male was particularly responsive to increasing Cys with 0.36% Cys providing for maximal recovery ($Y = -9{,}895.1 + 78{,}427.0\,X - 203{,}479.8\,X^2 + 174{,}367.6\,X^3$).

The reduced need for Cys with slow-feathering birds to optimize live performance is speculated to have accentuated the growth-depressing effect from increasing Cys

TABLE 9. Live performance of slow- and fast-feathering broiler males from 0 to 3 wk of age (experiment 2) preceding access to feeds having Cys progressively increase from a deficient level while Met was maintained constant and submarginal to its requirement[1]

Feathering	Starting BW (g)	3-Week BW (g)	BW gain (g)	F/G[2]	Mortality (%)
Slow	43.6	778	735	1.51	2.7
Fast	41.5	746	705	1.52	2.8
SEM	0.24	6.6	6.5	0.02	1.06
$P <$	***	**	**	NS	NS

[1]Values represent least-square means of 16 pens, each with 45 chicks at 1 d of age. Average temperature and relative humidity and their standard deviations for the period were 27 ± 3°C and 59 ± 10%, respectively.

[2]Feed conversion was corrected for mortality.

$^{NS}P > 0.10$; $^{**}P < 0.01$; $^{***}P < 0.001$.

given the existing submarginal Met. This imbalance between these SAA has previously been described with chicks (Featherston and Rogler, 1978; Sell et al., 1980). Furthermore, the lower feed conversion of fast- compared to slow-feathering males (1.81 vs. 1.88, $P < 0.001$, respectively) and their tendency to deposit less fat suggests that moderate environmental temperature (21 ± 3°C) might have also influenced maintenance energy need to accentuate repercussion of this imbalance. Similar findings were reported by Hanzl and Somes (1983) when comparing normal feathered and naked neck chicks reared at 21°C, observations that Wang (2000) attributed to changes in energy demand associated with the extent of feather cover.

Nitrogen balance was measured in the same manner as with Met experimentation, only it was conducted on d 30 rather than 29. Contrary to the similarity in retention observed when Met was examined, fast-feathering males utilized dietary crude protein more effectively than the slow-feathering counterparts (Table 14). This result agrees with the report by Wang (2000) who observed a greater deposition of protein with normal feathered compared to naked neck broilers at 7 wk of age reared in a comfortable environment. Contrary to expectation, N retention improved to a similar extent with slow- and fast-feathering males as Cys increased. The differential in rate of feather growth between fast and slow broilers begins to diminish by 4 wk of age (Ajang et al., 1993;

TABLE 10. Live performance of slow- and fast-feathering male broilers from 3 to 6 wk of age after receiving feeds having Cys progress from a deficient level while Met was constant and submarginal to its requirement[1]

Feathering	BW (g)	Gain (g)	F/G[2]	Mortality[3] Total (%)	Mortality[3] SDS (%)
Slow					
% Cystine	NS	NS	NS	NS	NS
0.32	2,618	1,840	1.86	0.1	0.1
0.34	2,613	1,834	1.85	3.1	3.0
0.38	2,630	1,852	1.89	0.01	0.01
0.46	2,580	1,802	1.93	3.1	1.1
SEM	17.9	17.9	0.02	1.03	0.88
Polynomial contrast					
Linear	NS	NS	*	–	–
Quadratic	NS	NS	NS	–	–
Cubic	NS	NS	NS	–	–
r^2	0.72	0.67	0.36	–	–
Fast					
% Cystine	**	**	0.07	NS	NS
0.32	2,520	1,773	1.86	2.3	2.3
0.34	2,618	1,872	1.78	4.1	1.0
0.38	2,616	1,870	1.80	0.8	0.7
0.46	2,607	1,861	1.80	4.2	2.1
SEM	10.5	10.5	0.02	1.51	1.14
Polynomial contrast					
Linear	*	*	NS	–	–
Quadratic	*	*	NS	–	–
Cubic	*	*	0.06	–	–
r^2	0.90	0.83	0.42		

[1]Values represent the average of four pens each with 25 birds at 3 wk of age and the start of experimentation. Average temperature and relative humidity with their standard deviations through the entire period were 21 ± 3°C and 64 ± 8%, respectively.

[2]Feed conversion was corrected for mortality.

[3]Percentages for total mortality, and sudden death syndrome (SDS) were transformed to the arcsine √ for ANOVA, whereas SEM values were estimates based on actual values.

$^{NS}P < 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

TABLE 11. Whole carcass yield of slow- and fast-feathering broiler males at 6 wk of age after receiving feeds from 3 wk having Cys progress from a deficient level while Met was constant and submarginal to its requirement

	Abdominal fat[2]		Carcass without abdominal fat[3]	
Contrast	Weight (g)	Carcass (%)	Weight (g)	Carcass (%)
Feathering	NS	NS	***	*
Slow	38	2.21	1,674	64.7
Fast	39	2.24	1,713	65.1
SEM	0.6	0.03	5.8	0.11
Cystine[1]	NS	NS	**	NS
0.32%	38	2.24	1,664	64.7
0.34%	40	2.28	1,712	65.0
0.38%	38	2.18	1,695	64.7
0.46%	38	2.20	1,701	65.0
SEM	0.79	0.04	8.2	0.16
Polynomial contrast				
Linear	NS	NS	NS	NS
Quadratic	NS	NS	0.08	NS
Cubic	0.06	NS	**	NS
r^2	0.48	0.37	0.80	0.36
Interaction	NS	NS	*	NS

[1]Values represent least square means of eight pens each providing ca. 22 carcasses.

[2]Abdominal fat expressed on an absolute basis and relative to the chilled carcass.

[3]Carcass without neck and giblets after 4 h of slush-ice chilling and removal of abdominal fat expressed on an absolute basis and relative to the full-fed live weight.

$^{NS}P > 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Smith, 1994); thus, sensitivity of N retention based on 1 d may be insufficient relative to measurements dependant on accrual from 21 to 42 d. Optimization in N retention at 95% of its maximum based on the regression equation ($Y = -5.6 + 346.0\ X - 436.7\ X^2$) approximated 0.38% Cys.

Estimating male broiler actual needs for Cys first involves balancing information encompassing 21 to 42 d with that specific for 31 d and then extrapolating from the submarginal to the actual estimate for Met. Taken together, slow-feathering males would need approximately 0.37% Cys vs. 0.42% Cys for fast-feathering males. Differences in feathering has been reported to alter Cys requirements in chicks from 0 to 3 wk (Engler et al., 1985; Kalinowski and Moran, 2001); however, minimal data exist to verify a continuance to 42 d of age. Although Pesti et al. (1996) observed significant differences in feather growth between normal and naked neck broilers beyond 3 wk, the magnitude was insufficient to separate their requirements for TSAA. Present results indicate that significant differences in feather development occur between slow- and fast-feathering males from 3 to 6 wk of age to warrant specific Cys requirements for each type of broiler.

Upon combining Met and Cys values in the present study, the resulting TSAA requirement values for slow- and fast-feathering broilers became 0.83 and 0.88%, respectively. These estimates are in agreement with earlier TSAA measurements for this age broiler (Jensen et al., 1989; Mendonca and Jensen, 1989; Thomas et al., 1992; Jeroch and Pack, 1995; Schutte and Pack, 1995a) and indicate that 0.72% recommended by NRC (1994) is inade-

TABLE 12. Yield of the whole carcass without abdominal fat of fast- and slow-feathering broiler males after receiving feeds having Cys progress from a deficient level while Met was constant and submarginal to its requirement[1]

	Slow		Fast	
Cystine (%)	Weight (g)	Carcass (%)	Weight (g)	Carcass (%)
	NS	NS	**	NS
0.32	1,687	64.4	1,643	65.0
0.34	1,711	65.0	1,713	65.0
0.38	1,693	64.4	1,697	65.0
0.46	1,686	64.8	1,716	65.3
SEM	10.8	0.17	6.0	0.18
Polynomial contrast				
Linear	NS	NS	**	NS
Quadratic	NS	NS	*	NS
Cubic	NS	0.07	**	NS
r^2	0.77	0.40	0.92	0.19

[1]Values represent least square means of four pens each providing ca. 22 carcasses. Carcasses were without neck and giblets after 4 h of slush-ice chilling and removal of abdominal fat and expressed on an absolute basis and relative to the full-fed live bird.

$^{NS}P > 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$.

TABLE 13. Breast meat yield of slow- and fast-feathering broiler males at 6 wk of age after receiving feeds from 3 wk with Cys progressing from a deficient level while Met was constant and submarginal to its requirement[1]

	Fillets		Tenders	
Feathering	Weight (g)	Carcass (%)	Weight (g)	Carcass (%)
Slow				
% Cystine	NS	NS	*	NS
0.32	386	22.8	82	4.85
0.34	392	22.9	84	4.90
0.38	386	22.8	83	4.89
0.46	383	22.7	82	4.88
SEM	1.8	0.10	0.2	0.03
Polynomial contrast				
Linear	NS	NS	NS	NS
Quadratic	NS	NS	*	NS
Cubic	0.07	NS	**	NS
r^2	0.93	0.62	0.97	0.43
Fast				
% Cystine	**	0.09	*	NS
0.32	380	23.1	78	4.75
0.34	402	23.5	83	4.86
0.38	394	23.2	83	4.89
0.46	398	23.2	83	4.85
SEM	1.9	0.06	0.8	0.03
Polynomial contrast				
Linear	*	NS	0.07	NS
Quadratic	0.06	NS	0.06	NS
Cubic	***	*	0.05	NS
r^2	0.92	0.80	0.79	0.56

[1]Values represent least square means of four pens each providing the front halves from ca. 22 carcasses for cone deboning.

$^{NS}P > 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

quate. All these cited studies converge at a TSAA value of 0.80% for broilers chickens from 3 to 6 wk of age, which is particularly similar with needs estimated for slow-feathering broilers in the present studies.

Contributions of Cys to the present TSAA estimates were 44 and 47% for slow- and fast-feathering broilers, respectively. Wheeler and Latshaw (1981) concluded that Cys supplied between 38 to 43% of the TSAA requirements from 3 to 6 wk of age based on multiple comparisons procedures, which Roth and Kirchgessner (1989) contend favor an underestimation. In the present study, Cys levels to optimize growth and carcass parameters were similar, whereas Met need was greater for the former than latter. In turn, a higher Cys replacement value would apply with live performance than carcass and may support the recommendations of 55 and 52% (digestible basis) of Graber et al. (1971) and Baker et al. (1996), respectively.

TABLE 14. Nitrogen balance of 31-d-old slow- and fast-feathering broiler males receiving feeds with Cys progressing from a deficient level while Met was constant and submarginal to its requirement for a 30-h collection period

	Nitrogen		
Contrast	Consumption (mg)	Excreted (mg)	Retention (%)
Feathering	***	***	*
Slow	5,494	2,043	62.8
Fast	4,909	1,762	64.1
SEM	49.9	29.0	0.42
% Cystine[1]	NS	0.07	*
0.32	5,262	1,985	62.3
0.34	5,208	1,897	63.6
0.38	5,184	1,827	64.8
0.46	5,151	1,900	63.2
SEM	70.5	41.0	0.59
Polynomial			
Linear	NS	NS	NS
Quadratic	NS	*	**
Cubic	NS	NS	NS
r^2	0.53	0.48	0.28
Interaction	NS	NS	NS

[1]All values represent least square means of 18 battery cages each having four birds.

$^{NS}P > 0.10$; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

REFERENCES

Ajang, O. A., S. Prijono, and W. K. Smith. 1993. Effect of dietary protein content on growth and body composition of fast and slow feathering broiler chickens. Br. Poult. Sci. 34:73–91.

Baker, D. H. 1986. Problems and pitfalls in animal experiments designed to establish dietary requirements for essential nutrients. J. Nutr. 116:2339–2349.

Baker, D. H. 1987. Construction of assay diets for sulfur-containing amino acids. Pages 297–307 in Methods in Enzymology. W. B. Jakoby and O.W. Griffith, ed. Academic Press, Orlando, FL.

Baker, D. H., S. R. Fernandez, D. M. Webel, and C.M. Parsons. 1996. Sulfur amino acid requirement and cystine replacement value of broiler chicks during the period three to six weeks posthatching. Poult. Sci. 75:737–742.

Bunchasak, C., G. Kimura, K. Tanaka, S. Ohtani, and C. M. Collado. 1998. The effect of supplementing cystine on the growth performance and liver lipid and phospholipid contents of broiler chicks. Jpn. Poult. Sci. 35:60–66.

Creek, R. D. 1968. Non equivalence in mass in the conversion of phenylalanine to tyrosine and methionine to cystine. Poult. Sci. 47:1385–1386.

Dozier, W. A., III, E. T. Moran, Jr., and M. T. Kidd. 2000. Responses of fast- and slow-feathering male broilers to dietary threonine during 42 to 56 days of age. J. Appl. Poult. Res. 9:460–467.

Engler, K., O. P. Thomas, and E. Bossard. 1985. The sulfur amino acid requirement of 3-week old broilers. Pages 5–10 in Proceedings of the Maryland Nutrition Conference. University of Maryland, College Park, MD.

Featherston, W. R., and J. C. Rogler. 1978. Methionine-cystine interrelations in chicks fed diets containing suboptimal levels of methione. J. Nutr. 108:1954–1958.

Fisher, M.-L., S. Leeson, W. D. Morrison, and J. D. Summers. 1981. Feather growth and feather composition of broiler chickens. Can. J. Anim. Sci. 61:769–773.

Gous, R. M., E. T. Moran, Jr., H. R. Stilborn, G. D. Bradford, and G. C. Emmans. 1999. Evaluation of the parameters needed to describe the overall growth, the chemical growth, and the growth of feathers and breast muscles of broilers. Poult. Sci. 78:812–821.

Graber, G., H. M. Scott, and D. H. Baker. 1971. Sulfur amino acid nutrition of the growing chick: effect of age on the capacity of cystine to spare dietary methionine. Poult. Sci. 50:1450–1455.

Hancock, C. E., G. D. Bradford, G. C. Emmans, and R. M. Gous. 1995. The evaluation of the growth parameters of six strains of commercial broiler chickens. Br. Poult. Sci. 36:247–264.

Hanzl, C. J., and R. G. Somes, Jr. 1983. The effect of the naked neck gene, Na, on growth and carcass composition of broilers raised in two temperatures. Poult. Sci. 62:934–941.

Hickling, D., W. Guenter, and M. E. Jackson. 1990. The effects of dietary methionine and lysine on broiler chicken performance and breast meat yield. Can. J. Anim. Sci. 70:673–678.

Huyghebaert, G., and M. Pack. 1996. Effects of dietary protein content, addition of nonessential amino acids and dietary methionine to cysteine balance on response to dietary sulphur-containing amino acids in broilers. Br. Poult. Sci. 37:623–639.

Jensen, L. S., C. L. Wyatt, and B. I. Fancher. 1989. Sulfur amino acid requirement of broiler chickens from 3 to 6 weeks of age. Poult. Sci. 68:163–168.

Jeroch, H., and M. Pack. 1995. Effects of dietary sulfur amino acids and crude protein on the performance of finishing broilers. Arch. Anim. Nutr. 48:109–118.

Kalinowski, A., and E. T. Moran, Jr. 2001. Sulfur amino acids requirement of slow- and fast-feathering male broilers from 0–21 days of age. Poult. Sci. 80(Suppl. 1):46(Abstr.).

Kirchgessner, M., H. Steinhart, and M. Kreuzer. 1988. Aminosäurenmuster im körper und einigen organen von broilern bei unterschiedlicher versorgung mit tryptophan und neutralen aminosäuren. Arch. Anim. Nutr. 38:905–919.

Lowe, P. C., and J. W. Merkley. 1986. Association of genotypes for rate of feathering in broilers with production and carcass composition traits. Effect of genotypes, sex, and diet on growth and feed conversion. Poult. Sci. 65:1853–1858.

Mendonca, C. X., and L. S. Jensen. 1989. Influence of protein concentration on the sulphur-containing amino acid requirement of broiler chickens. Br. Poult. Sci. 30:889–898.

Moran, E. T., Jr. 1981. Cystine requirement of feather-sexed broiler chickens with sex and age. Poult. Sci. 60:1056–1061.

Moran, E. T., Jr. 1994. Response of broiler strains differing in body fat to inadequate methionine: Live performance and processing yields. Poult. Sci. 73:1116–1126.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Ohta, Y., and T. Ishibashi. 1994. Dietary levels and ratio of methionine and cystine for maximum performance of broilers. Jpn. Poult. Sci. 31:369–380.

Pesti, G. M., B. Leclercq, A. -M. Chagneau, and T. Cochard. 1996. Effects of the naked neck (Na) gene on the sulfur-containing amino acid requirements of broilers. Poult. Sci. 75:375–380.

Roth, F. X., and M. Kirchgessner. 1989. Influence of the methionine:cysteine relationship in the feed on the performance of growing pigs. J. Anim. Physiol. A. Anim. Nutr. 61:265–274.

SAS Institute. 1990. SAS User's Guide, Statistics. Version 6 ed. SAS Institute Inc., Cary, NC.

Schutte, J. B., and M. Pack. 1995a. Sulfur amino acid requirements of broiler chicks from fourteen to thirty-eight days of age. 1. Performance and carcass yield. Poult. Sci. 74:480–487.

Schutte, J. B., and M. Pack. 1995b. Effects of dietary sulphur-containing amino acids on performance and breast meat deposition of broiler chicks during the growing and finishing phases. Br. Poult. Sci. 36:747–762.

Sell, D. R., W. R. Featherston, and J. C. Rogler. 1980. Methionine-cystine interrelationship in chicks and rats fed diets containing suboptimal levels of methionine. Poult. Sci. 59:1878–1884.

Smith, W. K. 1994. The physiology and metabolism of feathering. Pages 71–74 in Proceedings of the 9th European Poultry Conference. World's Poultry Science Association, Glasgow, UK.

Stilborn, H. L., E. T. Moran, Jr., R. M. Gous, and M. D. Harrison. 1994. Experimental data for evaluating broiler models. J. Appl. Poult. Res. 3:379–390.

Stilborn, H. L., E. T. Moran, Jr., R. M. Gous, and M. D. Harrison. 1997. Effect of age on feather amino acid content in broiler strain crosses and sexes. J. Appl. Poult. Res. 6:205–209.

Takahashi, K., and Y. Akiba. 1995. Effect of methionine supplementation on lipogenesis and lipolysis in broiler chickens. Jpn. Poult. Sci. 32:99–106.

Thomas, O. P., M. T. Farran, C. B. Tamplin. 1992. Broiler nutrition update. Pages 45–53 in Proceedings of the Maryland Nutrition Conference. University of Maryland, College Park, MD.

United States Department of Agriculture. 1989. Poultry Grading Manual. Agriculture Handbook No. 31. Agricultural Marketing Service, Washington, DC.

Wang, J. 2000. The effects of different feathering types in broilers kept under normal and high environmental temperatures on performance and metabolism characteristics. Tectum Verlag, Marburg, Germany.

Wheeler, K. B., and J. D. Latshaw. 1981. Sulfur amino acid requirements and interactions in broilers during two growth periods. Poult. Sci. 60:228–236.

Wylie, L. M., G. W. Robertson, M. G. Macleod, and P. M. Hocking. 2001. Effect of ambient temperature and restricted feeding on the growth of feathers in growing turkeys. Br. Poult. Sci. 42:449–455.