Influence of Dietary Nutrient Density, Feed Form, and Lighting on Growth and Meat Yield of Broiler Chickens

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ABSTRACT The objective of this study was to examine main and interactive effects of nutrient density (ND), feed form (FF; mash, pellet), and lighting program (12L:12D, 20L:4D) on production characteristics and meat yield of broilers raised to 35 d of age. Diets (starter, grower, and finisher) were formulated so that amino acid levels were in proportion to the dietary energy level. Lighting programs were initiated at 4 d of age. Body weight was not affected by ND when diets were fed in a pellet form but decreased in a linear manner with lower ND when fed as a mash. Final BW of birds fed mash were less than those of birds fed pellet diets. Feed to gain ratio decreased with increasing ND but was not affected by FF. Feed intake decreased with increasing ND and was lower for birds fed mash. The effect of ND on feed intake was less when birds were fed mash in contrast to pellet diets ($P_{ND \times F} < 0.0001$). Dietary ND had no effect on mortality, but feeding mash decreased mortality (3.8%) compared with feeding pelleted feed (5.6%). Lighting programs affected production characteristics independently of ND and FF. Use of 12L:12D reduced BW, feed to gain ratio, feed intake, and mortality compared with 20L:4D. Similarly, carcass components were not affected by ND when fed in pellet form but decreased with lower ND when fed as a mash. Overall, carcass yields were reduced when broilers were fed mash or provided with 12L:12D. Female birds had higher carcass yields and increased proportional breast meat deposition compared with males.

Key words: broiler, photoperiod, nutrition, meat yield

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INTRODUCTION

Dietary nutrient density is one of several nutritional factors that has a significant impact on the growth and health of broiler chickens, which in turn affect the economics of broiler production (Mabray and Waldroup, 1981; Reece and McNaughton, 1982; Campbell et al., 1988). It has been demonstrated that chickens will attempt to adjust their feed intake to satisfy their energy requirements, thereby affecting the efficiency of feed utilization (Pesti and Smith, 1984; Plavnik et al., 1997). In addition, manipulation of nutrient density has been shown to affect growth performance, carcass quality (Jones and Wiseman, 1985), and animal health with respect to the occurrence of metabolic disorders (Scott, 2002) and leg abnormalities (Julian, 1998; Kestin et al., 1999).

Lott et al. (1992) reported higher BW and improved feed efficiency with high-energy rations. In general, feed intake increases with dilution of nutrient density, but birds may have difficulty maintaining energy intake with high levels of dilution (Nielsen, 2004), which may adversely affect growth rate. Scott (2002) noted that the superior growth rate associated with high-density rations was lost at 35 d of age. In the above-mentioned research, varying nutrient density involved changing the dietary energy level while preserving the same energy to protein ratio, and in some situations, the energy to amino acid levels (Lys, sulfur amino acids; Griffiths et al., 1977; Holsheimer and Ruesink, 1993). A more accurate delivery of amino acids, such as the ideal protein concept (Baker and Han, 1994), may alter the response of broilers to changes in dietary nutrient density.

Nutritional and environmental management can have an impact on the performance and health of broiler chickens. Two factors in addition to nutrient density that are of interest are feed form and lighting programs. Today, the majority of broiler feed is in crumble or pellet form, whereas mash rations are still fed in areas where pelleting equipment is unavailable or considered uneconomical. Feed form has an impact on performance, with pelleting improving growth rate and feed efficiency (Greenwood et al., 2005; Lemme et al., 2006), but pelleting has also been associated with increasing mortality (Francesch et al., 1994; Engberg et al., 2002; Scott, 2002). In addition, lighting programs have been shown to affect the perfor-

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mance of broiler chickens. Chickens tend to eat in the light rather than the dark, which means that under continuous lighting programs, feed intake and growth rate should be maximized (Classen and Riddell, 1989). However, continuous lighting programs increase mortality due to metabolic disorders and leg abnormalities compared with birds exposed to periods of darkness (Classen et al., 1991; Renden et al., 1993; Sanotra et al., 2002). Feed intake is affected by light duration, indicating that there may be interactions between the lighting program, nutrient density, and feed form. The length of time required for a constant energy intake will be increased with low nutrient density and mash feeding; therefore, it is possible that shorter day lengths may result in adverse effects on production.

Body weight uniformity, both within and between broiler flocks, is becoming an increasingly important characteristic in broilers as markets are demanding more uniform carcasses. Dietary nutrient density, feed form, and barn lighting programs are some of the important factors that can influence broiler uniformity both within and between flocks (Scott, 2002).

Despite the potential for important interactive effects, relatively little research has investigated the interactions among lighting program, feed form, and nutrient density. Therefore, the aim of this study was to determine how the main effects of each of these factors and their interactions would affect the performance, feed efficiency, and meat yield of broiler chickens raised to 35 d of age. To increase the value of nutrient density comparisons, diets were formulated by using the ideal protein concept (Baker and Han, 1994) to reduce the potential for amino acid deficiency affecting the results.

MATERIALS AND METHODS

The experimental protocol was approved by the Animal Care Committee of the University of Saskatchewan and was performed in accordance with recommendations of the Canadian Council on Animal Care (1993) as specified in the Guide to the Care and Use of Experimental Animals.

Animals and Housing

A total of 4,800 male and female Ross 308 broilers were reared under 2 different lighting programs and were fed 1 of 3 nutrient-density diets provided in either a mash or a crumble or pellet form. Chicks were randomly placed into 1 of 8 environmentally independent rooms that each contained 12 pens (1.68 × 1.98 m). Each pen housed 25 male and 25 female birds and was provided with straw litter, a hanging feeder (0 to 21 d, 36 cm in diameter; 22 to 35 d, 44 cm in diameter), and a bell drinker (44 cm diameter). Birds had access to feed and water on an ad libitum basis. Room temperature was initially 35°C and was subsequently reduced by 2.8°C/wk to 22°C by 30 d.

Dietary Treatments

Three dietary nutrient density feeding programs that consisted of starter, grower, and finisher diets (Table 1) were formulated to meet or exceed NRC (1994) requirements and were provided in 1 of 2 feed forms (mash vs. crumble in the starter and grower phases, pellet in the finisher phase) during the production cycle. Rations were mixed at the University of Saskatchewan and pellet rations were pelleted at 50°C. Broilers are believed to consume feed to meet their energy requirements (Pesti and Smith 1984); therefore, total dietary Lys was balanced to dietary energy for the starter (0.41 g/kcal of ME), grower (0.36 g/kcal of ME), and finisher (0.31 g/kcal of ME) diets. The remaining essential amino acids were kept at minimum ratios to Lys. Diets were analyzed according to the Association of Official Analytical Chemists (1990) for protein (reference 976.06) and amino acid (reference 994.12) contents and were similar to formulated values (data not shown).

The quantities of the starter and grower diets fed to each treatment were based on the number of birds placed and were adjusted to ensure that the level of nutrient intake per bird was similar regardless of the dietary nutrient density treatment. Broilers fed the low-, medium-, and high-density diets were fed 0.777, 0.735, and 0.700 kg per bird in the starter phase and 1.210, 1.115, and 1.100 kg per bird in the grower phase, respectively. Finisher rations were fed as required until the end of the trial. To maintain pellet quality, the pellet binder was increased in the medium- and high-density finisher diets because of the increase in dietary fat.

Lighting Treatments

Two lighting treatments were used from 0 to 35 d of age. All birds were provided with 23L:1D (20 lx) from 0 to 3 d of age; lighting programs were initiated at 4 d of age and light intensity was reduced to 10 lx. The first lighting program was 20L:4D, which was used to stimulate feed intake and growth rate. The second lighting program (12L:12D) was chosen to restrict feed intake by limiting feeding time and, as a consequence, reduce growth rate.

Data Collection

Broiler performance and mortality were monitored throughout the production trial to determine the effect of nutrient density, feed form, and lighting program. Body weight and feed intake per pen were assessed at 0, 6, 13, 20, 27, and 34 d of age. Feed conversion ratio (feed:gain) was assessed during these periods and was corrected for mortality. A total of 4 rooms were randomly selected (2 for each lighting program) to assess BW uniformity at 35 d of age for a total of 100 birds per treatment (nutrient density × feed form × lighting treatment subclass). Uniformity was assessed by calculating the percentage of birds within a 15% range of the average weight of broilers for each treatment.

Table 1. Ingredient composition (%) and formulated nutrient profile of broiler starter, grower, and finisher diets[1]

Item	Starter			Grower			Finisher		
	L	M	H	L	M	H	L	M	H
Ingredient									
Barley	50.00	25.00	—	48.39	24.00	—	41.27	20.00	—
Corn	—	20.00	40.00	—	10.00	20.00	—	10.00	20.00
Wheat	16.46	17.06	12.71	22.46	33.77	41.57	35.08	41.53	47.34
Soybean meal	27.32	30.00	37.65	24.02	25.00	29.00	18.66	21.00	23.00
Canola oil	1.00	1.54	3.37	1.00	1.00	1.08	1.00	1.00	1.32
Tallow	—	1.00	1.00	—	1.88	4.00	—	2.24	4.00
Limestone	1.80	1.82	1.82	1.72	1.74	1.76	1.68	1.69	1.72
Dicalcium phosphate	0.89	0.95	0.97	0.81	0.85	0.87	0.75	0.79	0.83
Vitamin[2]-mineral[3] premix	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Sodium chloride	0.36	0.34	0.33	0.35	0.32	0.30	0.33	0.31	0.29
Choline chloride	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-Met	0.25	0.30	0.30	0.16	0.22	0.24	0.13	0.17	0.20
L-Lys HCl	0.14	0.20	0.11	0.05	0.11	0.08	0.06	0.08	0.11
Enzyme[4]	0.10	0.10	0.05	0.10	0.05	0.05	0.10	0.05	0.05
Salinomycin sodium[5]	0.50	0.50	0.50	0.10	0.10	0.10	0.10	0.10	0.10
Virginiamycin[6]	0.25	0.25	0.25	0.03	0.03	0.03	0.03	0.03	0.03
Pellet binder[7]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.40
Formulated nutrient profile									
ME (kcal/kg)	2,800	2,950	3,100	2,850	3,000	3,150	2,900	3,050	3,200
CP (g/kg)	207.6	210.1	226.9	196.8	197.6	207.0	180.3	184.0	186.9
Lys (g/kg)	11.6	12.3	12.9	10.2	10.7	11.3	9.1	9.6	10.1
Met (g/kg)	4.80	5.08	5.27	4.32	4.76	4.73	3.81	4.11	4.03
Ca (g/kg)	9.5	9.5	9.5	9.0	9.0	9.0	8.6	8.6	8.6
Nonphytate P (g/kg)	4.2	4.2	4.2	4.0	4.0	4.0	3.8	3.8	3.8

[1]Nutrient density: L = low-density, M = medium-density, H = high-density.

[2]Supplied per kilogram of diet: 11,000 IU of vitamin A (retinyl acetate + retinyl palmitate), 2,200 IU of vitamin D_3 (cholecalciferol), 30 IU of vitamin E (DL-α-tocopheryl acetate), 2.0 mg of vitamin K_3 (menadione), 1.5 mg of thiamine, 6.0 mg of riboflavin, 60 mg of niacin, 4 mg of pyridoxine, 0.02 mg of vitamin B_{12}, 10.0 mg of pantothenic acid, 6.0 mg of folic acid, 0.15 mg of biotin, and 0.625 mg of ethoxyquin.

[3]Supplied per kilogram of diet: 500 mg of $CaCO_3$, 80 mg of Fe, 80 mg of Zn, 80 mg of Mn, 10 mg of Cu, 0.8 mg of I, and 0.3 mg of Se.

[4]Low-nutrient-density (starter, grower, and finisher) and medium-nutrient-density diet in the starter used Avizyme 1100; remaining diets used Avizyme 1302 (Finn Feed, Prairie Microtech, Regina, Canada).

[5]Coccistac (Phibro Animal Health, Ridgefield Park, NJ).

[6]Stafac-44 (Phibro Animal Health).

[7]Pro-bond (pea starch) pellet binder (Parrheim Foods, Portage la Prairie, Manitoba, Canada).

Dead birds and culls were collected daily, weighed, and necropsied. Any skeletal abnormalities (tibial dyschondroplasia, osteomyelitis, etc.) were noted as they were discovered. Total mortality was expressed as a percentage of the number of birds alive at the beginning of the trial.

To determine the effect of sex on meat yield, 24 males and 24 females per treatment (nutrient density × feed form × lighting treatment subclass) were identified on the basis of their physical appearance (comb, spur, and feathering pattern) and randomly picked to assess meat yield. Meat yield was assessed by weighing the following components: live weight (feed-restricted weight), whole eviscerated carcass (excluding neck), abdominal fat pad, breast skin, pectoralis major and supracoracoideus, wings (whole), drums (whole), thighs (whole), and back (carcass remaining after previous components were removed).

Statistical Analysis

Data were analyzed by using PROC GLM of SAS (SAS Institute, 2002) as a 3×2 factorial nested within 2 lighting programs. The ANOVA included the main effects of nutrient density (3), feed form (2), and lighting program (2) as well as 2- and 3-way interactions that may have occurred between these factors. Meat yield data was analyzed to include the main effects of nutrient density (3), feed form (2), lighting program (2), and sex (2) in addition to 2-, 3-, and 4-way interactions. Mean values were separated by using Duncan's multiple range test. The data were assumed to be statistically significant when $P < 0.05$.

RESULTS

Broiler Performance

Nutrient density had a significant interaction with feed form for many of the performance parameters studied; as a consequence, the data will be reported on an interaction rather than a main effect basis (Tables 2 and 3). On the other hand, there were no significant interactions between nutrient density or feed form and lighting program, so only the main effects of lighting programs will be presented (Table 4).

BW. There were interactions between nutrient density and feed form on BW at all ages examined. Both main effect and interactive data with statistical interpretation are shown in Table 2. Body weight was not affected by nutrient density when diets were fed in crumble or pellet form. In contrast, BW decreased with reduced nutrient

Table 2. The effect of nutrient density (ND)[1] and feed form (FF)[2] on BW and feed intake of broiler chickens

Nutrient density and feed form	BW (kg)						Feed intake (kg/bird)					
	d 0	d 6	d 13	d 20	d 27	d 34	0–6 d	7–13 d	14–20 d	21–27 d	28–34 d	0–34 d
ND[1]												
L	0.042	0.115[b]	0.297[c]	0.639[c]	1.152[c]	1.779[b]	0.097	0.251	0.520[a]	0.846[a]	1.131[a]	2.881[a]
M	0.042	0.118[a]	0.311[b]	0.662[b]	1.206[b]	1.838[a]	0.098	0.255	0.508[a]	0.839[a]	1.109[a]	2.843[a]
H	0.042	0.119[a]	0.321[a]	0.681[a]	1.236[a]	1.832[a]	0.099	0.255	0.492[b]	0.815[b]	1.057[b]	2.754[b]
Pooled SEM	0.0001	0.0005	0.0016	0.0030	0.0050	0.0077	0.0009	0.0014	0.0048	0.0056	0.0088	0.0142
P-value	NS[3]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	NS	NS	0.0004	0.0008	<0.0001	<0.0001
FF												
Mash	0.042	0.108[b]	0.284[b]	0.609[b]	1.110[b]	1.699[b]	0.092[b]	0.237[b]	0.477[b]	0.777[b]	1.025[b]	2.631[b]
Pellet	0.042	0.127[a]	0.336[a]	0.712[a]	1.286[a]	1.933[a]	0.104[a]	0.270[a]	0.536[a]	0.890[a]	1.173[a]	3.021[a]
Pooled SEM	0.0001	0.0004	0.0013	0.0024	0.0041	0.0063	0.0007	0.0012	0.0040	0.0046	0.0072	0.0115
P-value	NS	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
ND × FF												
L												
Mash	0.042	0.103	0.263	0.568	1.038	1.634	0.090	0.229	0.488	0.788	1.039	2.650
Pellet	0.042	0.127	0.332	0.710	0.267	1.923	0.105	0.273	0.551	0.914	1.223	3.112
M												
Mash	0.042	0.109	0.286	0.614	0.124	1.726	0.94	0.238	0.480	0.786	1.043	2.660
Pellet	0.043	0.127	0.337	0.710	0.288	1.949	0.102	0.271	0.536	0.891	1.175	3.026
H												
Mash	0.042	0.112	0.303	0.645	1.169	1.738	0.092	0.244	0.461	0.766	0.993	2.582
Pellet	0.042	0.126	0.339	0.717	1.304	1.926	0.106	0.265	0.522	0.865	1.121	2.927
Pooled SEM	0.0001	0.0007	0.0023	0.0042	0.0071	0.0108	0.0012	0.0020	0.0068	0.0080	0.0125	0.0200
P-value	0.0485	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0040	<0.0001	NS	0.0545	0.0498	0.0103

[a–c]Means within a column and main effect with no common superscript differ ($P < 0.05$).

[1]Nutrient density: L = low density, M = medium density, H = high density. Means of 32 replicates of nutrient density having 50 birds in each replicate.

[2]Means of 48 replicates of feed form having 50 birds in each replicate.

[3]NS = $P > 0.10$.

density when diets were in mash form. Lighting program affected BW, with birds given 12L:12D being lighter than those exposed to 20L:4D from d 6 until the end of the trial (Table 4).

Feed Intake. Feed intake was affected by the interaction between nutrient density and feed form for all time periods examined, with the exception of 14 to 20 d of age. Feed intake declined in a linear manner as dietary nutrient density increased when birds were fed pelleted rations (Table 2). Feeding mash reduced feed intake significantly for all time periods, but the degree of reduction was greater when broilers were fed the low-density treatment. The effect of nutrient density on feed intake in relation to age is of interest and was demonstrated most accurately by examining the relative intake of pellet-fed broilers. Initially, there were no differences in feed intake due to nutrient density. However, as birds aged, the relative intakes of lower nutrient-density diets increased until they reached increases of 9 and 5% over the high-nutrient-density diet for the low- and medium-density diets, respectively, from 28 to 34 d. On a calculated basis, the low- and medium-density diets were 10 and 5% lower in nutrient density.

Broilers provided with 20L:4D ate more feed overall (2.99 kg per bird) than birds provided with 12L:12D (2.67 kg per bird; Table 4). The effect of light on feed intake was consistent for all time periods examined.

Feed Conversion Ratio. Overall, feed efficiency was affected by nutrient density and lighting program but not by feed form. Feed to gain ratio decreased in a linear fashion with increasing nutrient density (Table 3). Longer day lengths (20L:4D) increased the feed conversion ratio in comparison with birds exposed to 12L:12D (Table 4). There were no interactions between main effects for overall feed conversion.

An interaction was found between nutrient density and feed form for feed to gain ratio during the 0- to 6-d, 7- to 13-d, and 14- to 20-d time periods (Table 3). Only minor effects of feed form on feed to gain ratio were noted for high-nutrient-density diets, whereas relatively large differences were observed for the mash and pellet treatments for low-nutrient-density diets. Examination of the feed to gain ratio during the experiment revealed that nutrient density had little or no effect on this trait at 0 to 6 d of age if birds were fed pellet diets. However, as birds aged, there was an increasingly more important effect of nutrient density. This can be readily seen by comparing the relative feed to gain ratios of birds fed pellet diets of varying nutrient densities.

Mortality. Death and culling losses were unaffected by dietary nutrient density (Table 3). Feeding mash reduced the overall mortality as well as the mortality in every time period, starting at 14 d of age, in comparison with feeding pellet diets. Similarly, short day lengths (12L:12D) reduced mortality overall and mortality in the 21- to 27-d period in comparison with the longer day lengths (20L:4D; Table 4). There were no interactions between main effects for mortality.

Uniformity. The uniformity of broilers was affected only by feed form (Table 5) when assessed by the percent-

Table 3. The effect of nutrient density (ND)[1] and feed form (FF) on feed to gain ratio[2] (mortality corrected) and mortality of broiler chickens

Nutrient density and feed form	Feed to gain ratio						Mortality (%)					
	0–6 d	7–13 d	14–20 d	21–27 d	28–34 d	0–34 d	0–6 d	7–13 d	14–20 d	21–27 d	28–34 d	0–34 d
ND												
L	1.358[a]	1.385[a]	1.527[a]	1.653[a]	1.813[a]	1.640[a]	0.94	0.50	0.50	1.75	0.88	4.56
M	1.304[b]	1.317[b]	1.443[b]	1.553[b]	1.761[b]	1.565[b]	0.88	1.12	0.63	1.50	0.81	4.94
H	1.299[b]	1.259[c]	1.360[c]	1.483[c]	1.787[ab]	1.522[c]	0.63	0.75	0.81	1.63	0.88	4.69
Pooled SEM	0.0143	0.0092	0.0137	0.0117	0.0158	0.0067	0.219	0.198	0.172	0.324	0.235	0.545
P-value	0.0075	<0.0001	<0.0001	<0.0001	0.0675	<0.0001	NS[3]	0.0887	NS	NS	NS	NS
FF												
Mash	1.403[a]	1.352[a]	1.467[a]	1.555	1.747[b]	1.575	0.79	0.92	0.42[b]	1.08[b]	0.63	3.83[b]
Pellet	1.283[b]	1.288[b]	1.420[b]	1.571	1.827[a]	1.577	0.83	0.67	0.88[a]	2.17[a]	1.08	5.63[a]
Pooled SEM	0.0117	0.0075	0.0112	0.0096	0.0129	0.0055	0.179	0.162	0.140	0.264	0.192	0.445
P-value	<0.0001	<0.0001	0.0037	NS	<0.0001	NS	NS	NS	0.0237	0.0055	0.0949	0.0056
ND × FF												
L												
Mash	1.474	1.437	1.597	1.654	1.746	1.646	1.00	0.62	0.25	1.37	0.75	4.00
Pellet	1.242	1.332	1.456	1.652	1.881	1.634	0.87	0.37	0.75	2.12	1.00	5.12
M												
Mash	1.410	1.342	1.458	1.541	1.741	1.568	0.87	1.24	0.25	0.75	0.50	3.62
Pellet	1.199	1.291	1.428	1.565	1.780	1.562	0.87	1.00	1.00	2.25	1.12	6.25
H												
Mash	1.325	1.278	1.347	1.471	1.754	1.510	0.50	0.87	0.75	1.12	0.62	3.87
Pellet	1.273	1.241	1.375	1.495	1.820	1.534	0.75	0.62	0.87	2.12	1.12	5.50
Pooled SEM	0.0202	0.0131	0.0194	0.0166	0.0224	0.0095	0.311	0.280	0.243	0.456	0.332	0.770
P-value	<0.0001	0.0316	0.0002	NS	0.0946	NS	NS	NS	NS	NS	NS	NS

[a–c]Means within a column and main effect with no common superscript differ significantly ($P < 0.05$).

[1]Nutrient density: L = low density, M = medium density, H = high density. Means of 32 replicates of nutrient density having 50 birds in each replicate.

[2]Means of 32 (nutrient density) and 48 (feed form) replicates having 50 birds in each replicate.

[3]NS = $P > 0.10$.

age of birds within the 15% range of the average weight of broilers in each pen. The pellet rations had a greater percentage of broilers within the 15% range of the average pen weight (78.5%) than broilers fed mash (70.9%), indicating that there was greater flock uniformity when broilers were provided with pellet rations. There were no effects on uniformity for dietary nutrient density or lighting programs, and also no interactions between main effects (Table 5).

Meat Yield

The main effects of nutrient density, feed form, lighting program, and sex on meat yield are shown as actual yields in grams (Table 6) and on a proportional basis to carcass weight (Table 7).

Nutrient Density and Feed Form Interaction. Interactions between nutrient density and feed form were found for all actual carcass weights except for the supracoracoideus muscles, breast skin, and abdominal fat (Table 8). Nutrient density did not affect carcass characteristics when diets were fed in a pellet form, but when fed in mash form, low-nutrient-density diets produced smaller weights than other nutrient-density treatments. These interactions are likely a reflection of similar interactions in BW noted above. In addition to feed form interacting with nutrient density, feeding a mash diet reduced actual weights of all carcass components relative to those resulting from feeding pellet diets. There were no interactions between nutrient density and feed form when the carcass components were expressed as a percentage of the whole carcass. On a proportional basis, abdominal fat increased, and the drum and wing decreased as nutrient density increased (Table 7).

Lighting Programs. With the exception of abdominal fat, all carcass components weighed less for birds given 12L:12D in contrast to those given 20L:4D (Table 6). These differences are in agreement with the lighting program effects on BW noted above (Table 6). The carcass weight as a percentage of live weight for broilers given 12L:12D was lower than for those given 20L:4D. When expressing the carcass component weights as a percentage of carcass weight (Table 7), pectoralis muscle and total breast meat yield were lower for the 12L:12D treatment. In contrast, proportional drum, wing, and back weights were higher for the 12L:12D treatment.

Sex Effect. The sex of the broiler had an impact on many aspects of meat yield, as shown in Table 6. Male broilers had higher live weights, and consequently higher component weights, in contrast to females. On a proportional basis, females had higher carcass, pectoralis muscle, supracoracoideus, total breast, and breast skin yields and lower drum yield than males (Table 7).

DISCUSSION

The major objective of this research was to establish the main and interactive effects of nutrient density, feed form, and day length on broiler performance and carcass yield composition. In general, these treatments had sig-

Table 4. Effect of lighting programs on BW, feed intake, feed to gain ratio (mortality corrected), and mortality of broiler chickens[1]

Item	Lighting program	Age					
		d 0	d 6	d 13	d 20	d 27	d 34
BW (kg)	12L:12D	0.042	0.113[b]	0.290[b]	0.623[b]	1.142[b]	1.756[b]
	20L:4D	0.042	0.122[a]	0.330[a]	0.698[a]	1.254[a]	1.876[a]
	Pooled SEM	0.0001	0.0004	0.0013	0.0024	0.0041	0.0063
	P-value	NS[2]	0.0128	0.0006	<0.0001	<0.0001	<0.0001
		0–6 d	7–13 d	14–20 d	21–27 d	28–34 d	0–34 d
Feed intake (kg/bird)	12L:12D	0.093[b]	0.228[b]	0.465[b]	0.787[b]	1.071[b]	2.666[b]
	20L:4D	0.104[a]	0.279[a]	0.547[a]	0.880[a]	1.127[a]	2.987[a]
	Pooled SEM	0.0007	0.0012	0.0040	0.0046	0.0072	0.0115
	P-value	0.0006	<0.0001	<0.0001	<0.0001	0.0005	<0.0001
Feed to gain ratio	12L:12D	1.331	1.294[b]	1.401[b]	1.523[b]	1.744[b]	1.544[b]
	20L:4D	1.311	1.347[a]	1.486[a]	1.603[a]	1.830[a]	1.608[a]
	Pooled SEM	0.0117	0.0075	0.0112	0.0096	0.0129	0.0055
	P-value	NS	0.0001	0.0019	0.0049	0.0019	0.0002
Mortality (%)	12L:12D	0.75	0.75	0.42	1.08[b]	0.58[a]	3.58[b]
	20L:4D	0.88	0.83	0.88	2.17[a]	1.13[a]	5.87[a]
	Pooled SEM	0.179	0.162	0.140	0.264	0.192	0.445
	P-value	NS	NS	NS	0.0049	0.0603	0.0251

[a,b]Means within a column and main effect with no common superscript differ ($P < 0.05$).

[1]Means of 48 replicates of lighting programs having 50 birds in each replicate.

[2]NS = $P > 0.10$.

nificant individual effects on production traits, but interactive effects were also significant. These findings indicate the importance of considering both nutritional and management factors when making production decisions.

Growth rate was influenced by feed form and lighting program, and feed form also interacted with nutrient density. The growth rate decreased with decreasing nutrient density when diets were fed in mash form; this relationship was likely a reflection of the reduced ability of birds to eat the bulkier, and possibly less palatable, low-density mash ration (Scott, 2002). The interaction between nutrient density and feed form on feed intake supports this conclusion. The effects on growth rate of feeding mash and of short day length were expected and were similar to the results of previous research (Engberg et al., 2002; Scott, 2002; Classen et al., 2004; Svihus et al., 2004; Skinner-Noble et al., 2005). In both cases, the reduced growth was related to a reduction in feed intake.

Broilers had the ability to regulate feed intake based on the dilution of nutrient density when pellet rations were provided; those fed the high-density ration reduced their feed intake in comparison with those fed the low-density ration. However, this ability was limited during the first 2 wk of age, in agreement with Jones and Wiseman (1985). In contrast, broilers provided mash rations, especially those fed the low-density mash rations, seemed unable to regulate their feed consumption to achieve a similar energy intake as the other treatments. Scott (2002) also indicated a similar feed intake response of broiler chickens with mash rations.

From 7 to 13 and 14 to 20 d, feed to gain ratios for both mash- and pellet-fed broilers increased with decreasing nutrient density but the degree of change was larger for the birds fed mash. The lack of effect of nutrient density in pellet-fed birds from 0 to 6 d is of interest. These data plus equal growth for these treatments during this time suggest that the same amounts of digestible nutrients

Table 5. The effect of nutrient density (ND), feed form (FF), and lighting programs (LP) on uniformity[1] of broiler chickens at 35 d of age

Item	Percentage
ND[2]	
L	72.8
M	73.3
H	78.0
Pooled SEM	1.775
FF[3]	
Mash	70.9[b]
Pellet	78.5[a]
Pooled SEM	1.450
Lighting program[3]	
12L:12D	74.9
20L:4D	74.5
Pooled SEM	1.450
Source of variation (*P*-value)	
ND	NS[4]
FF	0.004
LP	NS
ND × L	NS
LP × FF	NS
ND × FF	NS
ND × LP × FF	NS

[a,b]Means within a column and main effect with no common superscript differ ($P < 0.05$).

[1]Uniformity was assessed by calculating the percentage of birds within 15% range of the average weight of broilers for each treatment.

[2]Nutrient density: L = low density, M = medium density, H = high density. Means of 8 replicates having 50 birds in each replicate.

[3]Means of 12 replicates each of feed form and lighting programs having 50 birds in each replicate.

[4]NS = $P > 0.10$.

Table 6. The effect of nutrient density, feed form, lighting program and sex on portion weights (g) of broiler chickens

Item	Nutrient density[1] L	Nutrient density[1] M	Nutrient density[1] H	Feed form Mash	Feed form Pellet	Light 12L:12D	Light 20L:4D	Sex Male	Sex Female	Pooled SEM
Live weight	1,821.4[b]	1,869.6[ab]	1,886.0[a]	1,728.9[b]	1,989.0[a]	1,802.5[b]	1,916.6[a]	1,975.1[a]	1,741.9[b]	13.43
Carcass weight	1,206.2[b]	1,245.8[a]	1,249.9[a]	1,144.5[b]	1,325.3[a]	1,184.2[b]	1,284.2[a]	1,303.8[a]	1,164.5[b]	8.82
Pectoralis muscle	254.8	261.6	262.3	234.3[b]	285.0[a]	239.3[b]	280.0[a]	272.1[a]	247.0[b]	2.54
Supracoracoideus	52.2	54.1	54.0	49.4[b]	57.5[a]	50.8[b]	56.1[a]	55.6[a]	51.3[b]	0.51
Total breast	307.0	315.7	316.3	283.7[b]	342.5[a]	290.1[b]	336.1[a]	327.6[a]	298.2[b]	2.92
Breast skin	46.6[b]	51.0[a]	50.4[a]	43.7[b]	55.1[a]	47.5[b]	51.3[a]	50.7[a]	48.0[b]	0.73
Abdominal fat	8.4[b]	9.3[ab]	11.9[a]	7.8[b]	12.0[a]	9.1	10.7	11.3[a]	8.5[b]	0.55
Thigh	223.6	230.1	229.4	211.3[b]	244.3[a]	219.7[b]	235.8[a]	239.1[a]	216.3[b]	1.71
Drum	176.9	180.7	179.1	169.6[b]	188.2[a]	174.9[b]	182.9[a]	192.3[a]	165.3[b]	1.25
Wing	142.5	145.0	145.0	135.4[b]	152.9[a]	141.3[b]	147.1[a]	152.2[a]	136.0[b]	0.91
Back	297.5[b]	308.9[a]	310.6[a]	288.7[b]	323.0[a]	297.1[b]	314.4[a]	324.4[a]	286.9[b]	2.16

[a,b]Means within a row and main effect with no common superscript differ ($P < 0.05$).

[1]Nutrient density: L = low density, M = medium density, H = high density.

were provided by the 3 diets. The diets were formulated on the basis of digestibility values derived in older broilers and it is possible that they did not accurately reflect digestibility in very young birds, as reported by Batal and Parsons (2002). In addition, it is possible that a portion of the larger response of mash-fed birds to nutrient density during early life was due to feed wastage. Feed wastage was monitored and wasted feed collected, but absolute recovery of waste feed was not possible. An alternative explanation may have been the result of differences in nutrient digestibility based on the dietary ingredients used. Nutrient digestibility may have been increased by pelleting in contrast to mash rations (Zelenka, 2003). Others have noted higher feed to gain values early in life for broilers fed mash in contrast to pellet rations (Holsheimer and Ruesink, 1993; Scott, 2002), and this may be due to factors other than wastage, such as the amount of energy expended to consume the mash ration. The lack of an overall effect of pelleting on feed to gain ratios disagrees with Engberg et al. (2002), Greenwood et al. (2005), and Skinner-Noble et al. (2005), who found that pelleted rations improved feed efficiency over mash rations. Greenwood et al. (2005) demonstrated a high rate of growth and increased digestible Lys requirements for optimal BW gain and feed efficiency in pellet-fed broilers compared with mash-fed broilers from 16 to 30 d of age. Skinner-Noble et al. (2005) indicated that pellet rations increased available dietary energy for BW gain, which improved feed efficiency by reducing the time spent eating and increasing the time spent resting. Other possible reasons for the reduced effect of pelleting on feed efficiency in the present research are the large differences in BW for the 2 treatments and the fact that the pelleting temperature in the present study was low (50°C) and would not have caused major effects on dietary constituents that might have improved digestibility.

The effects of lighting on production parameters were similar to previous research and independent of dietary nutrient density and feed form. Increased hours of darkness per day decreased BW after birds were on the lighting programs for only 2 d (6 d of age), and this difference continued to marketing. By end of the trial, the difference was 321 g, or approximately 3 d, to equal market weight. This difference is considerably larger than the approximately 80 g lower weight for 12L:12D in comparison with the 20L:4D seen by Classen et al. (2003). The reduction in live BW with prolonged exposure to darkness might be due to decreased duration of feed consumption (Renden et al., 1993), which implies that the 12L:12D lighting program was not sufficient to allow birds to achieve their

Table 7. The effect of nutrient density, feed form, lighting program, and sex on portion weights (% age of live weight at processing basis) of broiler chickens

Item	Nutrient density[1] L	Nutrient density[1] M	Nutrient density[1] H	Feed form Mash	Feed form Pellet	Light 12L:12D	Light 20L:4D	Sex Male	Sex Female	Pooled SEM
Carcass weight	66.3	66.2	66.3	66.0	66.6	65.7[b]	66.8[a]	65.8[b]	66.8[a]	0.18
Pectoralis muscle	20.9	20.9	20.8	20.3[b]	21.4[a]	20.1[b]	21.7[a]	20.7[b]	21.1[a]	0.09
Supracoracoideus	4.3	4.3	4.3	4.3	4.3	4.3	4.4	4.3[b]	4.4[a]	0.03
Total breast	25.3	25.2	25.2	24.7[b]	25.8[a]	24.4[b]	26.0[a]	25.0[b]	25.4[a]	0.09
Breast skin	3.8[b]	4.1[a]	4.0[ab]	3.8[b]	4.2[a]	4.0	4.0	3.9[b]	4.1[a]	0.05
Abdominal fat	0.7[b]	0.7[ab]	0.9[a]	0.7[b]	0.9[a]	0.7	0.8	0.8	0.7	0.05
Thigh	18.6	18.5	18.3	18.5	18.5	18.6[a]	18.4[a]	18.4	18.6	0.06
Drum	14.7[a]	14.5[b]	14.3[c]	14.8[a]	14.2[b]	14.8[a]	14.2[b]	14.8[a]	14.2[b]	0.04
Wing	11.9[a]	11.7[b]	11.6[b]	11.9[a]	11.6[b]	12.0[a]	11.5[b]	11.7	11.7	0.04
Back	24.8	24.9	24.9	25.3[a]	24.4[b]	25.2[a]	24.5[b]	25.0	24.7	0.10

[a–c]Means within a row and main effect with no common superscript differ ($P < 0.05$).

[1]Nutrient density: L = low density, M = medium density, H = high density.

Table 8. The interactions between feed form or lighting program and nutrient density[1] with respect to meat yield (as is basis) in broiler chickens

Nutrient density	Item	Live weight	Carcass weight	Pectoralis muscle	Supracora coideus	Total breast	Breast skin	Abdominal fat	Thigh	Drum	Wing	Back
	Feed form											
L	Mash	1650.1	1090.3	222.3	47.0	269.3	39.3	6.4	202.3	164.5	130.7	273.8
L	Pellet	1988.4	1326.9	288.6	57.6	346.2	54.2	10.5	245.8	189.8	154.8	322.2
M	Mash	1763.4	1170.7	241.5	50.2	291.7	46.4	8.0	216.2	172.4	137.5	294.2
M	Pellet	1975.8	1320.0	281.2	57.8	339.0	55.6	10.7	243.6	188.8	152.3	323.3
H	Mash	1770.6	1171.9	239.2	50.9	290.1	45.4	9.1	215.2	171.9	138.1	297.9
H	Pellet	2002.8	1329.0	285.3	57.1	342.4	55.4	14.6	243.5	186.3	151.8	323.3
P-value		0.0270	0.0143	0.0257	NS[2]	0.0257	NS	NS	0.0347	0.0426	0.0034	0.0172
	Lighting program											
L	12L:12D	1746.9	1135.6	229.5	49.4	278.9	42.0	7.2	210.0	170.7	138.1	286.6
L	20L:4D	1897.8	1273.9	279.1	54.9	334.0	51.1	9.6	236.7	182.8	146.7	308.0
M	12L:12D	1815.3	1198.3	241.9	51.5	298.4	50.1	9.3	223.6	177.0	142.6	298.9
M	20L:4D	1923.9	1294.0	281.9	56.7	338.6	52.1	9.4	236.8	184.5	147.5	319.2
H	12L:12D	1844.9	1215.6	245.9	51.4	297.3	50.0	10.6	224.9	176.9	143.0	305.2
H	20L:4D	1927.5	1284.7	279.0	56.7	335.7	50.8	13.2	234.0	181.3	147.0	316.2
P-value		NS	NS	NS	NS	NS	0.0366	NS	0.0418	NS	0.0263	NS

[1]Nutrient density: L = low-density; M = medium-density; H = high-density.

[2]NS = $P > 0.10$.

growth potential, especially for those on a low-density diet. The lower feed to gain ratio with increased darkness is likely related to reduced metabolism and activity during exposure to darkness; this finding is similar to previous research (Classen and Riddell, 1989; Classen et al., 1991).

Mortality was not influenced by dietary nutrient density, but was affected by feed form and lighting program. This contradicts the report by Scott (2002), who found that feed form did not affect mortality but that feeding a high-density ration resulted in a higher incidence of sudden death syndrome (**SDS**) compared with broilers fed a low-density ration. The lack of an effect of feed form on mortality observed by Scott (2002) was possibly because the mash diet was fed for only 12 d during the starter phase. Results from the current study demonstrate that broilers fed mash rations had a lower incidence of mortality than broilers fed pellet rations, and this agrees with Nir et al. (1995) and Engberg et al. (2002). The main cause of mortality in the current study was SDS. Several studies have found that lighting programs have a significant effect on mortality (Classen and Riddell, 1989; Classen et al., 1991; Renden et al., 1993; Scott, 2002), which agrees with the findings of the current trial. Broilers provided with 20L:4D had higher mortality rates with a higher incidence of SDS and ascites (1.26 and 0.16%, respectively) in contrast to those provided with 12L:12D (0.77 and 0.07%, respectively; Brickett et al., 2007). The results of the current study also demonstrated that the use of mash rations will result in poorer flock uniformity within the flocks than feeding pellet rations, which might also be true between flocks.

Treatments and interactions among treatments affected the actual carcass and carcass component weights, as would be expected based on the treatment effects on growth rate. When the data were examined as a proportion of carcass weight, no interactions among treatments were found. In general, the data suggest that nutrient density within the range tested in this study did not have a major effect on carcass composition and, in particular, no effect on the economically important breast meat yield. Previous work has indicated a reduction in carcass yield with lower nutrient density rations (Campbell et al., 1988; Holsheimer and Veerkamp, 1992; Holsheimer and Ruesink, 1993). It should be remembered that in the current study the diets were formulated on the basis of the ideal protein concept, and amino acid intake per bird was kept similar regardless of the dietary nutrient density treatment. When diets are ideally balanced for amino acids, the performance of the animal is expected to be optimized (Emmert and Baker, 1997). It is possible that the approach of maintaining amino acid intake maintained protein deposition in the carcass. Feeding mash had no impact on carcass yield but did negatively affect breast meat deposition while increasing the proportions of the drums and wings, which are considered less valuable carcass components in the North American market. Hence, the findings draw attention to the need to consider not only the reduced growth rate of mash-fed birds but also the impact on carcass yield. Shorter day lengths (12L:12D) reduced both the carcass yield and the proportion of breast meat in comparison with longer day lengths. Others have reported a decrease in breast meat yield with increased dark exposure (Renden et al., 1992). Reductions in these economically important response criteria must be counterbalanced against the beneficial effects of shorter day lengths on mortality and feed efficiency when deciding on an appropriate day length. Carcass comparisons between males and females revealed that females had a higher carcass yield and increased proportional breast meat deposition, and at the same time, the percentage of drum increased. These results are similar to the findings of other researchers (Jones and Wiseman, 1985; Campbell et al., 1988).

In conclusion, dietary nutrient density, feed form, and lighting programs act independently and in an interactive fashion to influence broiler productivity and carcass characteristics. Broilers fed pellet rations had similar live weights and carcass yields regardless of nutrient density, so any of the nutrient densities in pellet form can be used in production without affecting market age and carcass yields. Broilers fed mash had lower BW and reduced carcass yields, and the effect was more pronounced with a low-density mash ration. Growth rate and breast meat yield were improved with 20L:4D; however, 20L:4D was associated with a reduction in feed efficiency and an elevation in mortality. Production decisions must therefore be based on consideration of these nutritional and management factors to obtain the desired level of productivity and yield.

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