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Influence of Lighting Schedule and Nutrient Density in Broiler Chickens: Effect on Growth Performance, Carcass Traits and Meat Quality

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ABSTRACT : The study was conducted to evaluate the effect of lighting schedule and nutrient density on growth performance, carcass traits and meat quality of broiler chickens. A total of 576 day old Arbor Acre male chickens was used with a 4×2 factorial arrangement. The four lighting schedules were continuous (23 L:1 D, CL), 20 L:4 D (12 L:2 D:8 L:2 D), 16 L:8 D (12 L:3 D:2 L:3 D: 2 L:2 D) and 12 L:12 D (9 L:3 D:1 L:3 D:1 L:3 D:1 L:3 D) and provided by incandescent bulbs. The two nutrient densities were high (H, starter diet: 13.39 MJ/kg apparent metabolisable energy (AME), 23.00% crude protein (CP); finisher diet: 13.39 MJ AME/kg, 19.70% CP) and low energy and protein level (L, starter diet: 12.03 MJ AME/kg, 20.80% CP; finisher diet: 12.14 MJ AME/kg, 18.30% CP). Houses with dark curtains and solid sidewalls were used. Chickens were randomly allocated to the 8 treatments with each treatment comprising 6 replicates of 12 chickens. Feed and water were available *ad libitum*. Lighting schedules showed no difference ($p>0.05$) in growth performance at the end of the experiment. 12 L:12 D significantly reduced ($p<0.05$) the concentration of malondialdehyde (MDA) compared to 23 L:1 D treatment. Intermittent lighting (IL) schedules produced higher protein content ($p<0.001$) in breast meat. Birds on high density diets had higher body weight (BW), feed intake (FI) ($p<0.001$), and feed conversion ratio (FCR) ($p<0.001$) throughout the experiment with the exception of 36 to 42 d. High nutrient density increased ($p<0.05$) abdominal fat, decreased ($p<0.05$) the moisture loss of meat, and reduced percentage of wings and legs. There was a significant lighting schedule×diet interaction ($p<0.001$) on FCR for days 8 to 14 and 15 to 21. Results indicated that IL can give similar growth performance in comparison with CL, meanwhile with positive effects on meat quality by increasing protein content and decreasing the concentration of MDA. High nutrient density resulted in greater growth performance. (**Key Words :** Broiler, Lighting, Nutrition, Performance, Carcass Trait, Meat Quality)

INTRODUCTION

Broiler chickens have usually been kept on a continuous or nearly continuous lighting (23 L:1 D, CL) schedule so as to maximize feed intake and growth rate (Campo and Davila, 2002). Several undesirable traits, however, including increased fat deposition, higher incidence of metabolic diseases, skeletal deformities, and circulatory problems can become quite prevalent for birds reared under a continuous lighting schedule (Buys et al., 1998; Kristensen et al., 2006; Olanrewaju et al., 2006). Different types of lighting programs such as intermittent (John et al., 1993; Rahimi et al., 2005; Onbasilar et al., 2007), increasing photoperiods (Blair et al., 1993; Renema and Robinson, 2001) and a wide range of light intensities (Yahav et al., 2000; Lien et al., 2007; Blatchford et al., 2009) have been tested during the last 5 decades. Some researchers observed that an intermittent lighting (IL) schedule significantly increased growth rate (Classen and Riddell, 1989; John et al., 1993; Buyse et al., 1996) and feed conversion ratio (FCR) of broilers (Apeldoorn et al., 1999; Ohtani and Leeson, 2000; Rahimi et al., 2005), whereas others indicated that photoperiod treatments had no effect on performance (Renden et al., 1996; Lien et al., 2007; Archer et al., 2009) or that IL reduced the FCR (Onbasilar et al., 2007) of chickens. Most research on effects of lighting schedule on carcass traits showed that there was no difference between IL and CL in the percentages of abdominal fat, wings, thighs and breast muscle (Renden et al., 1996; Chen et al., 2007; Onbasilar et al., 2007), whereas Malone et al. (1980) and Rahimi et al. (2005) reported that an intermittent lighting schedule significantly reduced abdominal fat ratio. Few reports have appeared, however, of the effect of IL on meat quality of

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broilers. Most of the above studies used short light-dark cycles (such as 1 L:3 D), which did not make full use of natural light. There was also a need to avoid natural light when the dark period was required, especially in houses with side wall curtains where natural light can leak into the shed.

High nutrient density diets can increase feed cost (Kamran et al., 2008), nitrogen excretion (Bregendahl et al., 2002) and fat deposition (Nahashon et al., 2005) as well as the incidence of metabolic disorders and leg abnormalities (Julian, 1998) in broiler production. Manipulation of nutrient density has been shown to affect growth performance and carcass quality. Most research found that feeding a high nutrient density diet increased body weight, decreased FCR (Leeson and Zubair, 1997; Tesseraud et al., 2003; Nahashon et al., 2005; Fan et al., 2008), and produced greater carcass (Nahashon et al., 2005; Brickett et al., 2007) and higher abdominal fat weight (Leeson and Zubair, 1997; Sikur et al., 2004; Fan et al., 2008) of birds compared with a low nutrient density diet. Others reported that a low nutrient density diet resulted in a poorer feed efficiency (Wu et al., 2007; Fanatico et al., 2008; Kamran et al., 2008) and no effect on carcass yield, breast meat yield, thigh yield and abdominal fat (Kamran et al., 2008). Only one study on the effect of nutrient density on meat quality reported that a high density diet led to a higher fat content and lower dry matter, ash and protein content and cooking loss of meat than for birds on a low density diet (Fanatico et al., 2007). MDA, as a lipid peroxidation index, is one of the major causes of quality deterioration in meat, and products made from the meat of such birds cause an increased risk of cardio-vascular diseases in humans (Karamouz, 2009), but few related studies had been done.

A small percentage of reports has focused on the interaction of lighting schedule and protein or energy levels on growth performance in broilers. Buys et al. (1998) reported that there was a significant lighting schedule by protein interaction on body weight, but Keshavarz (1998) did not observed such interaction. Few studies have been done to examine the effect of lighting schedule by nutrient density interaction on carcass traits and meat quality in broiler chickens.

Therefore, the objective of the present experiment was to evaluate the effect of four lighting programs and two nutrient density diets on growth performance, carcass traits and meat quality in broiler chickens.

MATERIALS AND METHODS

Animals and experimental design

A group of 576 day-old Arbor Acre male broiler chickens from a commercial hatchery (Lanzhou, China) were weighed, wing-banded and randomly assigned to eight experimental treatments, comprising a 4×2 factorial arrangement of light treatments and diets. Each treatment comprised six replicates of 12 chicks. The four light treatments were as follows: 23 h light (L):1 h dark (D); 12 L:2 D:8 L:2 D (20 L:4 D); 12 L:3 D:2 L:3 D:2 L:2 D (16 L: 8 D); 9 L:3 D:1 L:3 D:1 L:3 D:1 L:3 D (12 L:12 D). The two nutrient densities were high (H, starter diet: 13.39 MJ AME/kg, 23.00% CP; finisher diet: 13.39 MJ AME/kg, 19.70% CP) and low (L, starter diet: 12.03 MJ AME/kg, 20.80% CP; finisher diet: 12.14 MJ AME/kg, 18.30% CP) energy and protein level. The corn-soybean meal diets (Table 1) were formulated to meet the requirements for starter and finisher broilers of the experiment. Diets were provided in powder form.

Housing and management

A big room (12.6 m×7.6 m×3.0 m) was divided into four environmentally independent parts (3.15 m×7.6 m×3.0 m) with black-out cloth to ensure that the light treatments could not influence each other. Walls and ceilings in the rooms were painted white to ensure light intensity. Using black-out cloth on the surface of the windows provided darkness. In each part, 12 cages (1.3 m×0.78 m×0.58 m) were installed in a three tier battery system, six cages for high density and six for low density, two of which were located at three different tiers. Effect of location had been considered. Advantages of cage-rearing include better utilization of heated space, mechanization, no need for expensive litter, and reduced contact with feces. Broilers have been reared in cages without reductions in body weight at the time of slaughter (Hypes et al., 1994). The room was provided with electric heaters with thermostats to adjust the environmental temperature according to the age of the birds. Temperature was set initially at 33°C and gradually reduced by 1°C/2 d until 22°C was reached. Illumination was provided by 15-W incandescent bulbs (There has recently been a trend towards the use of fluorescent bulbs or high pressure sodium discharge lights because of their longer life and lower running costs). Automatic timers were used for intermittent lighting. All birds were provided with 23 L:1 D from 0 to 3 d of age. Lighting regimes were initiated at 4 d of age. Intensity of the light at feeder trough (1.3 m×0.15 m, feeder barrels were used before 3 wk of age) level was 7.81±3.11 lux from 0 to 21 days and 7.26±3.49 lux from 22 to 42 days. Light intensity was measured with the photoreceptor sensor of a light meter (Model: ZDS-100W; Shanghai Jiading Xuelian Meter Factory, China). The intermittent cycle started at 6 am. Feed and water (each cage contained two nipple drinkers, bell-type drinkers were used before 3 wk of age) were available *ad libitum* during the experiment.

Table 1. Ingredient and nutrient composition of diets[1]

Ingredients (%)	High nutrient density		Low nutrient density	
	Starter	Finisher	Starter	Finisher
Corn	45.77	53.76	59.40	64.90
Soybean meal	37.02	34.10	33.36	31.70
Rapeseed oil	7.00	6.15	0	0
Fish meal	7.00	3.00	3.90	0
Limestone	0.69	1.07	1.14	1.11
Calcium phosphate	1.54	0.99	1.18	1.31
NaCl	0.30	0.30	0.30	0.30
Methionine	0.08	0.03	0.12	0.08
Premix[2]	0.50	0.50	0.50	0.50
Choline chloride	0.10	0.10	0.10	0.10
Composition calculated (%)				
AME, MJ/kg	13.39	13.39	12.03	12.14
Crude protein[3]	23.00	19.70	20.80	18.30
Non-phytate phosphorus	0.45	0.35	0.45	0.35
Calcium	1.00	0.90	1.00	0.90

[1] Ingredient and nutrient composition reported on an as-fed basis.
[2] Supplied per kilogram of diet: Mn ($MnSO_4 \cdot H_2O$), 110 mg; Fe ($FeSO_4 \cdot H_2O$), 120 mg; Zn ($ZnSO_4 \cdot H_2O$), 90 mg; Cu ($CuSO_4 \cdot 5H_2O$), 8 mg; I (KI), 0.55 mg; Se ($NaSe0_3$), 0.26 mg. Retinol acetate, 14,000 IU; cholecalciferol, 2,800 IU; tocopherol, 23.80 IU; menadione, 1.96 mg; thiamin, 2.24 mg; riboflavin, 8.40 mg; pyridoxol, 4.76 mg; pantothenic acid, 11.20 mg; folic acid, 1.12 mg; niacin, 44.80 mg; biotin, 0.056 mg; cyanocobalamine, 0.056 mg.
[3] Analyzed.

All chickens were vaccinated for Marek's disease, Newcastle disease and infectious bronchitis. Housing ventilation was provided by electric exhaust fans. Four rooms were designed to provide identical conditions, except that lighting schedules were changed. Metabolic disorders and dead chickens were recorded daily.

Measurements

Growth performance : Feed consumption was recorded daily on a per-cage basis. The residual feed was collected once daily before the morning feeding. Body weight of birds was measured individually on a weekly basis. Feed/gain was calculated by cage at 7, 14, 21, 28, 35, and 42 d. In addition, feed consumed by birds that were culled from the trial was included but their growth was not.

Carcass traits : At 42 d of age, 1 chicken from each replicate was randomly selected and slaughtered after 12 h starvation, immersed in 60°C water for 2 min, and plucked in a rotary drum. The carcass was eviscerated manually by cutting around the vent to remove all of the viscera including the kidneys. Carcasses were weighed. Abdominal fat consisted of fat surrounding the gizzard and proventriculus (NY/T 823-2004, China). Each carcass was cut into its component parts: breast muscle, legs, leg muscle and wings. All weights were recorded to the nearest 0.1 g. Yields were calculated as a percentage of carcass weight.

Meat quality : Meat quality analysis was carried out on *pectoralis major* muscles. The pH value was measured 45 min post-mortem in the right *pectoralis major* with a portable pH meter (Model: PHB-4; Shanghai Precision & Scientific Instruments Co. Ltd., China) equipped with an insertion glass electrode calibrated in standard buffers at pH 4.00 and 6.86 at ambient temperature. Moisture loss rate was estimated as follows: A raw meat sample weighing about 10 g was placed between 18 pieces of 11-cm-diameter filter paper and pressed at 35 kg for 5 min (Wierbicki and Deatherage, 1958). Expressed juice was defined as the loss in weight after pressing and presented as a percentage of the initial weight of the original sample (Bouton et al., 1971). The concentrations of malondialdehyde (MDA) in breast muscle were assayed using assay kits purchased from Nanjing Jiancheng Insititute of Bioengineering (Nanjing, Jiangsu, China) and procedures followed according to the manufacturer's instructions. Dry matter, fat and crude protein content were analyzed according to the Association of Official Analytical Chemists (1990).

Statistical analysis

The data were analyzed by a two-way analysis of variance using the general linear models (GLM) procedure of SPSS 10.0 (1995). The model included main effects of lighting schedule, nutrient density and their interaction. Cage was the experimental unit. Significance was designated as $p<0.05$. Means were compared by S-N-K multiple-range test when a significant difference was detected.

RESULTS

Growth performance

Body weight, feed intake and feed conversion ratio for the different treatments are summarized in Table 2, 3 and 4.

Body weight : Body weight of chickens reared under 16 L:8 D were initially lower ($p<0.05$) than those under 23 L: 1 D and 12 L:12 D treatments at 7 d of age. The 12 L:12 D chickens, however, were inferior ($p<0.001$) to the other three lighting schedules at 14 d and 21 d of age. Birds on

Table 2. Effect of lighting schedule and nutrient density on body weight of broilers (g)

Lighting schedule	Nutrient density	0 d	7 d	14 d	21 d	28 d	35 d	42 d
23 L:1 D	High	39	139	374	676	1,024	1,551	2,191
	Low	39	119	310	569	848	1,310	1,843
20 L:4 D	High	39	137	375	690	1,035	1,590	2,293
	Low	39	118	309	566	841	1,295	1,821
16 L:8 D	High	39	134	366	677	1,040	1,593	2,264
	Low	39	116	305	585	862	1,337	1,893
12 L:12 D	High	39	140	360	663	1,030	1,583	2,213
	Low	39	117	294	547	853	1,306	1,812
	SEM	0.2	1.5	3.7	6.1	14.2	23.2	32.4
Lighting schedule	23 L:1 D	39	129[a]	342[a]	622[a]	936	1,431	2,017
	20 L:4 D	39	128[ab]	342[a]	628[a]	938	1,442	2,057
	16 L:8 D	39	125[b]	335[a]	631[a]	951	1,465	2,078
	12 L:12 D	39	129[a]	327[b]	605[b]	942	1,445	2,012
	SEM	0.2	1.0	2.6	4.3	10.0	16.4	22.9
Nutrient density	High	39	138	369	676	1,032	1,579	2240
	Low	39	117	304	567	851	1,312	1842
	SEM	0.1	0.8	1.8	3.0	7.1	11.6	16.2
		---------- p value ----------						
Lighting schedule		0.356	0.040	<0.001	<0.001	0.717	0.530	0.140
Nutrient density		0.628	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lighting schedule×nutrient density		0.272	0.380	0.904	0.071	0.920	0.677	0.254

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

Table 3. Effect of lighting schedule and nutrient density on feed intake of broilers (g)

Lighting schedule	Nutrient density	0 to 7 d	8 to 14 d	15 to 21 d	22 to 28 d	29 to 35 d	36 to 42 d	0 to 42 d
23 L:1 D	High	133	343	543	725	1,042	1,192	3,978
	Low	122	311	505	656	943	1,100	3,637
20 L:4 D	High	131	341	572	756	1,068	1,241	4,130
	Low	121	312	502	654	941	1,102	3,670
16 L:8 D	High	127	332	573	761	1,077	1,215	4,085
	Low	118	312	506	664	923	1,157	3,701
12 L:12 D	High	125	315	557	750	1,063	1,213	4,022
	Low	117	292	504	669	926	1,133	3,640
	SEM	1.7	2.4	7.4	13.5	17.3	18.0	46.4
Lighting schedule	23 L:1 D	128[a]	327[a]	524	690	992	1,146	3,807
	20 L:4 D	126[a]	327[a]	537	705	1,005	1,172	3,900
	16 L:8 D	123[b]	322[a]	540	713	1,000	1,186	3,893
	12 L:12 D	121[b]	304[b]	530	709	994	1,173	3,831
	SEM	1.2	3.3	5.2	9.6	12.2	12.7	32.8
Nutrient density	High	129	333	561	748	1,062	1,215	4,054
	Low	120	307	504	661	933	1,123	3,662
	SEM	0.8	2.4	3.7	6.8	8.7	9.0	23.9
		---------- p value ----------						
Lighting schedule		0.001	<0.001	0.170	0.380	0.900	0.172	0.158
Nutrient density		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lighting schedule×nutrient density		0.856	0.619	0.133	0.595	0.461	0.158	0.686

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

Table 4. Effect of lighting schedule and nutrient density on feed conversion ratio (F/G) of broilers

Lighting schedule	Nutrient density	0 to 7 d	8 to 14 d	15 to 21 d	22 to 28 d	29 to 35 d	36 to 42 d	0 to 42 d
23 L:1 D	High	1.32	1.47[b]	1.80[b]	2.08	1.98	2.11	1.85
	Low	1.53	1.63[a]	1.95[a]	2.37	2.04	2.08	2.02
20 L:4 D	High	1.34	1.43[b]	1.82[b]	2.28	1.93	2.10	1.83
	Low	1.53	1.64[a]	1.95[a]	2.38	2.04	2.10	2.02
16 L:8 D	High	1.34	1.44[b]	1.85[b]	2.10	1.95	2.13	1.84
	Low	1.54	1.37[c]	1.81[b]	2.40	2.01	2.09	2.00
12 L:12 D	High	1.24	1.45[b]	1.84[b]	2.04	1.93	2.21	1.85
	Low	1.50	1.65[a]	1.99[a]	2.19	2.05	2.25	2.06
	SEM	0.022	0.019	0.023	0.056	0.039	0.049	0.021
Lighting schedule	23 L:1 D	1.42[a]	1.55[a]	1.87[ab]	2.22[ab]	2.01	2.09[b]	1.93
	20 L:4 D	1.43[a]	1.54[a]	1.88[ab]	2.33[a]	1.98	2.10[b]	1.93
	16 L:8 D	1.44[a]	1.41[b]	1.83[b]	2.25[a]	1.98	2.11[b]	1.92
	12 L:12 D	1.37[b]	1.55[a]	1.92[a]	2.11[b]	1.99	2.23[a]	1.95
	SEM	0.016	0.013	0.017	0.042	0.028	0.035	0.015
Nutrient density	High	1.31	1.45	1.82	2.13	1.94	2.14	1.84
	Low	1.52	1.57	1.93	2.33	2.03	2.13	2.02
	SEM	0.011	0.009	0.012	0.029	0.020	0.025	0.010
		p value						
Lighting schedule		0.008	<0.001	0.006	0.005	0.872	0.025	0.406
Nutrient density		<0.001	<0.001	<0.001	<0.001	0.003	0.758	<0.001
Lighting schedule×nutrient density		0.349	<0.001	<0.001	0.233	0.808	0.873	0.679

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

high density diets had a heavier body weight (p<0.001) than those on low density diets throughout the experiment. There was no difference (p>0.05) in body weight between IL and CL at 28, 35 and 42 d of age and no lighting×diet interaction (p>0.05) for the whole period.

Feed intake : Feed intake (FI) of chickens reared under 16 L:8 D and 12 L:12 D were initially lower than those under 23 L:1 D and 20 L:4 D at 1 wk (p<0.05). It was lower (p<0.05) for the 12 L:12 D schedule than for other lighting treatments from 8 to 14 d. Birds on high density diets had a higher FI (p<0.001) than those on low density diets throughout the experiment. There was no difference (p> 0.05) between IL and CL for days 15 to 21, 22 to 28, 29 to 35 and 36 to 42 and no lighting×diet interaction (p>0.05) for the whole period.

Feed conversion ratio (FCR) : FCR of chickens reared under 12 L:12 D was superior (p<0.05) to those under other lighting schedules at 1 wk and 4 wk and inferior (p<0.05) at 6 wk. The 16 L:8 D schedule presented higher FCR (p<0.001) than others from 8 to 14 d and was superior (p<0.05) for the 12 L:12 D schedule for days 15 to 21 d. Chickens fed high density diets had higher FCR (p<0.001) than on low density diets throughout the experiment with the exception of 36 to 42 d. There was a significant lighting schedule×diet interaction (p<0.001) on FCR for days 8 to14 and 15 to 21. It was higher in high density groups under 23 L:1 D, 20 L:4 D and 12 L:12 D treatments, and lower or not different under the 16 L:8 D schedule.

Carcass traits

Breast muscle percentage of chickens reared under 12 L:12 D was significantly lower (p<0.05) than under 23 L:1 D and 16 L:8 D schedules (Table 5). Low density diet reduced (p<0.001) abdominal fat percentage and increased (p<0.05) percentage of wings and legs. There was no lighting schedule×diet interaction (p>0.05).

Meat quality

The 12 L:12 D lighting schedule reduced (p<0.05) the concentrations of MDA in comparison with 23 L:1 D (Table 6). Three IL schedules increased (p<0.001) meat protein of chickens. The low density diet increased (p<0.05) moisture loss of meat. There were no differences (p>0.05) in pH value and fat content of meat and no lighting schedule×diet interaction.

DISCUSSION

Research on intermittent lighting has been extensive but complicated by a wide variety of light-dark cycles and management system. Most research focused on short light-dark cycles gained more superior performance (Malone et al., 1980; Buyse et al., 1996; Rahimi et al., 2005). The present experiment was designed to make full use of

Table 5. Effect of lighting schedule and nutrient density on carcass traits of broilers (%)

Lighting schedule	Nutrient density	Dressed percentage	Half-eviseerated yield	eviseerated yield	Breast muscle	Leg muscle	Abdominal fat	Wings	Legs
23 L:1 D	High	90.30	83.63	70.31	24.51	20.27	2.90	11.11	29.64
	Low	89.96	83.44	69.97	23.74	21.39	1.30	11.58	30.84
20 L:4 D	High	90.02	83.69	70.27	23.17	20.53	2.88	11.33	29.13
	Low	90.59	83.73	70.03	23.69	20.59	1.72	11.90	30.26
16 L:8 D	High	90.79	84.15	70.52	24.10	20.05	2.72	11.09	29.36
	Low	89.28	82.75	67.83	23.61	20.91	1.76	12.01	30.48
12 L:12 D	High	89.72	83.12	69.80	21.61	19.39	2.70	11.55	29.13
	Low	89.40	82.62	68.82	22.67	20.67	2.00	11.48	29.95
	SEM	0.492	0.466	0.746	0.686	0.725	0.218	0.240	0.679
Lighting schedule	23 L:1 D	90.13	83.54	70.14	24.12[a]	20.83	2.10	11.34	30.24
	20 L:4 D	90.31	83.71	70.15	23.43[ab]	20.56	2.30	11.61	29.69
	16 L:8 D	90.04	83.45	69.17	23.85[a]	20.48	2.24	11.55	29.92
	12 L:12 D	89.56	82.87	69.31	22.14[b]	20.03	2.35	11.51	29.54
	SEM	0.348	0.329	0.528	0.485	0.512	0.154	0.170	0.480
Nutrient density	High	90.21	83.65	70.22	23.35	20.06	2.80	11.27	29.31
	Low	89.81	83.14	69.16	23.43	20.89	1.70	11.74	30.38
	SEM	0.246	0.233	0.373	0.343	0.362	0.109	0.120	0.339
		---------- p value----------							
Lighting schedule		0.479	0.311	0.407	0.031	0.742	0.697	0.716	0.753
Nutrient density		0.263	0.127	0.051	0.867	0.113	<0.001	0.009	0.032
Lighting schedule×nutrient density		0.229	0.433	0.339	0.514	0.838	0.223	0.238	0.993

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

daylight. Several different short light-dark intermittent lighting schedules were designed from the point of view that chicks would consume all the feed they desired within 1 h, and empty their crops sufficiently to eat again after 3 h (Barott and Pringle, 1951).

In the present study, body weight of chickens reared

Table 6. Effect of lighting schedule and nutrient density on meat quality of broilers

Lighting schedule	Nutrient density	pH	Moisture loss (%)	MDA (nmol/mg prot)	Dry matter (%)	Meat fat (%)	Meat protein (%)
23 L:1 D	High	6.35	9.65	7.42	24.85	2.46	23.99
	Low	6.20	18.13	6.03	24.33	2.34	23.85
20 L:4 D	High	6.26	10.89	4.25	25.12	2.30	24.14
	Low	6.42	11.96	4.87	24.41	2.55	24.39
16 L:8 D	High	6.58	13.33	4.60	24.79	2.80	24.41
	Low	6.42	17.07	4.55	24.77	2.56	24.51
12 L:12 D	High	6.85	8.12	3.02	24.76	2.66	24.51
	Low	6.57	11.08	3.11	24.07	2.47	24.67
	SEM	0.374	2.335	1.255	0.362	0.240	0.106
Lighting schedule	23 L:1 D	6.28	13.89	6.73[a]	24.59	2.40	23.92[c]
	20 L:4 D	6.34	11.42	4.56[ab]	24.76	2.43	24.27[b]
	16 L:8 D	6.50	15.20	4.57[ab]	24.78	2.68	24.46[ab]
	12 L:12 D	6.71	9.60	3.07[b]	24.42	2.56	24.59[a]
	SEM	0.264	1.651	0.888	0.256	0.170	0.075
Nutrient density	High	6.51	10.50	4.82	24.88	2.56	24.26
	Low	6.40	14.56	4.64	24.40	2.48	24.36
SEM		0.187	1.168	0.628	0.181	0.120	0.053
		---------- p value ----------					
Lighting schedule		0.541	0.092	0.048	0.723	0.643	<0.001
Nutrient density		0.160	0.018	0.839	0.067	0.651	0.234
Lighting schedule×nutrient density		0.126	0.444	0.875	0.758	0.736	0.316

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

under 16 L:8 D was lower at 7 d of age while chickens under 12 L:12 D presented inferior body weight at 14 d and 21 d of age. This was the result of decreasing the feeding time and feed intake (Buyse et al., 1996; Buys et al., 1998; Ohtani and Leeson, 2000). Subsequently, chickens reared under IL manifested catch-up growth. From 28 d post-hatching to the end of the experiment, there was no difference in weight of chickens for the four lighting treatments. The results showed that an intermittent lighting schedule was more beneficial to broiler production by saving electricity. Previous studies obtained similar results (Buyse et al., 1996; Hassanzadeh et al., 2000; Lien et al., 2007). For days 0 to 42, FCR was not different among the four lighting schedules and was the result of no difference for body weight and feed intake. These observations are similar to reports by Buckland et al. (1976) and Ohtani and Leeson (2000), whereas other researchers showed that IL can increase FCR of broiler chickens (Apeldoorn et al., 1999; Rahimi et al., 2005; Canan Bölükbas and Hakki Emsen, 2006). Of special mention is that most researchers used a floor-based system in their trials. Ketelaars et al. (1986) used a 3-tier battery system and indicated that the IL group tended to grow faster and to consume more feed, and the ratio of feed intake to weight gain was consistently lower. It is notable that the light-dark cycle in the studies showing improved FCR was shorter than in those studies which showed no effect. So it can be concluded that the FCR of chickens is associated with length of the light-dark cycle.

Dietary nutrient density is one of several nutritional factors that has a significant impact on the growth and health of broiler chickens. In the present study, heavier body weight of chickens fed on high nutrient density diets was the result of higher FI. The superior FCR was due to the degree of increase for body weight being greater than that for feed intake. Sikur et al. (2004), Fanatico et al. (2008) and Wu et al. (2007) reported similar results. It can be concluded that, within a certain range of nutrient density, increasing FI can induce the body weight to increase with increasing nutrient density, although animals have the ability to regulate feed intake based on the dilution of nutrient density (Kamran et al., 2008).

Abdominal fat weight is a reliable predictor of total fat weight and permits estimation of lean carcass (Cave, 1981). Fat deposition was considered to be, at least partially, responsible for feed conversion rate and actual feed intake (Buyse et al., 1996). In the current study, there was no difference for BW, FI and FCR between IL and CL through 0 to 42 d. So lighting schedule showed no effect on abdominal fat weight. Renden et al. (1996) and Chen *et al*. (2007) obtained similar results, whereas Buyse et al. (1996) and Rahimi et al. (2005) reported that an IL program significantly reduced abdominal fat weight of chickens and Ohtani and Leeson (2000) found that IL increased the weight of abdominal fat of chickens. In the present study, the greater abdominal fat of chickens in high density diet groups was the result of deposition of excess abdominal or carcass fat because of the increased dietary energy (Kamran et al., 2008). These results were similar to other findings (Sikur et al., 2004; Fan et al., 2008).

Breast muscle percentage of chickens reared under 12 L : 12 D was lower in this study and might be the result of decreasing duration of feed consumption and the birds not being able to achieve growth potential (Brickett et al., 2007). Chen et al. (2007) indicated that there were no differences among lighting treatments (17 L:7 D, 15 L:9 D, 13 L:11 D, 11 L:11 D) in breast muscle percentage. The higher ratio of wings and legs observed on the low density diet might be attributable to the birds being more active during the light phase (Balog et al., 1997), and the wings and legs gaining more exercise to a certain degree.

The extent of lipid peroxidation can be monitored by MDA levels (Long and Kramer, 2003). In the present study, we observed that the photoperiod of 12 L:12 D reduced MDA concentration by 54.35% in breast meat compared with 23 L:1 D treatment. Another two IL treatments showed 32.24% and 32.10% reduction although there was no significant difference. This may be the result of increased secretion of melatonin. Brennan et al. (2002) reported that melatonin was secreted during darkness by the pineal gland and melatonin could efficiently restrict excessive release of oxygen-free radicals (He, 2002).

Intermittent lighting was found to enhance protein content of breast meat in 6-wk-old broiler chickens when compared with CL. This may have occurred because IL promoted the retention of nitrogen (Buyse et al., 1996). Little research had been done to evaluate the effect of lighting schedule and nutrient density on moisture loss. Our results showed that high nutrient density decreased the moisture loss of meat. These results are similar to those of Fanatico et al. (2007) which indicated that a high density diet led to a higher dry matter and superior water-holding capacity than the low density diet.

It was noticeable that a lighting schedule by diet interaction was observed for FCR from days 8 to 14 and 15 to 21. Under 23 L:1 D, 20 L:4 D and 12 L:12 D treatments, high nutrient density increased FCR, but failed to increase it under 16 L:8 D. Related reports are rare and further study is required to define the interaction.

In addition, six birds were found with leg abnormalities, four of which were less than 7 d of age and the other two (one at 2 wk and the other at 6 wk) were in the high density 20 L:4 D group and the low density 16 L:8 D group. Two chickens died, both before 7 d of age. The abnormalities and mortalities before 7 d of age mostly occurred among

chickens that appeared weak upon arrival from the hatchery, so were unlikely to be related to the treatments.

In conclusion, chickens under four different lighting schedules produced similar growth performance at the end of the periods. Three IL schedules increased meat protein of chickens. 12 L:12 D schedule decreased the breast muscle ratio and concentrations of MDA. High nutrient density diets resulted in greater performance and lower moisture loss of meat. Low density diets increased wings and legs percentage and reduced abdominal fat rate. Lighting schedule and nutrient density had some interactive effects on broilers. Further study is needed to define the effect and the mechanism of lighting on performance, carcass traits and meat quality and the mechanism of lighting schedule by nutrient density interaction.

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