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Effect of Various Monochromatic LED Light Colors on Performance, Blood Properties, Bone Mineral Density, and Meat Fatty Acid Composition of Ducks

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Two experiments determined the effects of various monochromatic light emitting diode (LED) light colors on performance, blood properties, bone mineral density, meat quality properties, and fatty acid composition of ducks. In Experiment 1, 720 1-d-old Cherry Valley ducklings were divided into four light treatments (six replicate pens/treatment; 30 ducks/pen) and were assigned to 1) yellow (Y), 2) green (G), 3) blue (B), or 4) control white (fluorescent lamps). In Experiment 2, six LED light treatments with four replicates were assigned as blue (PB), bright blue (BB), sky blue (SB), greenish blue (GB), green (PG), and fluorescent white as a control treatment. In Experiment 1, G light increased body weight and weight gain compared with the control and Y light during the first 21 d. During d 22–42, weight gain increased in the G and B treatments ($P<0.034$). Body weight and weight gain were increased under the G light treatment ($P<0.036$) in Experiment 2. Blood values were not influenced by the light treatments but serum cholesterol level decreased under the PB treatment ($P<0.015$) compared to PG treatment. Whole blood viscosity at a shear rate of 1 per second decreased significantly under the PG treatment than that of control W treatment. Ducks reared under GB and PG light had increased monounsaturated fatty acids and unsaturated fatty acids/saturated fatty acids by altering the fatty acid composition in muscle. These results suggest that monochromatic PG and GB light color increased growth performance, blood properties, and muscular fatty acid composition, while providing similar bone and meat properties in Cherry Valley ducks.

Key words: blood composition, ducks, LED light color, meat quality, performance

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Introduction

Many avian species are wavelength sensitive and respond to different light color by stimulating the nerve. The eye (retina), the penial gland, and the deep brain tissue are the three major sites have been shown to contain photoreceptors (Rathinam and Kuenzel, 2005). Retinal cone cells contain five types of colored oil droplets that filter light and pass the signal to photoreactive pigments (Bowmaker and Knowles, 1977) and respond maximally to violet, blue, green, and yellow (Dartnall *et al*., 1983). The oil droplets also seem to enhance color discrimination by reducing overlap in cone sensitivity (Vorobyev, 2003). Therefore, in modern poultry industry, it is pointed out that long wavelength acts as a sexually stimulant (Hassan *et al*., 2013; Kim *et al*., 2012) and short wavelength enhances growth (Hassan *et al*., 2014; Kim *et al*., 2013; Cao *et al*., 2012) and immunity via sympathetic and parasympathetic nerve stimulation (Klinghardt, 2003). This nerve stimulation plays pivotal roles and regulates many physiological functions and therefore may offer exciting new alternatives to enhance poultry production. These alternative techniques may be important in Korea where birds are reared in indoor housing system, and these indoor houses are usually lit with an artificial lighting systems and that light is very different from natural light. Therefore, light wavelengths or color is one of the most important aspects and little is known how ducks respond to different light color and which light color(s) enhance duck performance.

Several researchers have used light emitting diode (LED) light color but focused on laying hens (Hassan *et al*., 2013; Kim *et al*., 2012) and broilers (Kim *et al*., 2013; Cao *et al*.,

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2012), whereas little is known about duck performance under LED light colors. Ducks are a poultry species but as waterfowl their digestive physiology, body composition and growth rate, and visual perception are different from those of chickens (Rahman *et al*., 2007; Siregar and Farrell, 1980). It has been generally assumed that light color does not need to be changed between poultry species and that light color from broilers could be used for ducks. But, the effects of light color to performance and physiology that alter blood properties are not well established. Therefore, the relation between light color and the performance is still an important issue. However, Martin (1993) reported that duck vision is based on lenticular (lens) mechanisms and that there are differences in retinal ganglion cell number between ducks and chickens (Rahman *et al*., 2007).

Our previous studies conducted on broilers chicks found that green (G), blue (B), and G×B light colors enhance performance, immunity and decrease blood cholesterol (Hassan *et al*., 2014). In our behavior observation trial, red and red–yellow light activated the bird's movement and fear responses while blue and green-blue decreased the movement and they spent more time sitting (Sultana *et al*., 2013, Prayitno *et al*., 1997) and thus impact on the welfare indicators (tibia dyschondroplasia, gait score) of broiler's (Sultana *et al*., 2016). However, we did not investigate the effect of different light colors on duck performance. Moreover, published information on the effect of monochromatic light on performance, blood properties, meat quality, and fatty acid content of ducks is very limited. Therefore, the light color that maximizes performance and improves meat quality and fatty acid composition of duck meat must be investigated. Thus, two experiments were conducted separately to identify the best light color for enhancing performance, bone, meat, and blood properties as well as meat fatty acid composition of Cherry Valley ducks.

Materials and Methods

Birds and Housing Management

A total of 720 1-day-old mixed sex Cherry Valley ducklings were purchased from a local hatchery, weighed, and placed in 24 lightproof pens (four light treatment×six replicate pens in Experiment 1 and six light treatments×four replicate pens in Experiment 2). Each pen contained 30 birds. The average initial body weight of the ducklings in each treatment was the same. Ducklings were housed in separate lightproof floor pens (5 m^2) with an initial stocking density of 6 birds/m^2 and were equipped with a ventilation fan in the roof of the central arena that circulated fresh air inside the pen.

The room temperature was maintained at 31℃ for the first week and was reduced by 2−3℃ per week until it reached 18℃, which was maintained until the end of the experiment. Mean relative humidity was maintained at 60−65% throughout the experiment. The ducks were reared during two growing phases, i.e., 0−21 and 22−42-d-of-age, with two diets containing 21% crude protein (CP) and 2950 kcal/kg metabolizable energy (ME) for d 1−21 and 18% CP and 3050 kcal/kg for the 22−42 d growing period, respectively. The commercial pellet diets were formulated as per the Korean Feeding Standards for Poultry (2007). All other protocols were as described by Hassan *et al*. (2014). All management of ducks and experimental procedures were conducted in accordance with the Institutional Animal Care and Use Committee at Chonbuk National University, Korea.

Experiment 1

A total of 720 1-d-old mixed sex Cherry Valley ducklings were equalized for mean body weight (mean weight, 56.54± 0.49 g) and divided into four lighting treatments with six replications each.

The light treatments were 1) yellow LED light (Y), at a peak wavelength of 595 nm, half band width of 590−600 nm, 2) Green LED light (G) at a peak wavelength of 530 nm, 3) Blue LED light (B) at a peak wavelength of 460 nm and 4) control (compact fluorescent white, 400−770 nm). According to Karakaya *et al*. (2009), light intensity was measured as W/m^2 of irradiance using a radiometer and irradiance was converted to illuminance so that average light intensity was 20±0.21 lux in each compartment, which enabled the birds to receive the same amount of light. The light plate and electric voltage was maintained as described previously by Hassan *et al*. (2014).

Pectoral Muscle Quality Determination

At the end of the experiment, 10 ducks per treatment were selected (weight close to the average bird pen) and killed by cervical dislocation, and the pectoral muscle was collected. The pH value of each pectoral muscle sample was determined using a digital pH meter (Seven Easy pH, Mettler-Toledo AG, Schwerzenbach, Switzerland). All other protocol was maintained following Hassan *et al*. (2014) and cooking loss was determined.

At deboning, a core sample (25×50 mm) was excised from the cranial end of the pectoralis major fillet, and initial weight was recorded. The sample was suspended on cheese cloth at 4℃ in a sealed plastic container and reweighed at 48 h PM. Drip loss is expressed as a percentage of the initial weight of the sample.

Ten pectoral muscle samples from each treatment were cut in cylindrical shapes (1.0×1.0×1.0 cm) and the average of each shearing value per treatment was determined according to Hassan *et al*. (2014) and expressed as kg/cm^2.

CIE L* (lightness), a* (redness), and b* (yellowness) color space values were obtained for pectoral muscle samples collected at 6 weeks of growth using a Minolta colorimeter (Minolta Chroma Meter CR-300; Ramsey, NJ, USA) and determined using the previous protocol (Hassan *et al*., 2014).

Blood Properties and Bone Mineral Density (BMD)

At the end of the experiment (6 weeks) and after a 12 h fast, 10 blood samples per treatment were taken by puncturing the wing vein, and serum was collected and stored at −70℃ until analysis. Biochemical blood parameters, including glucose (GLU, mg/dL), total protein (TP, g/dL), albumin (ALB, g/dL), total cholesterol (CHOL, mg/dL), triglycerides (TG, mg/dL), high density lipoprotein (HDL, mg/dL), aspartate aminotransferase (AST, U/I), and alanine

aminotransferase (ALT, U/I) concentrations were measured following the protocol of Hassan *et al*. (2014). At 6-weeks-of-age, 10 ducks per treatment were killed by cervical dislocation, and the tibia was removed from the muscle and an initial longitudinal scan was performed on each tibia. From this image, the centre point of the bone was determined, and BMD was measured by bone densitometry (pDEXA, Norland Medical Systems Inc., White Plains, NY, USA).

Experiment 2

In Experiment 1, we identified that duck growth performance was enhanced with a 460−560 nm wavelength range. Therefore, Experiment 2 was designed with six specific light wavelength treatments, including blue (PB, 430−440 nm), bright blue (BB, 460−470 nm), sky blue (SB, 480−490 nm), greenish blue (GB 500−510 nm), green (PG, 530−540), and white (W) with four replications each. The LED light plate and using system was used as described previously by Hassan *et al*. (2014). The six different LED light sources with a constant light intensity of 20 lux were applied to each group according to an identical light schedule (24L:0D from 0−4 d, 22L:2D from 5−10 d, 20L:4D from 11−17 d and 18L:6D from 18−42-d-of-age). A total of, 720 1-d-old mixed sexed Cherry Valley ducklings were purchased from a local hatchery. On arrival, the birds were equalized for weight (mean weight, 56.3±0.15 g) and randomly assigned to one of six treatments with four replicates of 30 ducklings each based on a completely randomized design. All other procedures were as described for Experiment 1. Blood, meat, and bone samples were collected and analyzed using the procedures described for Experiment 1.

Blood Properties

At 21 and 42-d-of-age three birds from each pen with a weight close to the average bird pen weight were chosen, leg banded, and blood samples were collected from the brachial vein and centrifuged to obtain serum. Similarly, the same leg banded ducks were identified at 42-d-of-age, and blood samples were collected in syringes containing heparin. The blood was allowed to clot for 2 h at room temperature and was centrifuged at 400×g for 8 min at 4℃. Sera were collected and stored at 4℃ for 4 h and then stored at −70℃ until analyses were conducted using a Konelab 20 analyzer (Thermo Fisher Scientific) as described by Hassan *et al*. (2014). Whole blood viscosity (WBV) was measured using a BVD-PRO1 (Bio-Visco, Seoul, South Korea) at two specific shear rates of 1 and 300 per second. To measure hematocrit (Hct), a fresh blood sample was introduced into a heparin-coated capillary tube, the end was sealed with putty, and the tube was centrifuged (Haematocrit centrifuge, Vision Scientific Model 12000 VS, 12000 RPM for 5 min) to sediment the cells. The straw colored supernatant was the plasma, and the white blood cells were the thin buffy coat at the top of the red blood cell (RBC) column. By determining the percent of the total represented by the packed cells, the percent of RBCs in whole blood was determined.

Measurement of Fatty Acids

At the end of the experiment, 10 ducks per treatment were randomly selected and killed, and pectoral muscle samples were collected, ground, and dried in a freeze dryer. A 0.5 g portion of freeze-dried sample was precisely weighed in a glass tube and dissolved in 2 mL of 14% boron-trifluoride in methanol to determine fatty acid composition of the breast muscle. The methanol and the tubes were tightly sealed with Teflon-lined caps and subjected to a heating block at 80℃ for 2 h, and every 15 min the sample was vortexed.

After a 15 min cooling period at room temperature, 3 mL of distilled water was added followed by 3 mL of hexane. The tubes were shaken and centrifuged at 2000 RPM for 5 min at 4℃. An aliquot of the upper hexane phase containing 1.5 m*l* of fatty acid methyl esters (FAME) was injected into the chromatograph. Fatty acids were chromatographed as methyl esters on a 30-m fused silica column with an internal diameter of 0.25 μm. A wall coated SP-2560 column (100 m ×0.25 mm×0.2 μm film thickness, Supelco, Belafonte, PA, USA) was used. Analysis was performed on an 7683B Series Injector (Agilent Technologies, Palo Alto, CA, USA) using an Agilent 1 μl 6890N Network GC System (Agilent Technologies) gas chromatograph equipped with a flame ionization detector. Helium was used as the carrier gas and nitrogen as the make-up gas. The split ratio was 100:1. The injection port, oven, and detector temperature was 250℃. The column temperature rose in a stepwise manner from 150℃ to 240℃ at a rate of 5℃/min and was then held for 10 min. The fatty acids were identified using a FAME standard and were expressed as a percentage of total known FAME.

Statistical Analysis

All data were analyzed by one-way analysis of variance using the PROC GLM procedure in SAS 9.1 (SAS Institute, Cary, NC, USA, 2004). The treatment arrangement consisted of different light color. Light color was fixed; whereas pens were random. For BW, ADG, FI and FCR the pens (n =4) were the experimental units. For other parameters (n=10) birds were considered as the experimental unit. Whenever significant differences were found between treatments ($P \leq 0.05$), values were compared by Duncan's new multiple-range (Steel and Torrie, 1980). A P-value<0.05 was considered significant.

Results

Experiment 1

Body weight, weight gain, feed intake, and FCR after the 6-week rearing period in the ducks reared under different light colors are shown in Table 1. G light increased body weight and weight gain during the first 21 d compared to Y and control W light ($P<0.012$). During d 22−42, weight gain was maximal under the G and B treatments compared to W light ($P<0.004$). In contrast, feed intake ($P<0.654$) and FCR ($P<0.712$) were not significantly different among the light colors at either 0−3 weeks or 4−6 weeks. Variations in light color did not significantly influence blood ALB, GLU, total CHOL, TG, or HDL contents. Liver function was evaluated to measure serum enzyme AST and ALT activities. The results showed that light color did not significantly influence AST or ALT levels in duck blood. The average tibial BMD in ducks was not significantly altered by light

Table 1. **Effect of various light colors on duck performance (Experiment 1)**

Treatment	Y	G	B	W	SEM	P value
Body weight (g)						
At 21 d	1332.10[b]	1347.13[a]	1336.34[ab]	1327.22[b]	2.33	0.012
At 42 d	3267.09[b]	3310.99[a]	3306.04[a]	3253.63[b]	7.43	0.004
Weight gain (g)						
0−21 d	1275.67[b]	1290.40[a]	1279.67[ab]	1270.88[b]	2.29	0.041
22−42 d	1934.99[ab]	1963.85[a]	1969.71[a]	1926.51[b]	6.52	0.034
0−42 d	3210.67[ab]	3254.25[a]	3249.38[a]	3197.39[b]	6.97	0.037
Feed intake (g)						
0−21 d	1807.09	1811.06	1784.80	1806.16	7.77	0.654
22−42 d	4272.07	4345.72	4250.68	4229.77	18.24	0.113
0−42 d	6079.14	6156.78	6035.48	6035.93	24.76	0.814
Feed conversion ratio						
0−21 d	1.425	1.403	1.394	1.421	0.012	0.385
22−42 d	2.217	2.212	2.162	2.205	0.011	0.127
0−42 d	1.893	1.897	1.857	1.887	0.013	0.571

[1] Means of 4 replicate pens (n=30 birds per pen); SEM, standard error of mean; [a, b] values in a row with no common superscripts differ significantly ($P<0.05$); PB, pure green; BB, bright blue, SB, sky blue; GB, greenish blue; PG, pure green; W, white; Data are means of 4 pens of 30 birds each.

Table 2. **Effect of various light colors on duck performance (Experiment 2)[1]**

Treatments[2]	PB (430−440 nm)	BB (460−470 nm)	SB (480−490 nm)	GB (500−510 nm)	PG (530−540)	W (400−770 nm)	SEM	P value
Body weight (g)								
At 21 d	1222.04[a]	1202.24[ab]	1200.62[ab]	1217.09[a]	1225.03[a]	1191.30[b]	3.635	0.027
At 42 d	3230.42[ab]	3229.72[ab]	3243.51[ab]	3277.34[a]	3284.56[a]	3175.21[b]	9.996	0.036
Weight gain (g)								
0−21 d	1166.04[a]	1137.60[ab]	1139.60[ab]	1161.03[a]	1168.99[a]	1135.23[b]	3.636	0.029
22−42 d	2008.37	2036.48	2047.89	2060.25	2054.40	1983.91	13.64.8	0.589
0−42 d	3174.41[ab]	3173.65[ab]	3187.49[ab]	3221.28[a]	3228.56[a]	3119.14[b]	9.984	0.036
Feed intake (g)								
0−21 d	1673.49	1645.02	1656.79	1672.01	1639.19	1664.77	7.605	0.759
22−42 d	4542.97	4673.26	4627.13	4738.28	4756.53	4443.0	35.12	0.064
0−42 d	6216.46	6318.28	6283.92	6410.29	6397.88	6107.77	32.97	0.059
Feed conversion ratio[3]								
0−21 d	1.435	1.447	1.454	1.441	1.403	1.466	0.008	0.341
22−42 d	2.263	2.295	2.259	2.300	2.317	2.241	0.013	0.615
0−42 d	1.958	1.991	1.971	1.991	1.982	1.958	0.007	0.712

[1] Means of 4 replicate pens (n=30 birds per pen); SEM, standard error of the mean; [a, b] values in a row with no common superscripts differ significantly ($P<0.05$); Y, yellow; G, green; B, blue; W, white; [3] Corrected for mortality.

color (Table 3).

Experiment 2

Growth Performance

A similar results trend was obtained compared to Experiment 1, as feed intake decreased in the W light treated ducks in Experiment 2 (Table 2). Body weight and weight gain increased under the GB and PG light during weeks 0−3. Therefore, body weight and weight gain also increased under the GB and PG light treatment ($P<0.036$) in Experiment 2. However, no additional effect was found in weight gain among the BB, SB, and GB treatments.

Meat Quality

Meat pH, color, cooking loss, shear force and drip loss were not significantly different among the ducks reared under different light colors.

Blood Properties and BMD

The blood properties were influenced by wavelength at 6-weeks-of-age (Table 3). Serum CHOL level decreased under the PB treatment ($P<0.015$).

Muscular Fatty Acid Composition

The influence of different light colors on fatty acid composition in thigh muscle after the 6 week rearing period is shown in Table 4. The concentrations of palmitoleic acid (C16:1), and oleic acid (C18:1n9) in thigh muscle were significantly higher in ducks reared under the PG light treatment than those reared under the other light ($P<0.005$, $P<0.001$).

Table 3. **Effect of various light colors on duck blood composition at 6 weeks (Experiment 2)[1]**

Treatments[2]	PB (430−440 nm)	BB (460−470 nm)	SB (480−490 nm)	GB (500−510 nm)	PG (530−540)	W (400−770 nm)	SEM	P value
Alb (g/d*l*)	2.232	2.087	2.208	2.209	2.231	2.214	0.019	0.268
TP (g/d*l*)	6.342	5.686	6.050	5.985	6.343	6.074	0.074	0.144
Glu (mg/d*l*)	131.654	143.561	128.985	127.194	122.092	127.83	3.284	0.620
TG (mg/d*l*)	242.516	229.048	232.749	257.693	249.220	260.215	6.955	0.707
CHOL (mg/d*l*)	278.792^{b}	300.882^{ab}	317.326^{ab}	312.645^{ab}	332.970^{a}	317.137^{ab}	4.262	0.015
HDL (mg/d*l*)	134.342	134.168	140.646	138.831	151.292	135.471	2.75	0.533
LDL (mg/d*l*)	106.35	121.39	131.83	122.27	131.66	129.25	2.65	0.074
Serum enzyme activities								
AST (U/L)	16.585	15.984	15.216	16.931	17.035	17.780	0.543	0.798
ALT (U/L)	35.423	38.502	36.734	36.650	36.936	37.709	1.026	0.980
Bone mineral density								
BMD (g/cm^2)	0.206	0.219	0.213	0.205	0.219	0.213	0.002	0.344

[1] Means of 10 birds selected from each treatment group (3 birds from each of the two pens and 2 birds from another two pens); SEM, standard error of the mean; [a, b, c] values in a row with no common superscripts differ significantly ($P<0.05$); [2] PB, pure blue; BB, bright blue, SB, sky blue; GB, greenish blue; PG, pure green, W, white; ALB, albumin; TP, total protein; Glu, glucose; TG, triglycerides; CHOL, cholesterol; HDL, high density lipoprotein; LDL, low density lipoprotein; AST, aspartate aminotransferase; ALT, alanine aminotransferase; BMD, bone mineral density

Table 4. **Effect of various light colors on thigh meat fatty acid composition of ducks (Experiment 2)[1]**

Treatment	PB (430−440 nm)	BB (460−470 nm)	SB (480−490 nm)	GB (500−510 nm)	PG (530−540)	W (400−770 nm)	SEM	P value
C14:0	0.36	0.37	0.37	0.39	0.54	0.42	0.021	0.241
C14:1	2.54	2.34	2.01	1.89	1.52	2.10	0.084	0.089
C16:0	17.72	16.59	17.24	17.27	19.49	19.14	0.376	0.103
C16:1	2.07^{b}	2.52^{b}	2.12^{b}	2.54^{b}	3.26^{a}	2.51^{b}	0.101	0.005
C18:0	13.76^{a}	12.99^{ab}	12.75^{ab}	11.60^{b}	9.27^{c}	11.72^{b}	0.328	0.0004
C18:1n9	29.72^{b}	30.22^{b}	31.65^{b}	34.67^{b}	39.63^{a}	34.11^{b}	0.812	0.001
C18:1n7	2.60	2.46	2.04	2.17	2.16	2.05	0.120	0.127
C18:2	18.20	18.34	16.84	17.80	16.89	18.48	0.205	0.049
C18:3	0.20	0.13	0.201	0.15	0.17	0.16	0.013	0.678
C20:1	0.49	0.40	0.46	0.53	0.51	0.49	0.019	0.172
C20:2	0.56	0.63	0.51	0.65	0.61	0.69	0.022	0.175
C20:4	0.46	0.39	0.41	0.39	0.28	0.39	0.017	0.083
C20:3	0.67	0.65	1.09	0.68	0.45	0.47	0.17	0.063
C20:5	0.94	0.84	0.74	2.51	1.27	0.60	0.31	0.538
C22:1	9.94^{ab}	11.30^{a}	9.93^{ab}	7.55^{bc}	5.67^{c}	8.22^{bc}	0.44	0.001
C24:1	0.13^{ab}	0.09^{abc}	0.11^{abc}	0.14^{a}	0.07^{c}	0.08^{bc}	0.01	0.009
MUFA	47.21^{b}	49.25^{a}	48.32^{ab}	49.49^{a}	52.82^{a}	49.54^{a}	0.82	0.022
PUFA	20.93	20.87	19.79	22.20	19.67	20.79	0.44	0.625
UFA	68.42^{ab}	70.12^{a}	68.11^{b}	70.65^{a}	70.56^{a}	70.33^{a}	0.71	0.014
SFA	31.85^{a}	29.95^{b}	30.36^{b}	29.26^{b}	29.30^{b}	31.29^{b}	0.61	0.042
UFA/SFA	2.14^{b}	2.35^{ab}	2.24^{ab}	2.41^{a}	2.40^{a}	2.25^{ab}	0.05	0.0001

[1] Means of 10 birds selected from each treatment group (3 birds from each of the two pens and 2 birds from another two pens); SEM, standard error of the mean; [a,b,c] values in a row with no common superscripts differ significantly ($P<0.05$); PB, pure green; BB, bright blue, SB, Sky blue; GB, greenish blue; PG, pure green, W, white; monounsaturated fatty acids (MUFA): $C_{14:1}+C_{16:1}+C18_{1n9}+C_{181n7}+C_{20:1}+C_{22:1}+C_{24:1}$; PUFA: $C_{18:2}+C_{18:3}$ + $C_{20:2}+C_{20:4}+C_{20:3}+C_{20:5}$; unsaturated fatty acids (UFA): MUFA+PUFA; saturated fatty acids (SFA): $C_{14:0}+C_{16:0}+C_{18:0}$

In contrast, Stearic acid level was significantly lower in PG light treatment than in the other light treatments ($P<0.0004$). The different light colors did not have any significant effect on C18:1n7, C18:3, C20:1, C20:2, C20:3, C20:4, or C20:5 concentrations in thigh muscle. The concentration of monounsaturated fatty acids (MUFA) level was significantly higher in BB, GB, PG and W light treatments than in PB light treatment ($P<0.022$). Polyunsaturated fatty acids were not significantly influenced by light color. Furthermore, the concentration of unsaturated fatty acids (UFA) increased under the GB, PG, BB and W treatments and saturated fatty acids (SFA) increased under the PB light treatment. There-

Table 5. **Effect of various light colors on whole blood viscosity of ducks (Experiment 2)[1]**

Treatment	PB (430−440 nm)	BB (460−470 nm)	SB (480−490 nm)	GB (500−510 nm)	PG (530−540)	W (400−770 nm)	SEM	P value
At 3rd weeks of age								
Hct (%)	36.69	37.93	36.53	36.67	36.44	37.93	0.29	0.495
Whole blood viscosity (mP) under different shear rate								
300 s^{-1}	36.03	35.22	35.37	35.78	34.06	36.65	0.42	0.607
1 s^{-1}	200.15^{a}	182.32^{ab}	192.01^{ab}	190.28^{ab}	169.18^{b}	205.97^{a}	3.28	0.020
At 6th weeks of age								
Hct (%)	36.60	35.55	36.27	36.25	35.0	37.07	0.31	0.563
Whole blood viscosity (mP) under different shear rate								
300 s^{-1}	32.73^{ab}	32.25^{ab}	32.13^{ab}	33.71^{ab}	29.33^{b}	35.19^{a}	0.41	0.045
1 s^{-1}	145.36^{b}	143.43^{b}	150.13^{ab}	163.69^{ab}	140.57^{b}	190.06^{a}	3.58	0.044

[1] Means of 10 birds selected from each treatment group (3 birds from each of the two pens and 2 birds from another two pens); SEM, standard error of the mean; $^{a, b, c}$ values in a row with no common superscripts differ significantly ($P<0.05$); PB, pure green; BB, bright blue, SB, sky blue; GB, greenish blue; PG, pure green, W, white; WBV, whole blood viscosity; mP, millipoise; Hct, hematocrit

fore, UFA/SFA level was significantly higher in GB and PG light treatment than in PB light treatment ($P<0.0001$).

Blood Viscosity

The effects of light color on average Hct and whole blood viscosity (WBV) at 3- and 6-weeks-of-age are shown in Table 9. Hct was not influenced by the light treatments. WBV was dependent on shear rate and was highest under the low shear rate of 1 per second. WBV decreased significantly under the PG light treatment ($P<0.05$) compared to that of birds under W light. However, no significant differences were observed among the PB, BB, SB, GB, or PG treatments.

Discussion

The results show that different light colors affected growth, blood viscosities, and muscle fatty acids but had no effect on meat quality of ducks. We found that G light significantly increased body weight and weight gain among the light treatments during the 6 week growth period in Experiment 1. Significantly higher body weight grain was observed in birds reared under the PG light treatment at both growth phases in Experiment 2.

The results of the two Experiments were similar possibly because PG light decreased WBV and increased blood flow, which would increase delivery of oxygen and nutrition to tissues leading to increased growth (Dauchy *et al*., 2013). The weight gain observed in ducks reared under G and PG light may also indicate that G light has an effect on increased feed intake. No difference in FCR was observed but an effect on weight gain was observed, indicating increased feed intake. However, due to a lack of previous studies regarding the effect of light color on duck performance, our results were somewhat similar to our results in broilers (Hassan *et al*., 2013) when we found that G, B and G×B light color enhanced growth performance.

In experiment 1, variations in light color did not significantly influence serum GLU and total CHOL contents. But in follow up studies, birds reared under PB light had reduced serum total CHOL concentrations. It might be due to B light stimulates the anterior hypothalamus, which is the main regulatory part of the parasympathetic nervous system (Klinghardt, 2003) and, thus, stimulates bile secretion, which accounts for the majority of CHOL breakdown in the body. The present results are in agreement with our previous results on broiler chicks (Hassan *et al*., 2014) which confirmed that B light reduced serum GLU and thus decreases CHOL levels. In human studies, Naveen *et al*. (2006) observed that B light significantly reduces breathing rate and diastolic blood pressure and, thus, reduces serum GLU and CHOL concentrations.

In ducks, the most abundant fatty acid is oleic acid (C18:1n9), which improves meat palatability. Ducks reared under PG light had significantly increased oleic acid (C18:1n9). On the other hand, MUFAs, and UFA/SFA contents in thigh muscle was increased in BB, GB, PG and W light treatments in compared with PB. The possible mechanism behind this effect is unclear but PG light decreased stearic acid (C18:0) in thigh muscle; thus, desaturase activity may have converted stearic acid to oleic acid. Thereby, the ratio of UFA/SFA fatty acids increased compared with PB. There are few reports of the effects of light color on blood properties, and there are no reports on the effects of light color on muscular fatty acid composition. Therefore, observations made here reveal that CHOL concentrations in thigh muscle were positively correlated with the change in serum CHOL. Komprada *et al*. (1999) found that CHOL content and fatty acid composition of chicken tissues are influenced by growth rate. However, CHOL in breast and thigh muscles tended to decrease with increasing growth rate. It is still unclear exactly how light color alters blood properties and meat fatty acid composition. We hypothesize that stearic acid reduces CHOL absorption by altering hepatic bile acid synthesis and gallbladder bile acid composition. Therefore, further study is required to evaluate the influence of light color on bile, melatonin, and insulin secretion and the association among melatonin, bile, insulin, and fatty acid synthesis, which may provide clues to its role in fatty acid metabolism in ducks.

Blood viscosity decreased significantly at both shear rates under the PG treatment probably due to increased parasym-

pathetic activity.

Our previous results demonstrated that B and G light calm birds and reduces anxiety (Sultana *et al*., 2013), and anxiety is related with blood viscosity (Levine *et al*., 1954). The present results also indicate that G light reduced protein content in blood; thus, modifying the degree of aggregation of RBCs, which may reflect blood viscosity. These results are consistent with those of Vandewalle *et al*. (1988).

Based on two experiments, monochromatic PG and GB light color increased growth performance and blood properties, while providing similar bone and meat properties in Cherry Valley ducks. Ducks reared under PG, GB, BB and W light showed increase MUFA and GB and PG light treatment increased UFA/SFA content due to by altered muscle fatty acid composition. Moreover, blood viscosity decreased under PG light. In addition, PG light did not show any adverse effects on BMD. Therefore, these results led to the conclusion that ducks reared under PG and GB light may have improved blood CHOL and UFA/SFA ratio.

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