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Effect of digital livestock system on animal behavior and welfare, and fatty acid profiles of egg in laying hens

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ABSTRACT. Digital livestock system through convergence of livestock production and information and communication technology is being applied to livestock farms to improve animal behavior and welfare, production, and quality of animal food. In previously study, we noted that the egg production were greatly enhanced in laying hens using digital livestock system. The present study investigated effects of a digital livestock system on fatty acid profiles and cholesterol of eggs, animal behavior, and welfare of laying hens. A total of 300 laying hens (Hy-Line Brown) at 48 weeks old were divided into two treatment groups: conventional livestock system (CON) and digital livestock system (DLS) in a randomized complete block design for 10 weeks. Drinking, feather squatting, eating, moving, preening, and resting scores as behavior indicators of laying hens were significantly improved in the DLS group than in the CON group (all $P < 0.05$). Animal welfare scores such as appearance, feather condition, body condition, and health of laying hens were significantly higher in the DLS group than in the CON group ($P < 0.05$). Contents of oleic acid and unsaturated fatty acid of eggs were significantly increased in the DLS group compared to the CON group ($P < 0.05$). However, content of saturated fatty acid and n-6/n-3 fatty acid ratio of eggs of the DLS group were significantly lower than those in the CON group ($P < 0.05$). These results indicate that the digital livestock system can be used as a future livestock farming algorithm to significantly improve egg fatty acid profile, animal behavior, and welfare in laying hens.

Introduction

Digital livestock system through the convergence of animal production and Information and Communications Technology (ICT) has enabled the establishment of a climate-smart poultry production system (Goswami and Bhatt, 2017; Groher et al., 2020; Park, 2022). Digital livestock system using the convergence technology of animal farming and ICT such as big data analytics, machine learning, biometric sensors, block chain, Artificial Intelligences, Internet of Things (IOT) and drone has been developed. Digital livestock system as an application strategy for sustainable livestock production enables remote control through computer and smartphone (Mahale and Sonavane, 2016; Mansor et al., 2018; Neethirajan and Kemp, 2021; Park, 2022). This can monitor stable environments including temperature and humidity. It can remotely control supply period and amount of diet and drinking water through wireless sensor network via personal computer or a mobile device using artificialintelligence (Hitimana et al., 2018; Um et al., 2020). It can also solve various problems such as support animal welfare and health, increase farm income, and reduce environmental problems, thus enabling continuous poultry production

(Geetanjali et al., 2017; Neethirajan, 2020; Baker et al., 2022). Maintenance of animal health including laying hens is essential for animal welfare. It creates egg production and demand for high quality egg market (Zaninelli et al., 2016). It is difficult to control the whole farm with conventional poultry feeding system without automation due to labor shortage (Kim and Lee, 2015; Chen et al., 2016). Although feeding management of poultry house has been improved through automated facilities and environmental control sensors, there are a lot of difficulties in feeding management due to expansion of breeding scale (Um et al., 2020; Park, 2022). Poultry house is designed to enable modifications of environmental conditions including ventilation, cooling, heating, light, and noise. The micro-environment of the poultry house is closely correlated with the behavior, welfare, and health of animals (Corkery et al., 2013; Mahale and Sonavane, 2016). The poultry house enables environmental control including temperature, humidity, and ventilation through the enclosed feeding system. Expansion of breeding scale and increased production have been achieved (Park, 2022). Poor environment causes stress to animal, damages animal welfare, and incudces physiological and ethological responses, thus reducing poultry production (Muttha et al., 2014; Um et al., 2020).

Digital livestock system as application strategy for sustainable livestock production enables remote control through computer and smartphone, thus reducing time and labor for environmental management (including temperature, humidity, ventilation, ammonia, and carbon dioxide of laying hens) and feeding management (including tolerant tree, diet intake, egg production, and feces treatment) while promoting animal health and business management (Jones et al., 2005; Um et al., 2020; Park, 2022). Transmitted data should be received through a receiver and transmitted to General Packet Radio Service via micro-controller. Data are saved and updated on the webpage. Smart sensing platform can be used for monitoring environment variables and feeding management of poultry houses (Choukidar and Dawande, 2017; Neethirajan et al., 2020; Baker et al., 2022). Therefore, many countries have made efforts to improve the production, behavior, and welfare of layer using a digital livestock system based on such advantages. Improvement in the production of laying hens by using a digital livestock system and its mechanism has been reported in a previous study (Corkery et al., 2013; Zammit and Park, 2020; Park, 2022). The objective of this study was to determine effects of a digital livestock system on cholesterol content and n-6/n-3 fatty acid ratio of eggs as well as behavior and welfare of laying hens.

Material and methods

Animals and experimental design

The animal experiment was carried out as a scientific and ethical procedure in accordance with the laboratory animal guideline presented by the NRC (2011). A total of 300 laying hens (Hy-Line Brown) at 48 weeks old were assigned into two treatment groups: conventional livestock system (CON) and digital livestock system (DLS). These animals were allocated into six replicate cages (25 birds per replicate) of each treatment group in randomized block design.

Diet and feeding management

Diet was prepared to meet the nutrient requirement of laying hens presented by NRC (1994) (Table 1). Both groups were reared in enriched cage systems of animal welfare type (medium, 25 hens per cage) (FAWC, 2007) for 10 weeks in the research center of Warrick University. Such cage system met the EU Directive 1999/74/EC. The system design for automation of poultry house in the DLS group consisted of internal and external monitoring

Table 1. Formula and chemical composition of basal experimental diet (as-fed, %)

Ingredients	%
Yellow corn grain	53.50
Soybean oil meal (44%)	20.30
Corn gluten meal	4.13
Wheat bran	10.00
Beef tallow	1.00
Limestone	9.87
Dicalcium phosphate	0.50
Sodium chloride	0.30
DL-methionine (50%)	0.20
L-lysine hydrochloride (78%)	0.05
Mineral plus vitamin premix[1]	0.15
Chemical composition, %	
metabolic energy, mJ/kg	12.81
crude protein	17.10
lysine	0.78
methionine	0.56
methionine + cysteine	0.75
calcium	3.80
available phosphorous	0.37

[1] supplied per kg of diet: mg: Fe (ferrous sulfate) 80, zinc (zinc oxide) 80, Mn (manganese sulfate) 70, Cu (copper sulfate) 7, I (calcium iodate) 1.20, Se (sodium selenite) 0.30, Co (cobalt) 0.70, menadione 3.0, thiamin 2.5, riboflavin 5.0, pyridoxine 4.0, cyanocobalamin 0.02, niacin 44, pantothenic acid 17, folic acid 1.5, biotin 0.18; IU: vitamin A (retinyl acetate) 10 500, vitamin D_3 (cholecalciferol) 4 100, vitamin E (dl-α-tocopheryl acetate) 45

environmental management using temperature, humidity, ammonia, and carbon dioxide sensors for environmental factors, environmental safety using feed bin, drinking water, ventilation fan, heater, and cooling pad control device, load cell for checking feed intake, drinking water measurement, and water pressure sensor, feeding management for feces treatment, and business management equipment and smartphone for measuring egg production (Um et al., 2020; Park, 2022). These laying hens had free access to diet and drinking water. The environment of the poultry house in both groups was adjusted to have temperature of 20 °C to 23 °C, humidity of 60% to 70%, and light cycle of 18L:6D (18 h light:6 h dark). After applying the diet, daily egg production was recorded from the 4th week to the 10th week.

Animal behavior indicators

Animal behavior indicators were assessed in 25 animals at the 7th week and the 10th week (10:00 to 12:00 h, 14:00 to 16:00 h) after experiment began. Results are presented as frequency of occurrence. Animal behavioral indicators such as drinking, feather squatting, eating, moving, preening, and resting score were measured using a video camera (Camlife Image Recording Instruments V11.50, TianMin Products Science and Technology Development Co., Shenzhen, GD, China) as described previously (Albentosa et al., 2002; Park et al., 2018). Evaluation of animal behavior indicators was based on the scientific concept of animal behavioral traits from the UK Farm Animal Welfare Council (FAWC, 2007).

Animal welfare indicators

Animal welfare indicators were determined by randomly selecting 25 animals from each treatment group at the 7th week to the 10th week after experiment began. Animal welfare indicators included appearance, feather condition, body condition such as the comb, beak, keel bone damage, and plumage, and health score of laying hens (Sosnówka-Czajka et al., 2022). The appearance as a plumage were obtained for six different areas (neck, breast, back, wings, tail, and vent) of the body. Feather condition was defined as follows: score of 1, normal; score of 2, deterioration; score of 3, marked deterioration; score of 4, little no feather coverage; score of 5, severely damaged (Tactacan et al., 2009; Welfare Quality, 2009). Body condition as a gait score was defined as follows: 1, normal; 2, slight gait defect; 3, uneven gait; 4, obvious, moderate gait abnormality; 5, severe walking difficulties; and 6, unable to walk (Welfare Quality, 2009). Health condition as a claw score and keel bone deformation score was defined as follows: 1, normal; 2, slightly deformed, less than 10%; 3, deformed, 10% to 50%; and 4, deformed, more than 50% (Welfare Quality, 2009).

Fatty acid profiles of eggs

During the period between the 5th week and the 10th week after the experiment began eggs were collected and fatty acid compositions were analyzed. Lipid was extracted from eggs using a mixed solution of chloroform and methanol at a ratio of 2:1. Saponification was carried out using 0.5 N methanolic NaOH solution. Methyl ester was produced using BF3-methanol. Then 2 ul of supernatant was injected into a gas chromatography (GC) (model GC-15A; Shimadzu Corp., Kyoto, Japan) with a SP™-2560 Capillary GC Column (L × I.D. 100 m × 0.25 mm, df 0.20 μm Omegawax 320 capillary column; Sigma-Aldrich Co., St. Louis, MO, USA) to analyze fatty acid (Park, 2010). American-made Supelco (37 component FAME Mix; Sigma-Aldrich Co., St. Louis, MO, USA) was used as the standard reagent and nonadecanoic acid (19:0) was used as the internal standard.

Egg cholesterol

Cholesterol contents in eggs were analyzed using direct saponification gas chromatographic method (Riu et al., 2010). 5α-cholestane (Sigma Chemical Co., St, Louis, MO, USA) was used as cholesterol standard and internal standard. A gas chromatographic system (model GC-15A; Shimadzu Co., Kyoto, Japan) with a fused silica capillary column (L × I.D. 15 m × 0.32 mm) was used to analyze cholesterol content.

Statistical analysis

SPSS/Windows version 21.0 (statistical package for the social science, SPSS Inc., Chicago, IL, USA) was used for all statistical analyses of data. The replicate cage was applied as experiment unit for all data. A difference in average value was measured by one-way analysis of variance (ANOVA) and standard error for average value of the group was presented. Significant difference ($P < 0.05$) was tested at 95% confidence level by Turkey's multiple range test.

Results

Results of laying hen's behavior indicators from the digital livestock system are shown in Table 2. Drinking, feather squatting, eating, moving (walking-standing), preening, and resting scores as behavior indicators of laying hens in the DLS group were significantly improved than in the CON group (all $P < 0.05$).

Table 2. Animal behavior indicators observed for laying hens reared in digital livestock system (% frequency of occurrences)

Attribute	Experimental group		
	CON	DLS	*P*-value
Drinking	5.18 ± 0.16[b]	7.07 ± 0.21[a]	0.034
Feather squatting	8.37 ± 0.27[b]	9.31 ± 0.20[a]	0.019
Eating	27.39 ± 0.97[b]	36.28 ± 1.06[a]	0.017
Moving	18.21 ± 0.55[b]	23.83 ± 0.81[a]	0.027
Preening	2.18 ± 0.06[b]	3.76 ± 0.19[a]	0.028
Resting	38.66 ± 1.27[a]	36.03 ± 1.33[b]	0.038

CON – conventional feeding system, DLS – digital livestock system; data are presented as mean value ± SEM (standard error of the mean), n = 25; [ab] – means within a row with different superscripts are significantly different at $P < 0.05$

Animal welfare indicators (appearance, feather condition, body condition such as the comb, beak, keel bone, claw, and plumage) of laying hens were significantly higher in the DLS group in comparison with those in the CON group ($P < 0.05$; Table 3).

Table 3. Animal welfare indicators observed for laying hens reared in digital livestock system (5 scores)

Attribute	Experimental group		
	CON	DLS	*P*-value
Appearance	3.15 ± 0.16[b]	4.17 ± 0.16[a]	0.017
Feather condition	3.02 ± 0.05[b]	4.05 ± 0.13[a]	0.022
Body condition	3.18 ± 0.18[b]	4.34 ± 0.15[a]	0.033
Health	3.34 ± 0.07[b]	4.58 ± 0.15[a]	0.025

CON – conventional feeding system, DLS – digital livestock system; data are presented as mean value ± SEM (standard error of the mean), n = 25; [ab] – means within a row with different superscripts are significantly different at $P < 0.05$

Table 4. Fatty acid profiles of egg from laying hens reared in digital livestock system (% of total fatty acid)

Fatty acids	Experimental group		
	CON	DLS	*P*-value
C14:0	0.31 ± 0.007	0.33 ± 0.006	0.481
C16:0	22.80 ± 0.70[a]	20.15 ± 0.39[b]	0.031
C16:1	2.18 ± 0.08	2.72 ± 0.06	0.337
C18:0	18.12 ± 0.55[b]	16.02 ± 0.41[a]	0.023
C18:1n-9	41.52 ± 1.26[b]	46.11 ± 1.73[a]	0.028
C18:2n-6	14.05 ± 0.45[a]	13.07 ± 0.35[b]	0.031
C18:3n-3	0.67 ± 0.003[b]	1.33 ± 0.07[a]	0.027
C20:3n-3	0.01 ± 0.001[b]	0.08 ± 0.001[a]	<0.001
C20:3n-6	0.07 ± 0.02[a]	0.02 ± 0.001[b]	<0.001
C20:4n-6	0.22 ± 0.08[a]	0.11 ± 0.08[b]	0.018
C22:1n-9	0.05 ± 0.001	0.06 ± 0.001	0.518
Saturated fatty acid	41.23 ± 1.36[a]	34.59 ± 1.43[b]	0.032
Unsaturated fatty acid	58.77 ± 1.82[b]	65.41 ± 2.16[a]	0.028
n-6/n-3	21.08 ± 0.76[b]	9.36 ± 0.65[a]	0.031

CON – conventional feeding system, DLS – digital livestock system; data are presented as mean value ± SEM (standard error of the mean), n = 15; [ab] – means within a row with different superscripts are significantly different at $P < 0.05$

Contents of unsaturated fatty acid and oleic acid of eggs were siginificantly higher while contents of saturated fatty acid and the ratio of n-6/n-3 fatty acid were lower in the DLS group compared to those in the CO group ($P < 0.05$; Table 4).

Cholesterol contents of eggs in the DLS group were significantly lower than those in the CO group ($P < 0.05$; Table 5).

Table 5. Cholesterol content of egg from laying hens reared in digital livestock system

Attribute	Experimental group		
	CON	DLS	*P*-value
Egg yolk, g/60 g of egg	15.85 ± 0.40	15.67 ± 0.37	0.387
Total cholesterol, mg/g of yolk	10.01 ± 0.33[a]	8.97 ± 0.31[b]	0.025
g/60 g of egg	158.6 ± 4.46[a]	140.5 ± 3.65[b]	0.037

CON – conventional feeding system, DLS – digital livestock system; data are presented as mean value ± SEM (standard error of the mean), n = 15; [ab] – means within a row with different superscripts are significantly different at $P < 0.05$

Discussion

The improved data about animal behavior and welfare in laying hens reared under DLS group system can be considered as adaptation to the environment (Tables 2 and 3). Birds are social animals that live together in natural conditions. Laying hens can perform natural behaviors such as drinking, feather squatting, eating, moving (walking-standing), preening, resting, perching, nesting, and dustbathing by providing perch, nest, and dustbath (Albentosa and Cooper, 2004; Sözcü et al, 2022). In this study laying hens in the DLS group were found to have better behavior indicators than those in the CON group. This might be attributed to better environment and feeding management with the central control system and remote control using smart phone for laying hens in the DLS group (Mahale and Sonavane, 2016; Meseret, 2016; Hitimana et al., 2018; Park, 2022). Behavioral indices of the DLS group should be more prevalent than those of the CON group (Pickel et al., 2010; Yildirim and Taskin, 2017) since normal behaviors such as drinking, feather squatting, eating, moving (walking-standing), preening, and resting scores are considered comfortable behaviors. DLS group in this study did not affect the overall feathering cover of laying hens. Body condition score in laying hens of DLS group was better than that of the CON group. Birds with poor feathers not only present a problem for welfare, but also affect egg production (Tactacan et al., 2009; Sosnówka-Czajka et al., 2010; Sözcü et al., 2022). Bad environment and feeding management conditions of laying hens of CON group might have increased feather loss compared to the DLS group, thus impairing animal welfare (Blatchford et al., 2016; Widowski et al., 2017). The high score of feather loss in laying hens of CON group might have contributed to wing feather deterioration (Lay et al., 2011; Sosnówka-Czajka et al., 2010). In this study, appearance, feather condition, body condition such as the comb, beak, keel bone damage, and plumage, and health score of laying hens of the DLS group were improved compared to the CON group. This might be due to more perching and walking caused by good control of environmental and specification management for laying hens in the DLS group, thus improving the standing behavior which can exercise bird's leg and muscles. As a result, appearance, feather condition, body condition, and health score are improved in the DLS group. The more existence of perch is very important to bird's claw condition (Appleby et al., 2004; Webster, 2004). Conversely, laying hens of the CON group performed more standing but less walking, ultimately leading to lower gait scores (Appleby et al., 2004; Lay et al., 2011; Blatchford et al., 2016; Sözcü et al., 2022). Good flock management is known to prevent keel bone deformation and osteoporosis by stimulating the absorption of nutrients essential for bone metabolism and absorption of minerals essential for bone and eggshell formation (Webster, 2004; Beloretchkov, 2010).

Unsaturated fatty acid is an important element for prevention of cardiovascular diseases and development and function of brain and nerve cells (Husted and Bouzinova, 2016). Oleic acid can especially improve the taste and flavor of egg and lower bad cholesterol in the blood at the same time (Park and Park, 2012; Risso and Carelli, 2017; Husted and Bouzinova, 2016). The ideal ratio of n-6/n-3 fatty acid in the food is known to be 10:1 or less for metabolic disease prevention and health of human being (Husted and Bouzinova, 2016; Park and Park, 2012). The results of this work, te ratio of n-6/n-3 fatty acid was almost 10:1 in eggs of the DLS group. Zammit and Park (2020) have shown that the balance of microorganism in the caecum of laying hens in the DLS group is greatly inproved in comparison with that in the CON group, especially the count of *Lactobacillus* is higher in the DLS group. However, total bacteria and counts of coliform and *Escherichia coli* were lower in the CON. This was because real-time environmental, feeding management and animal care of laying hens by a digital livestock system were improved, thus improving animal behavior, animal welfare, nutrients, and lipid metabolism in the liver of animals (Wang et al., 2009; DEFRA, 2010; Holt et al., 2011). The lipid improvement in eggs of the DLS group might be related to this fact (Table 4, Table 5).

Conclusions

A digital livestock system could further improve the behavior and welfare of laying hens as well as egg cholesterol and fatty acid profiles compared to conventional livestock systems. Such results found for laying hens by the digital livestock system were due to automatic environmental, feeding and animal management using central control by computer, and smartphone through sensing platform. Therefore, digital livestock systems should be considered as future livestock algorithms to improve animal behavior and welfare, growth performance, and quality of animal food.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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