Lack of access to an open water source for bathing inhibited the development of the preen gland and preening behavior in Sanshui White ducks

Jiandui Mi,[*,†,‡] Hongling Wang,[*,†,‡] Xiaohui Chen,[*,†,‡] Kate Hartcher,[§] Yan Wang,[*,†,‡] Yinbao Wu,[*,†,‡] and Xindi Liao[*,†,‡,1]

**College of Animal Science, National Engineering Research Center for Breeding swine Industry, South China Agricultural University, Guangzhou 510642, China; †Ministry of Agriculture Key Laboratory of Tropical Agricultural Environment, South China Agricultural University, Guangzhou 510642, China; ‡Guangdong Provincial Key Lab of Agro-Animal Genomics and Molecular Breeding and Key Lab of Chicken Genetics, Breeding and Reproduction, Ministry of Agriculture, Guangzhou 510642, China; and §Centre for Animal Welfare and Ethics, The University of Queensland, St Lucia, 4072, Australia*

ABSTRACT As a species of waterfowl, ducks rely on access to water to facilitate feeding behaviors. Further, wet preening behavior in ducks relies on access to water and is a key behavior for duck welfare. Traditionally, Chinese duck farms provide not only free access to drinking water in the duck house but also an open water pool outside of the house. However, recent restrictions prohibit the use of an open water pool for raising ducks in some areas of China. Little is known about the effects of not providing an open water pool on duck welfare, in particular, the development of the preen gland and wet preening behaviors. The preen gland secretes oil which is crucial for maintaining plumage conditions. A total of one hundred twenty 1-day-old Sanshui White ducks (**SSWD**) were randomly divided into 2 groups and fed for 6 wk with access to a water pool (**WP**) or without access to a water pool and provided drinking water only (**LWP**). The live body weights of ducks from the WP group were significantly increased compared with those of ducks in the LWP group starting from 3 wks of age ($P < 0.05$). Feed intake was increased in the WP group at 2 wk of age and from 4 to 6 wk of age ($P < 0.05$). The feed conversion ratio (**FCR**) was significantly different only at 4 and 5 wks of age, when the FCR was increased by 5.7% and 9.5%, respectively, in the LWP group compared with the WP group ($P < 0.05$). Lack of access to an open water pool significantly inhibited the growth of the preen gland based on its weight, size, and quantity of oil secretions ($P < 0.05$). In addition, the proportion of ducks exhibiting wet preening behavior was significantly reduced in the LWP group compared with the WP group ($5.5 \pm 0.2\%$ vs. $24.8 \pm 2.1\%$, $P < 0.05$). This study indicated that a lack of access to an open water source had negative impacts on the development of the preen gland and on the preening behavior of SSWD.

Key words: preen gland, preening behavior, duck, welfare

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INTRODUCTION

China is the world's largest producer and consumer of duck meat, slaughtering 3.2 billion ducks in 2017 and comprising for more than 75% of the world's total duck production (Yan, 2004) and 55% of the total annual value of the commercial waterfowl (including meat duck, egg duck, Muscovy duck, goose, and other species) industry worldwide (Mai and Wang, 2013; FAO, 2016). Access to open water sources is important to allow ducks to perform innate behaviors, including wet feeding, wet preening, and swimming. Typically, duck production systems in China have provided open water sources. However, because of biosecurity concerns and the increased risk of disease proliferation in wet environments in intensive production systems, the duck industry has been moving toward a "dry-feeding system", which lacks access to a pool of water (**LWP**) and provides drinking water from bells only (Liste et al., 2013). Ducks may be housed on litter or on plastic slats under LWP conditions. Because ducks are a species of waterfowl, being raised without access to an open water

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[1]Corresponding author: xdliao@scau.edu.cn

source for swimming and performing wet preening behaviors may negatively affect their health and welfare (O'Driscoll and Broom, 2011, 2012; Liste et al., 2012a; Farghly and Mahmoud et al., 2018). One motivation of ducks to access an open water source is to alleviate heat stress in the hot season (Ruis et al., 2003; Farghly et al., 2017, 2018). Providing a water pool also appears to promote wet preening behavior, and the depth and cleanliness of the water source also impact duck bathing behavior (Liste et al., 2012b; O'Driscoll and Broom, 2012). The expression of these natural behaviors provides positive feedback, and positive affective states are an important aspect of good animal welfare. Wet preening behavior is an important innate behavior of ducks and is normally performed upon leaving the water. Further, wet preening behavior is important for the distribution of preen oil and maintaining feather condition and good health, as outlined above. Research investigating the effects of the lack of access to an open water source on duck health, behavior, and welfare is necessary.

As a species of waterfowl, ducks have evolved with biological features, both behavioral and physical, suited for an aquatic habitat. The preen gland (**PG**) is a holocrine gland located at the base of the tail that produces preen oil that is distributed through the feathers by the duck's bill (Moreno-Rueda, 2017). Hypothesized functions of the preen gland and preen oil include plumage maintenance, defense against ectoparasites, waterproofing, drag reduction, pollutant excretion, interspecific communication, and symbiotic mediation, which means that preen oil may affect bird fitness by an indirect effect on symbiotic and mutualistic organisms living on birds (Moreno-Rueda, 2017). Partial removal of the preen gland has been commonly used to determine its functions (Jawad et al., 2016a, 2016b). Three weeks after partial removal of the preen gland, increased breast and back relative weights were found in male Akar Putra chickens and increased breast relative weight was observed in females (Jawad et al., 2016a). Removal of the preen gland also positively affects the digestive system and growth hormone concentration (Jawad et al., 2016b). After removal of the preen gland, total duodenum, jejunum, and ilium wall thickness as well as growth hormone levels were increased compared with those in birds that retained their preen glands (Jawad et al., 2016b). Other studies have demonstrated that fatty acids in preen gland oil differ based on various factors, such as age (Sandilands et al., 2004a, 2004b), and inhibit the growth of feather-degrading bacteria (Shawkey et al., 2003). Preen gland size can change the properties of preen oil, which affects bird health (Moreno-Rueda, 2016). The size and microstructure of the preen gland also correlate with its function (Lucas and Stettenheim 1972; Jacob and Ziswiler 1982; Chiale et al., 2014, 2017). Preen gland functions may also be affected by environmental factors (Chiale et al., 2014). The absolute and relative preen gland weights were not influenced by floor substrates or whether birds were feather pecked (Sandilands et al., 2004a). However, these parameters were affected by age and related body weight changes (Brake et al., 1993; Sandilands et al., 2004a). Information is lacking on the effects of water pool provision on preen gland development and other factors in waterfowl such as ducks.

In summary, there is a need for research to investigate the effects of the lack of open water access on the development of the PG, health, preening behavior, and meat production in ducks. This experiment therefore aimed to investigate the effects of access to water for bathing on the growth, functions and development of the PG, and the expression of preening behavior and productivity (including the feed conversion ratio [**FCR**] and carcass traits) in Sanshui White ducks (**SSWD**).

MATERIALS AND METHODS

Animals and Housing

This study was conducted at the Sanshui District Joint Livestock and Poultry Breeding Farm Foshan City, Guangdong Province. The animal care and use procedures were approved by the Institutional Animal Care and Use Committee of South China Agricultural University (SYXK2014-0136). Ducks were raised from the day of hatching to 6 wk of age in a well-ventilated duck house with a half-open rolling curtain on the south-facing side. The duck house was orientated north and south, as well ventilated and had sufficient sunlight to light the house without the need for electric lights. A total of 120 SSWD were randomly assigned to 2 groups: a control group raised with a traditional feeding system with a water pool (**WP**) and the treatment group raised with a dry-feeding system without a water pool (**LWP**). Both groups were raised on metal slats (2 × 5 m) throughout the experimental period, which is typical of duck housing for meat production in China. All other housing features and procedures were the same for both groups throughout the 6-wk study period. Adequate clean drinking water was provided through bell drinkers (1 drinker/5 ducks), and the water was changed 3 times per day to keep the water clean. Both groups had the same number of drinkers in the same location. Feed was provided *ad libitum* and consisted of starter from days 1 to 14 and finisher from days 14 to 42. Feed composition is presented in Supplementary Table 1. Feed was provided manually at 08:00 and 18:00 daily. Each group was provided with the same amount of feed in a bucket (1 bucket/5 ducks) in the same location. The WP group was given a 5 m (width) × 6 m (length) pool filled with water to a depth of 60 cm. The water in the pool for the WP group was changed every morning. The metal bed was washed and disinfected every 4 to 5 d. A uniform immunization schedule was used for both groups (Supplementary Table 2).

Measurement of Productivity

Feed intake was recorded daily throughout the experimental period. All ducks were weighed at the start and end of the study, and feed was adjusted every wk to maintain management manual growth rates. To avoid the effects of feed intake on duck weights, birds were fasted overnight, excluding ducklings at hatching, and weighed at 08:00. The birds had *ad libitum* access to drinking water throughout this period.

At 6 wk of age, 12 ducks per group with weights close to the average within each group were selected for slaughter. Slaughter methods complied with the standard of ZBB43001_85. The following measures were obtained after slaughter and calculated relative to live weight (%): dressing percentage, semieviscerated weights, all-eviscerated weights, breast muscle rate, leg muscle rate, breast fat rate, leg fat rate, liver fat rate, abdominal fat rate, and skin fat rate. In addition, leg muscle fiber density, leg muscle fiber diameter, liver, spleen, thymus, tibia weight, fat-free tibia weight, tibia ash, tibia calcium, and tibia phosphorus were determined after slaughter.

Measurement of PG

A total of 4 ducks (2 male and 2 female ducks) were randomly selected from each group every wk throughout the experiment (7, 14, 21, 28, 35, and 42 d), weighed, and then culled. The procedure for PG removal was conducted according to the method of Jawad et al. (2015). Gland weight was measured using an electronic balance, and the gland length, width, and depth were measured using a slide gauge. The PG was surgically removed from each slaughtered duck to measure the volume of oil contained in each gland. Paper was weighed first, and the paper was then used to absorb oil secreted from the gland. The gland was squeezed by hand with sterile gloves to measure the oil production of the PG. When the weight of the paper with oil no longer increased, the gland was no longer squeezed.

Preening Behavior

From the second to sixth wk of age, the preening behavior of the ducks was observed 3 d a wk over 6 h per day from 8:00 to 11:00 and 15:00 to 18:00. For 5 min of each hour, the number of ducks performing preening behaviors was counted in the entire pen. As a result, there were seventy-two 5-min observations per group throughout the experiment. The frequency of observed preening behavior (%) was calculated using the following formula:

Preening behavior frequency (%) = [(Total number of ducks in each observation period with wet preening behavior)/(total number of ducks in one group)] × 100%.

Data Analysis

Data were analyzed using SAS 9.2 via the MIXED procedure according to the model: $Y = \mu + T + A + B + (T \times A) + E$, where Y is the dependent variable, μ is the overall mean, T is the effect of treatment, A is the effect of age, B is the effect of animal, T × A is the interaction between treatment and age, and E is the residual error. Treatment and age were considered fixed effects, and animal was considered a random effect. Polynomial contrasts for the effect of treatment as well as for the treatment × age interaction were used to evaluate the main effects. The original mean % of preening behavior of the ducks was used in this study. Comparisons between treatments within the same age were made using *t* tests when the treatment × age interaction was significant. These *t* tests were performed to ensure that interpretations of the contrasts were clear. Differences were considered significant at $P < 0.05$.

RESULTS

The effects of drinking systems on the productivity of meat ducks are shown in Table 1. Body weight, feed intake, and FCR were significant under treatment, age, and the interaction between treatment and age ($P < 0.001$). Next, we focused on the effect of different treatments on these parameters. The live body weight of ducks from the WP group was significantly increased compared with that of ducks in the LWP group starting at 3 wks of age ($P < 0.05$). Feed intake was increased in the WP group at 2 wk of age and from 4 to 6 wk of age ($P < 0.05$). The FCR was significantly different only at 4 and 5 wk of age, when the FCR increased by 5.7% and 9.5% in the LWP group at 4 and 5 wk of age compared with the WP group ($P < 0.05$).

The effects of feeding systems on carcass characteristics, meat quality, immune system function, and tibia quantity of meat ducks are shown in Table 2. All-relative eviscerated weights were increased in the LWP group compared with the WP group ($P < 0.05$). The other parameters of carcass characteristics were not influenced by the feeding system. Abdominal fat and leg muscle fiber density were increased in the WP group compared with the LWP group ($P < 0.05$). Other meat quality indices were not influenced by the 2 feeding systems. Thymus weight was also increased in the WP group compared with the LWP group ($P < 0.05$). Tibial characteristics were not affected by the 2 feeding systems.

The effects of access to a water pool on the development of the preen gland weights are shown in Table 3. The weight and relative weight of the PG were significantly affected by age, treatment, and the interaction between treatment and age (all P-value = 0.003 or less). The weight of the PG increased with age in both the WP and LWP groups. However, the relative weight of the PG increased from hatching (wk 0) to 1 wk of age and then decreased thereafter ($P < 0.001$). This finding indicated that the growth rate of the PG of the SSWD was reduced compared with growth in live weight after the first week. The mean PG weight for WP and LWP ducks was the same on the day of hatching (mean 0.1 ± 0.01 g). The mean PG weight of ducks in the WP group was consistently significantly increased compared with that of ducks in the LWP group from

Table 1. The effects of access to a water pool on the productivity of meat duck (mean ± SE).

Aged (wk)	Feeding system	Body weight (g)	Feed intake (g)	Feed conversion ratio
Hatch Day	WP	29.67 ± 0.47	—	—
	LWP	29.87 ± 0.51	—	—
1	WP	200.10 ± 3.35	24.59 ± 0.76	1.01 ± 0.03
	LWP	201.00 ± 4.50	25.33 ± 0.77	1.04 ± 0.00
2	WP	623.40 ± 3.16	91.64 ± 1.30^{A}	1.26 ± 0.02
	LWP	606.03 ± 11.13	87.73 ± 2.33^{B}	1.27 ± 0.01
3	WP	$1{,}125.33 \pm 9.17^{A}$	158.90 ± 1.86	1.56 ± 0.03
	LWP	$1{,}081.67 \pm 9.39^{B}$	154.67 ± 2.03	1.61 ± 0.02
4	WP	$1{,}626.67 \pm 17.64^{A}$	187.33 ± 3.14^{A}	1.82 ± 0.01^{B}
	LWP	$1{,}508.33 \pm 16.41^{B}$	173.95 ± 1.84^{B}	1.93 ± 0.05^{A}
5	WP	$2{,}130.00 \pm 15.28^{A}$	196.24 ± 2.65^{A}	2.00 ± 0.02^{B}
	LWP	$1{,}886.67 \pm 29.06^{B}$	176.67 ± 2.35^{B}	2.21 ± 0.03^{A}
6	WP	$2{,}500.00 \pm 20.82^{A}$	174.90 ± 1.23^{A}	2.23 ± 0.05
	LWP	$2{,}323.33 \pm 28.87^{B}$	156.38 ± 3.27^{B}	2.23 ± 0.05
SEM		273.62	2.60	0.001
P-value	Treatment	<0.001	<0.001	<0.001
	Age	<0.001	<0.001	<0.001
	Treatment*Age	<0.001	<0.001	<0.001

Mean values with different superscript in column between WP and LWP are significant different ($P < 0.05$).
Abbreviations: LWP, Lack of water pool; WP, providing with water pool.

3 wk of age ($P < 0.05$). The absolute weights of the PG at 3, 4, 5, and 6 wk of age in the WP group were greater by 7.11%, 16.74%, 41.89%, and 56.37%, respectively, than those in the LWP group. Preen gland weights at 6 wk of age in the WP and LWP groups were 4.66 g and 2.98 g, respectively. Moreover, the weight of the PG relative to body weight was consistently significantly higher in the WP group than in the LWP group by 15.13%, 22.19%, 11.11%, 24.19%, 48.53%, and 61.16% (Table 3, $P < 0.05$). It therefore appears that the lack of access to a water pool had a negative effect on PG development.

Preen gland sizes of SSWD from 0 to 6 wk are recorded in Table 4. Preen gland size (length, width, and depth) was also significantly different based on treatment, age, and interaction between the 2 (all $P < 0.05$). Preen gland size (length, width, and depth) increased throughout the entire 6-wk period, with a rapid change in the first 3 wk. The width and depth of the PG in both the WP and LWP groups rapidly decreased after 3 wk of age. Significant differences in PG length and width were observed between the WP and LWP groups from 5 wk of age, and significant differences in PG height were found from 3 wk of age. From 3 to 6 wk, the PG was higher in the WP birds than in the LWP birds by 9.65%, 9.38%, 21.94%, and 30.91% ($P < 0.05$). The lack of an open water source appeared to negatively impact the morphological development of meat-duck PG by reducing the height, length, and width of the PG.

Oil weight and percentage of oil relative to gland weight for both feeding systems were significant for treatment, age, and the interaction between treatment and age ($P < 0.001$, Table 5). Oil production increased with age in both systems. Ducks in the WP group produced more oil than birds in the LWP from 1 wk of age ($P < 0.05$). At 6 wk of age (42 d), the weight of the oil secreted by the PG in the WP group was almost double that of oil secreted

Table 2. The effects of access to a water pool on the carcass characteristics, meat quality, immune system function, and tibial quantity (mean ± SE).

	Items			
Feeding system	Dressing percentage (%)	Semieviscerated weights rate (%)	All-eviscerated weights rate (%)	Breast muscle rate (%)
WP	84.25 ± 0.23	76.73.10 ± 0.73	69.66 ± 1.08^{B}	7.93 ± 0.97
LWP	86.05 ± 1.15	79.14 ± 1.71	72.78 ± 1.31^{A}	7.95 ± 0.57
	Leg muscle rate (%)	Breast fat rate (%)	Leg fat rate (%)	Liver fat rate (%)
WP	11.36 ± 0.63	0.90 ± 0.03	1.40 ± 0 0.05	4.41 ± 0.17^{B}
LWP	11.44 ± 10.96	0.94 ± 0.03	1.45 ± 0.12	6.15 ± 1.75^{A}
	Abdominal fat rate (%)	Skin fat rate (%)	Leg muscle fiber density (piece/mm^2)	Leg muscle fiber diameter (μm)
WP	1.65 ± 0.29	24.53 ± 1.58^{B}	570.98 ± 92.17^{A}	38.06 ± 1.84
LWP	1.62 ± 0.29	25.07 ± 0.67^{A}	508.48 ± 8.48^{B}	23.95 ± 6.44
	Liver (g/kg)	Spleen (g/kg)	Thymus (g/kg)	Tibial weight (g)
WP	21.75 ± 0.91	0.57 ± 0.03	2.50 ± 0.15^{A}	17.10 ± 0.71
LWP	21.81 ± 0.73	0.61 ± 0.03	1.68 ± 0.05^{B}	16.85 ± 0.41
	Fat-free tibia weight (g)	Tibia ash (g)	Tibia calcium (%)	Tibia phosphorus (%)
WP	6.20 ± 0.12	3.24 ± 0.03	18.54 ± 0.14	9.17 ± 0.03
LWP	6.14 ± 0.26	3.10 ± 0.11	18.75 ± 0.12	9.23 ± 0.04

Mean values with different superscript in column between WP and LWP are significant different ($P < 0.05$).
Abbreviations: LWP, Lack of water pool; WP, providing with water pool.

Table 3. The effects of access to a water pool on the development of preen gland weight (mean ± SE).

Age (wk)	Feeding system	Weight of PG (g)	Relative weight of PG (g.kg^{-1})
0	—	0.11 ± 0.01	2.87 ± 0.13
1	WP	0.75 ± 0.05	3.88 ± 0.05^{A}
	LWP	0.66 ± 0.10	3.37 ± 0.06^{B}
2	WP	1.60 ± 0.50	3.80 ± 0.16^{A}
	LWP	1.59 ± 0.11	3.11 ± 0.01^{B}
3	WP	2.26 ± 0.11^{A}	2.40 ± 0.05^{A}
	LWP	2.11 ± 0.04^{B}	2.16 ± 0.04^{B}
4	WP	2.79 ± 0.50^{A}	2.31 ± 0.36^{A}
	LWP	2.39 ± 0.25^{B}	1.86 ± 0.18^{B}
5	WP	3.76 ± 0.47^{A}	2.02 ± 0.20^{A}
	LWP	2.65 ± 0.28^{B}	1.36 ± 0.14^{B}
6	WP	4.66 ± 0.29^{A}	1.95 ± 0.07^{A}
	LWP	2.98 ± 0.17^{B}	1.21 ± 0.17^{B}
SEM		0.058	0.022
P-value	Treatment	<0.001	<0.001
	Age	<0.001	<0.001
	Treatment*Age	<0.001	0.003

Mean values with different superscript in column between WP and LWP are significant different ($P < 0.05$).
Abbreviations: LWP, lack of water pool; WP, providing with water pool.

in the LWP group ($P < 0.05$). Oil weight as a percentage of gland weight (%) rapidly increased in the first 3 wk and plateaued after 3 wk of age at 48.82% (WP) and 40.05% (LWP) ($P < 0.05$). The lack of a water pool appeared to decrease the secretion function of the PG.

Preening behavior was also influenced by treatment, age, and the interaction between treatment and age ($P < 0.001$, Table 6). The frequency of preening in the LWP group was significantly reduced compared with that in the WP group during all observations from 2 to 6 wk of age ($P < 0.05$). This finding indicated that access to open water was an important factor influencing preening behavior in the SSWD.

DISCUSSION

Effects of Access to Bathing Water on the Morphology of the Preen Gland

Lack of access to an open water source for bathing was significantly associated with reduced growth and oil function of the PG. Although Sandilands et al. (2004b) reported that flooring materials (either wire or litter floors) had no significant effects on PG weight in layer hens, this study showed that the PG increased in weight and dimensions in ducks with access to bathing water compared with those without a bathing pool. Ducks with no bathing water produced less PG oil than birds with access to bathing water. These results indicate

Table 4. The effects of access to a water pool on the size of preen gland weight (mean ± SE).

Age (wk)	Feeding system	Length (mm)	Width (mm)	Height (mm)
Birthday	—	7.84 ± 0.43	3.26 ± 0.26	2.58 ± 0.25
1	WP	13.79 ± 0.69	6.49 ± 0.18	5.53 ± 0.23
	LWP	12.72 ± 0.71	6.13 ± 0.32	5.07 ± 0.30
2	WP	18.70 ± 0.71	8.47 ± 0.36	7.48 ± 0.26
	LWP	18.39 ± 1.56	8.09 ± 0.57	7.09 ± 0.38
3	WP	21.01 ± 0.93	9.12 ± 0.18	8.18 ± 0.7^{A}
	LWP	19.88 ± 1.03	9.40 ± 0.09	7.46 ± 0.15^{B}
4	WP	21.48 ± 1.26	9.78 ± 0.42	8.16 ± 0.41^{A}
	LWP	20.99 ± 1.29	9.43 ± 0.40	7.46 ± 0.20^{B}
5	WP	24.62 ± 0.30^{A}	10.86 ± 1.02^{A}	9.06 ± 0.91^{A}
	LWP	22.96 ± 0.49^{B}	9.48 ± 0.65^{B}	7.43 ± 0.36^{B}
6	WP	26.59 ± 0.54^{A}	11.11 ± 0.21^{A}	9.74 ± 0.32^{A}
	LWP	24.99 ± 0.29^{B}	9.56 ± 0.42^{B}	7.44 ± 0.22^{B}
SEM		0.942	0.175	0.122
P-Value	Treatment	<0.001	<0.001	<0.001
	Age	<0.001	0.004	<0.001
	Treatment*Age	0.030	<0.001	<0.001

Mean values with different superscript in column between WP and LWP are significant different ($P < 0.05$).
Abbreviation: LWP, Lack of water pool; WP, providing with water pool.

Table 5. The effects of feeding systems on the oil weight in the preen gland (mean ± SE).

Aged (wk)	Feeding system	Oil weight (g)	Percentage of oil weight in gland weight (%)
Birthday	—	0.01 ± 0.00	12.46 ± 0.63
1	WP	0.14 ± 0.01^{A}	18.97 ± 0.51^{A}
	LWP	0.12 ± 0.02^{B}	17.43 ± 0.33^{B}
2	WP	0.51 ± 0.01^{A}	27.05 ± 0.51^{A}
	LWP	0.39 ± 0.03^{B}	24.78 ± 0.06^{B}
3	WP	1.11 ± 0.06^{A}	48.82 ± 0.28^{A}
	LWP	0.85 ± 0.01^{B}	40.05 ± 0.53^{B}
4	WP	1.33 ± 0.25^{A}	47.46 ± 1.61^{A}
	LWP	1.01 ± 0.10^{B}	42.15 ± 0.36^{B}
5	WP	1.75 ± 0.20^{A}	46.61 ± 0.90^{A}
	LWP	1.10 ± 0.12^{B}	41.64 ± 0.36^{B}
6	WP	2.18 ± 0.14^{A}	46.82 ± 0.23^{A}
	LWP	1.22 ± 0.07^{B}	41.07 ± 0.25^{B}
SEM		0.005	0.307
P-Value	Treatment	<0.001	<0.001
	Age	<0.001	<0.001
	Treatment*Age	<0.001	<0.001

Mean values with different superscript in column between WP and LWP are significant different ($P < 0.05$).

Abbreviations: LWP, lack of water pool; WP, providing with water pool.

that bathing water is an important factor that promotes PG growth in ducks.

In addition, lower rates of preening behavior were observed when ducks did not have access to bathing water, which may have resulted in inhibition of the development of this gland because of the lack of stimulation (Montalti and Salibián, 2000). Although PG is not essential for survival, it has functions that are important for welfare and productivity in poultry (Ruiz-Rodriguez et al., 2009). The PG is important in secreting oil, which is then distributed throughout the feathers by preening behavior to maintain the luster, flexibility, and integrity of the feathers (Ruiz-Rodriguez et al., 2009). Preen gland also has other important functions including pheromone production, plumage cleanliness, and thermoregulation.

Secretions from the PG exhibit strong hydrophobicity, which is very important in maintaining the flexibility and waterproof characteristics of feathers, especially for waterfowl. This feature also aids in thermoregulation, as it keeps water away from the skin. In addition, this oil can prevent feathers from being damaged by parasitic microorganisms (Barcus et al., 2017). Preen gland also plays very important roles in the adaptation of stress and other biochemical processes (Moreno-Rueda, 2017). The accumulation of fat droplets is potentially increased in birds with access to water; in contrast, there is no need for waterproofing of feathers in birds without access to bathing water (Ishida et al., 1973). However, oil from the PG may have additional functions in addition to maintaining body temperature and waterproofing feathers. The oil may be involved in energy supply or the metabolism of fat in the body, which needs further investigation (Moreno-Rueda, 2017).

These important functions of the PG detailed above indicate that not providing a water pool for bathing may negatively affect the health and welfare of ducks. In addition, lack of access to an open water source may affect thermoregulation, especially in summer, when ducks may be under heat stress. Without a water pool, the manure of ducks accumulates in the house. If manure is not regularly collected and treated, odor and ammonia might be produced by manure fermentation. These factors would not only influence the health of workers and ducks but also have an impact on human populations living nearby. Thus, systems without bathing water will also require improved waste management and odor control. These factors are all likely to influence the health of ducks.

Table 6. The effects of access to a water pool on the preening behavior (%, mean ± SE).

Aged (wk)		WP	LWP
2		10.1 ± 2.2^{A}	6.4 ± 1.5^{B}
3		16.5 ± 2.0^{A}	4.8 ± 0.6^{B}
4		19.0 ± 1.0^{A}	4.6 ± 0.6^{B}
5		23.6 ± 5.2^{A}	5.2 ± 0.7^{B}
6		24.8 ± 2.1^{A}	5.5 ± 0.2^{B}
SEM		0.005	0.307
P-value	Treatment	<0.001	<0.001
	Age	<0.001	<0.001
	Treatment*Age	<0.001	<0.001

Mean values with different superscript in column between WP and LWP are significant different ($P < 0.05$).

Abbreviations: LWP, lack of water pool; WP, providing with water pool.

Effects of Access to Bathing Water on Production Characteristics

Lack of access to an open water source for bathing increased the FCR, which means ducks would consume more feed for the same meat yield if the industry transitions from WP to LWP. In summer, ducks might also be at risk of heat stress. Heat stress decreases bodyweight and increases body fat. Howlider and Rose (1987) found that increasing the ambient temperature by 1°C caused the total fat to increase by 0.8% and the abdominal fat rate by 1.6%. Hacina et al. (1996) found that after 32°C heat stress, the body weights of chickens were 47% lighter than those housed at 22°C, and abdominal fat, skin fat, and muscle fat increased by 15%, 21%, and 22%, respectively. This study found that LWP ducks had reduced body weight. The fat increased in the liver and skin by 28% and 2%, respectively, whereas no changes in breast, leg, or abdominal fat were noted. This finding may be because the average temperature in summer is 30°C. Temperature control is therefore particularly important in summer, and heat stress is particularly risky for birds without an open water source in which to bathe. Providing more water for birds bathe and wet preen could help ducks to lose heat and increase feed intake.

The liver, spleen, and thymus are important organs, and their functions can be affected by heat stress (Blalock, 1989). The liver and spleen were not influenced by the 2 different treatments ($P > 0.05$). The thymus, which is central to cell immunity, was smaller in the LWP group than in the WP group in this study, possibly indicating that cell immunity was influenced by the absence of a water bath, which affects bird resistance to disease and the efficacy of vaccinations.

Effects of the Presence of Bathing Water on Preening Behavior

The rates of preening behavior were reduced in ducks without access to a water pool compared with ducks with a water pool for bathing. Because the PG secretes oil for preening feathers (George et al., 2006), the relationships among environmental conditions, PG growth, and preening behavior are predicted to exhibit the features below.

There are 3 potential hypotheses to explain the reduction in preening behavior: (1) The expression of preening behavior is dependent on both genetics and environmental factors. The lack of bathing water may inhibit preening behavior. Because preening behavior distributes the oil secreted by the PG throughout the feathers for waterproofing, without water and a need to waterproof the feathers, there was a reduced need for preening given the lack of access to water and the need to waterproof the feathers. (2) The decrease in preening behavior in the LWP group compared with the WP group directly reduces the stimulation of the PG and therefore could result in reducing its subsequent growth and secretions. Preening behavior increased with age in the WP group. However, under LWP conditions, preening behavior was significantly reduced at a very young age without the opportunity for water bathing. (3) Preening behavior could also differ under various temperatures. This experiment was conducted in summer, when there was a need for the ducks to open their mouths to pant for evaporative cooling, which may correlate with lower rates of preening behavior. Conversely, ducks with access to bathing water would also have been able to use the cooling function of the water and rely less on panting, with more relative time for preening behavior. However, the motivation and functions of preening behavior need further investigation. Finally, although this study provided interesting results, it should be noted that the experimental design was limited by the lack of replicates at the group level and that replicates were performed at the individual bird level. Further studies are needed to investigate the preliminary results from this study.

CONCLUSION

Given the developing economic and social indices in many developing countries, there is also an increase in consumer requirements for higher-animal welfare products. As a result, livestock production needs to change to meet market demand. However, intensive production can result in animals being exposed to unnatural conditions, potentially resulting in compromised animal welfare. Under these circumstances, production systems remove the pool of water for ducks to bathe in, which appears to inhibit the growth of the PG and the expression of preening behavior, as well as worsening FCR and decreasing some measures of productivity. It is crucial to avoid animal welfare problems by considering the effects of housing systems on the biology and behavior of animals. This information will become particularly important as consumer expectations change, and there is a higher demand for good animal welfare in livestock production throughout the world. Changing the commercial housing systems for intensive duck meat production in China by removing access to open water sources for bathing is likely to negatively affect the development of the PG in SSWD, inhibit natural preening behaviors, reduce immunity and productivity, and reduce the overall health and welfare of ducks. A relationship is noted between the development of the PG and behavioral expression, and this relationship could be explored further. New production systems should consider how to reduce the impact of changes on duck welfare.

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SUPPLEMENTARY DATA

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