

Effects of integrated rice-duck farming system on duck carcass traits, meat quality, amino acid, and fatty acid composition

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ABSTRACT Integrated rice-duck farming (RD) system, which aims to improve the welfare of ducks, has gained popularity in Asian countries. However, the effects of RD system on the carcass and quality traits of duck meat have not been evaluated. Here, a paddy field experiment was conducted to examine the effects of RD system on the carcass and quality traits of duck meat. A total of 180 Jinding ducklings (7 days old) were randomly divided into 2 rearing systems of floor pen rearing (FPR) system and RD system. After 11 weeks, 12 ducks from each rearing system (6 males and females each) were used for carcass traits, meat quality, amino acid, and fatty acid analyses. The results showed that ducks reared in the RD system had higher carcass yield and intramuscular fat content ($P < 0.05$) than those reared in the FPR system; however, ducks reared in the RD system had lower protein and

moisture content ($P < 0.05$). Additionally, the concentration of essential amino acids, including Tyr, Val, Met, Phe, His, Ala, Arg, and Pro, was higher in the breast muscle of ducks reared in the RD system than those reared in the FPR system. Furthermore, higher saturated fatty acid (C12:0, C14:0, C16:0, C18:0, and C21:0), monounsaturated fatty acid (C16:1, C18:1, and C18:1T), and polyunsaturated fatty acid (C22:2, C18:2n-6, and C22:6n3) content was recorded in the breast muscle of ducks reared in the RD system than those reared in the FPR system ($P < 0.05$). Taken together, our results indicated that the RD system improved the carcass traits, intramuscular fat, essential amino acids, and polyunsaturated fatty acids profiles of the ducks. These findings suggest that the RD system is an effective strategy to improve the welfare and meat quality of ducks.

Key words: integrated rice-duck farming, duck, carcass trait, meat quality

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INTRODUCTION

In recent years, there have been growing concerns for animal welfare and meat quality and an increase in the demand for organically reared animals (Magdelaine et al., 2008; Chen et al., 2018). Free-range rearing systems have been shown to improve poultry welfare (Jones et al., 2007; Yilmaz et al., 2016). Integrated rice-duck farming (RD) system, as a mode of free-range rearing system, in which ducks could swim and walk freely, has been more and more popular in many Asian countries, including China, Japan, South

Korea, and Vietnam (Jiaen et al., 2016). The RD system affords the ducks an environment similar to their natural habitat, thus, allowing them to exhibit their natural behavior. Moreover, the ducks are advantageous to the rice farming operation, as they control weeds, pests, and plant diseases; improve soil properties and aeration (Claire et al., 2015); and improve rice yield (Yuan et al., 2008).

In modern duck meat production, intensive systems reduce the welfare of ducks, as they are unable to exhibit their natural behaviors, such as swimming (Raud and Faure, 1994; Jones et al., 2009; Abdel-Hamid et al., 2020). Although intensive production systems have improved the productivity of ducks, such as egg yield and weight gain (Duru et al., 2006), these systems has been linked to increased incidence of feather pecking, skeletal injuries, contact dermatitis (foot, toe, hock, and breast lesions), and poor meat quality (Dawkins et al., 2017). It was reported that improving bird welfare

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significantly improved the quality and flavor of duck meat and meat products (Chen et al., 2013). However, few studies have been performed regarding the effects of RD system on the carcass and quality traits of duck meat. The objective of the present study was to examine the effects of the RD system on the carcass traits, meat quality, amino acid, and fatty acid profile of ducks.

MATERIALS AND METHODS

Ethics Statement

All animal procedures were implemented in strict accordance with the Institutional Animal Care and Use Committee of Yangzhou University (approval number: 151-2014). All experimental ducks were managed and handled according to the guidelines established and approved by the Regulations for the Administration of Affairs Concerning Experimental Animals (Yangzhou University, China, 2012). All efforts were made to minimize the suffering of the animals.

Experimental Design

The study comprising of 2 rearing systems, RD system and floor pen rearing (FPR) system, was carried out in 2018 at Zhenjiang Teaching and Research Farm (32° 12'N, 119°30'E), Yangzhou University, Yangzhou, China. The study was laid out in a completely randomized design, with 3 replicates per treatment. The size of the rice paddy plot was 3335 m² (66.7 m × 50 m). We obtained 180 fertile Jinding duck eggs from the National Waterfowl Gene Bank, Taizhou, China (Luo et al., 2019). The eggs were incubated contemporaneously and the hatched ducklings were housed in the same environment (temperature, humidity, ventilation, and other variables) in Zhenjiang Tiancheng Agricultural Science, Zhenjiang, Jiangsu, China, until they were 7 days old. In the birdhouse, the lighting was continuous, and the temperature was set initially at 32°C and reduced gradually by 1°C per day. The relative humidity was set initially at 75% and reduced gradually by 5% per week until reaching 55%. The feed and water were given during the daytime, and all the ducklings ducks had free access to feed and water. Half of the ducklings were introduced into the paddy fields at a density of 18 ducklings/666.67 m² (Li et al., 2012; Xu et al., 2017), and the remaining half were reared under the FPR system. All the ducks were reared with the same diet (Table 1).

Carcass Characteristics

At the end of the experiment (84 days old), after 12 h of fasting, 6 male and 6 female birds from each treatment were randomly selected, weighed (live weight, LW), and slaughtered in a poultry processing plant. The defeathered carcass, including the head and feet, was weighed to determine the carcass weight. The

Table 1. Ingredient and nutrient levels of the experimental diets.

Item	Content
Ingredients (%)	
Wheat	100
Nutrient levels	
metabolic energy/MJ kg ⁻¹	12.73
Crude protein (%)	14.20
Calcium (%)	0.31
Phosphorus (%)	0.50

Premix provided per kilogram of diet: bentonite, 44.46 g; lysine, 3.24 g; DL-MHA-FA (88%), 0.99 g; threonine, 0.73 g; sodium chloride, 4.40 g; sodium bicarbonate, 2.00 g; sodium sulphate, 2.00 g; Herbalife, 0.20 g; choline chloride (60%), 1.00 g; Jin Duowei, 0.53 g; Jin Yv Kang, 0.15 g; C-811 enzyme, 0.30 g.

carcass was then eviscerated manually and weighed to determine the semi-eviscerated weight, which was measured as the carcass weight minus the weights of the trachea, esophagus, gastrointestinal tract, crop, spleen, pancreas, gallbladder, and gonads. Eviscerated weight was measured as the semi-eviscerated weight minus the weights of the head, feet, heart, liver, gizzard, glandular stomach, and the abdominal fat. The breast and thigh muscles were separated and weighed, and their weights were denoted as breast muscle rate and thigh muscle rate, respectively.

Physical Properties and Proximate Composition of Meat

After slaughter, the breast and thigh muscles were stored in a chilling room at 4°C. The pH of the muscles was recorded 24 h post-mortem using a pH meter (DELTA 320, Mettler Toledo, Shanghai, China). The moisture, intramuscular fat, protein, and collagen content was analyzed using a FoodScan Meat Analyzer (FOSS 78,800, Dedicated Analytical Solutions, Hillerod, Denmark) (Anderson, 2007). Tendons and muscle membranes were removed from samples of the breast and thigh muscles. Thereafter, the muscles were cut into pieces, ground into meat mud using a high-speed universal crusher, and stored in sample cups for further analyses. Measurements were taken on a mixture of 3 individual geese in the same group and repeated 3 times.

Amino Acid Composition

Amino acid content of the meats was determined to evaluate the biological value of muscle protein following the procedure described by Xu et al. (2019), using an L-8900 amino acid analyzer (HITACHI, Tokyo, Japan) with some modifications. Briefly, approximately 100 mg of breast muscle sample was ground to mud using a high-speed universal crusher. Thereafter, the meat mud was transferred a glass bottle, and 10 mL of 6 mol HCl was added. After filling with nitrogen, the mixture was hydrolyzed at 110°C for 22 h. Subsequently, the hydrolysate was transferred into a 50 mL volumetric flask and diluted with ultrapure water in a calibrated tube. The

solution was filtered into an autosampler vial using a 0.22 μm membrane filter.

Fatty Acid Composition

Fatty acid composition of the breast muscle samples was determined following the method described by Demirel et al. (2004), using a ThermoFisher Trace 1310 ISQ (ThermoFisher, Waltham, MA) with some modifications. Briefly, the extracted lipid was hydrolyzed in 8 mL of KOH-methanol ($C = 0.5 \text{ mol L}^{-1}$). After shaking for 1 min, the mixture was reacted in 95°C water for 10 min to obtain the free fatty acid mixture. During saponification, continuous shaking of the glass bottles was needed. The free fatty acid mixture was esterified in 7 mL BF₃-methanol solution ($W = 15\%$) under continuous agitation. After shaking for 10 s, the mixture was reacted in 80°C water for 20 min. After adding 10 to 30 mL n-hexane, the mixture was shaken for 2 min and then centrifuged at 3000 rpm for 15 min. Furthermore, 800 μL fatty acid methyl esters were separated and analyzed using a GC-2010 plus gas chromatograph (Shimadzu, Kyoto, Japan) equipped with an AOC-20i auto-injector (Shimadzu, Kyoto, Japan) and a chromatographic column, TG-5MS for fatty acid methyl esters (30 m \times 0.25 mm \times 0.25 μm). The injector and detector temperatures were maintained at 250°C and 260°C, respectively. Nitrogen was used as a carrier gas at a flow rate of 2.5 mL min⁻¹. The column temperature profile was as follows: hold at 140°C for 5 min, increase to 180°C at 8°C min⁻¹, increase to 210°C at 4°C min⁻¹, and hold at 210°C for 5 min. Subsequently, the temperature was increased to 230°C at 10°C min⁻¹ and then kept constant for 10 min. The total analysis time was 34.5 min. The fatty acids were identified by comparing the retention times of the peaks with those of known standards (Sigma, Louis, MO).

Statistical Analysis

Data obtained from the study were subjected to 1-way or 2-way analysis of variance (ANOVA) using SPSS 22.0 software (SPSS, Chicago, IL) and significant means were compared Duncan's multiple range test of the same software. The data were statistically significant at $P < 0.05$. Values were expressed as mean \pm SE of the mean.

RESULTS

Carcass Characteristics

To assess the effect of rearing systems on the carcass characteristics of ducks, we examined the carcass traits of Jinding ducks reared in RD system and FPR system. As shown in Table 2, ducks reared in the RD system had significantly higher ($P < 0.05$) live weight, carcass weight, carcass yield, eviscerated yield, and thigh muscle rate compared with those reared in FPR system.

Table 2. Effects of the integrated rice-duck farming on carcass traits of Jinding ducks.

Items	Group	
	Fenced-in rearing (FPR) system	Integrated rice-duck farming (RD) system
LW (g)	821.80 \pm 108.92 ^a	1,386.00 \pm 153.01 ^a
Carcass weight (g)	667.00 \pm 100.04 ^a	1,229.22 \pm 162.23 ^a
Carcass yield (%)	81.16 \pm 2.41 ^a	88.69 \pm 4.03 ^a
Eviscerated yield (%)	71.55 \pm 8.77 ^a	79.70 \pm 5.14 ^a
Semi-eviscerated yield (%)	57.17 \pm 2.99	60.37 \pm 3.19
Breast muscle (%)	10.36 \pm 3.15	11.15 \pm 1.12
Thigh muscle (%)	7.39 \pm 1.51 ^a	9.87 \pm 0.98 ^a

Abbreviation: LW, live weight.

Values are mean \pm SE, n = 12.

^aWithin a column for each factor, different superscripts indicate significant differences ($P < 0.05$). Eviscerated yield, % = Eviscerated Weight/LW \times 100; semi-eviscerated yield, % = semi-eviscerated weight/LW \times 100; breast muscle, % = breast muscle weight/eviscerated weight \times 100; thigh muscle, % = thigh muscle weight/eviscerated weight \times 100; Carcass yield, % = Carcass weight/LW \times 100.

However, rearing systems did not significantly affect ($P > 0.05$) semi-eviscerated weight and breast muscle rate.

Meat Quality

To assess the effect of rearing system on the quality of duck meat, we examined the carcass pH and proximate compositions, including the moisture, protein, fat, and collagen content of the breast and thigh muscles of the ducks. As shown in Table 3, rearing systems significantly affected ($P < 0.05$) the carcass pH, protein, moisture, intramuscular fat, and collagen content of the ducks. The carcass pH of ducks reared in the FPR system was significantly higher ($P < 0.05$) than that of ducks reared in the RD system. Additionally, the moisture and protein content of the breast and thigh muscles of ducks reared in the RD system was significantly lower ($P < 0.05$) than that of ducks reared in the FPR system. However, ducks reared in the RD system had significantly higher ($P < 0.05$) intramuscular fat content than ducks in the FPR system. The mean intramuscular fat content of the breast and thigh muscles of ducks reared in the RD system was 19.4% and 20.8% greater than that of the breast and thigh muscles of ducks reared in the FPR system, respectively. The collagen content of the thigh muscle of ducks reared in the FPR system was higher than that of the thigh muscle of ducks reared in the RD system; however, the collagen content of ducks reared in the FPR system was significantly lower ($P < 0.05$).

Amino Acid Composition

The results of the effects of rearing systems on the amino acid composition of breast muscle of the ducks are shown in Table 4. The rearing systems did not significantly affect ($P > 0.05$) asparagic acid (**Asp**), threonine (**Thr**), serine (**Ser**), glutamic acid (**Glu**), glycine (**Gly**), cysteine (**Cys**), isoleucine (**Ile**), leucine (**Leu**), and

Table 3. Effects of the integrated rice-duck farming on meat quality of Jinding ducks.

Rearing groups	Muscular tissues	pH	Protein content (%)	Moisture content (%)	Intramuscular fat content (%)	Collagen content (%)
Fenced-in rearing system	Breast	6.07 ± 0.25 ^a	23.63 ± 0.30 ^b	76.06 ± 0.32 ^a	2.07 ± 0.05 ^b	1.24 ± 0.23 ^c
	Thigh	6.28 ± 0.23 ^a	24.83 ± 0.69 ^a	75.44 ± 0.46 ^b	3.37 ± 0.19 ^a	2.19 ± 0.17 ^a
Integrated rice-duck farming system	Breast	5.83 ± 0.03 ^b	23.17 ± 0.44 ^b	73.29 ± 0.38 ^c	2.54 ± 0.07 ^b	1.91 ± 0.10 ^b
	Thigh	6.01 ± 0.08 ^a	23.45 ± 0.04 ^b	73.58 ± 0.51 ^c	3.33 ± 0.04 ^a	1.96 ± 0.07 ^b
Rearing groups	Fenced-in rearing system	6.10 ± 0.22	24.23 ± 0.11	75.79 ± 0.48	2.72 ± 0.68	1.71 ± 0.53
	Integrated rice-duck farming system	5.94 ± 0.11	23.31 ± 0.14	73.44 ± 0.46	2.80 ± 0.39	1.93 ± 0.09
Muscular tissues	Breast	5.96 ± 0.22	23.46 ± 0.41	74.68 ± 1.46	2.31 ± 0.25	1.57 ± 0.39
	Thigh	6.11 ± 0.19	24.37 ± 0.87	74.51 ± 1.06	3.36 ± 0.16	2.10 ± 0.18
<i>P</i> -value (two-way ANOVA)						
Rearing groups		0.000	0.000	0.000	0.000	0.000
Muscular tissues		0.046	0.000	0.008	0.000	0.000
Rearing groups * Muscular tissues		0.000	0.000	0.000	0.000	0.000

Values are mean ± SE, n = 12.

^{a-c}Within a column for each factor, different superscripts indicate significant differences ($P < 0.05$).

lysine (**Lys**) content of the ducks. However, the concentrations of essential amino acids (**EAA**), including valine (**Val**), methionine (**Met**), phenylalanine (**Phe**), histidine (**His**), and arginine (**Arg**), and non-essential amino acids, including tyrosine (**Tyr**), alanine (**Ala**), and proline (**Pro**), were significantly higher in ducks reared in the RD system ($P < 0.05$) than in ducks in the FPR system.

Fatty Acid Composition

The fatty acid profiles of the ducks are shown in Table 5. The RD system significantly altered the fatty acid profiles in the breast muscles of ducks. The breast muscle of ducks reared in the RD system had significantly higher ($P < 0.05$) saturated fatty acid (C12:0,

C14:0, C16:0, C18:0, and C21:0), monounsaturated fatty acid (C16:1, C18:1, and C18:1T), and polyunsaturated fatty acid (C22:2, C18:2n-6, and C22:6n3) content than that in the breast muscles of ducks reared in the FPR system. However, the oleic acid (C23:0) content of the breast muscles of the ducks was not significantly affected by the rearing systems.

DISCUSSION

The RD system affords ducks an environment that is similar to their natural habitat, allowing them to exhibit their natural behavior, thus, improving the welfare of the ducks. Several researchers have reported that improving bird welfare significantly improved the quality and flavor of poultry meat and meat products (Fanatico et al., 2005; Wang et al., 2009; Chen et al., 2013). In the present study, we found that the RD system improved the LW, carcass weight, carcass yield, and eviscerated yield of the ducks compared with that in

Table 4. Effects of the integrated rice-duck farming on amino acid composition of breast muscle of the Jinding ducks (% of dry meat weight).

Items	Group	
	Fenced-in rearing (FPR) system	Integrated rice-duck farming (RD) system
Flavor amino acid		
Asparagic acid (Asp)	1.88 ± 0.05	1.88 ± 0.04
Proline (Pro)	0.47 ± 0.03 ^a	0.54 ± 0.06 ^a
Arginine (Arg)	1.33 ± 0.02 ^a	1.39 ± 0.03 ^a
Serine (Ser)	0.78 ± 0.01	0.81 ± 0.01
Glutamic acid (Glu)	3.10 ± 0.04	3.20 ± 0.04
Glycine (Gly)	0.89 ± 0.02	0.90 ± 0.06
Alanine (Ala)	1.19 ± 0.03 ^a	1.26 ± 0.03 ^a
Cysteine (Cys)	0.27 ± 0.01	0.30 ± 0.05
Essential amino acid		
Valine (Val)	0.97 ± 0.02 ^a	1.02 ± 0.02 ^a
Threonine (Thr)	0.99 ± 0.02	0.99 ± 0.01
Isoleucine (Ile)	0.97 ± 0.03	0.98 ± 0.02
Leucine (Leu)	1.68 ± 0.04	1.74 ± 0.03
Tyrosine (Tyr)	0.80 ± 0.03 ^a	0.89 ± 0.02 ^a
Lysine (Lys)	1.83 ± 0.05	1.91 ± 0.03
Histidine (His)	0.62 ± 0.07 ^a	0.72 ± 0.04 ^a
Flavor amino acid and essential amino acid		
Phenylalanine (Phe) Δ^*	0.85 ± 0.04 ^a	0.93 ± 0.03 ^a
Methionine (Met) Δ^*	0.51 ± 0.04 ^a	0.59 ± 0.02 ^a

Values are mean ± SE, n = 12.

^aValues within a row with different superscripts differ significantly at $P < 0.05$.

Table 5. Effects of the integrated rice-duck farming on fatty acid composition of breast muscle of the Jinding ducks (mg/kg).

Items	Group	
	Fenced-in rearing (FPR) system	Integrated rice-duck farming (RD) system
Saturated fatty acid		
C12:0	16.42 ± 2.76 ^b	53.89 ± 12.94 ^a
C14:0	110.23 ± 30.00 ^b	263.01 ± 46.70 ^a
C16:0	1,681.16 ± 401.09 ^b	4,255.92 ± 950.38 ^a
C18:0	1,012.99 ± 118.80 ^b	1,977.84 ± 358.35 ^a
C21:0	795.36 ± 158.65 ^b	1,156.84 ± 177.36 ^a
C23:0	186.12 ± 42.65	219.47 ± 53.37
Monounsaturated fatty acid		
C16:1	59.06 ± 12.65 ^b	302.96 ± 67.66 ^a
C18:1	1,842.49 ± 340.54 ^b	6,301.39 ± 1383.04 ^a
C18:1T	87.52 ± 20.63 ^b	309.34 ± 74.48 ^a
Polyunsaturated fatty acid		
C22:2	134.28 ± 31.80 ^b	432.08 ± 103.27 ^a
C18:2n-6	809.65 ± 189.74 ^b	2,479.68 ± 577.24 ^a
C22:6n-3 (DHA)	117.63 ± 33.78 ^b	209.24 ± 50.66 ^a

Values are mean ± SE, n = 12.

^{a,b}Values within a row with different superscripts differ significantly at $P < 0.05$.

the FPR system. These results are consistent with the findings of [Li et al. \(2018\)](#), who reported that ducks reared in paddy fields had faster growth rates and better carcass yield than those reared in the FPR system. As found in previous researches, RD system is that the rice field provides the ducks with feeds, such as plants and insects. This may be one of the reasons why ducks fed into the paddy fields grew faster and more meat production than those fed in conventional rearing system. In addition, the gain yield of the thigh muscle of ducks reared in the RD system increased by 2.48%, indicating that the RD system may improve thigh muscle gain. This is possible because of the ducks are unable to exhibit their natural behaviors, such as swimming.

The effect of the RD system on meat quality was further investigated. [Gan \(2003\)](#) reported that the advantage of RD system is that the rice field provides the ducks with feeds, such as plants, insects, and planktons. In the present study, we found that the protein and moisture content of ducks reared under the RD system was significantly lower than that of ducks reared under FPR system; however, ducks in the RD system had significantly higher intramuscular fat content. The level of intramuscular fat plays an important role in the quality of poultry meat ([Hocquette et al., 2010](#)). Therefore, the RD system improved the intramuscular fat content and quality of duck meat.

Meat is a rich source of essential amino acids for human nutrition ([Pereira and Vicente, 2013](#)). Amino acids are the building blocks of proteins; therefore, their composition and content in meat represent the protein quality of meat. Additionally, some amino acids play key roles in the aroma and flavor of meats. For example, Arg, Leu, Ile, Val, Phe, Met, and His impart a bitter taste; Glu and Asp, a pleasant fresh taste; and Gly, Ala, and Ser, a sweet taste ([Lorenzo and Franco, 2012](#)). Prior to this study, there were no reports on the effects of RD system on amino acid composition and content in ducks. The results of the present study showed that the RD system significantly increased the concentration of essential amino acids in the breast muscle, including Tyr, Val, Met, Phe, His, Ala, Arg, and Pro. Since the RD system improved the concentration of essential amino acids in the ducks compared with that in the FPR system, our findings indicate that the RD system could improve the protein content and flavor of meat.

Fatty acids also play important roles in the flavor and taste of meats ([Wood et al., 2004](#)). [Bernacki \(2001\)](#) reported that duck meat is rich in unsaturated fatty acids, which makes it tasty and a high nutritive value. Similarly, our results indicated that the total fatty acid composition of the breast muscle of ducks, including some unsaturated fatty acids, was higher than the fatty composition of lamb, pork, and beef ([Enser et al., 1996](#)). Additionally, our findings revealed that the RD system increased the PUFA (C22:2, C18:2n-6, and C22:6n-3) content of the breast muscles of the ducks. A higher PUFA content was associated with an improved meat flavor and accelerated pigment, and lipid oxidation in meat ([Ponnampalam et al., 2012](#)). Furthermore, n-6 and

n-3 PUFAs are important components in food and diet. Food and diet with high ratios of n-6/n-3 PUFA or n-3 PUFA content may decrease the risk of metabolic syndrome and inflammation ([Simopoulos, 2008](#)). These results indicated that the RD system could improve meat quality, including nutritional value and flavor.

In conclusion, the findings of the present study provides sufficient evidence that the RD system improved the carcass traits, intramuscular fat and essential amino acids content, polyunsaturated fatty acids profile, and consequently, the nutritional value and flavor of duck meat. Therefore, RD system is an effective strategy to improve the welfare of ducks and their carcass quality.

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DISCLOSURES

The authors declare there was no conflict of interest.

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