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Effects of different rearing systems on growth performance, carcass traits, meat quality and serum biochemical parameters in Gaoyou ducks

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ABSTRACT

Context. The rearing system is a critical non-genetic factor that can considerably affect poultry production. **Aims.** This study examined the effects of floor rearing systems (FRS), net rearing systems and cage rearing systems (CRS) on growth performance, carcass traits, meat quality and serum biochemical parameters of Gaoyou ducks. **Methods.** A total of 450 healthy 22-day-old male Gaoyou ducks with similar average bodyweight were randomly divided into the FRS, net rearing systems and CRS groups. The experiment lasted from 22 to 84 days of age. **Key results.** CRS ducks had a higher final bodyweight, average daily feed intake and average daily gain, and a lower feed-to-gain ratio $P < 0.05$). FRS ducks had higher breast and gizzard yields and shear force, and lower drip loss and abdominal fat content ($P < 0.05$). Moreover, FRS ducks had significantly lower glucose, total protein and triglyceride, and higher high-density lipoprotein cholesterol levels ($P < 0.05$). **Conclusions.** CRS was beneficial to the growth performance of Gaoyou ducks, whereas FRS was beneficial to carcass traits, meat quality and some serum biochemical parameters. **Implications.** The results indicated that the CRS and FRS had their own advantages. Thus, an appropriate rearing system should be selected according to the production target and market demand.

Keywords: carcass yield, China, Gaoyou duck, growth performance, meat quality, poultry production, rearing system, serum biochemical parameters.

Introduction

China is a major producer and consumer of ducks (Damaziak *et al.* 2014; Zou *et al.* 2014; Tao *et al.* 2020), with an annual duck production exceeding 4.1 billion in 2021, accounting for approximately 68% of the word's total production (Hou and Liu 2021). Duck production may partly meet the increasing demand for animal protein. Gaoyou ducks, one of the most important and popular local duck breeds in China, is an excellent dual-purpose (lean type), has been farmed for thousands of years, and is protected in preserve areas and in preserve farms (Gaoyou Breeder Duck Farm; Zhao *et al.* 2015). It is highly regarded for its adaptability, resistance to roughage and being good at diving (Chen *et al.* 2010). Moreover, it not only shows fast growth, good meat quality and a high egg production rate, but is also well-known for its good production of double-yolk eggs (or even three yolks; Ming-liang *et al.* 2017; Zhang *et al.* 2021). The average bodyweight (BW) of the Gaoyou ducks is approximately 2.5 kg at 70 days old (Zhu *et al.* 2017; Shu *et al.* 2019). Its annual egg production of 500 days can reach 200, and the average egg weight is ~85 g (Zhang *et al.* 2011). Therefore, Gaoyou duck is mainly used for meat and egg breeding.

For a long time, floor rearing systems (FRS), net rearing systems (NRS) and cage rearing systems (CRS) have been the main rearing systems for poultry breeding and production in China (Li *et al.* 2017*a*; Zhang *et al.* 2018). The rearing system is a critical non-genetic factor that can considerably affect poultry production (Liu et al. 2011; Jin et al. 2019; Guo et al. 2020; Wan et al. 2021), and has remarkable effects on behaviour (El-Edel et al. 2015), health (Kolluri et al. 2014; Grafl et al. 2017; Zhao et al. 2019; Pinto da Rosa et al. 2021), gut microbial diversity (Hubert et al. 2019; Hou et al. 2020), mortality (Zhao et al. 2019), average daily feed intake (ADFI; Bai et al. 2022), carcass traits (Damaziak et al. 2014; Abo Ghanima et al. 2020; Bai et al. 2022), meat quality (Almasi et al. 2015; Chen et al. 2015; Michalczuk et al. 2018; Abo Ghanima et al. 2020; Huo et al. 2021), immunity (Abo Ghanima et al. 2020), feather conditions (Liu et al. 2022), semen (Du et al. 2021) and gene expression (Kolluri et al. 2014), and animal welfare is also an issue (Chen et al. 2015; Fu et al. 2015; Huo et al. 2021). For example, ducks raised under CRS condition had higher feed efficiency and better BW. In addition, CRS is an effective way to maximise the use of space and stocking density, reducing management costs and contaminant exposure compared with other rearing systems. However, ducks also experience considerable stress when reared in high density in confined spaces. In contrast, FRS is natural, environment friendly and animal welfare-promoting. This system has gained increasing attention due to improved duck comfort, and provided natural and organic poultry production for consumers, whereas this system has a certain negative impact on growth performance. Compared with ducks in the CRS and FRS group, ducks in the NRS group showed better plumage condition and foot-pad status.

Previous studies indicated that the growth performance of Pekin ducks (Abo Ghanima et al. 2020), Cherry Valley ducks (Chen et al. 2015), Muscovy ducks (Damaziak et al. 2014; Krunt et al. 2022) and Chaohu ducks (Zhang et al. 2018) was significantly affected by different rearing systems, but the results were variable. In addition, with the rapid development of the duck industry and the limited resources, such as land area, the rearing of ducks has gradually changed from outdoor or semi-outdoor to indoor systems (Zhang et al. 2019; Tao et al. 2020). However, the advantages and disadvantages of FRS, NRS and CRS on growth performance, carcass traits, meat quality and serum indexes of Gaoyou ducks have not been studied.

Therefore, the main purpose of the present study was to evaluate the effects of FRS, NRS and CRS on growth performance, carcass traits, meat quality and serum parameters of Gaoyou ducks in an effort to further understand their possible effects, and find a feasible and high-efficiency rearing system for Gaoyou ducks.

Materials and methods

The study protocol was approved by the Institutional Animal Care and Use Committee of the Jiangsu Institute of Poultry Science (Yangzhou, China; approval no. CAC-JIPS01342).

Animals and management

In the present study, 22-day-old ducks were used. First, 450 healthy ducks with similar BW were randomly divided into the FRS, NRS and CRS groups. There were five replicates per group and 30 ducks per replicate. For the FRS group, 150 ducks were kept in five indoor floor pens (4.2 m^2/pen, length × width: 2.1 × 2.0 m) with free access to outdoor concrete playgrounds (4.2 m^2/playground, length × width: 2.1 × 2.0 m) with a swimming pool (length × width × depth: 2 × 1 × 0.4 m, with water change every 3 days). The outside paddocks were separated by a 1.5-m high wall, a 1.0-m high plastic mesh and a plastic net at the top. Clean wood shavings (depth 5 cm) were used in the indoor area of all pens and cleaned weekly. For the NRS group, 150 ducks were placed on five stainless-steel frames covered with a flat plastic net with 0.8-cm diameter mesh holes (4.2 m^2/pen, length × width: 2.1 × 2.0 m) set at a height of 90 cm above the ground, and their droppings were cleaned weekly during the experiment period. Separation of the NRS replicate was achieved using wire fences. Ducks in the CRS group were placed in a four-tier cage stainless steel barrier equipped with linear feeders and automatic nipple drinking systems, and each cage included three birds. The dimensions of the cages were 70 (length) × 60 (width) × 45 cm (height). Each replicate consisted of 10 adjacent cages. The indoor house temperature (23 ± 2°C), relative humidity (RH: 60 ± 5.0%) and lighting period (23 h) of the three rearing systems were kept consistent, and the stocking density was 0.14 m^2/bird. Feed and water were offered *ad libitum*. Ducks were fed with the same commercial formula diet, which conformed to National Research Council nutrient recommendations (1994). The ingredients and nutrients of diets are listed in Table 1. The ducks were fed for 63 days. The total feed intake of each replicate was recorded weekly. Mortality was recorded when it occurred.

Growth performance

Growth performance parameters include initial BW, final BW, average daily gain (ADG), ADFI and feed-to-grain ratio (F/G). The initial BW of all ducks was measured at 22 days of age, and at 84 days of age, after a 12-h fast, we measured the final BW of all ducks. ADG, ADFI and F/G were calculated on a replicate basis.

Carcass traits and meat quality

On Day 84, individual duck BWs were recorded after fasting for 12 h. Four ducks were randomly selected for blood sample collection from each replicate, and then euthanised by electrical stunning followed by exsanguination. The partially eviscerated weight was measured after the feathers and nonedible viscera were removed. The full eviscerated weight was measured from the partially eviscerated weight after removal of the head, feet, heart, liver, gizzard, glandular stomach, lung and

Table 1. Ingredients and nutrients composition of basal diets for experimental ducks.

Items	Ages (days)	
	22–56	57–84
Ingredients (g/kg)		
Corn	638.4	643.4
Soybean meal	238.5	196.5
Wheat bran	47.5	60.0
Rapeseed meal	37.5	62.5
Limestone	10.1	10.3
Calcium phosphate	13.7	13.1
NaCl	3.0	3.0
D, L-Met	1.3	1.2
Premix[A]	10.0	10.0
Nutrient levels		
Metabolisable energy (Mcal/kg)	2.85	2.85
Crude protein (%)	17.25	16.13
Ca (%)	0.83	0.82
TP (%)	0.66	0.64
NPP (%)	0.38	0.37
Lysine (%)	0.83	0.74
Methionine (%)	0.40	0.38
Methionine + cysteine (%)	0.69	0.66

[A]Vitamin and mineral premix provided the following per kg of diet: vitamin A, 10 000 IU; vitamin D_3, 2625 IU; vitamin E, 20 IU; vitamin K_3, 2.6 mg; vitamin B_1, 2.45 mg; vitamin B_2, 10.25 mg; vitamin B_6, 3.2 mg; vitamin B_{12}, 0.025 mg; choline chloride, 1200 mg; biotin, 0.23 mg; nicotinic acid, 50 mg; folic acid, 1 mg; pantothenic acid, 18.25 mg; Fe, 60 mg; Cu, 10.2 mg; Mn, 85 mg; Zn, 40 mg; I, 0.38 mg; Se, 0.3 mg.
TP, total phosphorus; NPP, non-phytate phosphorus.

abdominal fat (including the leaf fat surrounding the cloaca and gizzard). Then, the breast muscle, gizzard, abdominal fat and leg muscle were all separated and weighed. The proportion of the partially eviscerated weight and eviscerated weight of the live BW was calculated. The proportions of the breast muscle, gizzard, abdominal fat and leg muscle were calculated as a percentage of the respective eviscerated weight.

The cooking loss, shear force, meat colour and pH were evaluated using the left breast muscle. Meanwhile, a sample of the right breast muscle was collected for drip loss and intramuscular fat assays. The cooking loss and drip loss values were measured as previously described (Wang *et al.* 2021*a*). The pH, meat colour and shear force were determined using a PHB-4 pH meter (Scientific Instruments, Shanghai, China), a tristimulus colorimeter (CR-410; Konica Minolta, Investment, Shanghai, China) and a digital texture analyser (C-LM3; Northeast Agricultural University, Harbin, China), respectively, following the methods of Wang *et al.* (2021*a*). For intramuscular fat measurements, samples were dried at 65°C, pulverised and examined using the Soxhlet method with diethyl ether as the extraction solvent.

Serum biochemical parameters

From each replicate, four ducks whose BWs were close to the average were randomly selected for blood sample collection. The serum glucose, albumin, uric acid, total phosphorus (TP), triacylglycerol (TG), total cholesterol, high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol levels were measured using commercial kits (Nanjing Jiancheng Institute of Bioengineering, Nanjing, China) in a digital spectrophotometer (Biomate 5; Thermo Electron Corporation, New York, NY, USA).

Statistical analyses

Statistical analysis of the data was performed using SPSS 20.0 for Windows statistical software (SPSS, Chicago, IL, USA). The data were analysed by a one-way ANOVA model followed by Duncan's multiple range analysis. The threshold for significance was set at $P < 0.05$. Data are expressed as the mean ± s.d.

Results

Growth performance

The growth performance of ducks under the three different rearing systems assessed in the present study is shown in Table 2. The rearing systems affected the final BW, ADFI and ADG, which were higher in the CRS group than in the NRS and FRS groups ($P < 0.05$). NRS and FRS ducks showed higher F/G values ($P < 0.05$). There were no significant differences in growth performance between the NRS and FRS groups ($P > 0.05$).

Carcass characteristics

The effects of different rearing systems on carcass characteristics are shown in Table 3. Ducks in the FRS group showed a higher percentage of breast muscle and lower abdominal fat content than those in the CRS and NRS groups ($P < 0.05$). In addition, compared with the CRS group, the FRS group displayed a higher ($P < 0.05$) percentage of gizzard. No significant differences were observed in terms of carcass characteristics between the CRS and NRS groups ($P > 0.05$). There were no differences in other carcass characteristics among the three groups ($P > 0.05$).

Meat quality

The effects of different rearing systems on meat quality are shown in Table 4. Ducks in the FRS group displayed higher shear force and lower drip loss than those in the CRS and

Table 2. Effects rearing system on growth performance of Gaoyou ducks.

Items	CRS	NRS	FRS	*P*-value
Initial BW (g)	614.98 ± 24.69	614.10 ± 26.34	613.49 ± 25.03	0.153
Final BW (g)	2609.90 ± 178.50a	2479.05 ± 151.86b	2420.66 ± 180.30b	0.021
ADG (g/day)	31.67 ± 2.11a	29.60 ± 1.68b	28.69 ± 1.40b	0.018
ADFI (g/day)	120.03 ± 8.00a	134.98 ± 7.67b	136.85 ± 6.68b	0.036
F/G (g/g)	3.79 ± 0.28b	4.56 ± 0.24a	4.77 ± 0.22a	0.012

a, b, Means in the same row with no common lowercase letter differ significantly ($P < 0.05$). Values are expressed as the mean ± s.d.
ADG, average daily gain; ADFI, average daily feed intake; F/G, feed to gain ratio; FRS, floor rearing systems; NRS, net rearing systems; CRS, cage rearing systems.

Table 3. Effects of rearing system on carcass traits of Gaoyou ducks.

Items (%)	CRS	NRS	FRS	*P*-value
Partially eviscerated carcass	82.70 ± 4.85	82.57 ± 5.03	83.39 ± 5.14	0.564
Full eviscerated percentage	72.15 ± 4.68	72.12 ± 5.05	73.26 ± 5.26	0.132
Breast muscle percentage	10.05 ± 0.55b	9.83 ± 0.58b	12.14 ± 0.65a	0.041
Leg muscle percentage	8.75 ± 0.55	8.86 ± 0.58	9.23 ± 0.65	0.185
Gizzard percentage	3.76 ± 0.24b	4.45 ± 0.28ab	5.28 ± 0.32a	0.025
Abdominal fat percentage	1.49 ± 0.10a	1.36 ± 0.08a	0.97 ± 0.064b	0.019

a, b, Means in the same row with no common lowercase letter differ significantly ($P < 0.05$). Values are expressed as the mean ± s.d. ($n = 20$).
FRS, floor rearing systems; NRS, net rearing systems; CRS, cage rearing systems.

Table 4. Comparison of meat quality traits among the FRS, NRS and CRS groups.

Item	CRS	NRS	FRS	*P*-value
Cooking loss (%)	27.35 ± 1.82	26.84 ± 1.74	27.16 ± 1.76	0.151
Shear force (N)	26.16 ± 1.42b	26.34 ± 1.50b	29.43 ± 1.72a	0.025
Drip loss (%)	1.26 ± 0.11a	1.19 ± 0.08a	1.02 ± 0.07b	0.042
IMF (%)	3.56 ± 0.25	3.42 ± 0.22	3.51 ± 0.27	0.342
L^*	38.15 ± 2.52a	35.66 ± 2.61b	35.87 ± 2.70b	0.036
a^*	11.26 ± 0.98	10.74 ± 0.76	11.68 ± 0.89	0.092
b^*	18.23 ± 1.25	18.45 ± 1.46	17.85 ± 1.39	0.275
$pH_{24\ h}$	5.76 ± 0.38	5.81 ± 0.42	5.82 ± 0.41	0.234

a, b, Means in the same row with no common lowercase letter differ significantly ($P < 0.05$). Values are expressed as the mean ± s.d. ($n = 20$).
IMF, intramuscular fat; L^*, lightness; a^*, redness; b^*, yellowness; FRS, floor rearing systems; NRS, net rearing systems; CRS, cage rearing systems.

NRS groups ($P < 0.05$). The L^* value of the breast muscle was higher in the CRS group than in the FRS and NRS groups ($P < 0.05$). There were no differences in other meat quality parameters among the three groups ($P > 0.05$).

Serum biochemical parameters

The effects of different rearing systems on serum biochemical parameters are shown in Table 5. The ducks in the FRS group exhibited lower serum glucose, TP and TG contents, and higher serum HDL-C contents than those in the CRS and NRS groups ($P < 0.05$). There were no significant differences in serum biochemical parameters between the CRS and NRS groups ($P > 0.05$). No significant effect on other serum biochemical parameters was observed ($P > 0.05$).

Discussion

Growth performance is an important index used to evaluate poultry production (Zhang *et al.* 2018). Previous studies have indicated that the growth performance indicators of ducks (Zhang *et al.* 2018; Bai *et al.* 2020, 2022; Zhu *et al.* 2020) and chickens (Dong *et al.* 2017; Jin *et al.* 2019; Wang *et al.* 2021*b*; Molee *et al.* 2022) were affected by rearing systems. Bai *et al.* (2022) and Zhu *et al.* (2020)

Table 5. Effects of rearing system on serum biochemical parameters of Gaoyou ducks.

Item	CRS	NRS	FRS	*P*-value
Glucose (mmol/L)	10.59 ± 0.63a	10.64 ± 0.72a	9.12 ± 0.61b	0.035
Albumin (g/L)	13.24 ± 0.82	14.51 ± 0.89	13.21 ± 0.90	0.682
Uric acid (μmol/L)	287.46 ± 20.02	295.54 ± 21.12	301.12 ± 24.23	0.423
Total protein (g/L)	39.32 ± 2.68a	39.60 ± 3.03a	36.25 ± 3.12b	0.028
TG (mmol/L)	1.12 ± 0.07a	1.03 ± 0.08a	0.71 ± 0.06b	0.044
TC (mmol/L)	4.35 ± 0.26	4.62 ± 0.30	4.29 ± 0.38	0.652
HDL-C (mmol/L)	2.76 ± 0.19b	2.58 ± 0.18b	3.87 ± 0.29a	0.015
LDL-C (mmol/L)	1.44 ± 0.09	1.57 ± 0.12	1.51 ± 0.10	0.463

a, b, Means in the same row with no common lowercase letter differ significantly ($P < 0.05$). Values are expressed as the mean ± s.d. ($n = 20$).
TG, triacylglycerol; TC, total cholesterol; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; FRS, floor rearing systems; NRS, net rearing systems; CRS, cage rearing systems.

found that in ducks, the CRS rearing had positive effects on the BW, BWt gain and ADFI. Dong *et al.* (2017) and Jin *et al.* (2019) found that in chickens, the CRS is advantageous in terms of productivity parameters, resulting in a significantly lower F/G than NRS or FRS. Similarly, our present study revealed that Gaoyou ducks reared in CRS had better final BW, ADFI and ADG compared with ducks reared in NRS and FRS ($P < 0.05$). In addition, ducks in the CRS group had lower F/G values than those in the NRS and FRS groups ($P < 0.05$). Thus, the CRS may improve the growth performance of Gaoyou ducks compared with the NRS and FRS. As is well known, poultry faeces are the infection sources of many diseases. Ducks raised in CRS have a lower chance of exposure to faeces and are in better health, which is conducive to promoting feed intake and growth (Liu *et al.* 2011). Furthermore, compared with CRS ducks, NRS and FRS ducks have more opportunities and space to peck, walk, run, and exhibit natural behaviours for physical exercise, which increases energy consumption, and in turn affects BW (Starčević *et al.* 2021; Wang *et al.* 2021*a*). In addition, free-range systems are subject to many inherent and uncontrollable factors (Pettersson *et al.* 2016), and they can cause a stress reaction and harm the growth performance of the poultry. For these reasons, it is easily to understand why ducks raised in CRS exhibit better growth performance.

Carcass traits are important indexes, because they may affect both consumers' purchase intention and poultry production profits (Zhang *et al.* 2018). Consistent with a previous study (Sari *et al.* 2013; Li *et al.* 2017*b*; Jin *et al.* 2019), we found that ducks reared in FRS had higher breast yield than those reared in CRS. However, Bai *et al.* (2022) reported that the rearing method had no significant effects on breast yield of a small-sized meat duck. Moreover, it was reported that different rearing methods had no significant effects on the carcass traits of birds (Chen *et al.* 2013). One possible explanation for the differences in findings of different studies was the use of different breeds with different growth rates. Interestingly, ducks in the FRS group had a higher gizzard yield and lower abdominal fat yield than those in the CRS group ($P < 0.05$). This result is consistent with that of Bai *et al.* (2022), who reported that ducks in the CRS group had a higher abdominal fat yield and lower gizzard yield than those in the FRS group. The lower abdominal fat content of FRS ducks noted in this study can probably be attributed to the fact that the FRS ducks had more opportunities and space to peck, walk, run, and exhibit natural behaviours, which may result in a greater expenditure of energy and consequently lower fat deposition.

In recent years, consumers have paid more attention to the demand for high-quality meat, especially in China. As is well known, local poultry breeds generally have better meat quality than modern commercial poultry breeds (Zhang *et al.* 2018). In the current study, meat quality was evaluated based on cooking loss, drip loss, shear force, intramuscular fat, meat colour and pH of the breast muscle. Water-holding capacity refers to the ability of meat to retain water during slaughter, storage, processing, and transportation, and is usually described in terms of drip loss. Shear force, which represents how easily the muscles can be chewed or cut, is one of the most important sensory characteristics of meat. Meat with a higher L^* value and lower a^* value is generally considered easier to increase the occurrence of pale, soft and exudative meat, and is positively related with higher drip loss. In the present study, ducks from the FRS group displayed a higher shear force and lower drip loss than those in the CRS and NRS groups ($P < 0.05$), which is consistent with previous studies (Yang *et al.* 2014; Li *et al.* 2017*b*). Under FRS conditions, substantial physical activity can promote the development and density of muscle fibres in poultry, which may be a major factor in increased shear force and decreased drip loss. This finding was explained by a higher myofibrillar protein-to-collagen ratio and muscle hypertrophy (Aalhus *et al.* 1991). In addition, FRS birds had more opportunities and space to peck, walk, run, and exhibit natural behaviours for physical exercise, which increases the percentage of (type I and type IIa) oxidative fibres (Oksbjerg *et al.* 1994). The L^* value of the breast muscle was higher in the CRS group than in the FRS and NRS groups ($P < 0.05$), indicating that FRS is beneficial to the meat quality of Gaoyou ducks. Similarly, it was demonstrated that Chaohu ducks and a small-sized meat duck reared in FRS had lower L^* values compared with ducks raised in NRS or CRS (Zhang et al. 2018; Bai et al. 2022).

Serum biochemical parameters are indicators of the physiological and metabolic state of animals, and are influenced by a variety of factors, including different rearing systems (Rehman et al. 2017; Zhang et al. 2018). Our results showed that serum glucose and TP contents were significantly higher in the CRS and NRS groups than in the FRS group, which may be related to the duck's reduced exercise under CRS and NRS conditions, as exercise can briefly accelerate glucose metabolism, increase protein synthesis and lead to loss of TP in the blood (Rehman et al. 2017). Furthermore, we suspect that CRS and NRS conditions may promote gluconeogenesis, which needs to be investigated in future studies. Similarly, it was demonstrated that Chaohu ducks and Wannan Yellow chickens reared in FRS had lower serum glucose and TP contents compared with birds reared in the NRS or CRS conditions (Zhang et al. 2018; Jin et al. 2019). Meanwhile, the present study showed that ducks reared in CRS and NRS conditions have higher serum TG levels, and lower HDL-C levels than those reared in FRS conditions ($P < 0.05$), which are all blood indicators that are closely related to fat deposition (Zhang et al. 2015). This result is consistent with that of Jin et al. (2019), who reported that ducks raised in CRS have higher serum TG levels and lower levels of HDL-C than those raised in FRS. TG is an ester derived from glycerol and fatty acids, and it is difficult for triacylglycerol-rich lipoproteins, such as chylomicrons and large very low-density lipoprotein cholesterol to cross the endothelial barrier and enter the arterial intima (Brighenti 2007). Low-density lipoprotein cholesterol plays an important role in the transportation of total cholesterol from the liver to other tissues, whereas HDL-C plays a key role in the transportation of total cholesterol from other tissues to the liver for excretion (Xiao et al. 2017). This indicates that the CRS and NRS significantly promotes fat deposition compared with that by the FRS, and were in accordance with the improved abdominal fat percentage content of ducks raised in CRS and NRS.

Conclusions

In conclusion, the CRS can improve the growth performance of Gaoyou ducks, affecting parameters, such as BW, ADG, ADFI and F/G, whereas the FRS is beneficial for carcass traits, meat quality and some serum biochemical parameters. Thus, CRS and FRS have their own advantages, and the appropriate rearing system should be chosen based on the production target and market demand.

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Data availability. The data presented in this study are available by reasonable request from the corresponding author.

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