Research Note: Effects of cage and floor rearing systems on growth performance, carcass traits, and meat quality in small-sized meat ducks

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ABSTRACT This study was performed to evaluate the effects of different rearing methods on the growth performance, carcass yield, and meat quality of small-sized meat ducks. A total of 420 healthy 21-day-old birds was randomly allocated to 2 treatment groups (6 replicates per treatment, sex ratio 1/1) and subjected to 2 rearing methods (furnished cage and plastic wire-floor) until d 63. Growth performance was measured in all birds. Three males and 3 females from each replicate were randomly selected and evaluated to determine the carcass yield and meat quality. In terms of growth performance, the rearing method affected the final body weight, average daily feed intake, and average daily gain, which were higher in the cage group ($P < 0.05$) than in the floor group, with a similar feed/gain in both groups. For slaughter performance, ducks in the cage group showed a higher abdominal fat yield and lower gizzard yield than those in the floor group ($P < 0.05$). For meat quality, the L* value of the breast muscle was higher in the cage group than in the floor group ($P < 0.05$). The pH recorded at 1 h was lower and pH recorded at 24 h was higher in the cage group ($P < 0.05$). The shear force and water loss rate were both lower in the cage group ($P < 0.05$). Additionally, the moisture content was lower and intramuscular fat content was higher in ducks fed in cages ($P < 0.05$). Our results indicate that the cage rearing system improved the growth performance and meat quality of ducks, which is appropriate for small-sized meat ducks.

Key words: meat duck, rearing system, growth performance, carcass yield, meat quality

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INTRODUCTION

Meat duck production is an important industry in China, with an annual output of more than 4.5 billion ducks, accounting for 68% of meat duck production worldwide in 2020 according to statistics from the Food and Agriculture Organization (Hou and Liu 2021). Most meat ducks in China are Pekin duck and its series products, which quickly grow to large sizes. However, because of consumer demand for high-quality products, small-sized meat ducks with good performance and excellent meat quality have been recognized. Compared to large-sized meat ducks (market age: 35−42 d, BW >3.0 kg), small-sized meat ducks (market age: 63−70 d, BW <2.0 kg) from the lineage of Chinese indigenous ducks exhibit good flavor, high nutrient level, high meat yield, long growth period, and low feed conversion rate. According to statistics from the China Animal Agriculture Association, the output of small-sized meat ducks is increasing annually, with a total production of approximately 750 million in 2020.

At present, there are no standards for the feeding, breeding, production, and rearing systems of small-sized meat ducks. A series of our work focuses on the rearing methods of small-sized meat ducks, including the effects of the cage, floor, net, fermentation bed, and other specific patterns under intensive management and breeding systems (Bai et al., 2020). The various rearing systems used for ducks can affect animal welfare, fattening performance, meat quality, stress resistance, and product price (Onbaşilar and Yalçin, 2017). Starčević et al. (2021) reported that ducks reared in an intensive system exhibited better growth performance and meat

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quality than those reared in a semi-intensive system. Huo et al. (2021) suggested that an integrated rice-duck farming system is an effective strategy for improving the welfare and meat quality of ducks compared to the floor pen rearing system. Zhang et al. (2019) found that the cage pattern affects the expression of inflammatory injury factors in ducks. Chen et al. (2018) observed that the growth rate and feather quality were better in the net group, whereas slaughter performance was better in the cage group. Li et al. (2016) suggested that the cage pattern is an appropriate choice for achieving high egg quality. Taken together, few studies have been performed to examine the effects of rearing systems on small-sized meat ducks.

The objective of our series work and the present study was to investigate the effects of cage and floor rearing systems on the growth performance, carcass yield, and meat quality of small-sized meat ducks.

MATERIALS AND METHODS

Ethics Statement

All experimental procedures were approved by the China Council on Animal Care and Ministry of Science and Technology of the People's Republic of China. All experimental ducks were managed and handled according to the guidelines established and approved by the Animal Care and Use Committee of Yangzhou University (approval number: 151-2014). All efforts were made to minimize animal suffering.

Animals and Experimental Design

A total of 500 mixed-sex 1-day-old small-sized meat ducks (H strain with black beak, black shank, and white feather) were obtained from the Ecolovo Group, China. For the first 3 wk, all ducks were raised in pens (15 birds/m^2) before the experimental period. At 21 d of age, after removing ducks with the largest and smallest BW and birds that were dead or had leg problems, the remaining 420 birds (210 males and 210 females) were selected for the experiment. All ducks were raised contemporaneously and housed in the same environment in an experimental facility until d 63. The formal experiment was carried out using 2 different rearing methods: a furnished cage rearing system and a plastic wire-floor rearing system with the same stocking density of 7 birds/m^2. All ducks were randomly divided into 2 treatment groups with a male/female ratio of 1:1. Each treatment had 6 replicates, which were balanced for the average initial BW. For the cage pattern, 210 birds were kept in 30 cages with a length, width, and depth of 140 × 70 × 38 cm (approximately 1 m^2 per cage). Each replicate consisted of 5 adjacent cages. The feed lines were placed on one side of the cage. A nipple drinking line was installed overhead in the middle of the cage (3−5 birds/nipple). For the floor pattern, 210 birds were kept in 6 plastic wire-floor pens (200 × 250 cm, 5 m^2). Each pen (replicate) was provided with 6 automatic drinking nipples and four feeders. The birdhouse was equipped with continuous lighting, and the temperature was initially set at 32°C and reduced gradually by 1°C per day until reaching 18°C. The relative humidity was initially set at 75% and reduced gradually by 5% per week until it reached 55%. During the experimental period, all ducks had free access to feed and water on an ad libitum basis, and the mortality and BW of dead birds in each treatment were recorded daily. All ducks were reared on the same diet (Table 1) from 22 to 63 d of age.

Growth Performance

The initial BW was recorded at the beginning of the experiment (22 days old). On d 63, after fasting for 12 h, the final BW, feed intake, and mortality were recorded for each replicate. Growth performance parameters, such as average daily feed intake (**ADFI**), average daily gain (**ADG**), and feed/gain (**F/G**) were calculated on a replicate basis and adjusted for mortality.

Carcass Characteristics

At the end of the experiment (63 days old), after 12 h of fasting, 3 males and 3 females from each replicate were randomly selected, weighed (live weight, **LW**), and then slaughtered in a poultry processing plant. The defeathered carcass, including the head and feet, was determined as the carcass weight (**CW**). The carcass was then eviscerated manually and weighed as the semi-eviscerated weight (**SEW**), which was measured as the

Table 1. Compositions and nutrients of the experimental diets.

Item	0−7 d	8−21 d	22−42 d	43−63 d
Ingredient (%)				
Corn	10.32	10.63	47.18	21.27
Wheat middling	15.41	15.00	6.89	20.00
Wheat bran	-	-	20.00	30.01
Rice noodles	35.21	34.99	-	10.00
Rice bran	15.81	15.00	3.00	5.00
Peanut meal	-	-	3.00	2.37
Corn gluten meal	-	-	5.00	-
Soybean meal	12.63	13.70	5.94	2.50
Nucleotide slag	2.00	2.00	-	-
Limestone powder	1.52	1.58	1.90	1.96
Calcium hydrogen phosphate	1.10	1.10	1.09	0.89
Compound premix[1]	6.00	6.00	6.00	6.00
Total	100	100	100	100
Formulated nutrient profile (g/kg)				
Crude protein	210.00	180.00	150.00	140.00
Crude fat	20.00	30.00	35.00	35.00
Crude fiber	50.00	50.00	70.00	70.00
Crude ash	70.00	80.00	100.00	100.00
Calcium	10.00	10.00	10.00	10.00
Phosphorus	6.00	5.50	4.50	4.50
Sodium chloride	6.00	6.00	6.00	6.00
Methionine	4.00	4.00	2.80	2.80
Moisture	140.00	140.00	140.00	140.00

[1]Supplied per kilogram of total 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 Yvkang, 0.15 g; C-811 enzyme, 0.30 g.

carcass weight after removing the trachea, esophagus, gastrointestinal tract, crop, spleen, pancreas, gallbladder, and gonads. The eviscerated weight (**EW**) was measured as the SEW after removing the head, feet, heart, liver, gizzard, glandular stomach, and abdominal fat. The carcass yield was calculated as the percentage of LW. The breast muscle, thigh muscle, gizzard, and abdominal fat pad, including the leaf fat surrounding the cloaca and gizzard, were separated and weighed, and their weights were denoted as **BMW, TMW, GW**, and **AFW**, respectively. The breast and thigh muscle yields were calculated as the percentage of EW. The lean meat percentage was calculated as (BMW +TMW)/EW, gizzard percentage was calculated as GW/(GW+EW), and abdominal fat percentage was calculated by AFW/(AFW + EW), following the standard issued by the Ministry of Agriculture and Rural Affairs (2004).

Meat Quality

The left breast and thigh muscles were collected to measure the meat color, pH, water loss rate (**WLR**), and shear force. The Commission Internationale de l'Eclairage color measurements, lightness (L*), redness (a*), and yellowness (b*), of the muscles were measured using a Chroma meter (CR-400, Konica Minolta, Tokyo, Japan). The pH value was recorded at 1 h (pH_1) and 24 h (pH_{24}, muscle was stored for 24 h at 4°C) post-slaughter using a pH meter (pH-STAR, Matthaus, Berlin, Germany). According to Tang et al. (2009), the WLR and shear force were measured using a meat quality pressure meter (Meat-1, Tenovo Food, Beijing, China) and a digital tenderness meter (C-LM3B, Tenovo Food), respectively.

The right muscle samples were used to measure the proximate composition. All exterior fat and connective tissue were removed before proximate analysis, which was performed to determine the percentage of moisture, protein, intramuscular fat (**IMF**), and collagen. Each sample was coarsely ground using a tabletop grinder to obtain a sample of approximately 200 g. Samples were analyzed using an Association of Official Analytical Chemists-approved (Anderson, 2007) near-infrared spectrophotometer (FOSS FoodScan 78800; Dedicated Analytical Solutions, Hilleroed, Denmark). Independent readings (n = 15) were taken for each sample and averaged to obtain the final reported values. All measurements were performed in triplicate.

Statistical Analysis

Statistical analyses were performed using SPSS for Windows (version 22.0, SPSS, Inc., Chicago, IL). The data was analyzed using one-way analysis of variance. Duncan's multiple comparison test was used to test the differences in significance. The data were assumed to be statistically significant at $P < 0.05$.

RESULTS AND DISCUSSION

Growth Performance

The effects of the rearing system on growth performance are presented in Table 2. There were five deaths in the cage group, with an average survival rate of 97.62%, whereas the average survival rate of the floor group was 97.14%. Therefore, there were no differences in mortality between the two rearing systems ($P > 0.05$), which is consistent with the results of Liu et al. (2011). The results revealed no difference in the initial BW ($P > 0.05$); however, the ducks in the cage group had higher final BW, ADFI, and ADG than those in the floor group during the experimental period ($P < 0.05$). In addition, ducks in the cage group had a slightly lower F/G ratio than those in the floor group, but the differences were not significant ($P > 0.05$). Sun et al. (2016) found no differences in the production performance of Muscovy ducks between cage and floor rearing systems, where the F/G ratio was also lower in the cage group. Dong et al. (2017) found that Xianju chickens from the cage rearing system had an advantage in terms of productivity parameters with a significantly lower F/G ratio than those from floor and net systems. The differences in the growth performance of ducks from the two rearing systems may be attributed to the different intensities of several animal activities, which are important in duck performance parameters. Ducks reared in the floor rearing system had more space to peck, walk, run, and exhibit natural behaviors; this resulted in high energy consumption, which limited growth, and is similar to the results of Starčević et al. (2021). Thus, the cage pattern may be more efficient and can improve the growth performance of small-sized meat ducks compared with the floor rearing system. Similarly, Zhu et al. (2020) found that the final BW of both male and female Gaoyou ducks was higher in the cage group than in the floor group. Wang et al. (2021) reported that cage-reared broilers exhibited better growth performance and higher evisceration percentages compared to floor-reared broilers.

Table 2. Effects of the rearing method on growth performance of small-sized meat ducks from 22 to 63 days of age.[1]

	Rearing system			
Items[2]	Cage	Floor	SEM	*P*-value
Initial BW (g)	613.20	626.33	4.040	0.133
Finial BW (g)	1968.41[a]	1914.89[b]	12.069	0.040
Average daily feed intake (g/bird per day)	175.77[a]	167.82[b]	1.188	<0.0001
Average daily gain (g/bird per day)	32.27[a]	30.68[b]	0.258	0.004
Feed/gain (g/g)	5.45	5.47	0.030	0.755
Mortality (%)	2.38	2.86	0.654	0.735

[a,b]Within a row for each factor, different superscripts indicate significant differences ($P < 0.05$).
[1]Data represent 6 replicates, 35 birds per replicate.
[2]Initial BW, initial body weight on d 22; final BW, final body weight on d 63.

Carcass Characteristics

Slaughter performance is among the most critical indicators of the economic profit of meat animals (Li et al., 2017b; Yu et al., 2020). Therefore, the effects of the rearing method on slaughter performance were investigated. The data for all carcass traits, including LW, CW, SEW, EW, BMW, TMW, GW, and AFW, were normal, with a carcass yield, semi-eviscerated yield, and eviscerated yield of >82%, 77%, and 70%, respectively. As shown in Table 3, the rearing method did not significantly affect slaughter performance, including carcass yield, semi-eviscerated yield, eviscerated yield, breast muscle yield, thigh muscle yield, and lean meat yield ($P > 0.05$), which is consistent with the results of Zhu et al. (2020). In our previous work, the rearing method only affected the thigh muscle yield, with no differences in most other parameters related to slaughter performance (Bai et al., 2020). However, Sari et al. (2013a) reported that native Turkish ducks showed better slaughter and carcass traits and feed conversion efficiency in the floor system than in the cage system. They also found that the LW and body measurements of Pekin ducks were higher on the floor than those in the cage system (Sari et al., 2013b). The reason for the differences between their results and ours may be related to the breed and growth rate of ducks; notably, the floor rearing system appears to be more suitable for large-sized meat ducks. Interestingly, ducks in the cage group had a higher abdominal fat yield and lower gizzard yield than those in the floor group ($P < 0.05$). Similarly, Liu et al. (2011) found that different rearing systems had significant effects on the abdominal fat yield and gizzard yield of geese. Castellini et al. (2002) and Lewis et al. (1997) considered that the loss of abdominal fat occurred because of greater motion when the animals were reared in systems with more space.

Table 3. Effects of the rearing method on carcass yield of small-sized meat ducks at 63 days of age.[1]

Items[2]	Rearing system		SEM	P-value
	Cage	Floor		
Carcass yield (%)	82.68	83.65	0.258	0.060
Semi-eviscerated yield (%)	77.28	77.93	0.310	0.300
Eviscerated yield (%)	70.70	71.05	0.320	0.592
Breast muscle yield (%)	13.51	13.36	0.153	0.638
Thigh muscle yield (%)	10.86	11.12	0.170	0.450
Lean meat yield (%)	24.37	24.48	0.258	0.826
Abdominal fat yield (%)	2.10[a]	1.76[b]	0.067	0.010
Gizzard yield (%)	3.79[b]	4.48[a]	0.070	<0.0001

[a,b]Within a row for each factor, different superscripts indicate significant differences ($P < 0.05$).

[1]Data represent 6 replicates, 6 birds per replicate.

[2]Carcass yield, % = carcass weight / live weight × 100; eviscerated yield, % = eviscerated weight / live weight × 100; semi-eviscerated yield, % = semi-eviscerated weight / live weight × 100; breast muscle yield, % = breast muscle weight / eviscerated weight × 100; thigh muscle yield, % = thigh muscle weight / eviscerated weight × 100; lean meat yield, % = (breast muscle weight + thigh muscle weight) / eviscerated weight × 100; abdominal fat yield, % = abdominal fat weight / (abdominal fat weight + eviscerated weight) × 100; gizzard yield, % = gizzard weight / (gizzard weight + eviscerated weight) × 100.

Meat Quality

Meat quality is essential for meat consumption, which is typically reflected by several characteristics such as the pH, WLR, meat color, shear force, and proximate composition. The effects of the rearing system on meat quality characteristics are shown in Table 4. In terms of physical traits, the L* value of the breast muscle was higher in the cage group than in the floor group ($P < 0.05$), indicating that the breast meat of ducks fed in cages was brighter. However, the rearing method had no significant effect on other meat color values of both the breast and thigh muscles ($P > 0.05$). The pH_1 was lower and pH_{24} was higher in the cage group ($P < 0.05$). Generally, the pH value of meat is directly related to not only muscle acidity, but also meat color, drip loss, and shear force (Attia et al., 2017). Although the pH of meat is influenced by numerous factors, the initial pH mostly depends on the different preslaughter treatments of animals (Rosenvold and Andersen, 2003). The lower initial pH in cage-reared ducks detected in the current study suggests that these animals were exposed to more stress during preslaughter procedures than those reared in the floor system. In addition, the pH value of the breast muscle was lower than that of the thigh muscle. Because the breast muscle contains more white muscle fibers (Type II) that have stronger acid production capacity after slaughter, while the thigh muscle contains more red muscle fibers (Type I) (Klont et al., 1998). Tenderness (typically defined by shear force) is considered as the most important quality. The shear force of both the breast and thigh muscles in the cage group was lower than that in the floor group ($P < 0.05$). Milošević et al. (2003) revealed that the meat of birds fed in a free-range rearing system had a greater shear force, because of their higher activity levels, which is consistent with our results. In addition, WLR is generally used to measure the water-holding capacity. A lower water-holding capacity in muscles can lead to the loss of nutrients and flavor, resulting in a decline in meat quality. In the present study, we found that the WLR of the breast muscle was lower in the cage group ($P < 0.05$), indicating a greater water-holding capacity and better meat quality.

Analysis of the proximate composition showed that the moisture, protein, and collagen contents in the breast muscle were approximately 1.5, 3, and 1% higher than those in the thigh muscle, respectively, whereas the IMF content of the breast muscle was approximately 3.5% lower than that of the thigh muscle. The moisture content of the breast muscle in the cage group was lower than that in the floor group ($P < 0.05$), indicating a higher nutrient content in the muscle. It is thought that a higher IMF content reflects the succulence, flavor, and nutritional value of meat (Bosselmann et al., 1995; Ruiz et al., 2001; Yang et al., 2015). In this study, the IMF contents of both the breast and thigh muscles in the cage group were greater than those in the floor group ($P < 0.05$), which is consistent with our previous work (Bao et al. 2019; Bai et al. 2020) and the work of Li et al. (2017a). The lower IMF content in floor-reared

Table 4. Effects of the rearing method on meat quality of small-sized meat ducks at 63 days of age.[1]

Items	Rearing system	Meat color[2]			pH[3]		Shear force (N)	Water loss rate[4] (%)	Proximate composition			
		L*	a*	b*	pH_1	pH_{24}			Moisture (%)	Protein (%)	Intramuscular fat (%)	Collagen (%)
Breast muscle	Cage	38.69^{a}	14.60	4.52	5.83^{b}	5.84^{a}	17.10^{b}	44.01^{b}	73.83^{b}	23.53	2.30^{a}	1.60
	Floor	36.96^{b}	15.27	4.48	5.90^{a}	5.70^{b}	20.72^{a}	48.56^{a}	74.43^{a}	23.58	1.86^{b}	1.80
	SEM	0.337	0.191	0.156	0.015	0.184	0.842	0.952	0.086	0.059	0.044	0.053
	P-value	0.009	0.076	0.900	0.011	<0.0001	<0.0001	0.016	<0.0001	0.670	<0.0001	0.057
Thigh muscle	Cage	39.55	15.70	7.14	6.69^{b}	6.74^{a}	15.20^{b}	37.33	72.40	20.60	5.96^{a}	0.70
	Floor	40.28	14.43	6.83	6.88^{a}	6.45^{b}	18.89^{a}	38.63	72.66	20.88	5.14^{b}	0.78
	SEM	0.560	0.374	0.262	0.021	0.021	0.702	0.759	0.175	0.091	0.204	0.025
	P-value	0.519	0.090	0.558	<0.0001	<0.0001	0.008	0.396	0.467	0.131	0.043	0.131

[a,b]Within a column for each factor, different superscripts indicate significant differences ($P < 0.05$).
[1]Data represent 6 replicates, 6 birds per replicate.
[2]L*, lightness; a*, redness; b*, yellowness.
[3]pH_1, pH value measured 1 h after slaughter; pH_{24}, pH value measured 24 h after slaughter.
[4]Water loss rate, % = ($W_{Initial}$ - W_{Final}) / $W_{Initial}$ × 100.

birds may have resulted from the increased activity which affected the energy balance and lipid metabolism. Additionally, the rearing method had no significant effect on the protein and collagen contents ($P > 0.05$). Similarly, there were no differences in the compositions of several chemicals, particularly the protein content, in the meat in ducks (Michalczuk et al., 2016,2017; Huo et al., 2021), chickens (Castellini et al., 2002; Bogosavljević-Bošković et al., 2012), and geese (Liu et al., 2011) reared in different systems.

In conclusion, our results support that the cage rearing system can improve the growth performance and several important meat quality traits, such as lightness, pH, shear force, WLR, moisture content, and IMF content, thus improving the nutritional value and economic value of meat ducks. The present study is a continuation of our previous work mentioned above, which confirms that the cage rearing system is a feasible and effective pattern for small-sized meat ducks.

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DISCLOSURES

The authors declare that they have no competing interests.

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