Effect of marketable age on proximate composition and nutritional profile of breast meat from Cherry Valley broiler ducks

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ABSTRACT Marketable age is an important determinant of meat quality. Cherry Valley duck (SM3 medium) is the most efficient Pekin-type duck and is the most widely farmed breed globally. However, whether marketable age determines the meat quality of Cherry Valley ducks is not well documented. The objective of this study was to investigate the effect of marketable age on the proximate composition and nutritional profile of breast meat from Cherry Valley broiler ducks. Ducks at 28, 38, 42, and 45 days old were selected and slaughtered, and their proximate composition, cholesterol and essential mineral compositions, and amino acids and fatty acid profile of breast meat lipid were determined. The results showed higher protein content and lower intramuscular fat content were observed in the 38-day-old ducks than in the 28-day-old birds ($P < 0.05$). Additionally, 38-day-old ducks contained higher Fe and Mg contents ($P < 0.05$), whereas 28-day-old birds had higher Zn and Ca contents ($P < 0.05$). The essential amino acid content in 38-day-old was about 95.29 g/kg, higher than that in 28-day-old birds ($P < 0.05$). The contents of C20:5 n-3, omega-6 polyunsaturated fatty acids, and polyunsaturated fatty acids were the highest in 38-day-old birds ($P < 0.05$), whereas the content of C20:4 n-6, DHA (C22:6 n-3), and saturated fatty acids in 28-day-old birds was the lowest ($P < 0.05$). Finally, a comprehensive evaluation model of multiple traits was developed by applying principal component analysis, and the meat nutrition of 38-day-old ducks was identified as the optimal. Taken together, the meat of 38-day-old ducks had an advantage in proximate composition, minerals content, essential amino acids, and fatty acids, and 38 d might be recommended as an appropriate marketable age to provide duck meat of high nutrition value.

Key words: marketable ages, meat quality, principal component analysis, amino acid, fatty acid

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INTRODUCTION

Duck meat is consumed worldwide, and the human consumption of duck meat continues to rise annually. China is not only a major country that produces duck meat but is also one of the major consumers of duck meat. Recent statistics released in 2020 showed that approximately 3.5 billion meat ducks were consumed in China, accounting for approximately 85% of the global production of meat ducks (Hou and Zhi, 2021). Consumers prefer duck meat because of its delicate flavor and texture, as well as its nutritional value because it has appreciable amounts of digestible protein, polyunsaturated fatty acids, essential vitamins, and mineral elements (Liu et al., 2013; Sohaib et al., 2015; Bai et al., 2020).

The marketable age or the slaughter date is an important determinant of meat quality in ducks (Poureslami et al., 2010; Liu et al., 2013). In China, some ducks are marketed before 30 days of age, whereas some are marketed after 49 days of age (Zhang et al., 2017; Zhou et al., 2017; Wang et al., 2020). Witak (2008) found that the protein and fat content in the breast and leg muscles of Peking duck meat had significantly higher nutrition value at 9 wk of age than in 7 and 8 wk of age. Kokoszyński et al. (2019; 2020) revealed that potassium, iron, cooking loss and protein contents in the breast muscles increase with age in Polish Peking ducks. The lactate and anserine contents also increased with age, whereas the amount of fumarate, betaine, taurine,

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inosine, and alkyl-substituted free amino acids decreased (Liu et al., 2013). These results suggest that the marketing age has a significant effect on meat nutrition in duck, but the effect varies among different breeds.

The Cherry Valley duck is the most efficient Pekin-type duck and is the most widely farmed breed worldwide (Cherry Valley Farms (UK) Limited, 2021). Ducks at 28 to 45 days old are usually sold as conventional meat products in Chinese duck industry. However, whether marketable age determines duck meat quality is not well documented. In this study, the 28-, 38-, 42-, and 45-day-old Cherry Valley ducks (SM3 medium) were slaughtered, and their proximate composition, cholesterol and essential mineral compositions, as well as their amino acid and fatty acids profile were determined. Furthermore, principal component analysis was applied to establish a more accurate and comprehensive model for evaluating the relationship between marketable age and the nutrient contents of commercial ducks. As a result, the data obtained will provide a more comprehensive understanding of the effects of marketable ages on the nutritional content of duck meat and provide alternatives for the reasonable marketable age of duck.

MATERIALS AND METHODS

Ethics Approval

All animal experiments were approved by the Institutional Animal Care and Use Committee of Yangzhou University (approval number: 151-2018). All procedures were performed in accordance with the Regulations for the Administration of Affairs Concerning Experimental Animals (Yangzhou University, China, 2012) and the Standards for the Administration of Experimental Practices (Jiangsu, China, 2008). Additionally, no endangered or protected species were included in this study.

Birds and Meat Sampling

A total of 400 Cherry Valley ducks (SM3 Medium) were raised in an enclosed windowless duck shed with fans in Jiangsu Suqian Zhongke Poultry Industry Co. LTD (Suqian, China). All ducks were raised in plastic mesh beds at 50 cm above the ground floor. The indoor temperature ranged from 4 to 25°C. Specifically, 30°C was maintained when ducks were 1 to 3 days old, and then gradually decreased to 25°C until the 14-day-old. The indoor humidity was maintained at 65 to 75%. The building was illuminated with warm white lights (840 lm), and the maximum lighting duration during the growth period was 14 h/d. Ducks were fed with complete starter and grower/finisher diets. The ingredient composition, basic chemical composition, energy value, and selected amino acids content of these diets are shown in Table 1. During the whole experimental period, all ducks had free access to feed and water. At each marketable age (28, 38, 42, and 45 days old), 3 male ducks and 3 female ducks with similar weight were randomly selected and anesthetized with pentobarbital sodium, and then sacrificed by via jugular puncture after fasting for 12 h. Duck breast muscle samples were immediately collected and stored at 4°C for meat quality measurement, and a portion of samples were placed in 4% formaldehyde for paraffin section preparation.

Table 1. Ingredients and nutrient levels of the diets for ducks.

	Starter	Grower/finisher
Ingredients (g/kg of fed))	1 to 21 d	22 to 45 d
Corn	560.00	741.00
Soybean meal	275.00	184.00
Wheat meal	100.00	8.70
Fish meal	50.00	55.00
Limestone	10.00	7.00
Salt	2.40	2.40
DL-Methionine	1.60	0.90
Vitamin−mineral premix	1.00	1.00
Total	1000	1000
Nutrient levels (%)		
Metabolizable energy (MJ/kg of fed)	12.34	12.97
Crude protein	22.00	18.00
Lysine	1.23	0.94
Methionine	0.52	0.4
Methionine + cysteine	0.85	0.66
Tryptophan	0.29	0.23
Threonine	0.91	0.76
Calcium	0.87	0.75
Total phosphorus[1]	0.41	0.39

[1]Supplied per kilogram of total diet: Cu ($CuSO_4 \cdot 5H_2O$), 10 mg; Fe ($FeSO_4 \cdot 7H_2O$), 60 mg; Zn (ZnO), 60 mg; Mn ($MnSO_4 \cdot H_2O$), 80 mg; Se ($NaSeO_3$), 0.3 mg; I (KI), 0.2 mg; choline chloride, 750 mg; vitamin A (retinyl acetate), 8,000 IU; vitaminD_3 (Cholcalciferol), 3,000 IU; vitamin E (DL-α-tocopheryl acetate), 20 IU; vitamin K_3 (menadione sodium bisulphate), 2 mg; thiamin (thiamin mononitrate), 1.5 mg; riboflavin, 4 mg; pyridoxine hydrochloride, 3 mg; cobalamin, 0.02 mg; calcium-D-pantothenate, 10 mg; nicotinic acid, 50 mg; folic acid, 1 mg; and biotin, 0.15 mg.

Determination of Proximate Composition

Breast muscle samples from each treatment were collected to measure the proximate composition. All exterior fat and connective tissue were removed before the proximate analysis, which was performed to measure the percentage of protein and intramuscular fat (**IMF**) in each sample. Each sample was coarsely ground using a tabletop grinder to obtain a sample of approximately 200 g. An Association of Official Analytical Chemists −approved (Anderson, 2007) near-infrared spectrophotometer (FOSS Food Scan 78,800; Dedicated Analytical Solutions, Hillerod, Denmark) was applied to analyze the samples. Independent readings (n, 5, 15) were taken from each sample and were averaged to obtain the final reported values. All measurements were performed in triplicates.

Histological Features of Duck Breast Muscle Fibers

For conventional histology analysis, duck breast muscle samples were embedded in paraffin, and 8−μm−thick serial sections were prepared and stained with hemotoxylin and eosin according to standard protocols. All sections were analyzed using Olympus BX51 microscope (Olympus, Tokyo, Japan). Finally, the

cross-sectional area (**CSA**) of breast muscle fibers was measured using ImagePro Plus software (Media Cybernetics, MD).

Determination of Minerals Content

The content of minerals, including zinc, iron, magnesium, and calcium, in duck breast muscles was analyzed. Breast muscle samples weighing approximately 2 g (accurate to 0.001 g) were cut and placed in a digestion tube containing perchloric acid. Next, 30 mL of concentrated nitric acid (perchloric acid to concentrated nitric acid ratio 1:4) was added, and the samples were covered. The samples were then allowed to digest by placing on a heating plate at 160°C for 2 h and then allowed to cool naturally. After cooling, the tubes were filled to a volume of 50 mL with ultrapure water and incubated for 15 min. Next, 10 mL of solution was measured using an atomic absorption spectrophotometer (PerkinElmer Optima 7300 V ICP, PerkinElmer, Waltham, MA).

Amino Acid Profile of Duck Breast Muscle

Duck breast muscle samples (2 g) were collected and placed in 20 mL hydrolysis tubes containing 16 mL of 6 mol/L HCl. The samples were then subjected to vacuum degassing for 30 min, and then the tubes were filled with nitrogen gas and were sealed. Thereafter, the samples were incubated at 110°C for 22 to 24 h for hydrolysis. After the samples were cooled, they were transferred nondestructively to 50 mL capacity bottles with deionized water. Next, 1 mL of the hydrolysate was extracted, the acids were removed under vacuum, and the samples were dried. Thereafter, 1 mL of water was added, and the tubes were pumped dry, followed by the addition of 1 mL of water and subsequent draining. To fully dissolve the samples, 1 mL HCl (0.02 mol/L) was added. Subsequently, 500 μL of the above solution was measured in a 5 mL centrifuge tube, followed by the addition of 250 μL triethylamine acetonitrile (1 mol/L) and 25 μL phenyl isothiocyanate acetonitrile (0.1 mol/L). The resulting solution was evenly mixed and allowed to rest for 1 h. Next, 2 mL of n-hexane was added to the mixture, and it was allowed to rest for 10 min. Finally, all samples were sifted through a 0.22 water-based membrane and separated using an amino acid automatic analyzer (Hitachi L-8900, Hitachi, Tokyo, Japan).

Determination of Cholesterol

To determine the content of cholesterol, 1 g (accurate to 0.001 g) of the sample was weighed and placed into a 50-mL plugged test tube. Next, 10 mL of potassium hydroxide (1.0 mol/mL) and 10 mL of absolute ethanol were added, and the solution was thoroughly mixed. The samples were added into a condensation tube and saponified for 1 h at 90°C until the solution was clear. Then, the solution was transferred into a 50 mL separatory funnel, and 10 mL of ether was added to the separatory funnel. The funnel was shaken gently, and the water layer was poured into the plugged test tube. Next, 10 mL of ether was added to the plugged test tube, and gently shaken, and the ether layer was transferred to a separatory funnel. Subsequently, 10 mL of ether was extracted from the plugged test tube, and the ether layer was moved into a separatory funnel. The solution in the separatory funnel was washed 3 times with water (15 mL). After stratification, the aqueous layer was discarded. The ether layer was dried with anhydrous sodium sulfate (20 g), and then transferred to a fresh plugged test tube. After drying with nitrogen gas, the solution was dissolved in 1 mL of anhydrous ethanol and passed through a 0.45-mm filter membrane for gas chromatography analysis (Agilent 7890a, Agilent Technologies, Santa Clara, CA).

Fatty Acid Profile of Duck Breast Muscle

A total of 2 g (accurate to 0.001 g) dried breast muscle sample was weighed, and the crude fat was extracted with a Soxhlet extractor (FOSS Soxtec 2050; Hillerod, Denmark). Subsequently, 8 mL of sodium hydroxide methanol and defatted zeolite were added. One condensation tube was fixed to the flask containing the sample until the oil droplets disappeared. The reflux speed was maintained at 45 s/drop for 8 min. A proper amount of boron trifluoride−methanol solution was added to the upper part of the condensation tube using a pipette or an automatic liquid feeder. The solution was then boiled for 3 min. An appropriate amount of isooctane was added to the upper part of the condensation tube, heating was stopped, and the condensation tube was removed. Then, 20 mL of saturated NaCl solution was added immediately before the flask was cooled. The solution was then vigorously shaken for 20 s, and a saturated NaCl solution was added to the neck of the flask at the same time. Next, 2 mL of the upper isooctane layer was transferred into a test tube, and its contents were dehydrated by adding an appropriate amount of anhydrous sodium sulfate. The solution was then filtered using a 0.45-mm filter membrane for gas chromatography analysis (GC; Model 7890A, Agilent Technologies, Palo Alto, CA).

The gas chromatograph was equipped with a capillary column (30 mm × 0.25 mm innowax, 0.25 film thickness; Agilent Technologies). Nitrogen (1.0 mL/min) was used as the carrier gas, and a split/splitless injector was used at a split/splitless ratio of 30:1. The injector and detector temperatures were maintained at 250°C and 300°C, respectively. The column oven temperature was maintained at 140°C for 5 min after sample injection and was programmed to increase from 140 to 220°C at a rate of 5°C/min, maintaining the temperature at 220°C for 16 min. Finally, the separation conditions of the fatty acid methyl esters were recorded using the GC Chem Station software (Agilent Technologies). The fatty acids in muscle samples were identified by comparing the fatty

Table 2. Effects of marketable ages on proximate composition of breast meat from Cherry Valley broiler ducks.

Items	28 D	38 D	42 D	45 D
Protein (%)	20.43 ± 0.17^{d}	22.62 ± 0.54^{a}	21.90 ± 0.34^{b}	21.54 ± 0.27^{c}
Intramuscular fat (%)	3.46 ± 0.44^{a}	2.05 ± 0.10^{b}	1.73 ± 0.09^{c}	1.65 ± 0.15^{c}

[a-d]Mean values of traits in rows, marked with the different letters indicate significant differences ($P < 0.05$).

acid methyl ester profiles with the profiles of fatty acid methyl ester standards (Supelco, 37 Component fatty acid methyl ester mix C4−C24, catalog no. 47885-U, Supelco, Bellefonte, PA). The results were recorded as percentages of total fatty acid content.

Statistical Analysis

Statistical analysis was conducted using one-way analysis of variance (**ANOVA**) with SPSS software (version 19.0; SPSS, Inc., Chicago, IL). The general linear model describing the ANOVA was given as $x_{ij} = \mu + \alpha_i + \varepsilon_{ij}$, where x_{ij} is the observed measure, μ is the overall mean, α_i is the fixed effect of age, and ε_{ij} is the residual random error. Significant difference was considered as $P < 0.05$, and the means in each group were compared using Duncan's test. The comprehensive evaluation model of principal component analysis (**PCA**) was established.

RESULTS

Effect of Marketable Age on Proximate Composition of Duck Breast Meat

The data on protein and IMF contents of the breast meat of the Cherry Valley duck are summarized in Table 2. The protein content of duck breast meat slaughtered and collected at 38-day-old marketable age (38 D) was higher than that at other marketable ages ($P < 0.05$). The IMF content of duck breast muscle showed a downward trend with age, specifically, the content in 42 D and 45 D groups was significantly lower than that in the 28 D and 38 D groups ($P < 0.05$).

Effect of Marketable Age on Cross-Sectional Area of Duck Breast Muscle Fiber

The histological features and measurement statistics of the breast muscle fiber cross-sectional area were shown in Figure 1. As expected, the cross-sectional area of duck breast muscle fiber increased with age at slaughtered in the 4 groups (28 D, 38 D, 42 D, 48 D), specifically, increased sharply from 339.25 μm^2 (28 D) to 943.63 μm^2 (45 D). Significant differences were observed in the cross-sectional area between the ducks in the 28, 38, 42, and 45 D groups ($P < 0.05$), whereas no difference was observed between the 42 D and 45 D ducks, indicating that the rate of increase in muscle cross-sectional area might decrease with age.

Effect of Marketable Age on Mineral Composition of Duck Breast Meat

Mineral compositions of duck breast meat at different marketable ages were shown in Table 3. Significant differences were observed in mineral contents, including that of Fe, Zn, Ca, and Mg, between marketable ages. The content of Fe and Mg in duck breast meat collected in the 38 D group were significantly higher than that the other marketable ages ($P < 0.05$), and a downward trend in Fe and Mg content was observed in marketable

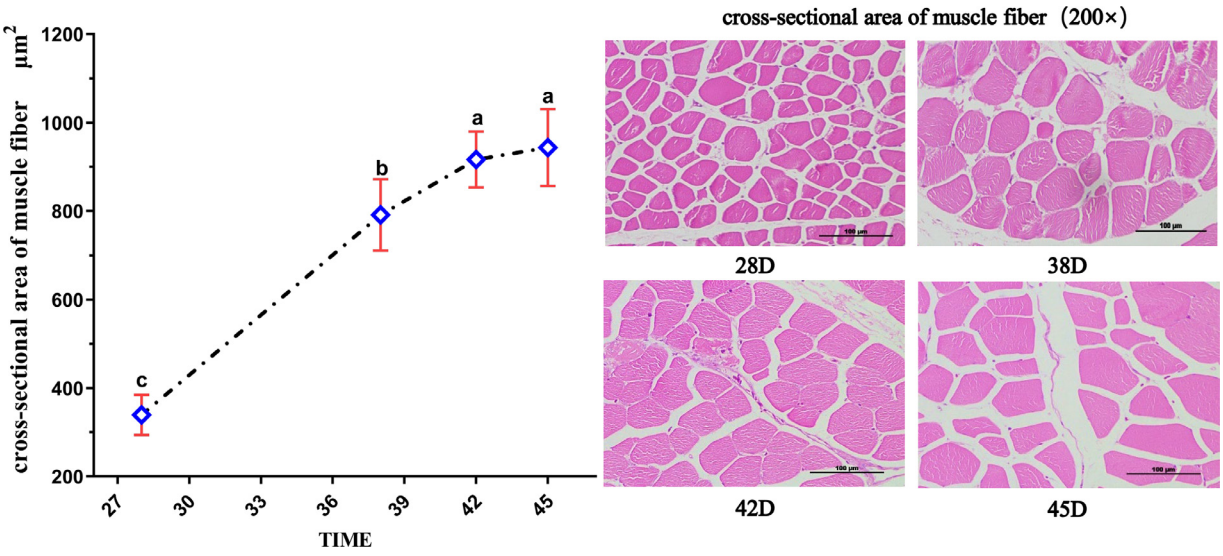

Figure 1. Effect of marketable age on the cross-sectional area of breast muscle fiber in Cherry Valley ducks. The red vertical bars represent the standard errors. Different letters (a, b, c) represent statistically significant differences ($P < 0.05$).

Table 3. Contents of some minerale in mg on 100 g meat from breast of Cherry Valley broiler ducks.

Items	28 D	38 D	42 D	45 D
Fe (mg/100g)	4.40 ± 0.23^{a}	4.40 ± 0.21^{a}	4.21 ± 0.10^{b}	3.35 ± 0.15^{c}
Zn (mg/100g)	1.91 ± 0.20^{a}	1.54 ± 0.08^{b}	1.47 ± 0.06^{b}	1.31 ± 0.04^{c}
Ca (mg/100g)	18.18 ± 1.58^{a}	10.98 ± 2.89^{b}	10.08 ± 2.60^{b}	7.67 ± 1.33^{c}
Mg (mg/100g)	25.58 ± 0.54^{c}	29.31 ± 0.44^{a}	28.25 ± 0.79^{b}	27.88 ± 0.88^{b}

[a-c]Mean values of traits in rows, marked with the different letters indicate significant differences ($P < 0.05$).

ages above 38D. Nevertheless, compared with other marketable ages, both of Zn and Ca in breast meat showed a higher content at 28 D marketable age ($P < 0.05$), and a significant decreasing tendency was shown over the study period.

Effect of Marketable Age on Amino Acid Profile of Duck Breast Meat

The amino acid composition of duck breast meat was listed in Table 4, which shows the dependency between marketable age and amino acid proportion. Compared with the other nonessential amino acids, Glu presented the highest proportion followed by Asp and Arg, particularly in the 38 D marketable age ($P < 0.05$). In contrast, contents of Pro, Ser, and Gly were obviously lower no matter at which marketable ages, and no more than 10 g/kg of meat. In addition, all the nonessential amino acids listed below had the highest proportion at 38 D marketable age. In terms of essential amino acids (**EAA**), most amino acids including Leu, Lys, Val, Phe, Ile, Tyr, and Thr were in a higher proportion at 38 D than the 28 age ($P < 0.05$). Similarly, the concentration of total flavor amino acids (**FAA**), sum of Glu, Pro, Ala, Ser, Gly, and Lie (Ma et al., 2020; Li et al., 2020), at 38 D market age was significantly higher than the 28 D marketable age ($P < 0.05$), which was observed to be 79.95 g/kg of meat.

Effect of Marketable Age on Cholesterol Content of Duck Breast Meat

Table 5 presents the cholesterol levels in duck breast meat at different marketable ages. A declining trend was observed in the cholesterol content from 28 to 45 D, and a significant difference was observed between 28 D and other marketable ages ($P < 0.05$). Additionally, the cholesterol proportion remained stable from 38 D to 42 D, and then dropped dramatically to about 90.16 mg/100 g of meat at 45 D ($P < 0.05$).

Effect of Marketable Age on Fatty Acid Profile of Duck Breast Meat

A considerable variation in fatty acid composition of duck breast meat was observed depending on the marketable ages (Table 6). The concentration of stearic acid (C18:0) at the 38 D and 42 D marketable ages was significantly higher than that at the 28 D and 45 D marketable ages ($P < 0.01$), whereas palmitic acid (C16:0) presented the lowest proportion at the 38 D marketable age compared to that in other ages ($P < 0.01$). It is

Table 4. Contents of amino acids of breast meat from Cherry Valley broiler ducks.

Amino acid	28 D	38 D	42 D	45 D
Nonessential amino acid				
Glu △	24.73 ± 5.73^{b}	33.72 ± 1.61^{a}	26.85 ± 0.21^{ab}	29.60 ± 6.22^{ab}
Asp	11.73 ± 6.44	17.05 ± 2.90	13.98 ± 2.95	16.55 ± 2.28
Arg	9.57 ± 3.12^{b}	14.37 ± 0.88^{a}	12.93 ± 2.38^{b}	13.03 ± 1.16^{b}
Pro △	6.99 ± 0.67^{b}	8.50 ± 0.41^{a}	8.17 ± 0.60^{ab}	$7.68 \pm 0.73a^{b}$
Ala △	8.86 ± 1.26^{b}	11.45 ± 0.41^{a}	10.48 ± 1.20^{ab}	10.52 ± 0.78^{ab}
Ser △	5.94 ± 1.44	7.68 ± 0.36	6.99 ± 1.07	7.00 ± 0.64
Gly △	7.79 ± 1.02	9.18 ± 0.64	8.38 ± 0.64	8.17 ± 0.85
Essential amino acid				
Leu	13.93 ± 1.57^{b}	17.45 ± 0.43^{a}	16.30 ± 1.54^{ab}	16.17 ± 1.09^{ab}
Lys	12.90 ± 3.09^{b}	18.20 ± 0.52^{a}	15.03 ± 1.13^{ab}	16.49 ± 1.05^{ab}
Val	7.64 ± 1.11^{b}	10.09 ± 0.20^{a}	9.03 ± 1.19^{ab}	9.95 ± 1.11^{ab}
Phe	6.43 ± 0.99^{b}	8.38 ± 0.26^{a}	7.59 ± 1.02^{ab}	7.96 ± 0.99^{ab}
Ile △	7.45 ± 1.04^{b}	9.98 ± 0.13^{a}	8.98 ± 1.15^{ab}	9.42 ± 0.76^{ab}
Tyr	5.78 ± 1.04^{b}	7.65 ± 0.17^{a}	7.06 ± 1.10^{ab}	7.21 ± 0.64^{ab}
Thr	6.23 ± 1.37^{b}	8.49 ± 0.31^{a}	7.70 ± 1.12^{ab}	7.93 ± 0.52^{ab}
His	3.68 ± 2.13	5.41 ± 0.46	3.52 ± 0.49	4.94 ± 0.63
Met	4.56 ± 0.69	6.00 ± 0.44	5.04 ± 1.02	6.47 ± 1.70
Cys	2.94 ± 1.37	4.63 ± 1.88	4.54 ± 1.52	3.90 ± 0.52
∑EAA	77.54 ± 9.98^{b}	95.29 ± 5.21^{a}	85.75 ± 9.03^{ab}	90.44 ± 7.60^{ab}
∑FAA	65.76 ± 7.15^{b}	79.95 ± 3.86^{a}	69.85 ± 4.69^{ab}	72.39 ± 9.26^{ab}

Note: △ represents flavor amino acids. ∑EAA, sum of Leu, Lys, Val, Phe, Ile, Tyr, Thr, His, Met, Cys. ∑FAA, sum of Glu, Pro, Ala, Ser, Gly, Ile.

Abbreviations: Asp, Aspartic acid; Arg, Arginine; Cys, Cystine; Ala − Alanine; Glu, glutamic acid; Gly, Glycine; His, Histidine; Ile, Lsoleucine; Leu, Leucine; Lys, Lysine; Met, Methionine; Phe, Phenylalanine; Pro, Proline; Ser, Serine; Tyr, Tyrosine; Thr, Threonine; Val, Valine.

[a-b]Mean values of traits in rows, marked with the different letters indicate significant differences ($P < 0.05$).

Table 5. Cholesterol content in mg on 100 g of breast meat from Cherry Valley broiler ducks.

Items	28 D	38 D	42 D	45 D
Cholesterol (mg/100 g)	136.26 ± 5.77^{a}	103.05 ± 4.82^{b}	104.27 ± 7.64^{b}	90.16 ± 7.73^{c}

[a-c]Mean values of traits in rows, marked with the different letters indicate significant differences ($P < 0.05$).

noteworthy that oleic acid (C18:1) presented the highest proportion in all four marketable ages compared to the other fatty acids in breast meat, moreover, the proportion decreased with age ($P<0.01$). The contents of C16:1 and C18:3n-3 fatty acids at 28 D were the highest, and the C20:1 content at 42 D was the highest compared to that in all the other ages ($P<0.01$). Additionally, duck breast meat contained a smaller amount of C20:3 n-6, C20:5 n-3 and C22:6 n-3 (DHA) at the 28 D marketable age than that in the other marketable ages ($P < 0.01$). Furthermore, there was a sharp increase in the proportion of C20:4 n-6 fatty acids (arachidonic acid) from 28 to 38 D ($P < 0.01$), after which the proportion began to stabilize. An upward trend in the proportion of saturated fatty acids from 35.17% (28 D) to 40.2% (38 D) ($P < 0.01$), was also observed, which stabilized in the ducks of the other groups. However, a significant decrease was observed in the proportion of MUFA between 28 and 38 D ($P < 0.01$). In contrast, an upward trend was revealed in the concentration of PUFA, omega 6 polyunsaturated fatty acids (n-6) and omega 3 polyunsaturated fatty acids (n-3) from 28 D to 38D, respectively ($P < 0.01$), but declined successively, except for n-3.

Establishment of Comprehensive Analysis and Evaluation Model

A comprehensive multi-index evaluation model of duck meat quality of different marketable ages was established based on PCA using SPSS software. After standardizing the data for each trait, the characteristic root and variance contribution rates of each principal component were obtained. The characteristic roots and variance contribution rates of the first and second principal components were 5.604 and 2.689 and 56.04 and 26.89%, respectively (Figure 2). Furthermore, the cumulative contribution rate reached 82.93%, which revealed that the information contained in all original

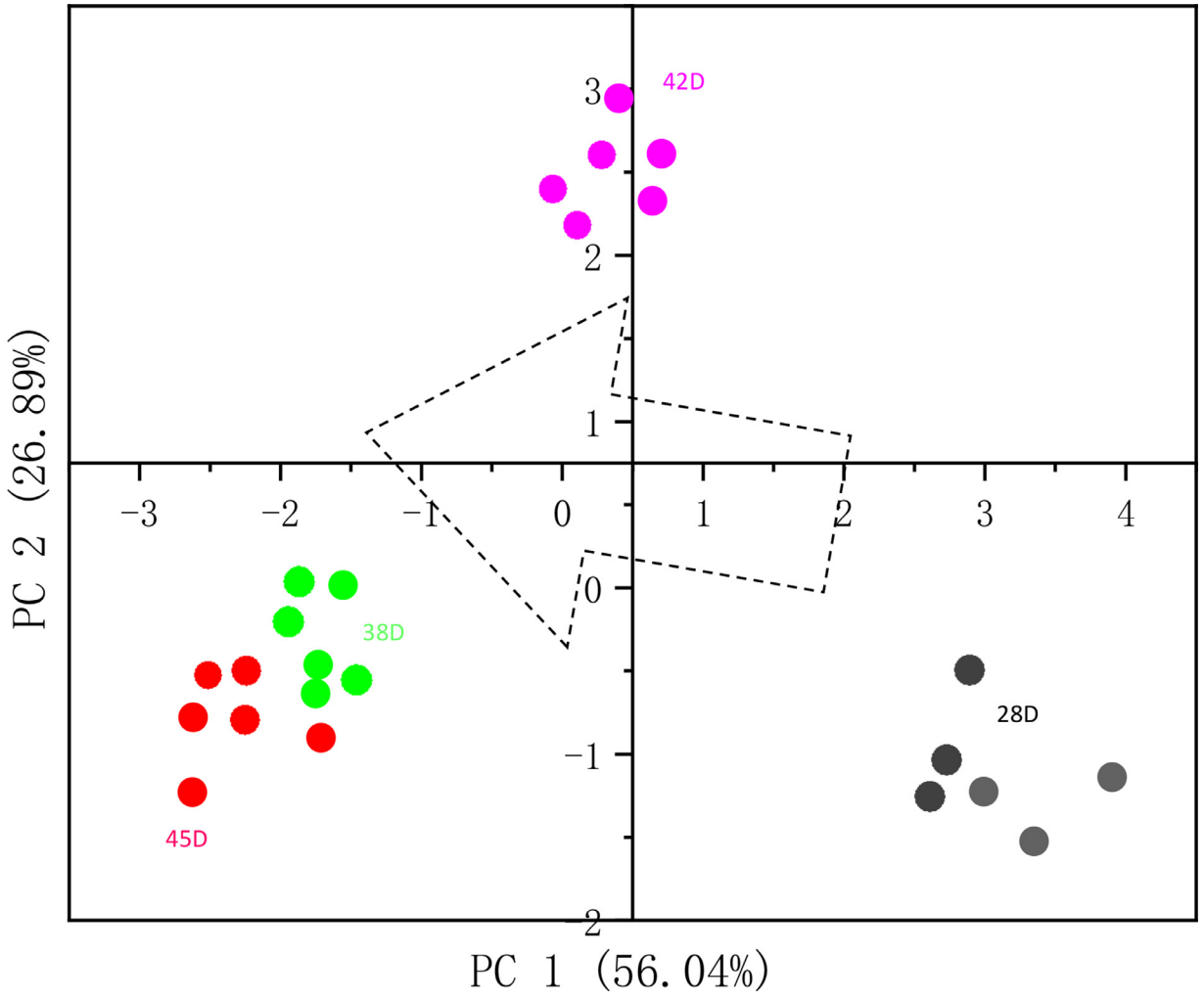

Figure 2. Principal component analysis (PCA) of the nutrient content of duck breast meat with marketable ages. 28 D: black stars; 38 D: green circles; 42 D: pink circles; 45 D: red circles.

Table 6. Fatty acids content (%) in lipid breast meat from Cherry Valley broiler ducks.

Fatty acids	28 D	38 D	42 D	45 D	*P*-value
C14:0	0.53 ± 0.04	0.36 ± 0.07	0.76 ± 0.68	0.62 ± 0.22	0.32
C14:1	0.10 ± 0.08^{c}	0.15 ± 0.07^{bc}	0.32 ± 0.23^{ab}	0.39 ± 0.18^{a}	0.02
C16:0	24.82 ± 0.42^{a}	22.32 ± 1.38^{b}	23.86 ± 1.65^{a}	24.29 ± 0.75^{a}	<0.01
C16:1	2.35 ± 0.03^{a}	1.40 ± 0.22 ^{c}	1.45 ± 0.09^{bc}	1.64 ± 0.21^{b}	<0.01
C17:0	0.19 ± 0.01	0.99 ± 0.63	0.37 ± 0.06	0.35 ± 0.06	0.02
C17:1	0.069 ± 0.01^{c}	0.15 ± 0.11^{b}	0.32 ± 0.03^{a}	0.21 ± 0.15^{ab}	0.02
C18:0	9.39 ± 0.24^{c}	15.18 ± 1.64^{a}	14.68 ± 0.97^{a}	12.80 ± 0.38^{b}	<0.01
C18:1	39.06 ± 0.74^{a}	29.23 ± 2.18^{c}	31.75 ± 1.56^{b}	32.63 ± 2.43^{b}	<0.01
C18:2 n-6	17.42 ± 0.70	18.42 ± 1.22	17.56 ± 2.09	17.61 ± 0.74	0.14
C20:1	0.18 ± 0.01^{c}	0.31 ± 0.01^{b}	0.49 ± 0.16^{a}	0.27 ± 0.05^{bc}	<0.01
C18:3 n-3	0.71 ± 0.03^{a}	0.54 ± 0.09^{bc}	0.49 ± 0.08^{c}	0.59 ± 0.07^{b}	<0.01
C20:2	0.68 ± 0.06^{ab}	0.48 ± 0.26^{b}	0.90 ± 0.39^{a}	0.65 ± 0.17^{ab}	0.19
C22:0	0.24 ± 0.01	0.52 ± 0.25	0.33 ± 0.09	0.32 ± 0.02	0.16
C20:3 n-6	0.49 ± 0.03^{ab}	0.55 ± 0.02^{a}	0.42 ± 0.09^{b}	0.27 ± 0.07^{c}	<0.01
C20:4 n-6	3.86 ± 0.18^{b}	7.62 ± 1.02^{a}	6.37 ± 0.46^{a}	5.86 ± 0.93^{a}	<0.01
C20:5 n-3	0.52 ± 0.03^{c}	0.92 ± 0.08^{a}	0.71 ± 0.05^{b}	0.49 ± 0.07^{c}	<0.01
C22:6 n-3	0.51 ± 0.03^{b}	1.48 ± 0.31^{a}	1.15 ± 0.03^{a}	1.03 ± 0.46^{a}	<0.01
SFA	35.17 ± 0.30^{b}	40.20 ± 1.74^{a}	39.89 ± 2.60^{a}	38.37 ± 0.92^{a}	<0.01
MUFA	41.72 ± 0.76^{a}	30.96 ± 2.29^{c}	33.93 ± 1.35 ^{b}	35.14 ± 2.35^{b}	<0.01
PUFA	23.11 ± 0.75^{c}	28.84 ± 1.06^{a}	25.23 ± 1.35^{b}	26.48 ± 1.51^{b}	<0.01
n-6	20.76 ± 0.86^{c}	26.32 ± 0.55^{a}	23.20 ± 2.18^{b}	23.73 ± 1.65^{b}	<0.01
n-3	1.66 ± 0.18	2.36 ± 0.69	1.89 ± 0.57	2.11 ± 0.41	0.13
n-6/n-3	12.71 ± 2.07	12.11 ± 3.92	13.23 ± 5.11	11.61 ± 2.32	0.87

Note: Saturated fatty acids (SFA) include: C14:0, C16:0, C17:0, C18:0, C22:0; Monounsaturated fatty acids (MUFA) include: C14:1, C16:1, C17:1, C18:1, C20:1; Polyunsaturated fatty acids (PUFA) include: C18:2n6, C18:3n3, C20:3n6, C20:4n6, C20:5n3, C22:6n3; n-6 include: C18:2n6, C20:3n6, C20:4n6; n-3 include: C18:3n3, C20:5n3, C22:6n3.

[a-c]Mean values of traits in rows, marked with the different letters indicate significant differences ($P < 0.05$).

meat quality indicators accurately reflected the comprehensive level of meat quality (Figure 2). The principal component comprehensive evaluation model of duck meat quality was calculated according to the eigenvectors and objective weights of the selected principal components. The formula obtained is as follows:

$$Y = 0.3178_{zx1} - 0.2532_{zx2} - 0.0277_{zx3} - 0.2250_{zx4} - 0.2402_{zx5} + 0.3192_{zx6} + 0.3112_{zx7} + 0.3079_{zx8} + 0.2489_{zx9} + 0.2953_{zx10}$$

where, ZX_1 represents breast muscle protein, ZX_2 represents breast muscle fat, ZX_3 represents Fe, ZX_4 represents Zn, ZX_5 represents Ca, ZX_6 represents Mg, ZX_7 represents flavor amino acid, ZX_8 represents essential amino acid, ZX_9 represents cholesterol, ZX_{10} represents polyunsaturated fatty acid.

All data from the 4 groups were substituted into the calculation using the evaluation formula. The results revealed that duck breast meat had the highest comprehensive score at the marketable age of 38 D, followed by 45, 42, and 28 D (Table 7).

DISCUSSION

Meat quality traits are complex and are influenced by many internal and external factors. Marketable age, as a key external factor, has been confirmed to be closely related to meat qualities (Van Ba et al., 2012; Khan et al., 2015; Liu et al., 2019). In the present study, the breast muscle of Cherry Valley broiler ducks at 38 days of age achieved the highest protein content and the relatively lower IMF. The total protein content is an important indicator for meat quality (Pintado and Delgado Pando, 2020), meaning that the meat at 38 d was superior in duck. Also, we observed that total protein content gradually decreased above 38 days of age. The results of the present study are similar to those of Kokoszyński et al. (2020), who demonstrated that the protein content of breast muscle in Pekin duck was reduced after seven weeks. The IMF content decreased with age from 28 to 45 D, which showed a similar trend to Pekin duck, wherein older ducks tended to have lower IMF content (Kokoszyński et al., 2019). The Cross-sectional area of duck breast muscle fibers increased with age, and the increase in muscle fiber development slowed down after 38 d. These results are similar to those obtained by Yu et al. (2021) and Chen et al. (2007).

Table 7. Comprehensive score of meat quality on different marketable ages using principal component analysis.

Group	ZX_1	ZX_2	ZX_3	ZX_4	ZX_5	ZX_6	ZX_7	ZX_8	ZX_9	ZX_{10}	Comprehensive score
28D	−0.48	−0.43	−0.02	−0.36	−0.40	−0.51	−0.44	−0.48	−0.41	−0.49	−2.19
38D	0.40	0.06	−0.02	0.02	0.05	0.37	0.44	0.35	0.08	0.24	0.87
42D	0.11	0.17	−0.01	0.09	0.10	0.12	−0.06	−0.03	0.06	0.02	0.58
45D	−0.03	0.20	0.05	0.25	0.25	0.03	0.06	0.17	0.27	0.22	0.74

Note: ZX_1 represents breast muscle protein, ZX_2 represents breast muscle fat, ZX_3 represents Fe, ZX_4 represents Zn, ZX_5 represents Ca, ZX_6 represents Mg, ZX_7 represents flavor amino acid, ZX_8 represents essential amino acid, ZX_9 represents cholesterol, ZX_{10} represents polyunsaturated fatty acid.

There is no doubt that high quality meat mainly reflects in rich minerals, essential amino acids, and unsaturated fatty acids. The poultry meat is one of the main sources of iron, zinc, cooper, and many other mineral elements for human (Lombardi Boccia et al., 2004). The present study revealed that the content of iron, zinc, and calcium in duck meat decreased with age from 28 D to 45 D, while the magnesium content reached the highest level at 38 days of age ($P < 0.05$). The similar trend of zinc and magnesium deposition were detected in Pekin duck (Kokoszyński et al., 2019, 2020), Generally, the mineral content of animals at different ages may be caused by a complex of effects including growth rate, physiological status and feeding system (Diniz et al., 2019). Therefore, an appropriate marketable age of meat ducks is the key to metallic deposition in the meat.

Additionally, the amount of amino acid in the meat has a direct effect on the nutritional value (Lund et al., 2011; Zhang et al., 2013). We observed that glutamate, aspartate, alanine, lysine, and leucine were the most abundant amino acids in Cherry Valley broiler duck meat, which is in agreement with the results of previous studies for chicken meat (Dalle Zotte et al., 2020). The 28-day-old ducks presented lower essential amino acid content than the 38-, 42-, and 45-day-old ducks. The results of the present study are similar to those obtained from previous studies on beef, which showed that the amino acid content of meat increased with age (Vopalensky et al., 2017). Additionally, the presence of unsaturated fatty acids in meat is thought to be beneficial for humans (Wood et al., 2004). In this study, the ratio of n-6 to n-3 (n-6/n-3) fatty acids in Cherry Valley broiler ducks ranged from 11.61 to 13.23, which is much higher than that in beef (2.11), mutton (1.32), and pork (9.22) (Enser et al., 1996). These data suggest that poultry meat contains higher content of n-6 fatty acids, thereby better meeting the nutritional needs of humans. We also found a higher content of arachidonic acid, DHA, and polyunsaturated fatty acids in 38-day-old ducks, as well as of stearic acid and saturated fatty acids in 42-day-old birds, compared to that of the other groups. Different peak contents of unsaturated and saturated fatty acids were found at different marketable ages, which suggested that the accumulation and metabolism of these 2 types of fatty acids were different throughout the growth process of ducks. These data provided a basis for further optimizing the marketable age of duck meat to contain a high amount of unsaturated fatty acids in the future.

The cholesterol content of ducks at different marketable ages was also determined, and it showed a decreasing trend with increasing age. The results of the present study are consistent with the findings of Li et al. (2018), who reported that cholesterol levels in duck meat decreased with age. Generally, high cholesterol content in meat is considered undesirable and unhealthy. We found that the content of cholesterol in Cherry Valley broiler duck meat ranged from 136 to 90 mg/100 g of meat, whereas that of chicken meat is 150 mg/100 g, indicating that duck meat might be a healthier alternative to chicken meat (Jiménez Colmenero et al., 2001; Dinh et al., 2011).

Finally, a multi-index model of duck meat quality was established to comprehensively evaluate duck meat quality at different marketable ages. Yang et al. (2011) constructed a meat quality index to assess meat quality performance using a model that coupled principal component analysis and linear programming techniques for a multidimensional analysis of preferences in broilers, and a model including crude protein, crude fat, ultimate pH, intramuscular fat, inosine monophosphate acid, muscle fiber number, muscle fiber diameter, and the drip loss. However, our model mainly focused on the nutritional content and quality of Cherry Valley broiler duck meat and found the highest comprehensive score at the 38 D marketable age. Together, these findings suggest that an age of 38 d might be recommended as an appropriate marketable age to provide high-nutritional duck meat.

CONCLUSIONS

In summary, marketable age is an essential factor that affects the proximate composition and nutritional profile of duck meat, and the meat of 38-day-old Cherry Valley ducks had the best proximate composition, essential mineral composition, and amount of essential amino acids and fatty acids. Hence, the age of 38 d might be recommended as the appropriate marketable age to produce high-nutrition duck meat based on our comprehensive multi-index evaluation model of duck meat quality.

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DISCLOSURES

The authors declare no conflict of interest.

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