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Quality evaluation of table eggs under different rearing systems in China

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Abstract

Because of the impact of the COVID-19 pandemic, more and more people are choosing to buy food online, including eggs. Although this mode of shopping is very modern, many Chinese consumers lack scientific knowledge when selecting eggs. In this study, we used the multivariate statistical analysis and sensory analysis to evaluate and compare the qualities of online sale of free-range and cage eggs. How feeding conditions influence the quality of eggs and how physical characteristics influence the price of eggs were also studied in this work. Our research showed that there is a lack of scientific support for distinguish free-range eggs from cage eggs on the appearance, the color of the yolk does not represent the amount of protein in yolk which may actually be affected by fodders. Moreover, the nutritional quality of free-range eggs is no better than that of cage eggs. Sensory analysis showed that free-range eggs taste better, which is likely because of the higher yolk ratio. Multivariate linear regression analysis showed that Rearing systems, fodder type and yolk color have significant impact on the price (Price = 0.428 × Rearing system −0.235 × Fodder type + 0.191 × Yolk color).

Keywords: egg quality; rearing system; egg storage; cage egg; free-range egg.

Practical Application: This work establishes a scientific basis for egg consumption choices and indicates that rearing system, fodder and season are three important factors that affect egg price and quality for eggs producers and retailers.

1 Introduction

As an important protein source in the human diet and one of the most consumed, eggs have been well researched, mainly in relation to production optimization and storage. Dietary supplements such as bacillus probiotics, dietary organic, yeast, inorganic iron, zinc-threonine, zinc-methionine, and zinc oxide have positive effects on laying performance, egg quality, and production (Behjatian Esfahani et al., 2021; Mazanko et al., 2018; Sarlak et al., 2021; Thanapal et al., 2021). However, excess dietary fluoride affected the formation of eggshell, reducing eggshell strength and thickness (Miao et al., 2017). Feeding conditions are also key factors for egg quality (Alshaikhi et al., 2021). Sudden increases in temperature and humidity can cause lowered immunity in laying hens (Soliman & Safwat, 2020). Furthermore, compared with high light intensity and feeding density, low and medium light intensity and stocking density can make hens produce heavier eggs (Erensoy et al., 2021). The storage of eggs also plays a crucial role in egg quality. With the extension of storage time, the freshness, nutrition, and taste of eggs decreased more rapidly at room temperature than at 4 °C. In addition to the low temperature environment, it is important that eggs should not be washed before storage to keep them fresh (Quan & Benjakul, 2018).

As a cheap and excellent source of nutrition, eggs have always been an important diet component for Chinese consumers. With the outbreak of COVID-19, more and more Chinese consumers are choosing to buy consumer goods such as vegetables, fruit, meat and eggs via online retail platforms (Hao et al., 2020). Traditional supermarkets have launched online shopping, while pure online supermarkets are also emerging. Online supermarkets do not provide a physical store, and only deliver products directly from a warehouse. After a consumer places an order through a mobile app, the order can be delivered within a short time. Although this mode of shopping is very modern and convenient, there is a limitation. Consumers can only get some information about eggs from the app, such as the photo of eggs, feeding methods of hens, etc., many consumers do not have enough scientific knowledge to judge the quality of eggs from the information. In fact, even when shopping in physical stores where consumers can personally see and touch eggs, some traditional ideas still affect their choice of eggs. In the Chinese consumer's view, free-range eggs are smaller than cage eggs, free-range eggs are more nutritious than cage eggs, small eggs are more nutritious than large eggs, and eggs with darker yolks are more nutritious. Apart from nutrition, the price is also an important factor that consumers consider when buying eggs. Concerning the perception of price, a previous study show that the factory farm white eggs' value is the one that least differed from the average market price of egg (Sass et al., 2018). Consumers' perception of eggs could be used by producers and traders in the egg production chain to improve production variables and quality parameters, as well as to invest in marketing strategies

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that are global or targeted at the different segments of egg consumers (Sass et al., 2020). Therefore, this study focuses on the quality of eggs sold online from the consumer's perspective and uses multivariate statistical analysis and sensory analysis to evaluate and compare the quality of free-range and cage eggs sold in Fujian Province's largest online supermarket. Multiple linear regression analysis was applied to determine several indicators affecting the price of eggs. Besides, one-factor analysis of variance (ANOVA) to was used to analyze how feeding conditions influence the quality of eggs. Through our research, we aim to have a better understanding of the quality of different types of eggs sold in online supermarkets, thus helping consumers to establish a scientific concept of choosing eggs for their needs. Similarly, egg producers can obtain a better understanding of the factors that affect the egg price and quality, thus produce more cost-effective eggs.

2 Materials and methods

Six different types of eggs (Cage 1, 2, 3 and Free-range 1, 2, 3) from the same egg producer (Hengliang agricultural technology Co., Ltd) sold in an online supermarket (Pupu Mall, Fujian Province, China) were evaluated. Cage 1 is featured by the fresh and seasonal grain feeding for the hens. Cage 2 is featured by primiparous egg. The hens of Cage 3 and Cage 2 are both fed by farm fodders (mainly corn and soybean). Hens of Cage 1, 2, 3 are raised in the same farm. The hens of Free-range 1 are raised in the osmanthus fragrans forest. The hens of Free-range 2 are raised on the grass. The hens of Free-range 3 are raised in the bamboo forest. The fodder for hens laying Cage 1, Free-range 1, 2 and 3 is organic fodder; the fodder for hens laying Cage 2 and 3 is farm fodder. We choose these 6 types of eggs from one brand (Hengliang egg) in order to minimize the interference caused by different brands. 20 eggs of each type were evaluated (10 in spring and 10 in winter) respectively (120 eggs in total). All analyses were conducted on the fifth day after the production date that was printed on the packaging.

Egg preservation tests were performed in spring. The trading time of eggs on the Chinese market is 21 days, and 10 eggs of each of the six types were analyzed after 5, 10, 15, and 20 days, using a total of 240 eggs. The eggs were stored in the warehouse of the online supermarket at room temperature, the average low temperature is 15 °C, the average high temperature is 22 °C, and the average humidity is around 70%.

2.1 Egg quality characteristics

Egg weight, egg shell weight, and yolk weight were measured on an electronic scale with a minimum weight of 0.01 g, and albumen weight was calculated according to the following Formula 1.

$$Albumen\ weight = Egg\ weight - (Yolk\ weight + Shell\ weight) \quad (1)$$

The height of the albumen was measured using a vernier caliper with a minimum scale of 0.001 mm. The measurements were recorded with the albumen and yolk in the natural position after the egg was broken out on a glass plate. The height of the albumen was measured at three locations where the albumen joins the yolk (around 1 cm from the yolk) and the readings were averaged. Shell thickness including the shell membrane was measured at the equator, sharp and blunt end using a vernier caliper. Protein content of the albumen and yolk were analyzed by tissue or cell total protein extraction kit (Solarbio, Beijing, China). Yolk color was evaluated using a Roche color range consisting of 15 yellow tones. Haugh unit (Sehirli & Arslan, 2022) is related to the albumen height and egg weight. Haugh unit score was calculated using the following Formula 2, where the height of the albumen in mm and the weight of the egg in g (Monira et al., 2003),

$$Haugh\ unit = 100 \times lg\left(Albumen\ height + 7.57 - 1.7 \times Egg\ weight^{0.37}\right) \quad (2)$$

Other calculations were performed according to the following Formulas 3-6 (Anderson et al., 2004).

$$Shape\ index = (Egg\ width / Egg\ length) \times 100 \quad (3)$$

$$Shell\ ratio = (Shell\ weight / Egg\ weight) \times 100 \quad (4)$$

$$Yolk\ ratio = (Yolk\ weight / Egg\ weight) \times 100 \quad (5)$$

$$Albumen\ ratio = (Albumen\ weight / Egg\ weight) \times 100 \quad (6)$$

2.2 Sensory analysis

Sensory analysis is a common method to evaluate food quality (Cai et al., 2022; Hu et al., 2022; Lopes et al., 2021; Zhang et al., 2021). The sensory evaluation of eggs was performed in the sensory analysis laboratory in Jimei University with the temperature of 22 °C and humidity of 60%. The panel for sensory evaluation was made up of 10 trained panelists. The 10 panelists were in good health and not allergic to eggs. Before the evaluation, panelists did not use cosmetics or perfume that could affect the evaluation of odors, and did not eat 1 hour before tasting. Each panelist was asked to rank the eggs for taste and smell. Taste and smell were both evaluated on a scale of 1to 6, with a score of 6 for the best egg, and a score of 1 for the worst. The six egg types were boiled in water for 10 min and then allowed to cool at room temperature. Then the egg shells were peeled and each egg was divided into four portions with a knife. Each panelist was provided with one portion of each egg, total 6 portions for each panelist. After eating each portion, the tasters cleaned their mouths with warm boiled water before tasting another portion.

2.3 Statistical methods

Statistical analyses were made using SPSS 25.0 (IBM Corp.) and Origin 2019b (Origin Lab Corp.). Data were analyzed using Principal Component Analysis (PCA) (Kherif & Latypova, 2020) with cage vs free-range eggs. ANOVA (Bertinetto et al., 2020) to was used to analyze how feeding conditions influence the quality of eggs. Spearman correlation analysis (de Winter et al., 2016) was used to analyze the correlations between quality characteristics of eggs. Non-parametric analysis was used in sensory analysis. Multivariate linear regression analysis (Liu et al., 2003) was used to analyze how physical characteristics influence the egg price. Difference was considered significant for $P < 0.05$.

3 Results and discussion

3.1 Egg quality analysis

The quality characteristics of free-range and cage eggs are shown in Table 1. Based on average values, the following observations were made: whole egg weight, shell thickness, shell ratio, yolk ratio, the yolk color and the price of free-range eggs was greater than these of cage eggs; shape index, shell ratio, albumen ratio and Haugh unit of cage eggs was greater than these of free range eggs. The normal distribution test for these traits was performed, all traits accorded with normal distribution except price and yolk color which is non-parametric.

The correlation between elements concerned by Chinese consumers (such as rearing system, yolk color, protein content and taste) were analyzed by Spearman correlation analysis; the results are shown in Table 1. The $P > 0.05$ means there is no significant correlation between the two variables; the $P < 0.05$ means there is significance correlation between the two variables, and the values of Spearman correlation (r_s) show how the two variables correlate (positive value indicates positive correlation, positive value indicates negative correlation, the bigger the value is, the stronger the correlation is). The further discussion of Table 1 will be shown in the following context.

Chinese consumers generally believe that free-range eggs are more nutritious, are smaller in size, and have a darker yolk. From correlation analysis, free-range eggs have more yolk ($r_s = 0.501$, 1 = organic fodder, 2 = farm fodder, seen in Table 1) and less albumen than cage eggs ($r_s = -0.510$, seen in Table 1), but the protein in yolk ($r_s = 0.118$, $P = 0.641$, seen in Table 1) and albumen is not significantly related to rearing system ($r_s = 0.096$, $P = 0.703$, seen in Table 1). So if consumers eat eggs mainly for protein intake, free-rang eggs do not actually contain more protein than cage eggs. For fitness enthusiasts who may prefer to eat egg albumen, cage eggs are the better choice since cage eggs have a higher albumen ratio. It is not reliable to judge rearing system in relation to egg size. Our analysis also showed that there is little correlation between weight and rearing system ($r_s = 0.027$, $P = 0.706$, seen in Table 1). It may be more feasible to assess the rearing system based on the yolk color, because our research shows that there is a significant correlation between yolk color and rearing system ($r_s = 0.201$, $P = 0.028$, seen in Table 1), with the yolks of free-range eggs being noticeably darker in color. However, this judgment standard may not be rigorous in the broader market because different feeds and feed additives can change the color of the egg yolk (Macit et al., 2021). Our correlation analysis also shows fodder types is related to yolk color ($r_s = -0.373$, seen in Table 1). We also noted that the yolk color of the same egg type may vary from winter to spring. Indeed, the yolk color of Free-range 1, 2, and 3 changed with the seasons and we speculate that the change of seasons led to changes in the natural food sources of the hens. The color change of egg yolk for Cage 1eggs was likely caused by the use of fresh grain for the hens, which would be changed with the season. Despite the noted variations in yolk color, there was no significant correlation between color and protein content ($P > 0.05$, Table 1).

Haugh unit is an important index to measure the freshness of eggs. Specifically, eggs with higher Haugh unit readings are considered to be fresher than eggs with lower readings (Nematinia & Abdanan Mehdizadeh, 2018). Table 1 shows the average Haugh unit of free-range eggs is lower than that of cage eggs ($r_s = -0.393$, seen in Table 1). We speculate that smaller Haugh units are observed for free-range eggs because free-range hens lay eggs outdoors and there may be some delay before the eggs are collected. Essentially, before collection, free-range eggs were stored outdoors in uncontrolled conditions of temperature and humidity, which would affect the freshness of the eggs (Yamak et al., 2021), whereas, the microclimate stability of cage system achieves bigger Haugh units. The Haugh unit of free-range and cage eggs decreased with the extension of storage time (Table 2), which is consistent with the results of previous studies (Baylan et al., 2011; Caglayan et al., 2009; Jayasena et al., 2012). Figure 1 illustrates the downward trend of Haugh unit for each egg type. Graphically, steeper decline in Haugh unit indicates worse preservation performance, so we

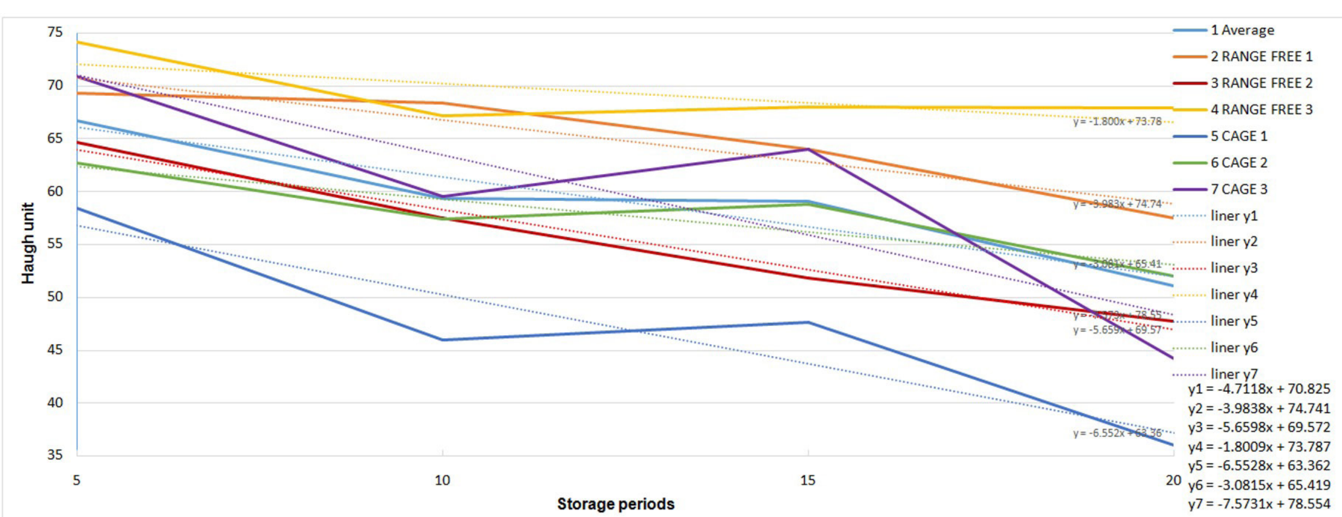

Figure 1. Haugh unit trendover time for free-range and cage eggs.

Table 1. Correlation analysis results for free-range and cage eggs.

		Rearing system	Price (rmb/each)	Weight (g)	Shell ratio (%)	Albumen ratio (%)	Yolk ratio (%)	Yolk color	Protein in yolk (mg/g)	Protein in albumen (mg/g)	Shape index	Shell thickness (mm)	Haugh unit	Taste score	Preservation ability	season	Fodder type
Rearing system	r_s	1	.878**	0.027	0.052	-.510**	.501**	.201*	0.096	0.118	-0.115	.209*	-.393**	.488**	-0.098	0	-.707**
	P	.	0	0.766	0.573	0	0	0.028	0.703	0.641	0.213	0.022	0	0	0.289	1	0
Price	r_s	.878**	1	0.046	0.051	-.528**	.507**	.338**	0.367	0.166	-0.078	0.174	-.377**	.600**	-0.086	0	-.828**
	P	0	.	0.617	0.583	0	0	0	0.134	0.51	0.398	0.057	0	0	0.352	1	0
weight	r_s	0.027	0.046	1	-.192*	-.369**	.375**	-0.105	.634**	-0.005	0.049	.363**	-.326**	-0.108	.755**	-.217*	-.213*
	P	0.766	0.617	.	0.035	0	0	0.254	0.005	0.984	0.597	0	0	0.241	0	0.017	0.019
Shell ratio	r_s	0.052	0.051	-.192*	1	0.119	-.272**	.276**	0.201	0.034	-0.16	.510**	0.049	-0.047	-.296**	0.036	-0.004
	P	0.573	0.583	0.035	.	0.196	0.003	0.002	0.423	0.893	0.081	0	0.598	0.609	0.001	0.696	0.969
Albumen ratio	r_s	-.510**	-.528**	-.369**	0.119	1	-.981**	0.162	-0.076	0.161	-0.028	-0.133	.505**	-.444**	-.198*	.189*	.537**
	P	0	0	0	0.196	.	0	0.078	0.763	0.523	0.762	0.149	0	0	0.03	0.039	0
Yolk ratio	r_s	.501**	.507**	.375**	-.272**	-.981**	1	-0.178	0.066	-0.126	0.043	0.036	-.499**	.437**	.223*	-0.177	-.521**
	P	0	0	0	0.003	0	.	0.052	0.794	0.618	0.641	0.692	0	0	0.014	0.053	0
Yolk color	r_s	.201*	.338**	-0.105	.276**	0.162	-0.178	1	0.39	.597**	-0.079	0.072	-0.059	0.154	-0.132	0.05	-.373**
	P	0.028	0	0.254	0.002	0.078	0.052	.	0.109	0.009	0.393	0.431	0.522	0.092	0.149	0.586	0
Protein in yolk)	r_s	0.096	0.367	.634**	0.201	-0.076	0.066	0.39	1	0.401	-0.259	.591**	-0.202	-0.028	0.311	.	-0.409
	P	0.703	0.134	0.005	0.423	0.763	0.794	0.109	.	0.1	0.299	0.01	0.42	0.911	0.21	.	0.092
Protein in albumen	r_s	0.118	0.166	-0.005	0.034	0.161	-0.126	.597**	0.401	1	-0.392	0.355	0.077	-0.085	-.593**	.	0
	P.	0.641	0.51	0.984	0.893	0.523	0.618	0.009	0.1	.	0.107	0.148	0.76	0.738	0.01	.	1
Shape index	r_s	-0.115	-0.078	0.049	-0.16	-0.028	0.043	-0.079	-0.259	-0.392	1	-0.128	0.076	0.13	.191*	-0.084	-0.074
	P	0.213	0.398	0.597	0.081	0.762	0.641	0.393	0.299	0.107	.	0.165	0.411	0.157	0.037	0.361	0.422
Shell thickness	r_s	.209*	0.174	.363**	.510**	-0.133	0.036	0.072	.591**	0.355	-0.128	1	-.206*	-0.165	0.154	-.202*	-0.101
	P.	0.022	0.057	0	0	0.149	0.692	0.431	0.01	0.148	0.165	.	0.024	0.071	0.094	0.027	0.271
Haugh unit	r_s	-.393**	-.377**	-.326**	0.049	.505**	-.499**	-0.059	-0.202	0.077	0.076	-.206*	1	-.188*	-.241**	-.200*	.394**
	P	0	0	0	0.598	0	0	0.522	0.42	0.76	0.411	0.024	.	0.039	0.008	0.028	0
Taste score	r_s	.488**	.600**	-0.108	-0.047	-.444**	.437**	0.154	-0.028	-0.085	0.13	-0.165	-.188*	1	-.371**	0	-.828**
	P	0	0	0.241	0.609	0	0	0.092	0.911	0.738	0.157	0.071	0.039	.	0	1	0
Preservation ability	r_s	-0.098	-0.086	.755**	-.296**	-.198*	.223*	-0.132	0.311	-.593**	.191*	0.154	-.241**	-.371**	1	0	0
	P	0.289	0.352	0	0.001	0.03	0.014	0.149	0.21	0.01	0.037	0.094	0.008	0	.	1	1
season	r_s	0	0	-.217*	0.036	.189*	-0.177	0.05	.	.	-0.084	-.202*	-.200*	0	0	1	0
	P	1	1	0.017	0.696	0.039	0.053	0.586	.	.	0.361	0.027	0.028	1	1	.	1
Fodder type	r_s	-.707**	-.828**	-.213*	-0.004	.537**	-.521**	-.373**	-0.409	0	-0.074	-0.101	.394**	-.828**	0	0	1
	P	0	0	0.019	0.969	0	0	0	0.092	1	0.422	0.271	0	0	1	1	.

*$P < 0.05$; **$P < 0.01$.

use the decline to present the preservation ability (bigger value means worse preservation ability). According to the slopes on Figure 1, the order in preservation performance was: Cage 3> Cage 1> Free-range 2> Free-range 1>Cage 2>Free-range 3. The independent-samples *t*-test shows there is a significant difference between free range and cage eggs only on the 5th day ($P < 0.05$, Table 2). With the increase of storage periods, there is no statistics difference in Haugh units between free range and cage eggs ($P > 0.05$, Table 2). This shows that different rearing systems cannot change the preservation ability of eggs, which is also proved by the correlation analysis between preservation ability and rearing system ($P > 0.05$, Table 1). Haugh unit is higher in winter ($r_s = -0.200$, 1 = winter, 2 = spring, Table 1) and the higher shell ratio the better preservation ability ($r_s = -0.296$, Table 1). Therefore, to retain the freshness of eggs, more attention should be paid to the preservation conditions and the factors which have influences on shell.

For yolk, albumen and freshness which are most concerned by consumers, we used ANOVA to analyze the effects of rearing system, fodder type and season on yolk ratio, albumen ratio and Haugh unit. The results showed rearing system ($P = 0.026 < 0.05$) and fodder type ($P = 0.001 < 0.01$) significantly affect the yolk ratio (P of season= $0.06 > 0.05$); rearing system ($P = 0.015 < 0.05$), fodder type ($P = 0.001 < 0.01$) and season ($P = 0.042 < 0.05$) significantly affect the albumen ratio; fodder type ($P = 0.03 < 0.05$) and season ($P = 0.006 < 0.01$) significantly affect the Haugh unit (P of rearing system = $0.08 > 0.05$). Estimated marginal means plots in Figure 2 showed how the three factors affect the quality of eggs. Higher yolk ratio could be achieved by free range rearing and organic fodder; higher albumen ratio could be achieved by cage rearing, farm fodder and laying eggs in spring. The multivariate ANOVA results could guide manufacturers to produce eggs with different characteristics according to customers' needs.

Principal Component Analysis was conducted to evaluate the difference of the egg quality parameters between cage and free-range eggs. The use of this technique allows identifying the main quality parameters that contribute to most of the observed variation in the observed results. As can be seen in Figure 3, most indicators are well represented in PC 1 and PC 2. As PC

Table 2. Haugh unit data for free-range and cage eggs according to storage period.

Storage periods	FREE RANGE 1	FREERANGE 2	FREERANGE 3	ALL FREERANGE	CAGE1	CAGE2	CAGE3	ALL CAGE	[1]P
5	69.31 ± 8.45	58.40 ± 4.99	62.71 ± 9.12	63.47 ± 8.53	64.67 ± 10.00	74.16 ± 5.66	70.88 ± 5.72	69.90 ± 7.97	*
10	68.35 ± 7.31	45.94 ± 12.50	57.42 ± 10.29	57.22 ± 13.61	57.50 ± 10.31	67.13 ± 7.24	59.48 ± 8.72	61.37 ± 9.24	[2]NS
15	64.00 ± 5.63	47.57 ± 7.62	58.73 ± 8.40	56.46 ± 9.97	51.82 ± 5.17	67.96 ± 6.30	64.00 ± 5.63	61.25 ± 8.86	NS
20	57.48 ± 7.18	36.01 ± 10.51	52.00 ± 7.95	48.49 ± 12.37	47.70 ± 7.63	67.89 ± 9.34	44.13 ± 9.99	54.08 ± 14.24	NS

Data given as mean ± SD. [1]The significance between free range and cage eggs. [2]Nonsignificant ($P > 0.05$). $^*P < 0.05$.

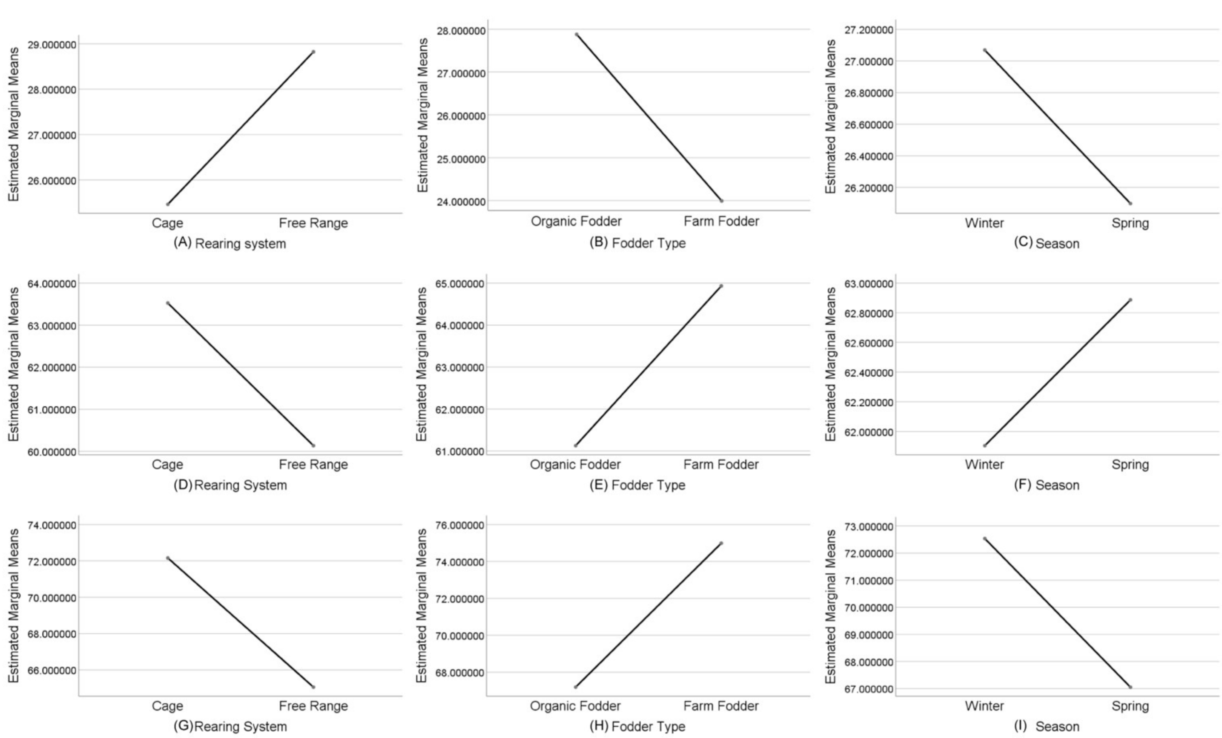

Figure 2. Estimated marginal means plots: Yolk ratio (A) Rearing system, (B) Fodder type, (C) Season; Albumen ratio (D) Rearing system, (E) Fodder type, (F) Season; Haugh unit (G) Rearing system, (H) Fodder type, (I) Season.

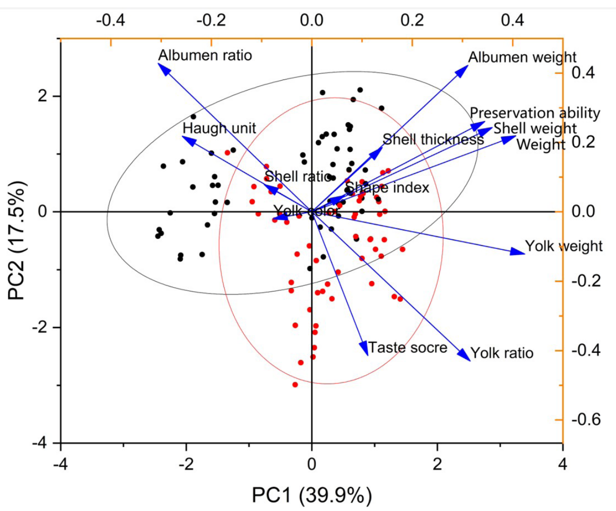

Figure 3. Principal component analysis (PCA) biplot of free-range and cage egg.

1 explained 39.9% of the total variance and PC 2 explained 17.5%, two dimensions were able to explain 57.4% of the quality parameters for different rearing systems. From the PCA biplot, about two-thirds of eggs are distributed in the similar area, which shows that there is no very obvious difference in appearance and quality characteristics of eggs on the whole. This result again shows that the view of Chinese consumers that free range eggs are of better quality is unscientific. About one third of the eggs is clearly separated because of the high contribution of albumen ratio, Haugh unit, yolk ratio and taste score, which is consistent with analysis in Table 1 and 3.

Based on the results of our studies, the nutritional aspects of eggs are mainly decided by rearing system and fodders. As for freshness of eggs, we have two suggestions for egg producers and retailers. First, free cage eggs should be collected in time to keep the freshness, especially in spring and summer. Through our analysis, we found that freshness of free range is lower than that of cage eggs; freshness of eggs is lower in spring than winter. These indicate free-range eggs are stored outdoors in uncontrolled conditions of temperature and humidity, which will affect the freshness of the eggs. Second, in traditional Chinese supermarkets, eggs are usually displayed for sale at room temperature for the convenience of customers. However, eggs sold online do not have to be stored this way. The nutrition of eggs is better preserved at a fixed low temperature and humidity rather than at room temperature. Therefore, before eggs are sold, we suggest that they be stored in the warehouse at constant temperature and humidity.

3.2 Sensory analysis

The taste score of taste and smell did not accord with normal distribution, so the non- parametric analysis was used. The ranks of taste given by the panelists were relatively uniform, while there were big differences in the ranks given for smell. This means that there were significant disagreements between panelists for smell assessment, even if the scores of some eggs appear similar

Table 3. Sensory analysis results of free-range and cage eggs.

Rear system	Score of taste	Score of smell
FREERANGE 1	4.5(3.75~5)	3(2~4.25)
FREERANGE 2	4(2.75~5)	2(1~3)
FREERANGE 3	6(3~6)	6(5~6)
ALL FREERANGE	5(3~5.25)	3(2~5)
CAGE1	4(3.75~6)	4.5(4~6)
CAGE2	2(1~3)	4(3~5)
CAGE3	1(1~2)	1(1~2)
ALL CAGE	2(1~4)	4(2~5)
[1]*P*	0	0.764

[1]Mann-Whitney U non-parametric test for rearing system. Data is given by 50 percentile (25 ~75 percentile).

in the summarized data. This suggested that there was more research value in analyzing the taste scores. The 50 percentile of free-range eggs were higher than those of cage eggs in terms of taste (Table 3). The Mann-Whitney U non-parametric test showed there was significant difference between Cage and Free range eggs in taste ($P < 0.01$, Table 3). Correlation analysis showed that albumen ratio was negatively correlated with the egg taste score ($r_s = -0.444$, $P < 0.01$, Table 1), while yolk ratio was positively correlated with the egg taste score ($r_s = 0.437$, $P < 0.01$, Table 1). According to the previous analysis, the yolk ratio of free-range eggs is higher, which is consistent with the results of the sensory analysis.

3.3 Price analysis

Before multivariate linear regression analysis, we used Spearman correlation analysis to determine any correlation between price and quality characteristics. The results showed significant positive correlations between price and rearing system ($r_s = 0.878$, 1 = Cage, 2 = Free range), taste score ($r_s = 0.600$), yolk color ($r_s = 0.338$), yolk ratio ($r_s = 0.507$). Significant negative correlations were observed between price and fodder type ($r_s = -0.828$, 1=Organic fodder, 2 = Farm fodder), albumen ratio ($r_s = -0.528$), Haugh unit ($r_s = -0.377$). Other characteristics did not affect the price and were not used as variables in the multivariate linear regression analysis ($P > 0.05$, Seen in Table 1). There exists multiple collinearity between yolk ratio and albumen ratio, fodder type and taste score through multiple collinearity test, we chose yolk ratio and fodder type as the variables in the multivariate linear regression analysis.

As shown in Table 4, the linear regression model had good fit ($R^2 = 0.608$), which means that the calculated results reliably reflect the impacts of different quality characteristics on the price. The regression equation was significant ($P < 0.001$), indicating that at least one variable can significantly affect the price. Multiple collinearity did not exist between variables (all VIF < 5). The yolk color, yolk ratio and Haugh unit did not significantly affect the price ($P > 0.05$). Rearing systems ($\beta = 0.428$, 1 = Cage, 2 = Free range), fodder type ($\beta = -0.235$, 1 = Organic fodder, 2 = Farm fodder), yolk color ($\beta = 0.191$) had significant and positive impacts on the price, and the final regression equation was obtained as:

Table 4. Multivariate linear regression analysis results for free-range and cage eggs.

Model	Unstandardized B	Coefficients Std. Error	Standardized Beta	t	*P*	VIF
Constant	-.298	.929		-.321	.749	
Fodder type	-.349	.143	-.235	-2.430	.017	2.699
Rearing system	.598	.123	.428	4.885	.000	2.214
Haugh unit	-.001	.005	-.019	-.258	.797	1.490
Yolk color	.074	.028	.191	2.671	.009	1.478
Yolk ratio	.020	.016	.115	1.309	.193	2.219
Shell thickness	13.590	8.396	.100	1.619	.108	1.09

The process value of the test (t); the significance of t test (P); the collinearity index (VIF); $R^2 = 0.608$; $P < 0.001$; Dependent: Price (rmb/each egg).

$$Price = 0.428 \times Rearing\ system - 0.235 \times Fodder\ type + 0.191 \times yolk\ color \quad (7)$$

According to Formula 7, we can infer that the price of eggs sold online is mainly determined by two aspects. One is the cost of producing eggs. For example, the organic fodder is more expensive than farm fodder, which makes price goes up; the free range rearing also increase the cost. The other factor is the preference of consumers. Chinese consumers prefer free range eggs and dark yolk color, which also make rearing system and yolk color play positive effect on price.

4 Conclusions

In conclusion, for some important quality indicators such as weight, albumen ratio, presentation ability and protein content, free-range eggs are no better than cage eggs. Yet the price of free-range eggs is twice that of cage eggs. Even for fitness enthusiasts who mainly eat albumen, the cage egg is a better choice because the albumen ratio of cage eggs is larger than that of free-range eggs. In terms of taste, free-range eggs are better than cage eggs. According to our research, this is because the yolk ratio of free-range eggs is higher than in cage eggs. In terms of yolk color perception by Chinese consumers, our research shows that the yolk color of free-range eggs is darker than that of cage eggs, but this is not the standard by which egg quality should be judged. This is because the yolk color can be determined by the fodder. Rearing system and fodder type significantly affect the yolk ratio; rearing system, fodder type and season significantly affect the albumen ratio; fodder type and season significantly affect the Haugh unit. This work establishes scientific basis for egg consumption for Chinese consumers and indicates rearing system, fodder and season are three important factors that affect egg price and quality for eggs producers and retailers.

Declaration of interest

The authors declare no competing interests.

Data availability statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author.

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Author contributions

Wenliang Liao: manuscript writing. Honghao Cai: manuscript writing, correction, project set-up and management. Huangqian Lian, Zheqi Huang, Yueyue Sun: date collection and analysis. Hui Ni: sensory analysis.

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