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Impact of different housing systems and age of layers on egg quality characteristics

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Abstract: The aim of this study was to investigate effects of conventional-cage (CC), enriched-cage (EC), and free-range (FR) systems and hen age on internal and external egg quality parameters of layers (Lohmann Brown). A total of 720 eggs were analyzed for egg weight (EW), shell weight (SW), yolk weight (YW), albumen weight (AW), shell thickness (ST), shell breaking strength (SBS), shape (SI), albumen (AI), yolk index (YI) of eggs, shell ratio of eggs (SR), albumen ratio of eggs (AR), yolk ratio of eggs (YR), yolk color (YC), and Haugh unit (HU). The highest EW, YW, AW, SW, AI, YI, HU (all $P < 0.001$), and SI values were found in FR system eggs compared with CC and EC system eggs ($P = 0.045$). The SBS, ST, YC, SR, YR, and AR were found similar in all housing systems. There was an interaction between the housing system and hen age for EW, SW, YW, AW, SBS, ST, AI, YC, HU, AR (all $P < 0.001$), SI ($P = 0.003$), SR ($P = 0.001$), and YR ($P = 0.001$) of eggs. It can be concluded that eggs in the FR system were better in overall quality than eggs from CC and EC systems.

Key words: Conventional cage, enriched cage, free range, age, egg quality traits

1. Introduction

For global commercial egg production it is estimated that over 75% of hens are reared in cages but new trends are emerging in rearing layers in animal-friendly systems. The alternative rearing systems have focused on developing better animal welfare and behavior for laying hens. In these systems, it is necessary that the system allow the birds to show their natural behaviors, decrease the probability of disease and injury, and increase productivity, egg quality, and food safety (1). However, production costs are important for producers and in alternative systems such as enriched-cage or no-cage systems production costs are high (2) and therefore salable egg number and also egg quality gain importance. Egg quality is an important factor influencing consumer purchase of eggs. In recent years, due to increasing awareness, consumers prefer to buy eggs with firm albumen, dense colored yolk, large size, and good quality (3).

There are many genetic and environmental factors that affect both the internal and external quality of eggs. Today, alternative systems have become more important and the effect of these systems on egg quality parameters needs to be determined (4). Thus, studies have been conducted on effects of different housing systems, such as conventional-cage, enriched-cage, and outdoor systems, on external and internal egg quality characteristics (4,5). However, there are limited studies evaluating differences among housing systems for egg quality traits across a production cycle from placement of hens at the beginning of laying until depopulation (6,7). Thus, the aim of the current study was to determine effects of conventional-cage, enriched-cage, and free-range production systems and increasing flock age on external and internal egg quality characteristics of laying hens.

2. Materials and methods

The material for the current research was obtained from 480 layers (Lohmann Brown) housed in conventional-cage (CC), enriched-cage (EC), and free-range (FR) production systems between 22 and 60 weeks of age. A total of 720 eggs were analyzed for external and internal egg quality traits.

The three housing systems were located within the same research unit of Uludağ University. Two cage systems, CC and EC, were installed in a windowed and fan-ventilated cage hen house with both cage types in the same room. The FR system was located 120 m from the cage hen house.

The CC system consisted of galvanized wire cages (50 × 45 × 45 cm) with a trough-type galvanized feeder, egg belt, manure belt, and nipple drinker. Each CC cage provided a total of 562.5 cm^2 floor area per hen.

The EC system cages met the requirements of EU Directive 1999/74/EC. The EC system consisted of 2 tiers, and each tier consisted of 2 cages (4 EC cages). The EC

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cage dimensions were 240 cm × 125 cm. Each EC cage provided a total of 750 cm^2 floor area per hen. The EC system cages consisted of galvanized wire cage with a trough-type galvanized feeder (12 cm of feeder per hen), egg belt, manure belt, and nipple drinkers (8 nipples per cage). Each EC cage also provided several amenities, including perches (18 cm of area per hen), nesting areas (102 cm^2 per cage) surrounded by an orange curtain, green artificial turf scratch pad area (45.92 cm^2 per cage), and nail shorteners (8 nail shorteners per cage).

The FR system consisted of indoor area and pasture area. The FR system's indoor area had a total of 7 hens/m^2. In the indoor area wood shavings were used as litter material. Rounded galvanized feeders and plastic drinkers were used in both areas. The perches (15 cm of area per hen) and nest box (4 hens per nest) were provided in the indoor area of the FR system. The FR system pasture area was covered by wire fences and shelter. The FR system pasture area had a total of 8 hens per m^2. A total of 60% perennial ryegrass (*Lolium perenne*), 10% white clover (*Trifolium repens*), and 30% alfalfa (*Medicago sativa*) were sown in the pasture area.

Hens were randomly placed into cages or pens of treatment groups and then weighed with a digital scale with ±0.1 g precision. A total of 160 hens were used in each of the CC, EC, and FR systems with 4 subgroups (n = 40 hen) defined as the replicates of each system. Hens were fed with a standard commercial layer diet (17% CP and 2750 kcal ME/kg between 18 and 40 weeks; 16% CP and 2700 kcal ME/kg and 0.7% P and 3% Ca between 41 and 60 weeks) in the CC, EC, and FR systems. The diets were formulated to National Research Council specifications (8). Feed and water were offered ad libitum. The photoperiod at the time of laying was 16L:8D in all treatment groups. The practices regarding the care and use of animals for research purposes were in accordance with the laws and regulations of Turkey and approved by the Animal Use and Ethics Committee of Uludağ University (Approval Number 2013-01/07).

The hen-day egg production was calculated by separating the number of daily picked up eggs by the number of layers on the same day. Based on the daily collected egg number, 50% production age and peak hen-day egg production age of hens were determined. A total of 720 eggs were measured in the study. Egg quality traits were assessed at 6 time points (at 50% egg production age, peak egg production age, and 30, 40, 50, and 60 weeks of age); 40 eggs from each housing system were randomly selected to determine the egg weight (EW), shell breaking strength (SBS), yolk weight (YW), yolk color (YC), shell weight (SW), shell thickness (ST), albumen weight (AW), shape index (SI), albumen index (AI), yolk index (YI), Haugh unit (HU), shell ratio (SR), yolk ratio (YR), and albumen ratio (AR) for each sampling period. The eggs were weighed and then cracked and the albumen was isolated from the yolk. The egg shells were swilled and dehydrated for 24 h in an oven at 105 °C, then weighed. ST was determined at the air cell, sharp end, and equator of egg points using a caliper and the averages of these sites were used. AW was calculated by subtracting YW and SW from the egg weight. The data for EW, YW, and SW (g) were recorded using a digital scale.

SI (%) and SBS (kg/cm^2) were measured using equipment developed by Rauch. Egg albumen length, albumen width, and yolk diameter (mm) were determined with a digital caliper (Mitutoyo Corp., Aurora, IL, USA). The yolk and albumen height (mm) were determined using a tripod micrometer. The ratios of egg SR, AR, and YR were formulated as (albumen or yolk or shell weight / egg weight) × 100. The YI was formulated as (yolk height / yolk diameter) × 100. AI was formulated as (albumen height / (albumen length + albumen width) / 2) × 100. HU was formulated as $HU = 100 \log (H + 7.57 - 1.7W^{0.37})$, where W refers to the egg weight (g) and H refers to the albumen height (mm). YC was determined with a Roche yolk color fan scale.

2.1. Statistical analysis

The egg quality traits were analyzed with ANOVA using the PROC GLM procedure of statistical analysis software (9). The housing system and age were the main effects. The egg quality traits during the laying period were analyzed using the mixed model (PROC MIXED) procedure for repeated measurements, and within each housing type (CC, EC, and FR) the number of cages/pens (replicates of each system; n = 4) was determined as the random factor in the model. Replicates within each group were determined as the error term of the egg quality traits. Differences were considered significant at $P \leq 0.05$. Significant differences among treatment means were determined by Duncan's multiple range test. Data are presented as the mean ± SE in all of the tables.

3. Results

During the experimental period, mean hen-day egg production and egg mass of the CC, EC, and FR systems were determined as 87.10, 87.26, and 89.27 ± 0.87% and 56.80, 56.66, and 59.76 ± 0.34 g, respectively ($P = 0.037$ and $P < 0.001$).

The effects of housing system and hen age on egg quality traits are given in the Table. The weights of egg, yolk, albumen, and shell and the Haugh unit and albumen index were higher in the FR system, but were similar in the CC and EC systems ($P < 0.001$). The highest shape index ($P = 0.045$) and yolk index ($P < 0.001$) were found in the FR system. The egg shell breaking strength, shell thickness, yolk color, and ratios of albumen, yolk, and shell were found similar in all housing systems (Table).

Table. The main effects of housing system and hen age on egg quality traits.

HS[1]	EW (g)	SW (g)	SBS (kg/cm^2)	ST (mm)	YW (g)	AW (g)	SI (%)	AI (%)	YI (%)	YC	HU	AR (%)	YR (%)	SR (%)
CC	58.35^{b}	5.68^{b}	2.23	0.397	14.07^{b}	38.60^{b}	78.31^{ab}	11.17^{b}	48.20^{c}	11.89	88.10^{b}	66.29	23.94	9.78
EC	57.75^{b}	5.69^{b}	2.17	0.400	13.94^{b}	38.12^{b}	78.07^{b}	10.91^{b}	49.02^{b}	11.98	87.98^{b}	66.19	23.92	9.88
FR	59.77^{a}	5.87^{a}	2.35	0.403	14.41^{a}	39.49^{a}	78.57^{a}	11.75^{a}	49.77^{a}	11.98	90.31^{a}	66.35	23.82	9.83
SE	0.25	0.03	0.06	0.002	0.07	0.21	0.14	0.14	0.21	0.08	0.44	0.13	0.12	0.05
A[2]														
I	43.44^{e}	4.31^{d}	1.76^{c}	0.377^{c}	9.00^{e}	30.13^{e}	77.00^{c}	14.55^{a}	55.86^{a}	11.45^{c}	97.56^{a}	69.29^{a}	20.77^{c}	9.93^{a}
II	54.41^{d}	5.45^{c}	2.47^{ab}	0.402^{b}	11.57^{d}	37.39^{d}	79.57^{a}	13.04^{b}	50.27^{b}	11.85^{bc}	94.17^{b}	68.64^{a}	21.35^{c}	10.01^{a}
III	59.27^{c}	5.89^{b}	2.67^{a}	0.400^{b}	14.09^{c}	39.29^{c}	79.60^{a}	11.13^{c}	48.30^{c}	11.80^{bc}	89.40^{c}	66.25^{b}	23.81^{b}	9.94^{a}
IV	63.59^{b}	6.32^{a}	2.60^{a}	0.421^{a}	16.40^{b}	40.87^{b}	78.58^{b}	9.97^{d}	46.03^{d}	12.02^{b}	84.48^{de}	64.24^{c}	25.82^{a}	9.94^{a}
V	65.29^{a}	6.28^{a}	2.20^{b}	0.403^{b}	16.78^{ab}	42.22^{a}	78.03^{b}	9.89^{de}	46.31^{d}	12.52^{a}	85.00^{d}	64.63^{c}	25.75^{a}	9.62^{b}
VI	65.74^{a}	6.24^{a}	1.79^{c}	0.397^{b}	16.98^{a}	42.51^{a}	77.12^{c}	9.07^{e}	47.18^{cd}	12.06^{ab}	82.18^{e}	64.63^{c}	25.87^{a}	9.51^{b}
SE	0.35	0.05	0.09	0.003	0.10	0.29	0.20	0.20	0.29	0.11	0.62	0.18	0.16	0.07
P-value														
HS	<0.001	<0.001	0.091	0.072	<0.001	<0.001	0.045	<0.001	<0.001	0.644	<0.001	0.679	0.741	0.205
A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
HS × A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.131	<0.001	<0.001	<0.001	0.001	0.001

[a–e] Means within main effect without a common superscript are different at P < 0.05.
[1]HS: Housing system, A: age of hen, CC: conventional-cage, EC: enriched-cage, FR: free-range system.
[2]AI: 50% HD production age, II: peak production age, III: 30 weeks of age, IV: 40 weeks of age, V: 50 weeks of age, VI: 60 weeks of age.
HS × A: Housing system and age of hen interaction.
EW: Egg weight, SW: shell weight, SBS: shell breaking strength, ST: shell thickness, YW: yolk weight, AW: albumen weight, SI: shape index, AI: albumen index, YI: yolk index, YC: yolk color, HU: Haugh unit, AR: albumen ratio, YR: yolk ratio, SR: shell ratio.

As expected, the investigated values changed along with the laying period; the age of layers affected egg weight, shell weight, albumen weight, yolk weight, egg shell breaking strength, shell thickness, shape index, albumen index, yolk index, yolk color, Haugh unit, albumen ratio, yolk ratio, and shell ratio (P < 0.001, Table). The egg weight, yolk weight, and albumen weight were growing continuously during the laying period (P < 0.001). The shell weight increased at 40 weeks of age, then stayed stable until the end of the production period (P < 0.001). The lowest egg shell breaking strengths were found at 50% hen-day egg production age and 60 weeks of age (P < 0.001). On the other hand, the highest shell thickness was found at 40 weeks of age (P < 0.001). The lowest shape index was found at 50% hen-day egg production age and 60 weeks of age (P < 0.001). The albumen index was decreased with increasing age (P < 0.001). The highest yolk index was found at 50% hen-day egg production age, and then it decreased with increased age until 40 weeks of age (P < 0.001). The yolk color score increased with age until 50 weeks of age (P < 0.001). The lowest Haugh unit was found at 60 weeks of age (P < 0.001). The albumen ratio decreased and yolk ratio increased with increasing age until 40 weeks of age. The lowest shell ratio was found at 50 and 60 weeks of age (P < 0.001).

The interaction of housing system × hen age was found significant for egg weight, shell weight, yolk weight, albumen weight, shell breaking strength, shell thickness, albumen index, yolk color, Haugh unit, albumen ratio (all P < 0.001), shape index (P = 0.003), yolk ratio, and shell ratio (P = 0.001), as given in the Table. The yolk index was not affected by the housing system × age interaction.

The effects of housing system × age interaction on egg weight, albumen weight, yolk weight, and shell weight are given in Figure 1 (all P < 0.001). The interaction of housing system and age was a result of heavier egg weight, albumen weight, yolk weight, and shell weight found in the FR system at 30 weeks of age than the CC and EC systems.

The effects of housing system × age interaction on Haugh unit, shell thickness, and shell breaking strength are given in Figure 2 (all P < 0.001). The Haugh unit was higher in the FR system than in the cage systems, and it was similar between the CC and EC systems at peak hen-day egg production age. Among all of the housing systems, the lowest egg shell breaking strength and shell thickness were found at the age of 50% hen-day egg production in the FR system.

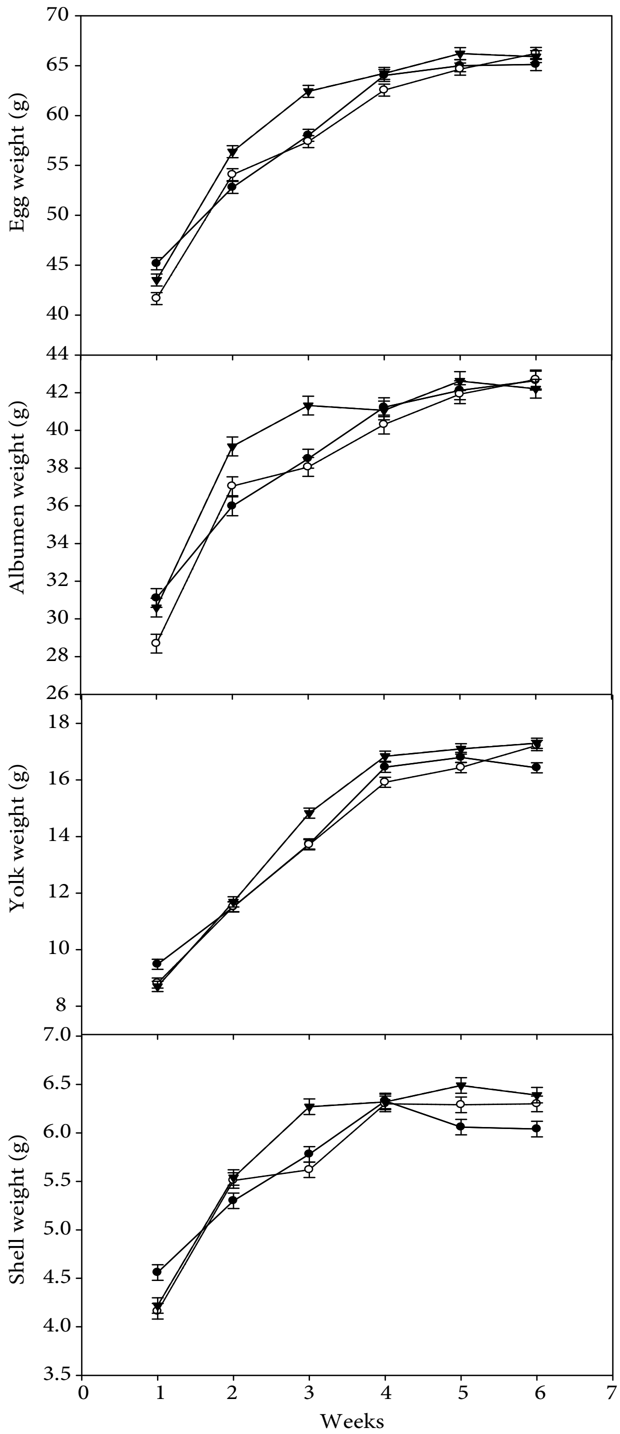

Figure 1. The interactions between housing system and age on egg weight, albumen weight, yolk weight, and shell weight of eggs.
Conventional cage (CC: closed circle), enriched cage (EC: open circle), and free range (FR: closed triangle); weeks: 1: 50% HD production age, 2: peak production age, 3: 30 weeks of age, 4: 40 weeks of age, 5: 50 weeks of age, 6: 60 weeks of age.

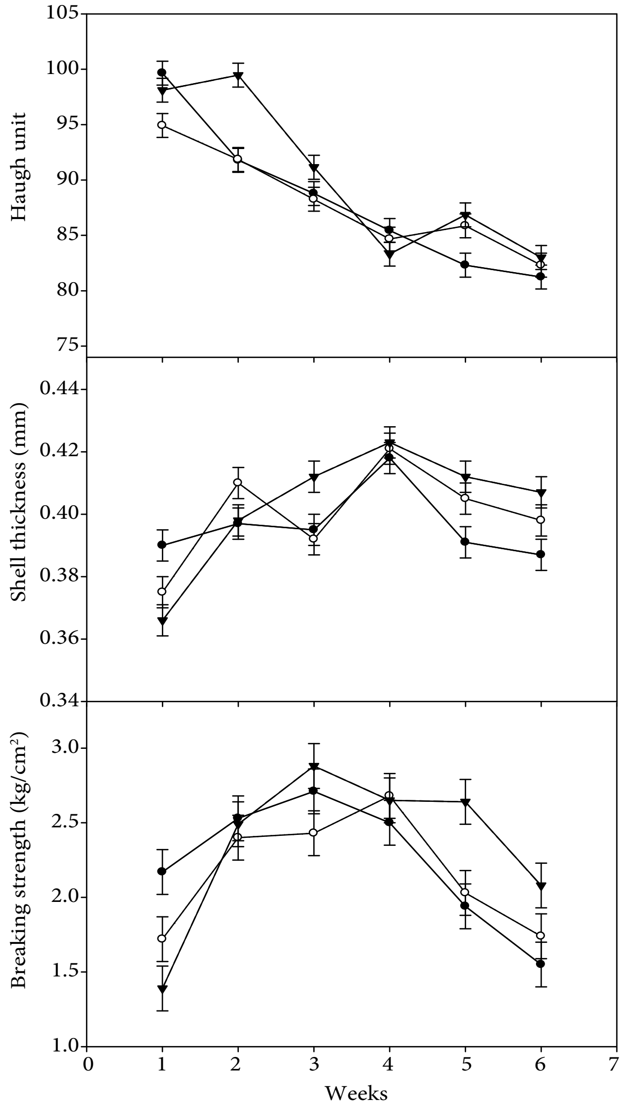

Figure 2. The interactions between housing system and age on Haugh unit, shell thickness, and breaking strength of eggs.
Conventional cage (CC: closed circle), enriched cage (EC: open circle), and free range (FR: closed triangle); weeks: 1: 50% HD production age, 2: peak production age, 3: 30 weeks of age, 4: 40 weeks of age, 5: 50 weeks of age, 6: 60 weeks of age.

The effects of housing system × age interaction on shape index (P = 0.003) and albumen index and yolk color (P < 0.001) are given in Figure 3. The highest shape index was found in the FR system at 30 weeks of age. The housing system and age interaction resulted from a higher albumen index of eggs in the FR system than in the CC and EC systems at peak hen-day egg production age. Lighter egg yolk color was found in the FR system at 50% hen-day egg production age than the other housing systems and darker egg yolk color was found in the EC and FR systems as compared to the CC system at 50 weeks of age.

The effects of housing system × age interaction on albumen ratio (P < 0.001) and yolk ratio and shell ratio (P = 0.001) are given in Figure 4. Among all of the housing systems the highest albumen ratio and lowest yolk ratio were found in the FR system at 50% hen-day egg production age. The lowest shell ratio was found in the CC system at 60 weeks of age.

4. Discussion

Egg weight is an important parameter for overall egg quality and economics of production. Some studies indicated that

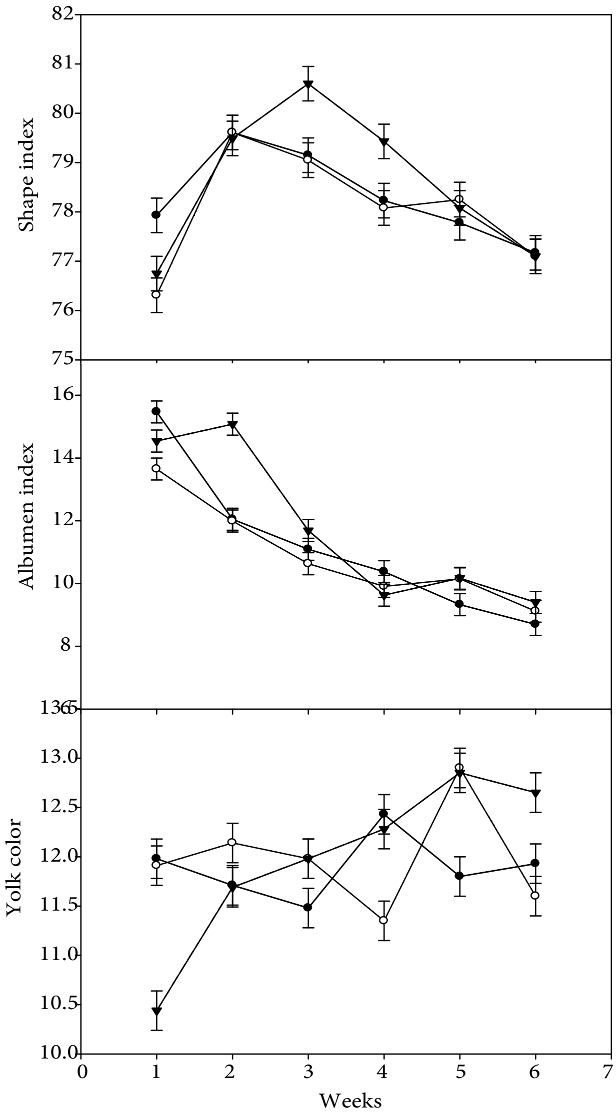

Figure 3. The interactions between housing system and age on shape index, albumen index, and yolk color of eggs.
Conventional cage (CC: closed circle), enriched cage (EC: open circle), and free range (FR: closed triangle); weeks: 1: 50% HD production age, 2: peak production age, 3: 30 weeks of age, 4: 40 weeks of age, 5: 50 weeks of age, 6: 60 weeks of age.

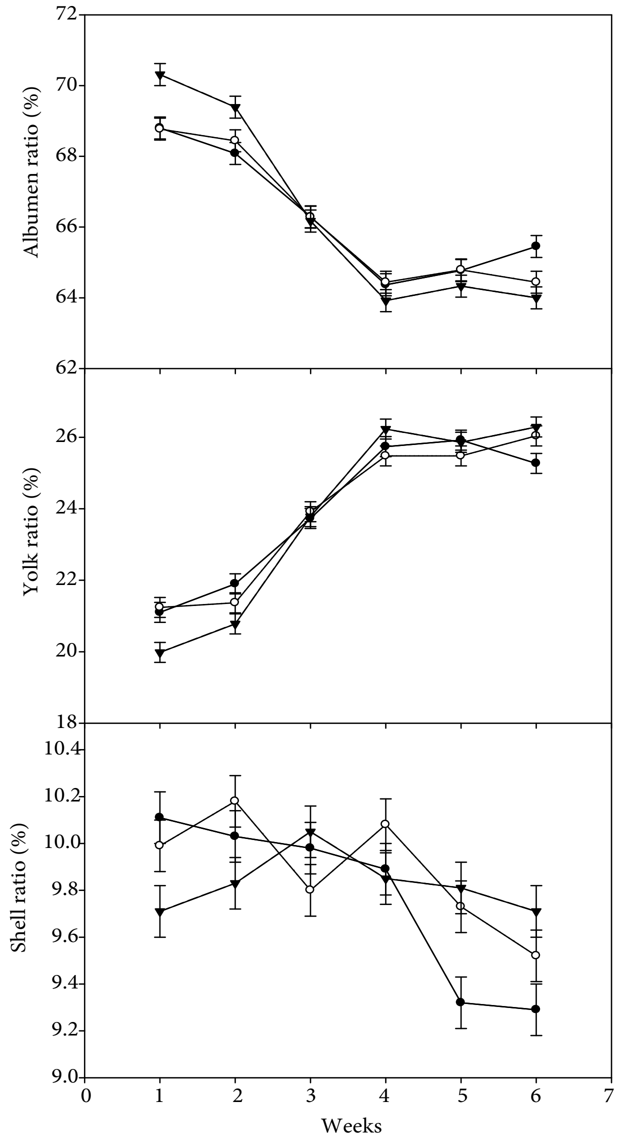

Figure 4. The interactions between housing system and age on albumen ratio, yolk ratio, and shell ratio of eggs. -
Conventional cage (CC: closed circle), enriched cage (EC: open circle), and free range (FR: closed triangle); weeks: 1: 50% HD production age, 2: peak production age, 3: 30 weeks of age, 4: 40 weeks of age, 5: 50 weeks of age, 6: 60 weeks of age.

egg weight was higher in cage systems than in floor systems or free-range systems (10). However, in some other studies, heavier eggs were found in litter systems than in cages (11,12). In the present study, eggs from the FR system were heavier than those from the CC and EC systems. Different commercial genotypes produce differently sized eggs, and thus the weights and proportions of egg, shell, albumin, and yolk vary (13). In the present study, egg shell weight, yolk weight, albumen weight, albumen index, and Haugh unit were higher in the FR system but were similar in the CC and EC systems. However, a higher Haugh unit value in conventional cages than other systems was reported previously (14,15). Samiullah et al. (3) found that egg weight, Haugh unit, shell weight, shell ratio, and shell thickness values of eggs in a conventional-cage system were higher than those of eggs in a free-range system and, similar to our results, those values increased with flock age, except for Haugh unit, which decreased. However, in other studies there were no differences between housing systems for shell weight (14,16) and Haugh unit (17). In this study generally the temperature was low in the FR system depending on outdoor access and this might have contributed to albumen quality and Haugh unit value of eggs.

According to previous studies, the egg shape index (17) and yolk index (14) were higher in cage-system eggs than in the free-range or litter system eggs. However, Englmaierová et al. (18) observed that the albumen and yolk index were higher in enriched cages and aviaries. In the present study, eggs from the FR system had the highest shape index and yolk index values among all of the housing systems, but some other researchers found that housing system did not affect yolk index and shape index (15,19).

Eggshell quality is important for economic reasons because a decrease in eggshell quality results in a decreased number of eggs for consumption. Previous studies compared traditional cages with other housing systems and observed thicker egg shells and better breaking strength in aviary and barn eggs (15,20). In the present study, housing systems did not affect egg shell thickness and shell breaking strength. There were no differences between conventional-cage and enriched-cage systems for egg shell strength (3,21). The shell thickness was not affected by the housing systems (4).

Englmaierová et al. (18) compared different housing systems and observed higher shell ratio in aviary eggs and higher yolk and albumen ratios in conventional-cage and litter system eggs. In the present study, albumen ratio, yolk ratio, and shell ratio of eggs were not affected by the housing system. Similar to our results, Şekeroğlu et al. (17) found that shell ratio was not different among housing systems.

Previously published results reported that housing systems of hens had significant effects on yolk color and darker yolk color was reported variously in the cage system (3,5), the barn system (11), the deep litter system (14), or in the FR system (22). The pigments in the feed affect yolk color and dark colored yolk would be expected in the FR system because the hens also feed on grass (4). However, in the present study, egg yolk color was not affected by the housing system, although a significant interaction was found between housing system and hen age. No difference in yolk color might be the result of the use of the same feed and vegetation in the outdoor area of the free range as a result of decreased seasonal conditions. Similar to our results, Şekeroğlu et al. (17) concluded that yolk color was not affected by the type of housing system.

Previous studies reported increased hen age being associated with increased yolk weight, albumen weight, and yolk ratio (23), but decreased albumen ratio (24), eggshell quality (25), and shape index (4). However, some authors found no significant effect of hen age on egg weight (12) and eggshell traits (26). In the present study, as expected, investigated values changed throughout the laying period; the age of hens affected the egg weight, shell weight, albumen weight, yolk weight, shell breaking strength, shell thickness, shape index, albumen index, yolk index, yolk color, Haugh unit, albumen ratio, yolk ratio, and shell ratio. The egg weight, yolk weight, and albumen weight increased at 50 weeks of age, but shell weight increased at 40 weeks of age and then remained constant until the end of the production period. These findings agree with those of Riczu et al. (27), who found that eggshell quality parameters deteriorate with increasing hen age, with the exception of eggshell weight, which increases with age. In the present study, the egg shell breaking strength was lowest at 50% hen-day egg production age and 60 weeks of age. On the other hand, egg shell thickness was high at 40 weeks of age. With advancing hen age, some egg quality traits changed in all investigated housing systems, in agreement with another study (3).

There were interactions between housing system and laying hen age on egg weight, eggshell content, and albumen height (4) and between age, strain, and housing systems for yolk and albumen weight, albumen height, and yolk color (28). In the present study, the interaction between housing system and hen age for egg weight, shell weight, yolk weight, albumen weight, shell breaking strength, shell thickness, albumen index, yolk color, Haugh unit, albumen ratio, yolk ratio, shell ratio, and shape index indicate that the pattern of change with increasing hen age was different among the housing systems. The interaction of housing system and hen age was a result of heavier egg weight, shell weight, yolk weight, and albumen weight in the FR system at 30 weeks of age than the CC and EC systems. Egg weight increased with age in the CC and EC systems, but, in the FR system, increased with age and then decreased. However, Samiullah et al. (3) found that egg weight was higher in the CC system for the whole laying period, but in the FR system egg weight increased at the beginning of the laying period and then remained constant. Zemkova et al. (12) observed that egg weight in the outdoor system hens decreased until 59 weeks of age and then increased, but Neijat et al. (29) found that shell thickness, shell ratio, yolk weight, albumen weight, and shell weight of laying hens in enriched-cage and conventional-cage systems were not different, and there was a cage × period interaction for eggshell weight and it was significantly higher in the enriched-cage than in the conventional-cage system in the late production period.

Eggshell strength and eggshell thickness increased toward peak production, then decreased with increased hen age in cage and outdoor systems (30). Thus, in the present study, among all of the housing systems the lowest egg shell breaking strength and shell thickness were found at the age of 50% hen-day egg production in the FR system. Van Den Bran et al. (4) also found that eggshell quality decreased with increased age in the cage system whereas, in the outdoor system, eggshell quality remained constant or even increased. Samiullah et al. (3) observed that breaking strength was higher in the free range system than in the conventional cage system at 45 and 55 weeks of age.

The albumen quality, measured as Haugh units, reflects the height of albumen and the egg weight (1). The housing system affected albumen quality with Haugh units being higher in the conventional-cage than in the floor system, and in the enriched-cage than in the conventional-cage system (5). In the present study, Haugh unit was higher in the FR system than in the cage systems, and it was similar between the CC and EC systems at peak hen-day egg production age. A slight increase and then decrease occurred in HU in the FR system at the same time as a linear decrease occurred in the CC system. This is different from the results of Ahammed et al. (15), who found a higher Haugh unit value in the conventional cage system than in aviary and barn systems in the first period of laying (21 to 41 weeks). In the present study, among the housing systems, the highest albumen ratio and lowest yolk ratio were found in the FR system at 50% hen-day egg production age. The lowest shell ratio was found in the CC system at 60 weeks of age. However, Samiullah et al. (3) found that yolk color, egg weight, shell thickness, shell weight, eggshell ratio, and Haugh unit were higher in the conventional-cage system than the free-range system and increased with flock age, except for Haugh unit.

Recently one of the main issues for the layer sector is improving the housing conditions for laying hens. Consumers prefer to eat healthy eggs and there is a perception that free-range eggs are more healthy than conventional ones. Quality of eggs is also an important factor for consumers. The weights of egg, yolk, albumen, and shell in FR system layers were increased more with hen age than were eggs from CC and EC layers. Egg breaking strength and eggshell thickness increased with onset of the laying period and then decreased with age in all housing systems. It is concluded that eggs from the FR layers were better for many egg parameters, and knowledge concerning egg quality traits in different housing systems may help producers to decide which housing system to choose.

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