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Determination of Genotype, Housing System and Age Effect on Egg Production and Quality Traits of Layers

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Abstract

This study was carried out to determine the effects of housing systems (free system-FR, conventional cage-CC and enriched cage-EC) on the egg production and quality traits of layer genotypes (Lohmann Sandy-LS, Lohmann White-LW and Lohmann Brown-LB) at 35, 45, 55 and 65 weeks of age. A total of 180 layers were used for egg production traits. A total of 45 eggs were analyzed for egg quality traits at each age period. The highest feed intake was in FR-reared LS layers at 35 wk of age (P=0.000). The lowest yolk index was in CC, and FR-reared LW layers at 65 wk of age (P=0.042). The lowest haugh unit was in EC-reared LB layers at 65 wk of age (P=0.041). The highest yolk color was in CC-reared LB layers and EC-reared LS and LB layers at 45 wk of age (P=0.009). It can be concluded that feed intake of layers, yolk index, haugh unit and yolk color of eggs are affected by the age and genotype of layers reared in different housing systems. The production and egg quality traits are affected by the age of layers. The genotype of layers influences the production and egg quality traits, excluding egg weight and yolk index. The housing system affected feed intake of layers and some egg quality parameters, except for yolk and shell weight, shell ratio, shell thickness, shape index and yolk color. The study could help breeders look for commercial genotypes for rearing in different housing systems.

Introduction

Concerns of consumers regarding animal welfare are prompting significant global changes to the implementation of cage-free housing systems for laying hens (Rodenburg *et al*., 2022). According to the Council Directive 1999/74/EC, all European countries have the capability to produce table eggs using various housing systems (cage and cage-free; litter, free-range, organic systems) (EU Commission, 2021). While enriched cage and litter systems are used for egg production in European countries, there is a growing interest in exploring alternative systems (Majewski *et al*., 2024). Although new trends emerge for animal-friendly systems in the rearing of hens, approximately 90% of hens used in global commercial egg production continue to be housed in cages (Ledvinka *et al*., 2012). But the traditional cage systems are known to significantly restrict the freedom of chickens and their capacity to exhibit normal behaviors (Lay *et al*., 2011).

Because of their high protein content, ease of preparation, widespread availability, and affordability when compared to other animal-based protein sources, eggs are an essential component of the human diet. The quality of an egg has a significant impact on consumer preferences, product value, and food safety (Hisasaga *et al*., 2020). The main goal in layer breeding is to obtain eggs of sufficient yield and quality at low cost.

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Commercial egg layer hybrids are used for rearing to obtain high production performance and egg quality (Tůmová *et al*., 2017; Sokołowicz *et al*., 2018). However, both internal and external variables; including genetics, age, laying cycle, diet, microclimate, management, and housing system, might affect the quality of eggs (Abebe *et al*., 2023; Alig *et al*., 2023). With the spread of alternative housing systems, there are many studies about the effects of rearing systems on egg yield and egg quality. Thus, some studies shown that the differences between layer performance and egg quality characteristics in cage and cage-free systems (Yılmaz Dikmen *et al*., 2016, 2017; Tutkun *et al*., 2018; Philippe *et al*., 2020). Egg quality and eggshell color are essential factors affecting consumer preferences (Scott and Silversides, 2000; Abebe *et al*., 2023). But, using suitable layer genotypes for different housing systems provides significant benefits for productivity (Castellini *et al*., 2016). However, there are limited studies effect of these housing systems on performance and egg quality of different layer genotypes (Sokołowicz *et al*., 2018; Rakonjac *et al*., 2021; Tainika *et al*., 2024; Aygün *et al*., 2025). And there have been few studies comparing differences in housing systems for egg quality attributes over the production cycle (Yılmaz Dikmen *et al*., 2017; Sokołowicz *et al*., 2018). Therefore, this study aimed to determine the effects of housing systems (FR, CC and EC) on egg production and quality traits of laying hen genotypes (LB, LW and LS) at different age periods.

Materials and methods

Practices regarding the care and use of animals for research purposes were in accordance with the laws and regulations of Türkiye and approved by the Animal Use and Ethical Committee of Bursa Uludağ University (Approval Number 2023-05/01). In this study, Lohmann Sandy (LS), Lohmann White (LW) and Lohmann Brown (LB) layer hen were used in free system (FR), conventional cage (CC) and enriched cage (EC) in Bursa Uludağ University, Agriculture Faculty, Research and Application Unit. The CC and EC cage systems were in same hen house. The cage house unit was 120 m from the FR house. The CC system consisted of 3 tiers, cage unit (50×45×45 cm), trough-type feeder, nipple drinker, egg cradle and manure belt. The CC cage provided 450 cm^2/hen. The EC system cages fulfilled the standards of EU Directive 1999/74/EC. The EC cage dimensions were 240×125 cm. The EC system consisted of 2 tiers, trough-type galvanized feeder, nipple drinkers, perches, nesting areas, scratch pad areas, nail shorteners, egg cradle and manure belt. The EC cage provided 750 cm^2/hen. The FR system consisted of pasture (4 m^2/ hen) and indoor areas (m^2/7 hen). The pasture area was protected by wire fences and shelter. The wood shavings litter, rounded feeders and drinkers, perches, and nest boxes were placed in FR system. In all systems, layers were fed with a diet containing 17% CP and 2.750 ME kcal/kg between the 18 and 40 weeks of age, 16% CP and 2.700 ME kcal/kg, 0.7% P and 3% Ca between the 41 and 65 weeks of age (NRC, 1994). Feed and water were offered *adlibitum.* The 16L:8D photoperiod was used at the time of laying.

A total of 180-layer hens, 20 from each genotype (LS, LW and LB) in each rearing system (FR, CC and EC) were used. In order to observe age-related changes in layers' egg production and egg quality throughout the laying period, data were taken at 35, 45, 55, and 65 weeks of age. For each system and genotype group, egg number, egg weight and feed consumption values were collected daily for 1 week in the relevant age periods. Then hen day egg production, egg mass, feed intake and feed conversion ratio (FCR) were calculated as formulas given below;

$$\text{Egg mass} = (\text{Hen day egg production x egg weight})/\ 100$$
$$\text{Feed intake} = (\text{Feed consumption}/\ \text{number of hens})$$
$$\text{Feed conversion ratio} = \text{Feed intake} \ /\ \text{Egg mass}$$

A total of 180 eggs were analyzed for egg inner and outer quality traits during study. At each age period, eggs were collected and randomly selected to determine the egg weight, shell weight, yolk weight, albumen weight, shell thickness, shell breaking strength, shape index, albumen index, yolk index, shell ratio, yolk ratio, albumen ratio, yolk color and haugh unit. Before egg quality determination, all eggs were stored for 24 hours, and per egg quality trait was calculated.

The shape index and shell breaking strength were measured using equipment. The albumen was separated from the yolk after the eggs were broken and weighed. After being swilled and dehydrated for 24 hours, eggshells were weighed. Shell thickness was determined at the air cell, sharp end, and equator of egg points using a caliper and the averages of these sites were used. The data for egg weight, yolk weight and shell weight (g) were recorded using a digital scale. The weight of the egg was subtracted from the weight of the yolk and shell to determine the albumen weight. The albumen length, width, and yolk diameter (mm) were measured using a digital caliper (Mitutoyo Corp., Aurora, IL, USA). A tripod micrometer was used to determine the yolk and albumen heights (mm). The yolk color was determined using a Roche yolk color fan scale. The albumen, yolk, and shell ratios, and albumen and yolk index and Haugh unit (Silversides *et al*., 1993) calculated as formulas given below;

$$\text{Yolk ratio (\%)} = (\text{Yolk weight/Egg weight})\ \text{x}\ 100$$
$$\text{Albumen ratio (\%)} = (\text{Albumen weight/Egg weight})\ \text{x}\ 100$$
$$\text{Shell ratio (\%)} = (\text{Shell weight/Egg weight})\ \text{x}\ 100$$
$$\text{Albumen index (\%)} = \left(\frac{\text{Albumen height}}{\frac{\text{Albumen length+Albumen width}}{2}}\right)\text{x}100$$
$$\text{Yolk index (\%)} = (\text{Yolk height}\ /\ \text{yolk diameter})\ \text{x}\ 100$$
$$\text{Haugh Unit (\%)} = 100\log(\text{Albumen height} + 7.57 - 1.7\text{xEgg weight}^{\ 0.37})$$

Statistical analysis

The data was analysed by analysis of variance General Linear Models using ANOVA with statistical software Minitab 17. Percentage data were analyzed following an arcsine square root transformation of the data. The age (35, 45, 55 and 65), housing system (FR, CC and EC), and genotype (LS, LW and LB) were the main effects. The model included effects of age, housing system, genotype, and all interactions. Data were presented as mean ± standard error (SE) in all the tables. Differences were considered significant at P ≤ 0.05 and the statistical difference at P < 0.10 was described as a tendency. The statistical model was as follows:

$$Y_{ijk} = \mu + a_i + b_j + c_k + (ab)_{ij} + (ac)_{ik} + (bc)_{jk} + (abc)_{ijk} + \varepsilon_{ijk},$$

where $Y_{ijk} = \mu^{th}$ observation value, μ = expected mean of the population, a_i = i. age effect (i= 35, 45, 55 and 65), b_j = j. housing system effect (j= CC, EC and FR), c_k = k. genotype effect (k= LS, LW and LB), $(ab)_{ij}$ = ij. Age and housing system interaction effect, $(ac)_{ik}$ = ik. Age and genotype interaction effect, $(bc)_{jk}$ = jk. Housing system and genotype interaction effect, $(abc)_{ijk}$ = ijk. Age and housing system and genotype interaction effect, ε_{ijk} = residual error.

Results

The age, housing system, genotype and interactions effects on egg production traits of layers are given in Table 1. The age and genotype of layers affected the hen day egg production, egg mass, feed intake and FCR (P=0.000). The lowest henday egg production, egg mass was found at 65 wks of age. The lowest feed intake was found at 45 and 55 wks of age. The henday egg production and egg mass were higher in the LS and LW genotypes. The lowest feed intake was found in the LB genotype. The FCR was higher in the LB genotype but similar in the LS and LW genotypes. The housing system considerably affected the feed intake of layers (P=0.000). The higher feed intake was found in the FR system but was found similar in the CC and EC system. The effect of housing system on hen day egg production tends to be significant and numerically higher hen day egg production was found in FR system (P=0.056).

The age and system interaction effect on egg mass and FCR was found significant (P=0.035 and P=0.001). The age and genotype interaction effect on egg production traits investigated were found significant (P=0.034; P=0.037; P=0.000 and P=0.041; respectively). The system and genotype interaction effect on hen day egg production and feed intake were found significant (P=0.026 and P=0.000; respectively) (Table 1).

The three-way interaction effect of age, housing system and genotype on egg production traits of layers are given in Table 2. The interaction between age, housing system and genotype was significant for feed intake (P=0.000). The highest feed intake was found in FR reared LS layers at 35 wk of age, and lowest feed intake was found in CC reared LS layers at 45 wk of age (P=0.000). The three-way interaction effect of age, housing system and genotype on hen day egg production, egg mass and FCR of layers was insignificant (P > 0.05).

In summary, as a main factors; age and genotype of layers influenced hen day egg production, egg mass, feed intake and FCR, but housing system affected only feed intake of layers. At 35 wk of age the highest feed intake was found in FR reared LS layers.

The age, housing system, genotype and interaction effects on egg quality of layers are given in Table 3 and Table 4. The layers' age affected the egg weight, albumen, yolk and shell weights, albumen, yolk (P=0.004) and shell (P=0.046) ratios (P=0.000). The highest egg weight, yolk weight, shell weight and yolk ratio were found at 65 wks of age. The lowest albumen weight, albumen ratio was found at 45 and 65 wks of age, respectively. The lowest shell ratio was found at 35 and 55 wks of age. The housing system considerably affected the egg weight (P=0.000), albumen weight (P=0.000), albumen ratio (P=0.005) and yolk ratio of layers (P=0.040). The highest egg weight, albumen weight, albumen ratio and lowest yolk ratio were found in EC system. The genotype of layers affected albumen and shell weight (P=0.004), yolk weight (P=0.000), albumen and yolk ratio (P=0.000), shell ratio (P=0.011). The highest yolk weight and yolk ratio, and lowest albumen weight and ratio was found in LW. The shell weight and shell ratio were higher in the LB genotype but lower in the LS genotype (Table 3).

The age and system interaction effect on egg weight and albumen weight were found significant (P=0.001 and P=0.026). The age and genotype interaction effect on egg weight, albumen weight, yolk weight, shell weight and yolk ratio were found significant (P=0.000; P=0.044; P=0.003; P=0.030 and P=0.050; respectively). The system and genotype interaction effect on egg weight, albumen weight and yolk ratio were found significant (P=0.001; P=0.000 and P=0.030; respectively) (Table 3).

The age of layers affected the SBS, ST (P=0.001), shape index (P=0.003), albumen index, yolk index, haugh unit and yolk color (P=0.000). The highest SBS and yolk color were found at 45 wks of age. The lowest shell thickness was found at 55 wks of age. The lowest albumen index, yolk index, shape index and haugh unit were found at 65 wks of age (Table 4).

The housing system considerably affected the albumen index (P=0.000), SBS (P=0.003), yolk index (P=0.007) and haugh unit (P=0.000). The SBS was found lower in the CC system but higher in the FR system. The haugh unit and albumen index were higher in the CC system, but similar in the FR and EC system. The yolk index was found higher in the EC but was lower in the FR system. The genotype of layers affected SBS (P=0.004), shell thickness (P=0.002), shape index (P=0.000), albumen index (P=0.002), haugh unit (P=0.013) and yolk

Table 1. Effect of age, housing system and genotype on egg production traits of layers

Age, week	Hen day production, %	Egg mass, g	Feed intake, g	FCR, g feed/g egg
35	88.02^{a}	53.24^{a}	114.21^{a}	2.22^{b}
45	92.49^{a}	54.51^{a}	108.11^{b}	2.00^{c}
55	91.64^{a}	54.82^{a}	108.90^{b}	2.03^{c}
65	77.51^{b}	48.32^{b}	112.70^{a}	2.43^{a}
SE	1.50	0.90	0.95	0.05
P	0.000	0.000	0.000	0.000
System				
CC	88.24	53.18	108.97^{b}	2.12
FR	89.11	53.47	113.64^{a}	2.17
EC	84.91	51.52	110.33^{b}	2.22
SE	1.30	0.78	0.82	0.04
P	0.056	NS	0.000	NS
Genotype				
LS	94.07^{a}	56.16^{a}	115.34^{a}	2.08^{b}
LW	90.55^{a}	55.28^{a}	110.18^{b}	2.05^{b}
LB	77.63^{b}	46.72^{b}	107.42^{c}	2.38^{a}
SE	1.30	0.78	0.82	0.04
P	0.000	0.000	0.000	0.000
Interactions				
A × S	NS	0.035	NS	0.001
SE	2.59	1.57	1.65	0.08
A × G	0.034	0.037	0.000	0.041
SE	2.59	1.57	1.65	0.08
S × G	0.026	NS	0.000	NS
SE	2.25	1.36	1.43	0.07
A × S × G	NS	NS	0.001	NS
SE	4.79	2.72	2.86	0.15

$^{a-c}$ values within columns with different superscripts are significantly different (P < 0.05). NS: Not significant
A: Age; S: Housing System; G: Genotype; CC: conventional cage, FR: Free range, EC: Enriched cage;
LS: Lohmann Sandy, LW: Lohmann White, LB: Lohmann Brown

Table 2. The three-way interaction effect of age, housing system and genotype on egg production traits of layers

Trait	Age, week	Housing System									SE	P
		CC			FR			EC				
		LS	LW	LB	LS	LW	LB	LS	LW	LB		
Hen day, %	35	94.29	97.14	71.43	95.89	91.43	80.00	97.74	92.86	71.43	4.49	NS
	45	93.30	96.43	94.90	95.71	96.99	83.57	97.14	92.48	81.90		
	55	95.24	95.71	95.92	97.14	93.98	82.71	97.32	91.73	75.00		
	65	83.93	75.71	64.84	93.98	81.95	75.94	87.14	80.16	53.97		
Egg mass, g	35	56.98	59.82	42.22	55.71	55.10	46.84	60.29	57.82	44.38	2.72	NS
	45	54.34	58.94	54.32	55.33	58.03	47.91	57.56	55.00	49.24		
	55	55.95	57.73	57.19	58.29	57.42	49.01	57.70	53.90	46.23		
	65	52.58	48.29	39.81	58.53	51.59	47.90	50.76	49.78	35.70		
Feed intake, g	35	117.65^{a-f}	117.23^{a-f}	104.47^{e-g}	131.84^{a}	103.44^{fg}	119.69^{a-e}	121.03^{a-c}	109.49^{b-g}	103.08^{fg}	2.86	0.001
	45	101.30^{g}	105.78^{c-g}	105.62^{c-g}	121.54^{ab}	112.18^{b-g}	105.76^{c-g}	108.51^{b-g}	104.86^{e-g}	107.45^{b-g}		
	55	109.33^{b-g}	107.90^{b-g}	104.93^{d-g}	114.21^{b-g}	108.75^{b-g}	106.38^{b-g}	109.58^{b-g}	106.76^{b-g}	112.31^{b-g}		
	65	114.49^{b-g}	115.44^{b-g}	103.60^{fg}	120.65^{a-d}	114.92^{b-g}	104.35^{e-g}	113.97^{b-g}	115.44^{b-g}	111.48^{b-g}		
FCR,g feed/g egg	35	2.14	1.98	2.52	2.39	1.93	2.80	2.00	1.90	2.32	0.15	NS
	45	1.87	1.80	1.95	2.22	1.94	2.21	1.92	1.92	2.21		
	55	1.98	1.91	1.84	1.96	1.90	2.19	1.96	2.07	2.44		
	65	2.25	2.51	2.64	2.07	2.26	2.22	2.25	2.45	3.18		

$^{a-o}$ values within columns and lines with different superscripts are significantly different (P < 0.05). NS: Not significant
A: Age; S: Housing System; G: Genotype; CC: conventional cage, FR: Free range, EC: Enriched cage; LS: Lohmann Sandy, LW: Lohmann White, LB: Lohmann Brown

Table 3. Effect of age, housing system and genotype on egg quality traits of layers

Age	Egg weight, g	Albumen weight, g	Yolk weight, g	Shell weight, g	Albumen ratio, %	Yolk ratio, %	Shell ratio, %
35	60.10^{b}	38.31^{a}	15.89^{b}	5.90^{b}	63.71^{a}	26.46^{b}	9.82^{b}
45	58.20^{c}	36.71^{b}	15.58^{b}	5.90^{b}	63.07^{ab}	26.76^{b}	10.15^{a}
55	59.95^{b}	38.00^{a}	16.04^{b}	5.91^{b}	63.35^{a}	26.77^{b}	9.87^{b}
65	62.11^{a}	38.66^{a}	17.13^{a}	6.31^{a}	62.22^{b}	27.61^{a}	10.16^{a}
SE	0.27	0.25	0.15	0.06	0.25	0.23	0.10
P	0.000	0.000	0.000	0.000	0.000	0.004	0.046
System							
CC	58.91^{c}	36.98^{b}	15.97	5.95	62.79^{b}	27.09^{a}	10.10
FR	59.79^{b}	37.54^{b}	16.22	6.01	62.80^{b}	27.13^{a}	10.06
EC	61.57^{a}	39.23^{a}	16.29	6.05	63.68^{a}	26.48^{b}	9.83
SE	0.24	0.22	0.13	0.06	0.21	0.19	0.09
P	0.000	0.000	NS	NS	0.005	0.040	NS
Genotype							
LS	59.93	37.89^{ab}	16.15^{b}	5.88^{b}	63.22^{a}	26.95^{b}	9.82^{b}
LW	59.99	37.41^{b}	16.61^{a}	5.97^{ab}	62.37^{b}	27.67^{a}	9.95^{ab}
LB	60.35	38.46^{a}	15.72^{c}	6.16^{a}	63.68^{a}	26.09^{c}	10.21^{a}
SE	0.24	0.22	0.13	0.06	0.21	0.19	0.09
P	NS	0.004	0.000	0.004	0.000	0.000	0.011
Interactions							
A × S	0.001	0.026	NS	NS	NS	NS	NS
SE	0.48	0.44	0.25	0.12	0.43	0.39	0.18
A × G	0.000	0.044	0.003	0.030	NS	0.050	NS
SE	0.48	0.44	0.25	0.12	0.43	0.39	0.18
S × G	0.001	0.000	NS	0.066	0.063	0.030	NS
SE	0.41	0.38	0.22	0.10	0.37	0.34	0.16
A × S × G	0.073	NS	NS	NS	NS	NS	NS
SE	0.83	0.76	0.44	0.20	0.75	0.69	0.32

a-c values within columns with different superscripts are significantly different (P < 0.05). NS: Not significant
A: Age; S: Housing System; G: Genotype; CC: conventional cage, FR: Free range, EC: Enriched cage
LS: Lohmann Sandy, LW: Lohmann White, LB: Lohmann Brown; SBS: Shell breaking strength, ST: Shell thickness

Table 4. Effect of age, housing system and genotype on egg quality traits of layers

Age	SBS,kg/cm²	ST,mm	Shape index, %	Albumen index, %	Yolk index, %	Haugh unit	Yolk color
35	1.79^{b}	0.406^{ab}	76.46^{a}	8.57^{a}	40.66^{a}	78.93^{b}	12.05^{b}
45	2.36^{a}	0.411^{a}	76.24^{a}	9.01^{a}	40.06^{ab}	83.78^{a}	12.40^{a}
55	1.55^{b}	0.394^{b}	75.53^{ab}	8.86^{a}	39.22^{bc}	83.26^{a}	11.80^{b}
65	1.46^{b}	0.410^{a}	75.06^{b}	7.39^{b}	38.59^{c}	74.65^{c}	11.82^{b}
SE	0.13	0.003	0.29	0.18	0.30	0.89	0.08
P	0.000	0.001	0.003	0.000	0.000	0.000	0.000
System							
CC	1.54^{b}	0.408	76.10	9.10^{a}	39.78^{ab}	82.79^{a}	12.08
FR	2.10^{a}	0.405	75.93	8.11^{b}	38.98^{b}	78.93^{b}	11.98
EC	1.72^{ab}	0.401	75.44	8.17^{b}	40.13^{a}	78.76^{b}	11.98
SE	0.11	0.002	0.25	0.16	0.26	0.77	0.07
P	0.003	NS	NS	0.000	0.007	0.000	NS
Genotype							
LS	1.62^{b}	0.398^{b}	76.45^{a}	8.05^{b}	39.58	78.67^{b}	12.08^{a}
LW	1.64^{b}	0.404^{ab}	74.23^{b}	8.88^{a}	39.33	81.91^{a}	11.83^{b}
LB	2.11^{a}	0.413^{a}	76.79^{a}	8.44^{ab}	39.98	79.90^{ab}	12.13^{a}
SE	0.11	0.002	0.25	0.16	0.26	0.77	0.07
P	0.004	0.002	0.000	0.002	NS	0.013	0.010
Interactions							
A × S	NS	NS	NS	0.004	NS	0.001	NS
SE	0.23	0.005	0.51	0.32	0.51	1.54	0.14
A × G	NS	NS	NS	0.069	0.039	NS	0.000
SE	0.23	0.005	0.51	0.32	0.51	1.54	0.14
S × G	NS	0.071	NS	NS	NS	NS	0.000
SE	0.20	0.005	0.44	0.28	0.45	1.34	0.12
A × S × G	NS	NS	NS	0.078	0.042	0.041	0.009
SE	0.40	0.010	0.88	0.56	0.89	2.67	0.25

a-c values within columns with different superscripts are significantly different (P < 0.05). NS: Not significant
A: Age; S: Housing System; G: Genotype; CC: conventional cage, FR: Free range, EC: Enriched cage
LS: Lohmann Sandy, LW: Lohmann White, LB: Lohmann Brown; SBS: Shell breaking strength, ST: Shell thickness

color (P=0.010). The SBS was higher in LB but was similar in LS and LW genotypes. The ST was found higher in the LB but was lower in the LS genotype. The shape index and yolk color were lower in the LW genotype but similar in the LS and LB genotypes. The haugh unit and albumen index were found higher in the LW, but lower in the LS genotype (Table 4).

The age and system interaction effect on albumen index and haugh unit were found significant (*P*=0.004 and P=0.001). The age and genotype interaction effect on yolk index and yolk color were found significant (P=0.039 and *P*=0.000). The system and genotype interaction effect on yolk color was found significant (*P*=0.000) (Table 4).

The three-way interaction effect of age, housing system and genotype on egg quality traits of layers are given in Table 5 and Table 6. The interaction between age, housing system and genotype was significant for yolk index (P=0.042), haugh unit (P=0.041) and yolk color (P=0.009). The highest yolk index was found in CC reared LW layers at 45 wk of age, and lowest was found in CC and FR reared LW layers at 65 wk of age. The highest haugh unit was found in CC reared LS layers at 45 wk of age, and lowest was found in EC reared LB layers at 65 wk of age. The highest yolk color was found in CC reared LB layers, and EC reared LS and LB layers at 45 wk of age, and lowest yolk color was found in FR reared LS layers at 55 wk of age and in EC reared LB layers at 65 wk of age. The three-way interaction effect of age, housing system and genotype on egg weight and albumen index of layers was tend to be significant (P=0.073 and P=0.078). The three-way interaction effect of age, housing system and genotype on albumen weight and ratio, yolk weight and ratio, shell weight and ratio, SBS, ST and shape index of layers was insignificant (P > 0.05).

In summary, as a main factors; age of layers influenced all investigated egg quality parameters, and housing system influenced egg weight, albumen weight and ratio, yolk ratio, shell breaking strength, index of albumen and yolk, and haugh unit. But genotype of layers affected all the egg quality parameters investigated, except for egg weight and yolk index. At 45 weeks of age, CC-raised LW layers had the highest yolk index, LS layers had the highest haugh unit and LB layers had the highest yolk color, and also EC- raised LS and LB layers had the highest yolk color.

Discussion

Enhancing the living conditions for laying hens has become a major concern for the layer industry. In the study, layer's age influenced hen day egg production, egg mass, feed intake and FCR. The henday egg production and egg mass was the lowest at 65 wks of age. Şekeroğlu *et al.* (2014) reported that hen age affected FCR and egg production rate, Yılmaz Dikmen *et al.* (2016) reported that age of hens affected hen day egg production, feed intake, egg mass and FCR of layers. Thus, Yılmaz Dikmen *et al.* (2016) reported that lowest henday egg production was at 60 wk of age. Indeed, a decrease in egg production with increasing age is an expected situation, also, since egg mass is determined with egg production, it was found to be lower with advancing age. But, in the study the lowest feed intake was at 45 and 55 wks of age of layers. During study, the season corresponded to summer and autumn in these age periods. The high air temperature in these periods might cause low feed consumption. In fact, Yakubu *et al*. (2007) investigated genotype and housing system (battery cage system and deep litter system) effect on the performance of Bovans Brown and Lohmann Brown layers in the wet and hot-dry seasons and found that hen-housed egg production, feed intake, and egg weight of layers improved in the wet season compared to the hot-dry season.

Studies have indicated that egg production in traditional cage, enhanced cage, barn and aviary system was similar (Neijat *et al*., 2011; Ahammed *et al.*, 2014). Some research found that conventional cage systems produced more eggs than aviary, floor systems, or free-range systems (Leyendecker *et al*., 2001; Erek and Matur, 2024). However, in the study, housing system tends to be affected hen day egg production and in terms of numbers higher hen day egg production was found in FR system. Support to this Yılmaz Dikmen *et al*. (2016) found that hen day egg production was comparable in the CC and EC systems, but higher in the FR system. According to certain research, rearing systems have an impact on egg mass (Onbaşılar *et al*., 2015; Erek and Matur, 2024). But in the study, housing systems were not affected by egg mass of layers. However, the housing system influenced feed intake of layers. The higher feed intake was in the FR system. These results were comparable to those of Yılmaz Dikmen *et al*. (2016) and Ahammed *et al*. (2014). It can be thought that layers reared in the free-range system were consumed more feed because they were more mobile than layers in the cage system. In addition, layers in the free-range system were consumed more feed in cold weather seasons, because they were more exposed to seasonal temperature changes. As a matter of fact, it was determined that feed intake was similar in CC and EC systems within the same poultry house. Despite this, housing systems were not found to have any effect on FCR of layers. But research suggests that different rearing systems have varying effects on FCR of layers (Ahammed *et al*., 2014; Onbaşılar *et al*., 2015; Yılmaz Dikmen *et al*., 2016).

The genotype affects the performance of layers, Rakonjac *et al*. (2021) whom investigated the effect of rearing systems (floor and organic) and genotypes, reported that Isa Brown hens had better egg production, egg mass, feed intake and FCR than New Hampshire hens. Also, Tutkun *et al.* (2018) whom compared the performance of free range reared Lohmann Brown and Atak-S, reported that egg production was similar between the genotypes, but there were differences in feed consumption and feed efficiency between the layers. In the study, hen day egg production, egg mass

Table 5. The three-way interaction effect of age, housing system and genotype on egg quality traits of layers

Trait	Age, week	Housing System									SE	P
		CC			FR			EC				
		LS	LW	LB	LS	LW	LB	LS	LW	LB		
Egg weight, g	35	59.82	56.25	57.15	59.54	59.13	61.72	61.57	61.28	64.43	0.83	0.073
	45	57.51	60.11	55.64	57.46	59.24	56.32	58.08	59.60	59.86		
	55	59.58	59.52	60.27	60.02	59.83	59.05	60.31	60.06	60.95		
	65	59.42	61.17	60.45	62.08	61.69	61.42	63.75	62.05	66.96		
Albumen weight, g	35	38.17	35.78	35.66	37.61	37.60	38.95	39.62	39.00	42.37	0.76	NS
	45	36.00	37.41	35.44	35.80	36.87	36.19	36.69	37.55	38.42		
	55	38.20	36.59	38.09	37.88	37.37	38.05	39.11	37.29	39.38		
	65	37.64	37.29	37.53	38.26	37.89	38.04	39.65	38.26	43.37		
Yolk weight, g	35	15.74	14.88	15.61	16.21	15.96	16.57	15.97	16.22	15.84	0.44	NS
	45	15.91	16.34	14.55	15.67	16.47	14.21	15.53	16.15	15.38		
	55	15.52	16.88	16.32	16.30	16.70	14.88	15.21	16.99	15.53		
	65	15.96	17.43	16.47	17.70	17.31	16.66	18.04	17.94	16.62		
Shell weight, g	35	5.90	5.59	5.87	5.71	5.56	6.20	5.97	6.05	6.22	0.20	NS
	45	5.58	6.35	5.64	5.99	5.89	5.91	5.85	5.89	6.05		
	55	5.85	6.04	5.85	5.83	5.74	6.10	5.98	5.78	6.04		
	65	5.81	6.44	6.44	6.11	6.47	6.69	6.01	5.84	6.96		
Albumen ratio, %	35	63.81	63.60	62.39	63.17	63.59	63.09	654.34	63.62	65.75	0.75	NS
	45	62.59	62.26	63.68	62.30	62.24	64.23	63.17	63.01	64.18		
	55	64.10	61.47	63.16	63.11	62.42	64.40	64.83	62.07	64.60		
	65	63.35	60.97	62.11	61.62	61.45	61.93	62.20	61.68	64.67		
Yolk ratio, %	35	26.31	26.43	27.30	27.22	26.99	26.86	25.95	26.46	24.58	0.69	NS
	45	27.68	27.16	26.16	27.27	27.81	25.26	26.74	27.10	25.71		
	55	26.05	28.38	27.10	27.17	27.96	25.24	25.24	28.30	25.49		
	65	26.86	28.48	27.22	28.52	28.05	27.16	28.36	28.89	24.98		
Shell ratio, %	35	9.87	9.96	10.30	9.59	9.41	10.04	9.70	9.90	9.66	0.32	NS
	45	9.72	10.56	10.14	10.42	9.94	10.49	10.08	9.88	10.10		
	55	9.83	10.14	9.73	9.71	9.60	10.35	9.91	9.62	9.90		
	65	9.78	10.53	10.65	9.84	10.49	10.89	9.42	9.42	10.33		

A: Age; S: Housing System; G: Genotype; CC: conventional cage, FR: Free range, EC: Enriched cage; LS: Lohmann Sandy, LW: Lohmann White, LB: Lohmann Brown NS: Not significant.

Table 6. The three-way interaction effect of age, housing system and genotype on egg quality traits of layers

Trait	Age, week	Housing System									SE	P
		CC			FR			EC				
		LS	LW	LB	LS	LW	LB	LS	LW	LB		
SBS, kg/cm^2	35	1.60	1.52	2.21	1.63	1.75	1.87	1.58	1.91	2.06	0.40	NS
	45	1.26	3.14	2.16	2.59	2.25	2.83	2.41	2.06	2.52		
	55	1.55	0.77	1.24	2.13	1.76	2.20	1.65	0.75	1.88		
	65	0.40	1.20	1.47	1.97	1.54	2.71	0.68	1.05	2.15		
ST, mm	35	0.400	0.412	0.427	0.396	0.397	0.407	0.400	0.402	0.412	0.010	NS
	45	0.394	0.432	0.404	0.415	0.406	0.416	0.419	0.405	0.409		
	55	0.400	0.400	0.394	0.383	0.389	0.409	0.388	0.384	0.400		
	65	0.390	0.426	0.424	0.406	0.410	0.431	0.386	0.390	0.425		
Shape index, %	35	77.40	76.20	77.20	77.60	74.60	77.60	75.80	73.80	78.00	0.88	NS
	45	76.20	74.80	76.80	76.60	74.20	78.00	77.40	75.20	77.00		
	55	76.40	73.20	76.80	75.80	74.00	76.80	75.80	74.60	76.40		
	65	78.00	74.20	76.00	77.80	73.00	75.20	72.60	73.00	75.75		
Albumen index, %	35	7.43	9.70	9.74	7.36	9.31	8.18	8.31	8.66	8.43	0.56	0.078
	45	9.12	11.59	8.35	7.91	7.86	8.52	9.81	9.40	8.53		
	55	9.54	10.73	9.80	8.13	9.69	8.89	7.12	7.18	8.03		
	65	7.27	7.26	8.67	7.26	7.06	7.12	7.39	7.45	7.06		
Yolk index, %	35	40.66^{a-c}	39.26^{a-c}	40.26^{a-c}	41.34^{a-c}	40.86^{a-c}	39.90^{a-c}	41.61^{a-c}	39.62^{a-c}	42.41^{ab}	0.89	0.042
	45	39.25^{a-c}	43.05^{a}	39.23^{a-c}	38.09^{a-c}	39.15^{a-c}	38.61^{a-c}	40.63^{a-c}	40.81^{a-c}	41.69^{a-c}		
	55	38.78^{a-c}	38.29^{a-c}	41.55^{a-c}	39.46^{a-c}	37.94^{bc}	39.73^{a-c}	38.75^{a-c}	39.19^{a-c}	39.29^{a-c}		
	65	39.18^{a-c}	37.06^{c}	40.79^{a-c}	37.56^{bc}	37.26^{c}	37.90^{bc}	39.59^{a-c}	39.48^{a-c}	38.44^{a-c}		
Haugh unit	35	74.25^{d-g}	83.87^{a-f}	81.71^{a-g}	74.16^{d-g}	82.51^{a-g}	76.23^{b-g}	78.92^{a-g}	80.06^{a-g}	78.74^{a-g}	2.67	0.041
	45	92.52^{a}	81.70^{a-g}	78.78^{a-g}	78.70^{a-g}	82.92^{a-g}	88.30^{a-d}	85.41^{a-g}	85.41^{a-g}	82.49^{a-g}		
	55	89.78^{a-c}	90.54^{ab}	87.50^{a-e}	80.76^{a-g}	86.73^{a-f}	83.27^{a-g}	74.53^{d-g}	78.30^{a-g}	78.00^{a-g}		
	65	72.55^{fg}	73.55^{d-g}	82.26^{a-g}	74.96^{d-g}	75.39^{c-g}	72.76^{e-g}	73.79^{d-g}	75.35^{c-g}	71.25^{g}		
Yolk color	35	12.40^{ab}	12.25^{a-c}	12.00^{a-c}	12.40^{a-c}	11.40^{bc}	12.00^{a-c}	12.40^{ab}	11.60^{a-c}	12.00^{a-c}	0.25	0.009
	45	12.00^{a-c}	12.00^{a-c}	12.80^{a}	12.20^{a-c}	12.40^{ab}	12.60^{ab}	12.80^{a}	12.00^{a-c}	12.80^{a}		
	55	11.80^{a-c}	11.60^{a-c}	12.60^{ab}	11.00^{c}	11.60^{a-c}	12.40^{ab}	11.80^{a-c}	11.80^{a-c}	11.60^{a-c}		
	65	12.20^{a-c}	11.80^{a-c}	11.60^{a-c}	11.40^{bc}	12.20^{a-c}	12.20^{a-c}	12.60^{ab}	11.40^{bc}	11.00^{c}		

$^{a-g}$ values within columns and lines with different superscripts are significantly different ($P < 0.05$). NS: Not significant; SBS: Shell breaking strength, ST: Shell thickness

A: Age; S: Housing System; G: Genotype; CC: conventional cage, FR: Free range, EC: Enriched cage; LS: Lohmann Sandy, LW: Lohmann White, LB: Lohmann Brown feed intake and FCR were affected by the layer's genotype. The LS and LW genotypes had higher henday egg production and egg mass than LB genotype. But LB genotype had lowest feed intake and higher FCR. Similar to our findings Aygün *et al*. (2025) who investigated performance of different genotype layers reared in free-range system, reported that Lohmann Sandy layers laid more eggs than the Lohmann Brown layers.

The significant interactions between genotype and housing system, genotype and season, housing system and season on layers' performance was reported by Yakubu *et al*. (2007) whom investigated genotype and housing system (battery cage system and deep litter system) effect on Bovans Brown and Lohmann Brown layer's performance at the wet and hot dry seasons. Thus, in the study, there were age and genotype interaction effect on investigated all egg production traits. There were age and housing system interaction effect on egg mass and FCR, also it was supported by Yılmaz Dikmen *et al*. (2016). There were housing system and genotype interaction effect on hen day egg production and feed intake of layers. Similarly, Rakonjac *et al*. (2021) reported that there was interaction between the rearing systems and genotypes for egg production, feed consumption, moreover for egg mass and FCR. Also, in the study, age, housing system, and genotype did not interact with hen day egg production, egg mass, and FCR. However, there was age, housing system and genotype interaction effect on feed intake; FR-raised LS layers had the maximum feed intake at 35 weeks of age, while CC-raised LS layers had the lowest feed intake at 45 weeks. These results demonstrate that LS genotypes respond to freedom of mobility and environmental weather conditions, consuming more feed in a rearing system allow both indoor and outdoor access than in cage systems at early and mid-flock ages. The quality of eggs has a great impact on consumer egg purchases, specially egg weight (Aygün and Narinç, 2024). The internal and exterior quality of eggs are affected by a variety of genetic and environmental factors. In various researches suggests that flock age have varying effects on egg quality parameters, thus some was reported that egg weight (Tůmová *et al*., 2017; Tainika *et al*., 2024), weight of yolk and albumen, and ratio of yolk increased with flock age (Suk and Park, 2001), but some was reported that albumen ratio (Rizzi *et al*., 2005), egg shell quality (Tainika *et al*., 2024), shape index (Van Den Brand *et al*., 2004, Tainika *et al*., 2024), yolk index, albumen height, haugh unit (Tainika *et al*., 2024) decreased with increased flock age, but some was reported that egg weight (Zemková *et al*., 2007), shape index, yolk index (Alkan, 2023), egg shell traits (Yannakopoulos *et al*., 1994) did not affect by flock age. In the study, layer's age influenced egg weight, weight of albumen, yolk and shell, ratio of albumen, yolk and shell, SBS, ST, shape index, albumen index, yolk index, haugh unit and yolk color. The highest egg weight, yolk weight, shell weight and yolk ratio were found at 65 wks of age. Our findings were in accordance with (Yılmaz Dikmen *et al*., 2017).

The lowest albumen weight was at 45 wks of age, and albumen ratio, albumen index, and haugh unit were at 65 wks of age. These finding agree with (Yılmaz Dikmen *et al*., 2017) who found that some albumen traits decrease in late flock age. Also, Riczu *et al*. (2004) suggested that shell quality traits decreased with flock age, while only eggshell weight increased. But, in the study, the lowest shell thickness was at 55 weeks of age, the shell ratio was at 35 and 55 weeks of age, and the highest SBS was at 45 weeks of age. In the study, the highest yolk color was at 45 weeks of age, and the lowest shape and yolk index were at 65 weeks of age. It is thought that the differences in egg quality traits with age may be due to the seasonal changes in production systems.

In the study, housing system influenced egg and albumen weight, ratio of albumen and yolk, SBS, index of albumen and yolk, and haugh unit of layers. Several research (Zemková *et al*., 2007; Yılmaz Dikmen *et al*., 2017) demonstrated that eggs were heavier in litter and FR systems than in cages. Also, some research demonstrated that eggs heavier in deep litter system than different vegetated FR system (Tainika *et al*., 2024). In other research, egg weight was higher in cage systems than in floor or FR systems (Leyendecker *et al*., 2001; Erek and Matur, 2024). Similarly, in the study, the highest egg weight was found in EC system. Yılmaz Dikmen *et al*. (2017) found that eggshell weight, yolk weight, albumen weight, albumen index, and Haugh unit were greater in the FR system compared to cage systems. However, in the study the highest albumen weight, albumen ratio, yolk index and lowest yolk ratio were in EC system. Also, according to earlier reports, conventional cages had a greater Haugh unit value than other systems (Ahammed *et al*., 2014; Samiullah *et al*., 2014). Similarly, in the study, albumen index and haugh unit were higher in the CC system but were similar in the FR and EC system. Some research suggests that different rearing systems have varying effects on shell traits of egg, thus Samiullah *et al*. (2014) demonstrated that shell weight, shell ratio, and shell thickness of eggs were heavier in traditional cage systems than in free range systems. In contrast, Erek and Matur (2024) demonstrated that shell weight was heavier in furnished cages than free range system. Tainika *et al*. (2024) reported that higher shell-breaking strength and thickness in free access to vegetated environments outdoor compared to deep litter system. But some studies reported no significant differences between housing systems in terms of shell thickness (Van Den Brand *et al*., 2004), shell breaking strength, and shell ratio (Yılmaz Dikmen *et al*., 2017). However, in the study higher SBS was in FR system, but it was lower in the CC system, and no differences were found between housing systems for shell weight, shell ratio and shell thickness. The housing system effect on yolk color was reported by several studies; thus, Samiullah *et al*. (2014) reported that dark color yolk was in the cage system, but Şekeroğlu *et al*. (2010) and Yılmaz Dikmen *et al*. (2017) reported that yolk color was not affected by the rearing system.

Thus, in the study there were no differences between housing systems for yolk color. During the study, the outdoor vegetation of the free-range system was exposed to seasonal changes, and it can be thought that the lack of difference in yolk color in housing systems is due to the use of the same feed in all systems. In various researches suggests that different rearing systems have varying effects on egg shape index, thus Şekeroğlu *et al*. (2010) reported that egg shape index was higher in cage systems than others, but Yılmaz Dikmen *et al*. (2017) reported that egg shape index was higher in free range systems than others, but Stojčić *et al*. (2012) and Ahammed *et al*. (2014) reported that egg shape index did not affect by housing system. Similarly, in the study there were no differences between housing systems for shape index. It is thought that the differences between our research findings and the findings of other studies may be due to the differences in the genotypes used and exposure to different seasonal changes in open production production systems.

The weights and ratios of the eggshell, albumen, and yolk vary according to the commercial genotype that produces the egg (Johnston, 2007). Rakonjac *et al*. (2021) investigated the effect of rearing systems (floor vs organic) and genotypes (Isa Brown vs New Hampshire) on egg quality, reported that egg weight, Haugh unit, albumen height, proportions of albumen, yolk and shell, shell thickness and breaking strength, and egg shape index affected by genotype of layers. Tainika *et al*. (2024) investigated the effect of rearing systems (free access to vegetated environments outdoor vs deep litter system) and genotypes (Lohmann Sandy vs Lohmann LSL Classic) on egg quality, reported that shell thickness, Haugh unit, shape index, albumen height and index, yolk index and color affected by genotype of layers. Thus, in the study, albumen, shell and yolk weight, albumen, yolk and shell ratio, SBS, shell thickness, shape index, albumen index, haugh unit and yolk color were affected by the layer's genotype. Aygün *et al*. (2025) reported that Lohmann Brown genotype had darker yolk color than Lohmann Sandy and ATAK-S genotypes. However, in the study, yolk color was lighter in the LW genotype but similar in the LS and LB genotypes. The SBS was found higher in LB but was similar in LS and LW genotypes. In contrast to our findings Aygün *et al*. (2025) who investigated performance of different genotype layers reared in free-range system, reported that Lohmann Sandy genotype demonstrated stronger resilience to egg breakage than Lohmann Brown and ATAK-S genotypes. And Tainika *et al*. (2024), reported that there was no difference in shell breaking strength of layer genotypes (Lohmann Sandy vs Lohmann LSL Classic). Also, in the study ST was found higher in the LB genotype but was lower in the LS genotype. In contrast to our findings Tainika *et al*. (2024), found that Lohmann Sandy eggs had higher shell thickness than Lohmann LSL Classic. In addition, Tainika *et al*. (2024), reported that Lohmann Sandy eggs had higher shape index, yolk index, and yolk color, but Lohmann LSL Classic eggs had greater albumen height, albumen index, Haugh unit. The highest albumen quality in free range reared Lohmann Brown genotype was reported by Aygün *et al*. (2025). But in the study, a higher albumen index, haugh unit and lower albumen weight and ratio, and shape index was found in the LW genotype. The highest yolk weight and yolk ratio was in LW genotype. The shell weight and shell ratio were higher in the LB genotype but lower in the LS genotype. However, Tutkun *et al*. (2018) whom compared to the egg quality traits of free range reared Lohmann Brown and Atak-S genotypes, reported that egg quality traits were similar between the genotypes. It is thought that the differences between our research findings and the results of other researches might be due to the differences in the genotypes used in the studies. The rearing system and flock age interactions effect on egg weight, albumen height and eggshell content was reported by (Van Den Brand *et al*., 2004) and egg weight, shell thickness, shell weight, shell ratio, haugh unit, albumen height and yolk color was reported by (Samiullah *et al*., 2014). Thus, in the study, there were interactions between age and housing system on egg weight, albumen weight, albumen index and haugh unit. Similarly, Yılmaz Dikmen *et al*. (2017) reported that there were housing system and hen age interaction effect on these egg quality traits. In the study, there were interactions between age and genotype on egg weight, albumen weight, yolk weight and ratio, shell weight, index and color of yolk. Also, interactions between rearing system and genotype of layers for egg weight, the proportions of albumen and shell, albumen height, haugh unit, shell thickness, and shell breaking strength was reported by (Rakonjac *et al*., 2021). Thus, in the study there were housing system and genotype interaction was on egg weight, albumen weight, yolk ratio and yolk color. The interactions between flock age, strain, and rearing systems on yolk and albumen weight, albumen height, and yolk color was reported by (Singh *et al*., 2009). The interactions between age, housing system and hen genotype on yolk index and yolk color was reported by (Tainika *et al*., 2024). Similarly, in the study, there was interaction between age, housing system and genotype on yolk index, haugh unit and yolk color. At 45 weeks of age, CC-raised LW layers had the greatest yolk index, LS layers had the largest haugh unit and LB layers had the highest yolk color, and also EC-raised LS and LB layers had the highest yolk color. But, at 65 weeks of age CC-and FR-raised LW layers had the lowest yolk index, EC-raised LB layers had the lowest haugh unit and EC- reared LB layers had the lowest yolk color, whereas at 55 wk of age FR- raised LS layers had the lowest yolk color. However, there was no any interaction between age, housing system and genotype on some other egg quality traits. Support to our findings, no interaction effect between age, housing system and hen on egg weight, shape index, shell breaking strength, albumen ratio, yolk ratio, shell ratio, shell breaking strength was reported by (Sokolowicz *et al*., 2018) and egg weight, shell breaking strength, shape index and albumen index reported by (Tainika *et al*., 2024).

Conclusion

The age and genotype of layers influenced hen day egg production, egg mass, feed intake and FCR, but housing system affected only feed intake of layers. The age of layers influenced all investigated egg quality parameters. And housing system influenced egg weight, albumen weight and ratio, yolk ratio, shell breaking strength, index of albumen and yolk, and haugh unit. But genotype of layers affected all the egg quality parameters investigated, except for egg weight and yolk index. It can be concluded that feed intake of layers, yolk index, haugh unit and yolk color of eggs are affected by the age and genotype of layers reared in different housing systems. We believe that results of this study might contribute to researchers and breeders looking for commercial genotypes for rearing in various housing systems.

Ethical Statement

This study was approved by the Bursa Uludağ University Animal Experiments Local Ethics Committee (Approval no: 2023-05/01).

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