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Original Article

The Effect of Different Cage Densities on Laying Performance and Egg Quality in Brown and White Laying Hens

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■Keywords

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ABSTRACT

In this study, the performance characteristics and egg quality of brown (Hy-Line Brown (HB)) and white (Isa Tinted (IT)) laying hens housed in three different cage densities were investigated. Low (5 hens/cage LCD), medium (7 hens/cage MCD) and high (10 hens/cage HCD) cage densities were used in the research. A total of 396 laying hens were used in the experiment by placing 198 HB and 198 IT layers in cages. The performance characteristics, egg production (EP), feed consumption (FC) and livability (L) were recorded at the same time every day. Egg weight (EW) and feed conversion ratio (FCR) were measured weekly, while body weight (BW) was evaluated monthly. Monthly analyzes were performed to determine egg internal and external quality characteristics. According to the results of the research, as the cage density increased, the EP, EW, FC, FCR, BW and L of both hybrids decreased. However, the ratio of broken-cracked eggs was less in HCD. It has been determined that the performance characteristics of HB laying hens are better than ITs. The effect of cage density on egg internal and external quality parameters was insignificant (except for shape index). The shape index was found to be similar at MCD and HCD, both showing higher values than LCD. The effect of hybrid (HB, IT) on egg external quality parameters was found to be significant only on EW (HB: 63.60 g; IT: 62.50 g); while among the internal quality parameters, only the effect on egg yolk was found to be significant (IT>HB).

INTRODUCTION

Chicken eggs are a very important food. The importance of chicken eggs for nutrition steadily increases worldwide, as they are easily accessible and cheap (Purdiyanto *et al*., 2023). Chicken eggs are an animal protein source with high biological value, containing elements that have an important role in human health, such as minerals, vitamins, essential amino acids and fatty acids (Aydın *et al*., 2015). Since eggs have an important function in human nutrition, it is normal for consumers to look for certain qualities in eggs. Factors that concern quality and consumer preferences in the food industry are egg size, cleanliness, freshness, nutritional value, color, hardness and taste (Samiullah *et al*., 2014). Egg quality or characteristics are affected by many factors, such as chicken genetics, nutrition, health status, age, egg storage conditions, or housing duration and conditions (Şeker *et al*., 2005; Petricevic *et al*., 2017; Galazka-Czarnecka *et al*., 2019). Modern-day egg producers often attempt to increase their net income by using available housing facilities at maximum capacity and increasing the number of laying hens per cage (Adams & Craiq, 1985; Dawkins *et al*. 2004; Kakhki *et al*., 2018). The effects of different cage densities on performance and egg quality parameters in laying hens have been investigated in several studies. However, a full consensus has not yet been achieved. For example, it has been reported that as cage density increases, some performance characteristics of laying hens and some internal and external egg quality characteristics are negatively affected (Kum & Güçlü, 2006; Yörük *et al*., 2008; Yardım *et al*., 2021). Conversely, there are also studies reporting that cage densities have no impact on egg production (Şahin *et al*., 2007; Geng *et al*., 2020). There is a need for more scientific studies on egg laying performance and quality in laying hens of body weights and genotypes at different densities.

Cage density in laying hens is one of the important environmental factors affecting egg laying performance and egg quality. Therefore, this study aimed to determine how the laying performance and egg quality characteristics of brown and white laying hens change in three different cage densities.

MATERIALS AND METHODS

Ethical Approval

Permission for this study was obtained from Atatürk University, Animal Experiments Local Ethics Committee, from decision numbered 2021-3/82, dated 14.04.2021. A research permit was obtained from the Food and Livestock Application and Research Center Directorate for the workplace (document number 36643897-000-E.2100056848), dated 25.02.2021. In order to perform egg quality analysis, a work permit was obtained from the Department of Animal Nutrition and Nutritional Diseases (document number 36643897-000-E.2100056912 dated 25.02.2021).

The research was carried out in the Poultry Unit of Atatürk University Food and Livestock Research and Application Center. The laying hen coop consisted of 3 blocks, 2 rows and 4 floors of battery type cages. There are a total of 240 cages, 120 in the front of a row and 120 in the back, and 720 cages in all 3 blocks. The cages have a 70 bottom slope and 2 nipples. Each cage is manufactured to be the same size (front height: 51 cm; rear height: 46 cm; width: 62.5 cm; depth: 60 cm). The manure in the coop is removed from the coop through belts. Ventilation inside the henhouse is provided with the help of chimneys on the ceiling of the coop, windows on the side walls, and 140 cm x 140 cm fans working with negative pressure effect. The lighting system consisted of 16 hours of light/8 hours of darkness. The temperature and humidity of the house are measured with fixed thermometers (hygro guard 30 novasina).

Animals and Study Design

In the study, a total of 396 hybrids were used, of which 198 IT were white layer hybrids and 198 HB were brown laying hybrids. Hybrids were used in the trial from 20 weeks of age to 60 weeks of age. In the study, subgroups were formed for the 3 different cage densities (5 hens/cage, area per hen 750 cm2; 7 hens/cage, area per hen 535.71 cm2; 10 hens/cage, area per hen 375 cm2) and 9 replications. A uniformity of 94% was achieved in terms of body weight (BW) among the white hybrids used in the experiment, and 93% among the brown hybrids. A total of 54 cages were used, 27 of which were on the window side, and 27 on the corridor.

Feed Material

Hybrids brought to the poultry unit during the pullet period were fed *ad libitum* with starter and grower feeds. The content of the feed used in the yield period of chickens is presented in Table 1.

Table 1 – Nutritional content of feeds used in the yield period.

Nutritional Values of Feeds	Egg Starter Feed (17-20th week)	Hens' Feed (First term) (21-45th week)	Hens' Feed (Second term) (46-60th week)
M. Energy (Kcal/kg)	2750	2750	2720
Crude protein (%)	17.50	16.26	15.83
Calcium (%)	2.00	3.57	3.74
Phosphorus (Top) (%)	0.65	0.52	0.47
Phosphorus (Hazm) (%)	0.45	0.37	0.33
Sodium (%)	0.16	0.15	0.15
Chloride (%)	0.16	0.15	0.15
License (%)	0.85	0.76	0.74
Hazm. License (%)	0.70	0.62	0.61
Methionine (%)	0.36	0.38	0.35
Hazm. Methionine (%)	0.29	0.31	0.29
Meth./Sistine (%)	0.68	0.70	0.64
Hazm. M/C (%)	0.56	0.57	0.53
Tryptophan %	0.20	0.19	0.17
Hazm. tryptophan (%)	-	0.15	0.14
Threonine (%)	0.60	0.56	0.52
Hazm. Threonine (%)	-	0.45	0.42
Linoleic Acid (%)	1.00	1.74	1.39

Determination of Performance Characteristics

Egg Production (EP) (%): The number of eggs deposited in the cages was recorded at the same time each day. The weekly EP was calculated noting the number of animals in the groups.

Average EP (%) = (total number of eggs/total number of chickens obtained during 7 days) x 100

Egg Weight (EW) (g): Evaluation of EW was made weekly in the study, using a balance sensitive to 0.1 g.

Average EW (g) = (Total EW/number of eggs)

Daily and Weekly Feed Consumption (FC) (g/day/chicken):

Daily FC (g) = (Weekly amount of feed consumed/Number of hybrids in groups)/7

Feed Conversion Ratio (FCR): Average chicken FC/((Average EPxAverage EW)/100)

Body Weight (BW) (g): The BW of the chickens were measured every 4 weeks with a scale sensitive to 5 grams, and the average BW was recorded.

Livability (L) (%): In order to calculate the L ratio, the number of dead chickens in the cages was recorded at the same time every day. In order not to deteriorate the cage densities in the group, chickens in the reserve group reared in the same cage densities were added to replace the dead chicken.

L (%) = (Number of live animals)/(Total number of animals)

Broken-Cracked Egg Rate (%): In the study, daily controls were made to calculate the broken-cracked egg rate in the cages. Broken-cracked eggs encountered in daily checks of egg production were also recorded.

Broken-Cracked Egg Ratio (%) = (Broken-cracked egg amount/Total egg amount)x100

Determination of Egg Internal and External Quality Characteristics: In order to determine internal and external egg quality characteristics, a total of 54 egg samples (one from each cage) were randomly collected every 4 weeks. These eggs were taken into viols and kept for 24 hours at room temperature at the Atatürk University Veterinary Faculty Animal Nutrition and Nutrition Diseases Laboratory. The eggs were analyzed after 1 day at room temperature. The first stage of the analysis is the shape index parameter. The shape index was measured manually with the shape index measuring device developed by Rauch. After measuring the shape index of all eggs due for analysis, other egg quality measurements were made with an egg analyzer (digital egg tester DET-6000). This device calculates index parameters such as EW (Wt (g)), White height (Ht (mm)), Egg yolk color (YF (Yolk fane)), Haugh unit (HU), Breaking strength (Str (Kg/f)), Shell thickness (Thk (mm)), Yellow height (YH (mm)), Yellow diameter (YD (mm)) and yolk diameter (YI). Blood-meat stains, another egg quality parameter, are present or absent on the broken egg; and parameters such as Ak index (stainless hardened caliper) and shell thickness were also manually examined.

Ak index % = (Ak height (mm)/Average of Ak length and width (mm) x100

Shell thickness was determined by a device (mitutoyo absolute Code No 547-360) that measured the shell thickness by separating the samples taken from the blunt, pointed and middle regions of the egg. The thickness of the egg shell was recorded by taking the average of the result obtained.

Statistical Analysis

In the analytical and descriptive analysis of the data obtained from the research was conducted using SPSS v. 18 packages. Analysis of variance in egg, performance and quality characteristics, Repeated Measures of the General Linear Model (GLM) procedure for added egg production (number), and normal distribution test (Shapiro-Wilk Test) for broken-cracked egg data were applied to the data obtained in the research. The Mann Whitney U test for binary group was used to the data that do not show normal distribution; and the Kruskal Wallis test was applied for the triple group. Blood-meat stains, an indicator of egg internal quality characteristics, were tested by multiple logistic regression analysis.

RESULTS

The difference between the groups in terms of cage density was found to be statistically very significant (p=0.004). It was observed that the BWs of both hybrids in the groups decreased with the increase in cage densities. When the live weights of brown and white hybrids were examined throughout the period, it was observed that brown hybrids were heavier and their body weight increased with age (p<0.001) (Table 2).

EP was found to be similar in the LCD (83.33%) and MCD (80.40%) groups, and higher than the HCD (72.75%) group. Additionally, it was determined that HB laying hens had higher EPs than IT laying hens (p<0.001).

Table 2 – Mean ($\bar{x}$) and Standard error (Sx) values of body weight (BW), egg production (EP), feed consumption (FC), feed conversion ratio (FCR), survivability (S) parameters (20-60th weeks).

Cage Density	Hybrid	BW (g)	EP (%)	FC (g)	FCR (g/g)	S (%)
LCD	Hy-Line Brown	2003.98±17.13	86.55±2.31	113.94±1.16	2.08±0.12	99.98±0.95
	Isa Tinted	1777.63±17.13	80.12±2.31	108.56±1.16	2.12±0.12	97.41±0.95
	Mean	1890.81^{A}±12.13	83.33^{A}±1.63	111.25^{A}±0.82	2.15^{B}±0.09	98.69^{A}±0.67
MCD	Hy-Line Brown	1978.85±17.13	85.79±2.31	112.25±1.16	2.11±0.12	99.98±0.95
	Isa Tinted	1762.39±17.13	75.02±2.31	108.10±1.16	2.54±0.12	97.98±0.95
	Mean	1870.62^{A}±12.13	80.40^{A}±1.63	110.17^{AB}±0.82	2.32^{B}±0.09	98.98^{A}±0.67
HCD	Hy-Line Brown	1920.36±17.13	85.12±2.31	112.63±1.16	2.13±0.12	99.97±0.95
	Isa Tinted	1743.77±17.13	60.39±2.31	103.83±1.16	3.24±0.12	92.84±0.95
	Mean	1832.57^{B}±12.13	72.75^{B}±1.63	108.23^{B}±0.82	2.69^{A}±0.09	96.40^{B}±0.67
			p			
CD	0.004	<0.001	0.030	<0.001	0.012	0.004
H	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CD^{x}H	0.349	<0.001	0.113	<0.001	0.013	0.349

LCD (5 hens/cage): low cage density; MCD (7 hens/cage): medium cage density; HCD (10 hens/cage): high cage density; Hy-Line Brown: brown hybrid; Isa Tinted: white hybrid; H: hybrid; CD: cage density; A,B: Differences between means with different letters in the same column are significant (p<0.05).

The average daily egg yields per hen recorded during the research period are shown in Figure 1; and the average daily egg yields according to cage density are presented in Figure 2.

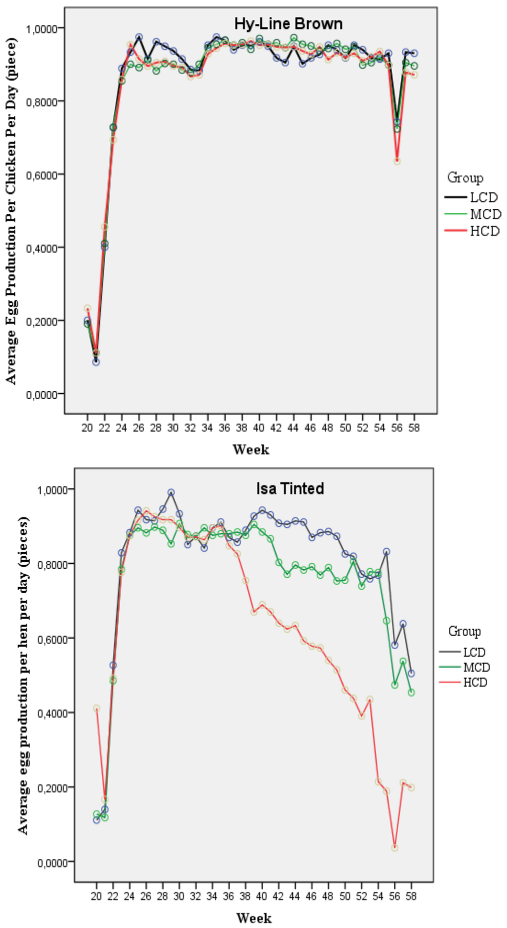

Figure 1 – Average daily egg production (number) of Hy-Line Brown and Isa Tinted hybrids (LCD (5 hens/cage): low cage density, MCD (7 hens/cage): medium cage density, HCD (10 hens/cage): high cage density).

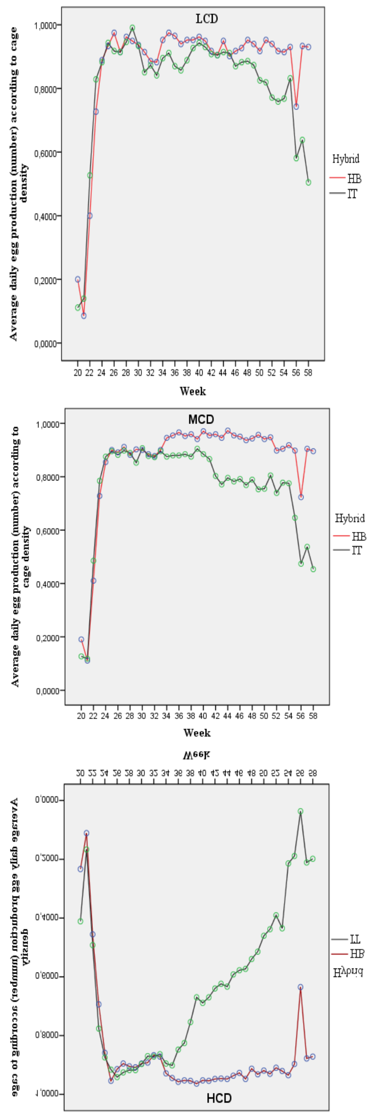

Figure 2 – Average daily egg production (number) for low (5 hens/cage (LCD)), medium (7 hens/cage (MCD)) and high cage density (10 hens/cage (HCD)) (HB: Hy-Line Brown; IT: Isa Tinted).

Table 2 shows that the effect of cage density (*p*<0.05) and hybrid (*p*<0.001) on FC was significant.

It was determined that the cage density and the effect of the hybrid on the FCR were very significant (*p*<0.001). It was determined that chickens in HCD had a worse FCR (2.69) compared to the other two groups (LCD (2.15) and MCD (2.32)). It was also observed that HB laying hens had better FCR than ITs (Table 2).

The effect of cage density on L was significant (*p*<0.01), with L (96.40%) in HCD being lower compared to the other two groups (LCD (98.69%) and MCD (98.98%). The effect of the hybrid on the L characteristic was very significant (*p*<0.001). It was determined that the L of HBs was higher than that of ITs. The effect of age on L was very important (*p*<0.001), with mortality rates increasing with age in general (Table 2).

The shape index of eggs obtained from LCD (77.09±0.17) was found to be lower than MCD (77.61±0.17) and HCD (77.70±0.17). Egg external quality parameters were found to be similar in both hybrids. In addition, it was determined that the effect of age on egg external quality parameters was quite significant (*p*<0.001) (Table 3).

Table 3 – Mean and standard error results (M±SE) of egg external quality parameters in different age periods (24-60th week).

Cage density	Hybrid	Age (week)	Egg weight (g)	Shape index (%)	Breaking strength (kg/cm^2)	Shell thickness (mm)
LCD	Hy-Line Brown	24-28	56.32±1.18	73.72±0.54	5.07±0.23	0.36±0.12
		32-36	61.17±1.18	79.33±0.54	4.94±0.23	0.41±0.12
		40-44	65.94±1.18	77.11±0.54	4.52±0.23	0.42±0.12
		48-52	67.01±1.18	77.72±0.54	4.54±0.23	0.45±0.12
		56-60	66.69±1.18	76.72±0.54	4.49±0.23	0.43±0.12
		Mean	63.43±0.53	76.92±0.24	4.71±0.10	0.41±0.00
	Isa Tinted	24-28	52.06±1.18	73.44±0.54	4.65±0.23	0.36±0.12
		32-36	59.55±1.18	77.83±0.54	4.59±0.23	0.41±0.12
		40-44	65.06±1.18	78.28±0.54	4.99±0.23	0.43±0.12
		48-52	66.46±1.18	78.44±0.54	4.67±0.23	0.45±0.12
		56-60	68.55±1.18	78.29±0.54	4.21±0.23	0.43±0.12
		Mean	62.33±0.53	77.26±0.24	4.62±0.10	0.42±0.00
	LCD		62.88±0.37	77.09±0.17^b	4.67±0.07	0.41±0.00
MCD	Hy-Line Brown	24-28	55.12±1.18	74.67±0.54	4.85±0.23	0.36±0.12
		32-36	61.96±1.18	79.56±0.54	4.88±0.23	0.41±0.12
		40-44	65.72±1.18	78.39±0.54	4.69±0.23	0.43±0.12
		48-52	67.45±1.18	78.22±0.54	4.26±0.23	0.45±0.12
		56-60	66.62±1.18	77.17±0.54	3.79±0.23	0.41±0.12
		Mean	63.37±0.53	77.60±0.24	4.49±0.10	0.41±0.00
	Isa Tinted	24-28	53.17±1.18	73.33±0.54	4.59±0.23	0.35±0.12
		32-36	61.43±1.18	79.11±0.54	4.71±0.23	0.40±0.12
		40-44	64.32±1.18	79.28±0.54	4.75±0.23	0.43±0.12
		48-52	66.60±1.18	78.39±0.54	4.45±0.23	0.42±0.12
		56-60	65.08±1.18	77.94±0.54	3.64±0.23	0.43±0.12
		Mean	62.12±0.53	77.61±0.24	4.43±0.10	0.41±0.00
	MCD		62.75±0.37	77.61±0.17^a	4.46±0.07	0.41±0.00
HCD	Hy-Line Brown	24-28	57.38±1.18	74.00±0.54	4.81±0.23	0.36±0.12
		32-36	63.35±1.18	79.06±0.54	4.88±0.23	0.42±0.12
		40-44	66.87±1.18	78.89±0.54	4.95±0.23	0.45±0.12
		48-52	66.49±1.18	78.67±0.54	4.51±0.23	0.43±0.12
		56-60	65.39±1.18	77.89±0.54	4.08±0.23	0.45±0.12
		Mean	63.90±0.53	77.70±0.24	4.65±0.10	0.42±0.00
	Isa Tinted	24-28	54.32±1.18	73.89±0.54	4.24±0.23	0.36±0.12
		32-36	62.98±1.18	78.28±0.54	4.43±0.23	0.39±0.12
		40-44	65.27±1.18	79.28±0.54	4.70±0.23	0.43±0.12
		48-52	66.26±1.18	78.50±0.54	3.92±0.23	0.47±0.12
		56-60	66.42±1.18	78.56±0.54	4.38±0.23	0.41±0.12
		Mean	63.05±0.53	77.70±0.24	4.34±0.10	0.41±0.00
	HCD		63.47±0.37	77.70±0.17^a	4.49±0.07	0.42±0.00

LCD (5 hens/cage): low cage density; MCD (7 hens/cage): medium cage density; HCD (10 hens/cage): high cage density; Hy-Line Brown: brown hybrid; Isa Tinted: white hybrid; H: hybrid; CD: cage density; a,b: Differences between means with different letters in the same column are significant (*p*<0.05).

It was determined that the effect of the hybrid was only significant for the yellow color (*p*<0.001); and that the effect of age on egg internal quality characteristics was quite significant (*p*<0.001) (Table 4).

Table 4 – Mean and standard error results (M±SE) of egg internal quality parameters in different age periods (24-60th week).

Cage	Hybrid	Age (Week)	Yolk color	Haugh unit	Ak index	Yellow index
LCD	Hy-Line Brown	24-28	8.94±0.28	143.24±9.78	13.09±0.66	0.50±0.01
		32-36	9.28±0.28	92.02±9.78	11.53±0.66	0.51±0.01
		40-44	10.78±0.28	83.77±9.78	9.67±0.66	0.50±0.01
		48-52	9.89±0.28	88.04±9.78	10.39±0.66	0.43±0.01
		56-60	9.72±0.28	82.70±9.78	8.94±0.66	0.42±0.01
		Mean	9.72±0.12	97.96±4.37	10.72±0.29	79.92±0.24
	Isa Tinted	24-28	8.83±0.28	88.71±9.78	12.04±0.66	0.51±0.01
		32-36	9.83±0.28	89.09±9.78	11.68±0.66	0.50±0.01
		40-44	10.83±0.28	85.22±9.78	10.20±0.66	0.48±0.01
		48-52	10.56±0.28	82.78±9.78	9.83±0.66	0.42±0.01
		56-60	10.44±0.28	81.12±9.78	9.41±0.66	0.43±0.01
		Mean	10.10±0.12	85.38±4.37	10.63±0.29	77.26±0.24
	LCD		9.91±0.09	91.67±3.09	10.68±0.21	0.47±0.00
MCD	Hy-Line Brown	24-28	8.61±0.28	89.11±9.78	12.25±0.66	0.50±0.01
		32-36	9.56±0.28	90.31±9.78	12.43±0.66	0.50±0.01
		40-44	10.61±0.28	83.04±9.78	9.40±0.66	0.46±0.01
		48-52	10.06±0.28	86.78±9.78	9.68±0.66	0.44±0.01
		56-60	9.70±0.28	81.16±9.78	8.65±0.66	0.41±0.01
		Mean	9.71±0.12	86.08±4.37	10.48±0.29	77.60±0.24
	Isa Tinted	24-28	9.33±0.28	89.81±9.78	12.22±0.66	0.51±0.01
		32-36	10.39±0.28	88.51±9.78	11.34±0.66	0.51±0.01
		40-44	10.94±0.28	81.92±9.78	9.42±0.66	0.49±0.01
		48-52	10.72±0.28	78.20±9.78	8.89±0.66	0.43±0.01
		56-60	9.72±0.28	83.23±9.78	9.42±0.66	0.42±0.01
		Mean	10.41±0.12	84.45±4.37	10.26±0.29	77.61±0.24
	MCD		85.27±0.09	85.27±3.09	10.37±0.21	0.47±0.00
HCD	Hy-Line Brown	24-28	8.33±0.28	91.55±9.78	12.86±0.66	0.51±0.01
		32-36	9.78±0.28	87.49±9.78	11.50±0.66	0.50±0.01
		40-44	10.56±0.28	84.63±9.78	10.02±0.66	0.47±0.01
		48-52	10.11±0.28	88.63±9.78	10.62±0.66	0.44±0.01
		56-60	10.22±0.28	84.32±9.78	9.44±0.66	0.41±0.01
		Mean	9.80±0.12	87.33±4.37	10.89±0.29	77.70±0.24
	Isa Tinted	24-28	8.61±0.28	92.84±9.78	13.02±0.66	0.50±0.01
		32-36	10.00±0.28	83.37±9.78	9.71±0.66	0.49±0.01
		40-44	11.28±0.28	76.68±9.78	8.84±0.66	0.48±0.01
		48-52	10.89±0.28	86.11±9.78	10.22±0.66	0.44±0.01
		56-60	10.56±0.28	79.31±9.78	8.75±0.66	0.42±0.01
		Mean	10.27±0.12	83.66±4.37	10.10±0.29	77.70±0.24
	HCD		85.49±0.09	85.49±0.09	10.50±0.21	0.47±0.00

LCD (5 hens/cage): low cage density; MCD (7 hens/cage): medium cage density; HCD (10 hens/cage): high cage density; Hy-Line Brown: brown hybrid; Isa Tinted: white hybrid; H: hybrid; CD: cage density.

It was observed that the ratio of broken-cracked eggs decreased as the cage density increased (*p*<0.001). The amount of cracked eggs was found to be higher in ITs compared to HBs (*p*<0.001). The effect of age on the rate of broken-cracked eggs was found to be very significant (*p*<0.001). The highest rate of broken-cracked eggs was detected in the 51-60th weeks.

In addition, blood-meat stains, cage density, and age were not affected (*p*>0.05). However, there is a very important difference between hybrids in terms of blood-meat stains, as it was determined that HBs had more blood-meat spots when compared to ITs (*p*<0.001).

DISCUSSION

In the study, the effect of hybrid, age and cage density on BW was found to be very significant. HB laying hens are heavier than IT laying hens. In another study on the subject, the BWs of IB, Atak-S and NW hybrids were examined and it was determined that the hybrid with white feather color was lighter than the others (Ozenturk & Yıldız, 2020). In other studies, it has been stated that brown laying hens are heavier than whites (Şekeroğlu & Sarıca, 2005; Çolak *et al*., 2010). In other studies that reached similar results to the current study, it was stated that BW increased with increasing ages (Türker *et al*., 2017; Boz *et al*., 2022). As a result of the research, it was observed that the BWs of both hybrids decreased with the increase in the cage densities. This situation may be associated with the cramped environment causing more stress to hens, and their eating less feed. Other studies on the subject showed that the BW was lower in the group with the highest prevalence (Yörük *et al*., 2008; Boz *et al*., 2022). However, in some studies, it was stated that cage densities had no effect on BW (Kum & Güçlü, 2006; Sarıözkan *et al*., 2009).

Egg yields of HBs were higher than that of ITs. Additionally, as cage density increased, EP decreased. EP may have decreased due to higher mortality rates and lower feed consumption of chickens in dense cages. Other studies on the subject have also stated that increasing cage density negatively affects EP (Kum & Güçlü, 2006; Yardim *et al*., 2021; Ogbuewu & Mbajiorgu, 2023). Conversely, there are also studies reporting that cage densities have no impact on egg production (Şahin *et al*., 2007; Geng *et al*., 2020). Although there is a study stating that the EP of white laying hens is higher than that of brown ones (Şekeroğlu *et al*., 2009), some studies and the results of the current study showed the opposite (Şekeroğlu *et al*., 2005; Akkuş *et al*., 2018). It was observed that the EP value increased with age in both hybrids (except for the 56th week). The reason for the decrease in the 56th week is thought to be due to the change in illumination intensity in the cannibalism group. In a study on the subject, it was stated that EP increases with age (Şekeroğlu *et al*., 2014; Tumova *et al*., 2017).

EW values were found to be higher in HBs. Since the live weight of brown hens is higher than that of white hens, their eggs may also be heavier. In several studies conducted on the subject, the eggs of brown hens were found to be heavier (Vits *et al*., 2005; Clark *et al*., 2008). According to the results of the current study and several similar studies, it was determined that EW increases with age (Dikmen *et al*., 2017; Tumova *et al*., 2017; Kraus *et al*., 2019).

In the current study, it was determined that the effect of cage density and hybrids on FC was significant. In some studies, which are in agreement with the results of the current study, it has been determined that the rate of FC is higher in LCD than in HCD (Akkuş *et al*., 2018; Yardim *et al*., 2021; Boz *et al*., 2022). At low cage density, hens may be fed more due to the greater feed area per hen. In other studies, it was stated that cage densities did not affect the FC rate (Kum & Güçlü, 2006; Sarıözkan *et al*., 2009). In their study, Fidan & Nazlıgül (2013) found that the rate of FC was higher at higher cage density. In the current study and a similar study, it was determined that brown laying hens consumed more feed (Riczu *et al*., 2004). Since brown hens are heavier than white hens, feed consumption may also be higher. However, some study results contradict this finding (Anderson *et al*., 2004; Yardım *et al*., 2021). In the current study, FC rate increased with age in both hybrids, except at weeks 52 to 59. The reason for the low FC in the last few weeks can be attributed to the fact that the periodic blood draw was performed between these weeks, or to the change in the intensity of illumination in the group with cannibalism. In general, FC rates may have increased with the increase in BWs of chickens with age. Studies on the subject stated that the rate of FC generally increases with age (Guo *et al*., 2012; Yardım *et al*., 2021).

It was determined that the cage density and the hybrid had a very significant effect on the FCR. As the cage density increases, the FCR of hens may decrease due to stress. Brown hens may also have better FCR because they are less affected by cage density than white hens. Studies on the subject support the results of the current study (Fidan & Nazlıgül, 2013; Yardim *et al*., 2021; Boz *et al*., 2022).

In the study, the effect of cage density on L was significant; and the effect of hybrid and age was found to be very significant. In other studies, it has been stated that the L value is affected by factors such as age, hybrid and cage density (Kakhki *et al*., 2018; Geng *et al*., 2020). It was determined that the L of HB laying hens (99.97%) was higher compared to ITs (96.07%). Since HBs are better in terms of live weight and stress resistance, their viability may also be better. In other studies on the subject, it has been stated that the L of domestic hybrids is generally better than that of foreign hybrids (Durmuş *et al*., 2009; Şık, 2020). In another study, it was stated that the L of IB laying hens was better than LSL (Abrahamsson *et al*., 1996). In the current study, the result that mortality rates increase with age is in line with the results of other studies on the subject (Nicol *et al*., 2006; Sherwin *et al*., 2010).

At the end of the study, it was observed that the ratio of broken-cracked eggs decreased as the cage density increased. The results of the study conducted by Guo *et al*. (2012) were similar to the results of the current study. In other studies, as the cage density increases, the rate of broken-cracked eggs increases (Vits *et al*., 2005; Kakhki *et al*., 2018). In some studies, it has been stated that the cage density has no effect on this feature (Lacin *et al*., 2008). The study found that the effect of hybrids on the broken-cracked egg ratio (IT>HB) was significant, which is in agreement with a similar study (Vits *et al*., 2005). In general, the rate of broken-cracked eggs is higher with advancing age. In general, as the size of the egg increases with age, the thickness of the shell becomes thinner. While a study on the subject supports the current study result (Tactacan *et al*., 2009), another study contradicts it (Petek *et al*., 2009).

In other studies, which reached similar results to the current research, the egg breaking strength property decreased with age (Kraus *et al*., 2019); in other studies, it was stated that it increased (Zita *et al*., 2009; Şekeroğlu *et al*., 2014). Contrary to all these studies, there are also studies that found that age has no effect on breaking strength (Ledvinka *et al*., 2012; Ozenturk *et al*., 2020). The effect of age on egg shell thickness was found to be quite significant. In general, it has been stated that the crustal thickness decreases with increasing age (Akkuş *et al*., 2018; Galazka-Czarnecka *et al*., 2019; Onbaşılar *et al*., 2019). However, it has been stated in other studies that the crustal thickness increases with age (Zita *et al*., 2009; Şekeroğlu *et al*., 2014).

The effect of cage density on the shape index is significant; and the effect of age was found to be very significant. The current study is in agreement with the results of many studies conducted with a similar approach (Zita *et al*., 2009; Dikmen *et al*., 2017; Kraus *et al*., 2019). However, in other studies, it was stated that the shape index was not affected by the cage densities (Geng *et al*., 2020; Ozenturk *et al*., 2020).

The effect of hybrid and age on egg yolk color was found to be very significant. In studies on the subject, it has been stated that the color of egg yolk changes according to the hybrid (Sarica *et al*., 2012; Hanusova *et al*., 2014), while it did not change in another study (Altun *et al*., 2022). In another study similar to the results of the present study, yellow color decreased with increasing age (Roll *et al*., 2012); in another study, however, it was stated that it increased (Orhan, 2001; Rakonjac *et al*., 2014). Dikmen *et al*. (2017) found that age has no effect on yellow color in a study they conducted.

The effect of age on the Haugh unit was found to be significant. The result of another study supports the current research result and it has been stated that this value decreases with age (Ozenturk *et al*., 2020). However, in another study, the effect of age on the Haugh unit was found to be insignificant (Şekeroğlu *et al*., 2014).

The effect of age on the white index and yellow index was found to be quite significant. In some studies, as in the current study, the white index decreases with age (Zita *et al*., 2009; Şekeroğlu *et al*., 2014); in some, it was stated that it increased (Orhan, 2001). Contrary to the current study, there is also a study stating that the effect of age on the yellow index is insignificant (Şekeroğlu *et al*., 2014).

There were more blood-meat stains in HBs compared to ITs. Egg blood-meat stain can be expressed as a physiological condition thought to be formed by the disruption of the integrity of capillary blood vessels as the maturing ovum falls into the infundibulum and the blood stain smears the yolk. Some studies have also stated that brown chickens have more blood-meat stains (Honkatukia *et al*., 2011; Ozenturk *et al*., 2020).

CONCLUSIONS

In general, performance characteristics varied according to cage density, age and hybrid. As the cage density increased, the performance of laying hens decreased. While the effect of age on internal and external egg quality parameters is very important; cage density and the effect of hybrid differed.

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Author contributions

AU, EL: conceptualization, investigation, data curation, writing—original draft preparation, formal analysis, supervision, writing—review and editing, methodology, investigation, visualization; AU: supervision, visualization. All authors reviewed the results and approved the fnal version of the paper.

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Data availability statement

Data is available upon request.

Conflicts of interest

The authors declare no conflict of interest.

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