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(RESEARCH ARTICLE)

Effect of genotype on slaughtering performance, blood analyses and meat quality of laying hens reared in different conventional cage densities

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Abstract

The aim of the study was to evaluate the effects of genotype on slaughtering performance, blood analyses and meat quality of laying hens reared in different conventional cage densities. Laying hen flocks consisted of 180 Novogen White, 180 ATAK-S and 180 ISA-Brown at 72 weeks old reared in different conventional cage densities (312.50 cm^2/hen and 468.75 cm^2/hen). In the trial, one bird per each replica (9 in replica) were selected from every treatment (6 in treatment, 54 birds in total), and their body weights were weighed. Then, they were slaughtered and the carcass traits and some organs were weighed. Also, the blood and breast meat samples were taken for biochemical and meat analyses. In general, the ISA-Brown and ATAK-S strains received higher values than the Novogen White strain in terms of carcass traits. Also, according to stress parameters, it was observed that ISA-Brown strain was more resistant than others in high cage density. Moreover, the bacterial count and meat quality results of hens, the ISA-Brown strain is better than other strains. However, the texture analyses results of the Novogen White strain are better than ISA-Brown and ATAK-S strains. As a result, the meat quality of the laying hens can be affected at different levels depending on the genetic structure of the chickens and the cage density of which they are reared.

Keywords: Chicken; Strain; Settlement frequency; Carcass; Texture; Stress

1. Introduction

In poultry farming, the number of animals reared per unit area is very important for the profitability of the business. In intensive poultry farming, production is carried out in cage systems. Some of the environmental factors that affect the yield characteristics of animals in cage systems are related to cage properties and cage conditions. Cage density (CD) or settlement frequency is an important stress factor in birds. Sheltering in crowded environments, or reduced cage floor space per animal, affects yield in the negative direction [1]. In conventional laying hen cages (CC), deprivation of physical space and inability to perform highly motivated behaviours causes to stress and inactivity [2].

Many changes that occur during the postmortem muscle metabolism affect the quality of the meat [3]. Meat quality is influenced by agents such as strain, stress and activity, and is determined relatively by measures of pH, tenderness and colour [2]. The usual muscle colour and tenderness values typically occur when final pH ranges between 5.9 and 6.1 [4-6]. On the other hand, a muscle pH lower than 5.8 is the link with paler and softer meat. However, a muscle pH greater than 6.2 links with darker and firmer meat [5-7]. The laying chicken meat is generally not preferred for human

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consumption [2]. Because, the laying hens have a low meat yield [8], less meat tender than broilers [9], and are also more exposed to splinter during meat processing [10].

In the past century, livestock production has progressively shifted to provide meats of high and consistent eating quality and to obtain high amounts of high-value proteins. And also, the people directed towards fostering a secure and highly convenient meat of consistent eating quality [11]. Among the poultry meat, which plays an important role in satisfying the animal product needs, the meats of broiler strains are generally preferred. However, as alternative meat sources were searched in recent years, in this study, it was tried to obtain alternative chicken meat strains by examining the general meat yield level and consumption status in some strains of laying hens. Thus, it was hypothesized that hens in different cage densities, who had to differ opportunity to locomotory behaviour, would differ improved meat quality among laying hen strains. So, the aim of the current study was to evaluate the effects of genotype on slaughtering performance, blood analyses and meat quality of laying hens which three different genotypes (Novogen White, ATAK-S and ISA-Brown at 72 weeks old) reared in different CD (312.50 cm^2/hen and 468.75 cm^2/hen).

2. Material and methods

2.1. Animal and experiment design

This research was carried out in accordance with the guidelines of the Atatürk University Local Board of Ethics Committee for Animal Experiments, which has approved the study protocol of this research (HADYEK decision no: 72). The animals were housed at the Poultry Research Centre of Veterinary Science at the Atatürk University. Laboratory analyses were conducted at the Veterinary Science of Atatürk University. Laying hen flocks consisted of 180 Novogen White, 180 ATAK-S and 180 ISA-Brown (consisting of total 540 hens). The birds that arrived at the facility at 19 weeks were housed at 21 °C and length of daylight was gradually increased from 13 to 17 h per d by 27 weeks of age. And, the daily 17-hour daylight period was continued until 72 weeks of age. The CC system consists of totaling 54 CCs, or 18 cages per strain. Each CC measured 62.5 cm wide by 60 cm deep and had a height of 46-51 cm. Laying hens were allocated into six treatments (3 strain x 2 cage densities) and nine replicates per treatment. At each replicate, eight or twelve birds were used in an environmentally-controlled room. The cage densities consisted of twelve (312.50 cm^2/hen) and eight (468.75 cm^2/hen) hens.

2.2. Processing and sample preparation

The feed was withdrawn twelve hours before slaughter. At the end of the trial (72 weeks old), one bird per each replica (9 in replica) were randomly selected from every treatment (6 in treatment, 54 birds in total). After marking and noting that specified treatment and replication's properties, they were weighed and then slaughtered by severing the jugular vein carcass to determine the carcass characteristics. After this applications the feathers, heads, chicken feet and inner organs (except kidneys and lungs) of the chickens were removed. And then the heads, chicken feet, hearts, livers, gizzards, spleens, abdominal fat and hot carcasses were weighed. The carcasses were kept at +4 °C for 24 h and were weighed cold posture; afterward the thighs (from articulatio coxae), wings (from articulatio humeri), breasts (from articulatio sternocostal), neck and back were removed according to regulates and requirements of Institute of Turkish Standards [12]. The organs were weighed with the skin [13]. The head, chicken feet, some internal organs, and carcass were calculated about BW at sacrifice [14].

2.3. Blood analyses

The animals included in the study were slaughtered at a slaughterhouse located at a distance of 100 m to the cages in which they were raised. Therefore, transport stress was eliminated. The blood samples were taken at slaughter, collected into vacuum tubes anticoagulant centrifuged at 3000 rpm for 10 minutes, at 4 ◦C and plasma stored at -20 °C until laboratory analyses. Oxidative stress is defined as an imbalance between the production of free radicals and reactive metabolites and, it can be determined with malondialdehyde (MDA), glutathione peroxidase (GPx), glutathione (GSH), superoxide dismutase (SOD) and catalase (CAT) measurements [15].

Plasma malondialdehyde (MDA) was analysed by the method of Yoshioka et al. [16], GSH levels were measured according to a method described by Tietze [17], SOD activities were determined using xanthine and nitroblue tetrazolium as the substrates, and were calculated from percent inhibition of formazan production [18]. GPx levels were determined according to methods of Matkovics [19] and CAT activity was determined with a spectrophotometric assay of hydrogen peroxide [20]. All of the biochemical parameters were measured with Biotek ELISA Reader (Bio Tek µQuant MQX200 Elisa reader/USA).

2.4. Determination of meat quality

The breast meat samples from the carcasses which had been washed and stored at 4 °C for 24 h were cut out. The chicken breast meat samples were placed on polyethylene plates, covered with stretch film. Subsequently, the samples were analysed for pH, thiobarbituric acid reactive substances (TBARS), aw and colour L*, a*, b* (L*: lightness; a*: redness; b*: yellowness) and for total aerobic mesophilic bacteria, total psychrophilic bacteria, *Coliforms, Enterobacteriaceae* and *Staphylococcus aureus* counts. The pH values of the samples were measured as described by Gokalp et al. [21]. Accordingly, 10 g was added 100 ml of distilled water. After being homogenised with an UltraTurrax device (IKA Werk T 25, Germany) for 1 minute, pH values were measured (WTW Inolab, Germany). The colour intensities (L*, a*, b*) of the cross-sectional areas of the breast meat samples were determined using a Minolta colorimeter (CR-200, Minolta Co, Osaka, Japan). Colour measurements were performed directly on the surface of muscle tissue, by removing the skin [22].

Water activity (aw) values were measured using the Aqualab 4TE (USA) device. Meat samples were placed in the container of the device for the reading of the aw values. The microbiological analyses of the samples were performed in compliance with the method described by Baumgart et al. [23]. Accordingly, 25 g of the meat samples were homogenized in 225 mL of sterile Ringer solution. Subsequently, serial dilutions of the homogenates were prepared. Inoculations were made using the spread plate technique. The TMAB and TPAB counts were determined on Plate Count Agar (PCA, Merck) incubated under aerobic conditions respectively at 30±1 °C for 72 ± 1 h and 7±1 °C for 10 days. For *Enterobacteriaceae* count, 1 mL of the appropriate dilutions were seeded on Violet Red Bile Dextrose Agar (VRBDA, Merck), and incubated at 30 °C under anaerobic conditions for 2 d. The *Coliforms* count 1 mL of the appropriate dilutions was seeded on Violet Red Bile Agar (VRBA, Merck), and incubated at 30 °C under anaerobic conditions for 2 d. *Staphylococcus aureus* count was determined on baird parker agar (BPA) incubated under aerobic conditions at 30±1 °C for 48±1 h. Bacterial counts were expressed in log cfu g-1 [22].

Texture profile analyses (TPA) was performed by using a TA.XT2 Texture Analyser (Stable Micro Systems, England). Chicken breast meat samples were cut into approximately 2 cm cubes. The core of the sample was compressed twice to 50% of their original height using a cylindrical-shaped piston, 6 mm in diameter. The texture probe was oriented perpendicular to the muscle fibers, and measurements were made at ambient temperature. Texture profile analyses (TPA) parameters of hardness, cohesiveness, adhesiveness, springiness and chewiness were determined [24].

2.5. Statistical analyses

The variables concerning slaughtering performance of hens, blood analyses, meat quality and texture profile analyzed completely randomized design using GLM procedure of SPSS 20 (Version 20, IBM Corp., Armonk, NY, USA). The statistical analyses of Tukey multiple range tests and variance were used to compare outcomes in unique groups. The level of significance for statistical differences in all analyses was assessed at $P < 0.05$.

3. Results

3.1. Slaughtering performance of hens

In Table 1, the body weight, some internal organ weights and slaughtering performance of the hens are reported. In treatment combined groups, the body weight and hot-cold carcass, feet, thigh, breast, wing, abdominal fat percentages of ISA-Brown and ATAK-S hens were heavier than the Novogen White hens. Besides, the head's percentages of hens were higher in Novogen White than the ATAK-S and ISA-Brown hens in treatment combined ($P < 0.001$). But, the other heart, liver, gizzard, spleen, neck and back percentages of hens were not found a significant difference among the treatment combined ($P > 0.05$). In strains combined groups, the feet and wing percentages of hens in CD-2 were higher than CD-1 ($P < 0.05$), and this situation was statistically significant. But, statistically, the other strain combined variables of hens were insignificant ($P > 0.05$). In addition, when the significant different between CD-1 and CD-2 in itself of the strains were examined, the feet in Novogen White, the thigh in ATAK-S, the heart and wing in ISA-Brown, CD-2 percentages were higher than in CD-1.

Table 1 Hen slaughtering performance

Variables		Novogen White	ATAK-S	ISA-Brown	*P*-value	Strains combined
Body weight (g)	CD-1	1613.22±31.48^{b}	1911.11±44.78^{a}	1911.11±117.85^{a}	0.013	1811.81±49.90
	CD-2	1589.44±51.56^{b}	1858.89±86.73^{a}	1821.67±63.48^{ab}	0.022	1756.67±44.77
	P-value	0.699	0.600	0.514		0.414
	Treatment combined	1601.33±29.45^{b}	1885.00±47.77^{a}	1866.39±65.83^{a}	*P*<0.001	1784.24±33.52
Hot carcass (%)	CD-1	59.75 ± 0.41^{b}	64.23 ± 0.96^{a}	63.37 ± 0.94^{a}	0.001	62.45 ± 0.59
	CD-2	59.47 ± 1.17^{b}	67.12 ± 1.48^{a}	64.21 ± 1.07^{a}	0.001	63.60 ± 0.93
	P-value	0.827	0.120	0.563		0.300
	Treatment combined	59.61 ± 0.60^{b}	65.67 ± 0.93^{a}	63.79 ± 0.70^{a}	*P*<0.001	63.03 ± 0.55
Cold carcass (%)	CD-1	59.70 ± 0.41^{b}	64.16 ± 0.96^{a}	63.25 ± 0.91^{a}	0.001	62.37 ± 0.58
	CD-2	59.37 ± 1.17^{b}	65.80 ± 1.12^{a}	63.97 ± 1.08^{a}	0.001	63.05 ± 0.82
	P-value	0.794	0.284	0.615		0.504
	Treatment combined	59.53 ± 0.60^{b}	64.98 ± 0.74^{a}	63.60 ± 0.69^{a}	*P*<0.001	62.71 ± 0.50
Head (%)	CD-1	4.51 ± 0.13^{a}	3.01 ± 0.11^{b}	3.15 ± 0.13^{b}	*P*<0.001	3.56 ± 0.15
	CD-2	4.50 ± 0.14^{a}	3.25 ± 0.17^{b}	3.04 ± 0.08^{b}	*P*<0.001	3.60 ± 0.15
	P-value	0.943	0.257	0.509		0.852
	Treatment combined	4.51 ± 0.09^{a}	3.13 ± 0.10^{b}	3.10 ± 0.08^{b}	*P*<0.001	3.58 ± 0.10
Feet (%)	CD-1	2.89 ± 0.08^{b}	3.40 ± 0.11^{a}	3.46 ± 0.13^{a}	0.002	3.24 ± 0.08
	CD-2	3.14 ± 0.08^{b}	3.87 ± 0.26^{a}	3.80 ± 0.12^{a}	0.011	3.60 ± 0.12
	P-value	0.040	0.119	0.066		0.014
	Treatment combined	3.01 ± 0.06^{b}	3.63 ± 0.15^{a}	3.63 ± 0.09^{a}	*P*<0.001	3.43 ± 0.07
Heart (%)	CD-1	0.55 ± 0.03	0.50 ± 0.02	0.51 ± 0.03	0.409	0.52 ± 0.02
	CD-2	0.53 ± 0.04	0.56 ± 0.03	0.58 ± 0.02	0.508	0.56 ± 0.02
	P-value	0.781	0.081	0.052		0.077
	Treatment combined	0.54 ± 0.02	0.53 ± 0.02	0.55 ± 0.02	0.831	0.54 ± 0.01
Liver (%)	CD-1	2.51 ± 0.18	2.22 ± 0.12	2.27 ± 0.12	0.311	2.33 ± 0.08
	CD-2	2.31 ± 0.11	2.08 ± 0.07	2.28 ± 0.15	0.285	2.22 ± 0.06
	P-value	0.368	0.300	0.957		0.307
	Treatment combined	2.42 ± 0.11	2.15 ± 0.07	2.28 ± 0.09	0.117	2.28 ± 0.05

Gizzard (%)	CD-1	2.49 ± 0.12	2.28 ± 0.09	2.24 ± 0.10	0.213	2.34 ± 0.06
	CD-2	2.51 ± 0.12	2.35 ± 0.15	2.15 ± 0.19	0.274	2.34 ± 0.09
	P-value	0.897	0.704	0.696		0.987
	Treatment combined	2.50 ± 0.08	2.32 ± 0.09	2.19 ± 0.11	0.065	2.34 ± 0.06
Thigh (%)	CD-1	19.48 ± 0.65	20.13 ± 0.41	20.32 ± 0.61	0.555	19.98 ± 0.32
	CD-2	19.34 ± 0.59^{b}	22.77 ± 0.87^{a}	20.78 ± 0.66^{ab}	0.009	20.96 ± 0.48
	P-value	0.869	0.014	0.611		0.095
	Treatment combined	19.41 ± 0.43^{b}	21.45 ± 0.56^{a}	20.55 ± 0.44^{ab}	0.016	20.47 ± 0.30
Breast (%)	CD-1	16.17 ± 0.23^{b}	17.69 ± 0.41^{a}	16.53 ± 0.42^{ab}	0.019	16.79 ± 0.24
	CD-2	16.16 ± 0.52	16.86 ± 0.38	16.11 ± 0.74	0.578	16.37 ± 0.32
	P-value	0.983	0.161	0.623		0.296
	Treatment combined	16.16 ± 0.27^{b}	17.27 ± 0.29^{a}	16.32 ± 0.41^{ab}	0.045	16.58 ± 0.20
Wing (%)	CD-1	5.66 ± 0.19^{a}	6.55 ± 0.13^{b}	6.20 ± 0.20^{ab}	0.005	6.14 ± 0.12
	CD-2	5.77 ± 0.18^{b}	6.69 ± 0.71^{b}	7.77 ± 0.35^{a}	*P*<0.001	6.75 ± 0.22
	P-value	0.670	0.614	0.001		0.018
	Treatment combined	5.72 ± 0.13^{b}	6.62 ± 0.13^{a}	6.98 ± 0.27^{a}	*P*<0.001	6.44 ± 0.13
Spleen (%)	CD-1	0.11 ± 0.01	0.09 ± 0.01	0.11 ± 0.01	0.308	0.10 ± 0.01
	CD-2	0.11 ± 0.01	0.13 ± 0.02	0.11 ± 0.01	0.581	0.12 ± 0.01
	P-value	0.663	0.110	0.738		0.284
	Treatment combined	0.11 ± 0.01	0.11 ± 0.01	0.11±0.01	0.998	0.11 ± 0.01
Abdominal fat (%)	CD-1	2.42 ± 0.22^{a}	4.12 ± 0.53^{b}	3.57 ± 0.60^{ab}	0.054	3.37 ± 0.30
	CD-2	1.85 ± 0.32	3.44 ± 0.55	3.38 ± 0.81	0.120	2.89 ± 0.36
	P-value	0.163	0.385	0.849		0.309
	Treatment combined	2.13 ± 0.20^{b}	3.78 ± 0.38^{a}	3.48±0.49^{a}	0.007	3.13 ± 0.23
Neck and back (%)	CD-1	18.28 ± 0.81	18.62 ± 1.13	19.59 ± 1.01	0.636	18.83 ± 0.56
	CD-2	17.58 ± 0.76	18.27 ± 1.62	18.77 ± 0.79	0.761	18.21 ± 0.63
	P-value	0.537	0.860	0.532		0.464
	Treatment combined	17.94 ± 0.55	18.45 ± 0.96	19.18 ± 0.63	0.491	18.52 ± 0.42

S: Strain; CD: Cage density; CD-1: 468.75 cm^2/hen (8 heads in each cage); CD-2: 312.50 cm^2/hen (12 heads in each cage); %: Percantage of data to body weight a, b: Values with different superscripts in the same row for each section are significantly different (P < 0.05)

3.2. Blood analyses of hens

The results of biochemical tests for MDA, GSH, SOD, GPx and CAT are shown in Table 2. When statistically significant differents are examined in the treatment combined groups, the MDA data of ISA-Brown hens were lower than the Novogen White and ATAK-S hens, but the SOD and GPx variables of ISA-Brown hens were higher than other strains. In the strain combined groups, all of the CD-1 variables except for the MDA received the highest value compared to CD-2. In addition, when the results between CD-1 and CD-2 in itself of the strains were examined, in all of other data except for the GPx of ATAK-S and ISA-Brown significant differences were found. As a result, when the stress parameters were evaluated, chickens in CD-1 experienced more stress than CD-2. In addition, it may be said that the ISA-Brown strain is more resistant to stress than the other strains.

Table 2 Flock biochemical results

Variables		Novogen White	ATAK-S	ISA-Brown	*P*-value	Strains combined
MDA	CD-1	7.46 ± 0.10	7.48 ± 0.09	7.46 ± 0.09	0.977	7.47 ± 0.05
	CD-2	16.42 ± 0.86^{a}	12.40 ± 0.47^{b}	10.77 ± 0.28^{b}	*P*<0.001	13.20 ± 0.57
	P-value	*P*<0.001	*P*<0.001	*P*<0.001		*P*<0.001
	Treatment combined	11.94 ± 1.16^{a}	9.94 ± 0.64^{ab}	9.11 ± 0.43^{b}	0.047	10.33 ± 0.48
GSH	CD-1	2.35 ± 0.09^{b}	2.62 ± 0.07^{a}	2.33 ± 0.09^{b}	0.042	2.43 ± 0.06
	CD-2	1.02 ± 0.02^{c}	1.26 ± 0.05^{b}	1.53 ± 0.09^{a}	*P*<0.001	1.27 ± 0.05
	P-value	*P*<0.001	*P*<0.001	*P*<0.001		*P*<0.001
	Treatment combined	1.68 ± 0.17	1.94 ± 0.17	1.93 ± 0.12	0.418	1.85 ± 0.09
SOD	CD-1	43.27 ± 1.72^{b}	45.82 ± 0.69^{ab}	47.37 ± 0.47^{a}	0.046	45.48 ± 0.70
	CD-2	35.02 ± 1.09^{c}	40.71 ± 0.67^{b}	43.94 ± 0.37^{a}	*P*<0.001	39.89 ± 0.84
	P-value	0.001	*P*<0.001	*P*<0.001		*P*<0.001
	Treatment combined	39.14 ± 1.41^{b}	43.36 ± 0.78^{a}	45.66 ± 0.51^{a}	*P*<0.001	42.69 ± 0.66
GPx	CD-1	0.45 ± 0.01	0.46 ± 0.01	0.47 ± 0.01	0.218	0.46 ± 0.01
	CD-2	0.42 ± 0.01^{b}	0.45 ± 0.01^{a}	0.46 ± 0.01^{a}	*P*<0.001	0.44 ± 0.01
	P-value	0.007	0.062	0.170		0.002
	Treatment combined	0.44 ± 0.01^{b}	0.45±0.01^{ab}	0.46 ± 0.01^{a}	0.001	0.45 ± 0.01
CAT	CD-1	257.84 ± 7.15	274.14 ± 8.32	257.87 ± 9.02	0.287	263.28 ± 4.79
	CD-2	215.06 ± 2.76	217.02 ± 2.09	216.88 ± 0.86	0.757	216.32 ± 1.16
	P-value	*P*<0.001	*P*<0.001	*P*<0.001		*P*<0.001
	Treatment combined	236.45 ± 6.38	245.58 ± 8.08	237.37 ± 6.63	0.606	239.80 ± 4.04

S: strain; CD: cage density; CD-1: 468.75 cm^2/hen (8 heads in each cage); CD-2: 312.50 cm^2/hen (12 heads in each cage); ^{a,b,c}: Values with different superscripts in the same row for each section are significantly different ($P < 0.05$).

3.3. Meat quality of hens

The results related to meat quality of hens used in the study are presented in Table 3. In the pH, aw, TBARS and colour (L*, a*, b*) parameters of hens meat samples were not detected a significant difference among the strains combined ($P > 0.05$). However, the water activity in the treatment combined was highest in ISA-Brown strain ($P < 0.05$). In terms of TBARS, Novogen White strain in CD-2 cages and ISA-Brown strain in CD-1 cages received the lowest value ($P < 0.05$). When the color parameters were examined, yellowness (b*) was observed in the lowest Novogen White strain ($P < 0.05$). When the pH, aw, TBARS and color parameters are considered as a whole, it may be said that ISA-Brown strain meats in CD-1 cages are better than others.

Table 3 The effects of housing environment on laying hen on pH, water activity, TBARS and colour parameters (L*, a*, b*) in chicken breast meat

Variables		Novogen White	ATAK-S	ISA-Brown	*P*-value	Strains combined
pH	CD-1	5.74 ± 0.17	5.76 ± 0.15	5.76 ± 0.17	0.996	5.75 ± 0.09
	CD-2	5.70 ± 0.15	5.80 ± 0.13	5.74 ± 0.15	0.887	5.75 ± 0.08
	P-value	0.859	0.836	0.904		0.941
	Treatment combined	5.72 ± 0.11	5.78 ± 0.10	5.75 ± 0.11	0.930	5.75 ± 0.06
Water activity	CD-1	0.9923 ± 0.002	0.9956 ± 0.001	0.9971 ± 0.001	0.102	0.9950 ± 0.001
	CD-2	0.9936 ± 0.002	0.9972 ± 0.002	0.9966 ± 0.001	0.256	0.9958 ± 0.001
	P-value	0.667	0.404	0.659		0.545
	Treatment combined	0.9930 ± 0.002^{b}	0.9964 ± 0.001^{ab}	0.9970 ± 0.001^{a}	0.027	0.9954 ± 0.001
TBARS	CD-1	2.90 ± 0.18^{a}	3.08 ± 0.55^{a}	1.64 ± 0.12^{b}	0.017	2.53 ± 0.24
	CD-2	1.67 ± 0.12^{b}	2.91 ± 0.47^{a}	3.61 ± 0.24^{a}	0.002	2.73 ± 0.26
	P-value	*P*<0.001	0.826	*P*<0.001		0.590
	Treatment combined	2.28 ± 0.21	3.00 ± 0.34	2.62 ± 0.32	0.258	2.63 ± 0.18
L*	CD-1	55.18 ± 1.15	54.02 ± 2.46	56.90 ± 1.53	0.591	55.36 ± 1.02
	CD-2	53.68 ± 2.24	53.24 ± 1.39	51.30 ± 2.22	0.673	52.74 ± 1.11
	P-value	0.585	0.789	0.058		0.090
	Treatment combined	54.40 ± 2.24	53.63 ± 1.35	54.15 ± 1.42	0.925	54.05 ± 0.77
a*	CD-1	2.37 ± 0.75	4.64 ± 1.81	3.26 ± 0.85	0.282	3.42 ± 0.54
	CD-2	3.21 ± 0.83	4.79 ± 1.11	3.73 ± 0.63	0.453	3.91 ± 0.50
	P-value	0.591	0.928	0.500		0.520
	Treatment combined	2.89 ± 0.59	4.71 ± 0.75	3.35 ± 0.49	0.114	3.67 ± 0.37
b*	CD-1	1.25 ± 0.26^{b}	3.58 ± 0.57^{a}	2.48 ± 0.59^{ab}	0.019	2.44 ± 0.36
	CD-2	2.28 ± 0.72	2.22 ± 0.83	2.41 ± 0.85	0.985	2.31 ± 0.44
	P-value	0.220	0.208	0.955		0.817
	Treatment combined	1.77 ± 0.43	2.90 ± 1.81	2.39 ± 0.46	0.273	2.37 ± 0.77

S: strain; CD: cage density; CD-1: 468.75 cm^2/hen (8 heads in each cage); CD-2: 312.50 cm^2/hen (12 heads in each cage); ^{a,b}: Values with different superscripts in the same row for each section are significantly different ($P < 0.05$). NS: Not significant ($P > 0.05$); *: $P < 0.05$; **: $P < 0.01$.

The microbiological results of hens meat used in the experiment are shown in Table 4. When the microbiological results of the breast meat were examined, a significant difference was observed only in *Enterobacteriaceae* counts in strain combined ($P < 0.05$). As for the treatment combined, there were statistically significant differences between TAMB ($P < 0.05$), TPAB ($P < 0.001$) and *Coliforms* ($P < 0.05$). In general, the Novogen White strain in CD-1 cages and ISA-Brown strain in CD-2 cages showed a lower bacterial count. Also, ATAK-S strain was different in both cages according to the type of bacteria. According to the bacterial data examined, it may be said that the ISA-Brow strain is superior to other strains in terms of cage density.

Table 4 The effects of housing environment on laying hen on total aerobic mesophilic bacteria (TAMB), total aerobic psychrophilic bacteria (TAPB), *Enterobacteriaceae*, *Coliforms*, and *Staphylococcus aureus* counts in chicken breast meat

Variables		Novogen White	ATAK-S	ISA-Brown	*P*-value	Strains combined
TAMB	CD-1	2.99 ± 0.29^{c}	3.79 ± 0.23^{b}	5.12 ± 0.10^{a}	0.002	3.97 ± 0.33
	CD-2	4.40 ± 0.20	4.09 ± 0.26	4.41 ± 0.15	0.503	4.30 ± 0.12
	P-value	0.016	0.043	0.017		0.349
	Treatment combined	3.70 ± 0.35^{b}	3.94 ± 0.17^{ab}	4.77 ± 0.18^{a}	0.021	4.13 ± 0.18
TPAB	CD-1	2.23 ± 0.12^{b}	3.33 ± 0.01^{a}	2.24 ± 0.04^{b}	*P*<0.001	2.60 ± 0.18
	CD-2	2.42 ± 0.03^{b}	3.40 ± 0.06^{a}	2.26 ± 0.03^{c}	*P*<0.001	2.69 ± 0.18
	P-value	0.196	0.254	0.732		0.718
	Treatment combined	2.33 ± 0.07^{b}	3.36 ± 0.03^{a}	2.25 ± 0.02^{b}	*P*<0.001	2.65 ± 0.13
Enterobacteriaceae	CD-1	2.77 ± 0.04^{b}	2.68 ± 0.12^{b}	3.18 ± 0.02^{a}	0.008	2.88 ± 0.18
	CD-2	3.14 ± 0.27	3.44 ± 0.16	2.98 ± 0.01	0.261	3.19 ± 0.11
	P-value	0.253	0.020	0.001		0.045
	Treatment combined	2.96 ± 0.15	3.06 ± 0.19	3.08 ± 0.05	0.809	3.03 ± 0.11
Coliforms	CD-1	2.43 ± 0.30	3.23 ± 0.12	2.90 ± 0.03	0.059	2.86 ± 0.15
	CD-2	3.99 ± 0.35^{a}	2.75 ± 0.23^{b}	2.86 ± 0.04^{b}	0.020	3.20 ± 0.23
	P-value	0.027	0.133	0.460		0.227
	Treatment combined	3.21 ± 0.41	2.99 ± 0.16	2.88 ± 0.03	0.644	3.03 ± 0.40
Staphylococcus aureus	CD-1	2.06 ± 0.06^{c}	3.35 ± 0.03^{a}	2.57 ± 0.07^{b}	*P*<0.001	2.66 ± 0.19
	CD-2	2.93 ± 0.05^{a}	2.43 ± 0.22^{b}	2.32 ± 0.09^{b}	0.045	2.56 ± 0.12
	P-value	*P*<0.001	0.014	0.080		0.650
	Treatment combined	2.49 ± 0.20	2.89 ± 0.23	2.45 ± 0.08	0.185	2.61 ± 0.11

S: strain; CD: cage density; CD-1: 468.75 cm^2/hen (8 heads in each cage); CD-2: 312.50 cm^2/hen (12 heads in each cage); ^{a,b,c}: Values with different superscripts in the same row for each section are significantly different ($P < 0.05$). NS: Not significant ($P > 0.05$); *: $P < 0.05$; **: $P < 0.01$.

The statistical analyses of various data recorded for textural parameters of breast meat samples are observed in Table 5. The hardness, cohesiveness, adhesiveness, springiness, gumminess and chewiness of chicken meat samples were not found a significant differences among the strains combined textural analyses results ($P > 0.05$). But, when the significant different between strains in itself of the CD-1 and CD-2 were examined, statistically significant differences were observed. Besides, the Novogen White strain exhibited the lowest hardness, cohesiveness, adhesiveness, gumminess and chewiness breast meat samples in the treatment combined. Therefore, it may be said that the texture analyses results of the Novogen White strain are better than ISA-Brown and ATAK-S strains.

Table 5 Textural parameters of breast meat

Variables		Novogen White	ATAK-S	ISA-Brown	*P*-value	Strains combined
Hardness (N)	CD-1	15.17 ± 3.45^{b}	29.21 ± 3.41^{a}	18.45 ± 1.37^{b}	0.011	21.11 ± 2.14
	CD-2	16.07 ± 4.15	19.29 ± 3.11	20.27 ± 2.23	0.643	18.54 ± 1.82
	P-value	0.870	0.057	0.628		0.367
	Treatment combined	15.62 ± 2.57^{b}	24.25 ± 2.66^{a}	19.61 ± 1.26^{ab}	0.037	19.83 ± 1.26
Cohesiveness	CD-1	0.28 ± 0.02^{b}	0.35 ± 0.03^{ab}	0.38 ± 0.02^{a}	0.026	0.34 ± 0.02
	CD-2	0.32 ± 0.05^{b}	0.35 ± 0.02^{ab}	0.44 ± 0.01^{a}	0.026	0.37 ± 0.02
	P-value	0.404	0.956	0.029		0.158
	Treatment combined	0.30 ± 0.02^{b}	0.35 ± 0.02^{ab}	0.41 ± 0.02^{a}	0.001	0.35 ± 0.01
Adhesiveness	CD-1	-1.38 ± 0.17^{ab}	-1.93 ± 0.44^{b}	-0.87 ± 0.08^{a}	0.050	-1.40 ± 0.18
	CD-2	-1.12 ± 0.31	-1.98 ± 0.51	-0.82 ± 0.14	0.087	-1.30 ± 1.78
	P-value	0.477	0.952	0.731		0.752
	Treatment combined	-1.25 ± 0.17^{a}	-1.95 ± 0.32^{b}	-0.85 ± 0.08^{a}	0.003	-1.35 ± 0.14
Springiness (mm)	CD-1	0.66 ± 0.04^{a}	0.51 ± 0.04^{b}	0.49 ± 0.03^{b}	0.011	0.55 ± 0.03
	CD-2	0.56 ± 0.06	0.58 ± 0.05	0.44 ± 0.03	0.121	0.53 ± 0.03
	P-value	0.215	0.303	0.303		0.565
	Treatment combined	0.61 ± 0.04^{a}	0.55 ± 0.03^{ab}	0.46 ± 0.02^{b}	0.009	0.54 ± 0.02
Gumminess (N)	CD-1	4.58 ± 1.14^{b}	10.13 ± 0.97^{a}	7.112 ± 0.69^{ab}	0.003	7.28 ± 0.75
	CD-2	5.81 ± 1.73	6.80 ± 1.30	8.93 ± 0.89	0.277	7.18 ± 5.50
	P-value	0.567	0.069	0.143		0.928
	Treatment combined	5.20 ± 1.00^{b}	8.46 ± 0.92^{a}	8.03 ± 0.60^{a}	0.023	7.23 ± 0.54
Chewiness (Nxmm)	CD-1	3.22 ± 0.92	5.17 ± 0.65	3.44 ± 0.36	0.121	3.95 ± 0.43
	CD-2	3.34 ± 0.97	4.15 ± 1.08	3.98 ± 0.50	0.795	3.82 ± 0.49
	P-value	0.934	0.440	0.408		0.850
	Treatment combined	3.28 ± 0.64	4.66 ± 0.62	3.71 ± 0.31	0.200	3.89 ± 0.32

S: strain; CD: cage density; CD-1: 468.75 cm^2/hen (8 heads in each cage); CD-2: 312.50 cm^2/hen (12 heads in each cage); ^{a,b}: Values with different superscripts in the same row for each section are significantly different ($P < 0.05$). NS: Not significant ($P > 0.05$); *: $P < 0.05$; **: $P < 0.01$.

4. Discussion

The different response in terms of hen slaughtering performance and body weight observed among the different genotypes is related to their genetic assessment [9]. Similarly, in this study, the body weights and carcass traits of three different genotypes founded differences between genotypes. The ISA-Brown and ATAK-S are genotypically larger strains than Novogen White and, therefore, they have higher values in body weight and many carcass traits. This situation is thought to be the reflection to phenotypic parameters of genotypic differences between strains.

Some researchers reported that reduced hen body weight in intermediate group size compared to large and small group sizes, which they attributed to social intolerance [25]. Besides, the cage density required for the wingspan of the commercial laying hen hybrids used today is not sufficient in the existing cage systems [26]. In this study, when the effect of cage density on carcass traits was examined, it was observed that CD-1 values, which are wide density, were higher than CD-2 at a significant level, especially in the feet and wings weights. As a consequence, this situation might be an indication of more affected by the cage density of the organs that are more contact with the cage of hens.

Stress leads to increasing whole body metabolism and therefore depletes muscle glycogen stores and stimulates protein catabolism, affecting body weight [2]. As seen in this study, the conventional cages have been shown many times to limit the natural movements of animals, to cause fear and stress [26]. In addition, the high density of chicken in CD-2 cages generally caused to have higher stress parameters than those in CD-1 cages. When examined in terms of strains, ISA-Brown, ATAK-S and Novogen White formed the order of resistance to stress, respectively. If breeders are forced to raise more animals in a cage, it may be said that the ISA-Brown strain is more resistant to the incidence of stress than the other strains here.

In the present study, the pH values of breast meat did not differ between strains. ($P > 0.05$). However, in the previous studies conducted on different genotypes, the pH values were different between strains [2, 9]. Also, the pH value (6.87 pH) of hen's breast meat stated by Altun and Atasever [27] was higher than the data in this study. The results concerning water activity in this study were higher than the water activity of hens breast meat average value (0.8890 aw) stated by other researchers [27]. The meat colour could be affected by the movement of the hens [9]. However, in this study, the different cage density was not affected the meat colour of hens. ($P < 0.05$). Only, the yellowness (b*) in the CD-1 cages showed a difference between strains. The results concerning TAMB and TPAB in this study were lower than the average data of hen's breast meat stated by Altun and Atasever [27]. The *Coliforms* and *Staphylococcus aureus* counts in chicken breast meat presented this study was similar to that reported by Efe and Gümüşsoy [28], but the *Enterobacteriaceae* count was higher than data reported by same researchers.

Hardness, cohesiveness, chewiness, and springiness are important parameters for the evaluation of meat textures, and, in particular, the value of cohesiveness and hardness has been recognized as an important indicator of the textural properties of the meat [29]. In this experiment, the Novogen White strain was exhibited the best results in terms of the value of cohesiveness and hardness. In some studies conducted in breast meats of laying hens with different genotypes, the authors reported that Hy-Line White presented the lowest tenderness, chewiness, and adhesivity, whereas the Hy-Line Brown showed the highest juiciness and solubility [9].

5. Conclusions

The effect of cage densities on carcass traits of hens was not found in many data, but many differences were observed due to genetic differences between strains. In particular, ISA-Brown and ATAK-S strains received higher values than the Novogen White strain in terms of carcass traits. Also, according to stress parameters, it was observed that ISA-Brown strain was more resistant than others in high cage density. Moreover, the bacterial count and meat quality results of hens, the ISA-Brown strain is better than other strains. However, the texture analyses results of the Novogen White strain are better than ISA-Brown and ATAK-S strains. As a result, the meat quality of the laying hens can be affected at different levels depending on the genetic structure of the chickens and the cage density of which they are reared. So, the further research is needed to determine meat quality of hens of these genotypes in a different phase of the laying cycle and in a different cage density.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interests.

Statement of ethical approval

This research was carried out in accordance with the guidelines of the Atatürk University Local Board of Ethics Committee for Animal Experiments, which has approved the study protocol of this research (HADYEK decision no: 72).

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