Poultry Studies, 19(2), 60-67
http://doi.org/ 10.34233/jpr.1206202

PROOF
RESEARCH PAPER

Effect of Chick Quality on Viability, Performance Traits and Meat Quality Characteristics of Broiler Chickens

Doğan NARİNÇ[1, *]

[1]Faculty of Agriculture, Department of Animal Science, Akdeniz University, 07070, Antalya, Turkey

Article History
Received: 18 Aug 2022
Accepted: 15 Nov 2022
First Online (17.11.2022)

***Corresponding Author**
Tel: +905065057659
E-mail: dnarinc@akdeniz.edu.tr

Keywords
Tona score
Mortality
Broiler production
Gompertz
Meat quality

Abstract

The chick quality in broiler production is a major factor that has a direct impact on the profitability of both hatcheries and producers. In recent years, there has been considerable interest in the correlations between chick quality, which is measured by quantitative or qualitative methods, and yield characteristics. This study aims to compare the viability, performance traits, and meat quality characteristics of broiler chickens classified into two chick quality categories based on the Tona score method. In the study, broilers in the first-grade group had a lower mortality rate of 1.67%, while the average mortality rate of those with poor chick quality was 23.33% ($P<0.05$). There were no statistically significant correlations between post-hatch performance and chick quality characteristics such as Tona score, chick weight, chick length (all $P>0.05$). According to the Tona score, there were no differences between the mean values of body weight, feed efficiency, Gompertz growth curve parameters, slaughter carcass traits, and meat quality characteristics of first- and second-grade broiler chickens (all $P>0.05$). Although there is no difference between high- and low-quality chicks in terms of performance characteristics, it is possible that the use of low-quality chicks in conventional broiler production will increase the general mortality of the flock. Due to their superior yield potential, it is recommended that low-quality chicks be utilized in more suitable production systems without culling, rather than in conventional broiler production.

Introduction

Commercial hatcheries that produce broiler chicks aim to generate a large quantity of high-quality chicks for maximum profit. A quality chick must exhibit optimal development during incubation, high viability, good development after hatching, and yield qualities that conform to industry standards (Decuypere et al., 2002; Decuypere and Bruggeman, 2007; Reijrink et al., 2010). High-quality chicks should have bright eyes, no abnormalities or scars on the body, a totally closed navel, be free of remnants of membranes and shells, and be entirely separated from the yolk. These chicks should be able to react. There should be no edema, lesion, or similar swelling in their bodies. They should react to external sounds or different stimuli. They should be active and related to their environment. There should be no edema, lesion, or similar swelling in their bodies (Tona et al., 2005a; Narinç and Aydemir, 2021a). Evaluation of chick quality is quite difficult, and there are a variety of quantitative and qualitative measurement techniques available. Morphological metrics, such as chick weight, chick length, leg length, body circumference, and shank diameter are quantitative methods used to evaluate chick quality (Tona et al., 2004b).

Chick weight is not necessarily a reliable predictor of chick quality since it may include yolk residue unrelated to chick development. Therefore, evaluating the quality of chicks based on their body weight is difficult and might be deceiving. Using yolk-free body weight instead of chick weight to measure the quality of a chick may provide more precise findings. Different studies have shown a positive relationship between yolk-free body weight and the subsequent performance of the bird (Molenaar 2018; Narinç and Aydemir 2021a). The length of a chick is measured by extending it along a ruler and determining the distance from its beak to its mid-nose. Numerous studies have shown that the length of a chick correlates with its yolk-free body weight and predicts its long-term performance. Determined as the ratio of chick weight to initial egg weight, the yield percentage assesses weight loss during incubation. Yield percentage and chick weight are unreliable measures of chick quality because they do not account for the quantity of yolk-free body mass (Molenaar et al., 2018).

In qualitatively determining the quality of chicks, each criterion is objectively determined, therefore these methods are more dependable (Boerjan, 2002; Tona et al., 2005b). To determine the quality of chicks, visual evaluation methods such as the Pasgar score and the Tona score are utilized. Using the agility, belly condition, leg, and beak structural criteria of newly hatched and dried one-day-old chicks, the Pasgar score is determined by removing one point for each unfavorable circumstance out of 10. The Tona score considers the general activity and look of newly hatched and dried one-day-old chicks, as well as the existence and quantity of yolk residue, the condition of the eyes, umbilical region, and legs, the presence and quantity of residual membranes, and yolk absorption. The Tona score is a qualitative method with a 100-point evaluation (Tona et al., 2005b).

In industrial broiler production, chick quality, which is evaluated by a quantitative or qualitative method, is used to classify chicks according to their physical characteristics (Tona et al., 2004a). The quality of chicks produced at hatcheries is assessed, and day-old chicks of a specific quality (first-grade) are sold to producers. Chicks of lesser quality are culled and removed from the production line. The hatchery industry would benefit from information on the emergence of second-grade chicks, as these chicks are culled shortly after hatching and consequently constitute a direct economic loss. The percentage of second-grade chicks obtained from breeder flocks has fluctuated between 0.25% and 20.6% in scientific studies (Tona et al., 2004a; Lourens et al., 2005; Reijrink et al., 2010; Van de Ven et al., 2012). Although most hatcheries collect data on second-grade chicks, they save this information for internal use and do not disseminate it. The primary reason for this is to avoid society's reaction to the culling. According to some researchers, second-grade chicks must be culled because their chances of survival are so low (Nowak et al., 2019). In addition, they stated that the presence of these birds on the farm could lower their production indices and reduce the amount of stocking density and feed available for quality chicks. It has been claimed that such chicks may also enhance the risk of disease transmission by creating a pathogen reservoir (Muhammad et al., 2009; Nowak et al., 2019).

Many genetic and environmental factors influence the deterioration of chick quality, and numerous studies have been done on this topic. The performance characteristics of these chicks are just as intriguing as the causes for their inferior status. Only one study has been carried out to determine whether these chicks actually have a decreased chance of survival and perform sub-optimally in conventional broiler production (Van de Ven et al., 2012). In the study conducted by Van de Ven et al. (2012), the performances of first- and second-grade chicks hatched using conventional incubation and patio systems were compared. Researchers claimed that second-grade chicks had a high mortality rate (65.16%), that their slaughter weight was 258 g lower, and that the general practice of culling these chicks in the hatchery was justifiable. However, the primary worry in their study was the potential for a deterioration in performance characteristics owing to the high mortality rate in the patio system and the absence of chick quality determination. However, the patio system is not commonly used in modern commercial broiler production, and it is of interest to examine the performance characteristics of second-grade chicks in the conventional broiler production system. The purpose of this study is to compare the mortality, growth, feed efficiency, slaughter-carcass, and meat quality characteristics of first-and second-grade broiler chickens reared in the conventional system.

Material and Methods

The study was carried out at the Faculty of Agriculture, Animal Production Facilities of Namık Kemal University, Tekirdağ, Türkiye. Animal material for the study comprised of broiler chickens obtained from a commercial company's hatchery operation. Utilizing the Tona score method, the quality of 7,870 one-day-old chicks from the 42-week-old Ross 308 breeder flock held by a commercial company was evaluated. Table 1 describes the procedure of the Tona score method used to determine the quality of the chicks in the study (Tona et al., 2003). During the classification of the chicks' quality, those with 95 to 100 points were considered first-grade, and those with lower scores were deemed second-grade. As a result of the chick quality evaluation, a total of 284 chicks with a Tona score below 95 were identified (second-grade chick rate 3.63%). Sixty chicks from the first grade and sixty chicks from the second grade were randomly selected and transported to the experimental facilities. The chicks were housed in environmentally controlled chambers with a

Table 1. Criteria for determining chick quality in Tona score method

Quality criterion	Determination Conditions	Score
Activity	Activity is assessed by laying the chick on its back to determine how quickly it returned to its feet. A quick spring back on to its feet was regarded as good, but trailing back on to its feet or remaining on its back was assessed as weak.	6-0
Down and appearance	The chick body was examined for dryness and cleanness. It was regarded as normal if it is dry and clean. If it is wet or dirty or both then it is not good.	10-8-0
Retracted yolk	The chick was put on its back obliquely on the hand palm until the abdominal movement totally stopped. The height of its abdomen was estimated. The consistency of the abdomen to touch was then estimated. If the height of the abdomen was estimated to be higher and harder to touch than normal, then yolk retracted was regarded as large and consistent.	16-12-8-4-0
Eyes	The chick was put on the legs, and its eyes were observed. The state of brightness and wideness of the gape of the eyelids were estimated.	16-8-0
Legs	The chick was put on its feet to determine if it remained upright well. The toes were examined for their conformation. If the chick remained upright with difficulty, articulations of the knees were examined to detect signs of inflammation or redness or both.	16-8-0
Navel area	Navel and surrounding areas were examined for the closure of the navel and its coloration. If the color was different from the skin color of the chick, then it was regarded as bad.	12-8-4-0
Remaining membrane	Observation of the navel area allowed estimation of the size of any remaining membrane. The size of any remaining membrane was classified as very large, large, or small.	12-6-0
Remaining yolk	Observation of the navel area allowed estimation of the size of any remaining yolk. The size of any remaining yolk was classified as very large, large, or small.	12-0

temperature of 34 °C. Then the temperature was decreased gradually to 22 °C at the end of the study. The wing numbers of day-old chicks were attached so that each measurement could be recorded individually. In the study, 6 floor pens with a stocking density of 10 broilers/m^2 were used, with shavings serving as the deep litter material. The temperature regime, lighting schedule, and feed were administered in accordance with the broiler company's guideline. The chicks were fed a broiler starting diet comprising 3000 kcal of ME/kg and 22% CP from day 1 to day 14. They were fed a grower diet comprising 3100 kcal of ME/kg and 20% CP from day 14 to day 28. Beginning on day 28, a diet containing 3200 kcal of ME/kg and 19% CP was provided. To obtain the estimates of individual growth curve parameters, all birds were weighed weekly from hatching to 6 weeks of age. The Gompertz nonlinear regression model (1) was used to estimate the growth curve of each chick.

$$\boldsymbol{y_t = \beta_0 e^{(-\beta_1 e^{-\beta_2 t})}} \text{ (1)}$$

Where yt is the weight at age t, β_0 is the asymptotic (mature) weight parameter, β_1 is the scaling parameter (constant of integration), and β_2 is the instantaneous growth rate (per day) parameter (Narinç and Genç, 2021). Parameter estimations were performed by the NLIN procedure of SAS 9.3 software (SAS Institute Inc., Cary, NC). The Gompertz model is characterized by an inflection point in a manner such that β_0/e of the total growth occurs before it and the remainder occurring after (Alkan et al., 2012). The coordinates of the point of inflection, weight (2) and time (3) at inflection point (IPW), were obtained as follows (Narinc et al., 2017).

$$\mathbf{IPW = \beta_0 / e} \text{ (2)}$$
$$\mathbf{IPT = ln(\beta_1) / \beta_2} \text{ (3)}$$

In the study, the feed consumption of the chickens was measured weekly in each floor-pen. The weekly feed conversion coefficients were determined individually by proportioning with the individual body weight gain.

All broilers were weighed at six weeks of age, eight hours after their feed was withdrawn, then slaughtered in an experimental processing facility. The birds were manually cut, bled, scalded (55 °C, 2 minutes), defeathered, manually eviscerated, and the abdominal fat pad (from the proventriculus surrounding the gizzard to the cloaca) was removed, refrigerated in an ice-water tank, and drained. The following day, upon dissection of the carcasses, the breast with bone and remaining abdominal fat were weighed using an electronic digital balance with a precision of 0.01 g. Slaughtering and dissection were carried out by the same experienced operators. The yields of cold carcass, breast, leg, wing, and total fat pad were evaluated in relation to 6-week-old body weight (Narinc et al., 2014). At the carcass dissection processing (about 24 h post-mortem), the ultimate pH values (pHU) were obtained by inserting the pH meter's electrode directly into the anterior part of the left Pectoralis major muscle. On the medial surface (bone-side) of each right breast fillet, the color of the breast flesh was evaluated using a Minolta Chromameter (CR-300). The CIE L*a*b* system was utilized, where L* represents the meat's lightness, a* its redness, and b* its yellowness (Narinç et al., 2013). Each right fillet was weighed, packaged, and frozen at -18 ° C for 28 days. At the end of the storage period, breast samples were thawed in a refrigerator (+4 °C) for 24 hours before being taken from their bags, wiped with paper, and weighed (thawed weight). After this, all muscle samples were immersed in plastic bags in an 80 °C water bath until they reached an internal temperature of 70 °C, then chilled, wiped, and weighed (cooked weight). Thawing loss (TL) was calculated as a percentage of the weight lost after thawing relative to the original muscle weight. The cooking loss (CL) was determined as the difference between the cooked and uncooked weights (Narinç et al., 2013). Texture Profile Analyzer (TA-XT plus Stuble Microsystems, Godalming, Surrey, UK) device with Warner-Bratzler (WB) shearing knife was used to measure the toughness of breast meat. Vertical samples (1x2x2 cm) were obtained from the fibers of cooked muscle. These samples were cut using a WB shearing knife and the shear force (WB) was measured in kilograms (Narinç et al., 2013).

First, parametric test assumptions for performance characteristics, growth curve parameters, slaughter-carcass traits, and meat quality characteristics were assessed. After confirming variance homogeneity and normal distribution for all variables, the One Sample T test was performed as a hypothesis test to compare the chick quality groups. SAS 9.4 software was used to conduct statistical analyses.

Results

The mean values of chick length, weekly live weight, feed conversion, and mortality of broiler chickens in two different chick quality groups, and statistical analysis results are shown in Table 2.

In terms of the mean values of chick length, chick weight, live weights at 35 and 42 days of age, there were no statistical differences between the first- and second-grade chick quality groups (all P>0.05). A similar situation is also valid for cumulative feed conversion ratios at 35 and 42 days of age, there were no statistically significant differences between the mean values of the experimental groups (both P>0.05). The cumulative mortality rate for second-grade broilers was 23.33%, while the cumulative mortality rate for first-grade broilers was 1.67% (P<0.05). The difference between mortality rates of broiler chickens from different classes of chick quality was statistically significant (P<0.05). The phenotypic correlation between day-old chick weight and day-old chick length was statistically significant and fairly strong (r = 0.68; P<0.05) for all chicks (data not shown in any table). The study revealed no relationships between Tona score and day-old chick weight (r=0.16; P>0.05) or length (r=0.05; P>0.05).

Table 3 presents the growth curve parameters estimated by the Gompertz function of chickens in two different chick quality classes. In terms of the model parameters and inflection point coordinates of the Gompertz growth curve model, there were no statistically significant differences between the means of the first- and second-grade chick quality groups (all P>0.05). Figure 1 shows the growth curves derived by the Gompertz function for broilers in the first- and second-grade chick quality groups. The mean values of carcass yield, carcass part percentages, ratios of edible internal organs and abdominal fat of chickens in two different chick quality classes and statistical analysis results are presented in Table 4. While the carcass yield of the chickens in the first-grade chick quality group was 70.99%, the mean of the other group was 71.14%, and there was no statistical difference between the groups (P>0.05). Similarly, there were no statistical differences between the groups in terms of the mean values for ratios of carcass parts (all P>0.05). In the study, the mean values for ratios of abdominal fat and edible inner organs of chickens in the first-grade chick quality group were 1.90% and 5.37%, respectively, compared to 1.74% and 5.45% in the second-grade chick quality group. There were no statistically significant differences between the groups regarding the means of both characteristics (both P>0.05). Table 5 and Table 6 provide the mean values of pH, color, thawing loss, drip loss, cooking loss, water holding capacity, and shear force characteristics of breast muscle samples from broiler chickens classified into groups based on chick quality, and statistical analysis results. There were no statistically significant differences between the groups of first- and second-grade chicks for any of the aforementioned meat quality characteristics.

Table 2. Some performance characteristics of broilers from different classes of chick quality

Chick Quality	Chick Length (mm)	Chick Weight (g)	BW 35 (g)	BW 42 (g)	FRC 35	FCR 42	Mortality (%)
Grade 1	176.11	44.44	1932	2675	1.73	1.83	1.67^{b}
Grade 2	174.99	43.73	1897	2635	1.71	1.81	23.33^{a}
SEM	8.64	0.85	26.93	39.20	0.11	0.12	2.29
P Value	0668	0.512	0.190	0.136	0.440	0.172	0.028*

BW: Body weight, FCR: Cumulative feed conversion ratio, *P<0.05

Table 3. The growth curve parameters estimated using the Gompertz function of broilers in two different chick quality classes

Chick Quality	β_0	β_1	β_2	IPW	IPA
Grade 1	6924	4.64	0.038	2547	40.92
Grade 2	6969	4.64	0.037	2563	41.51
SEM	456	0.35	0.005	168	1.71
P Value	0.522	0.778	0.885	0.522	0.716

β_0: Asymptotic body weight, β_1: Integration constant, β_2: Instantaneous growth rate, IPW: Body weight at inflection point, IPA: Age at inflection point

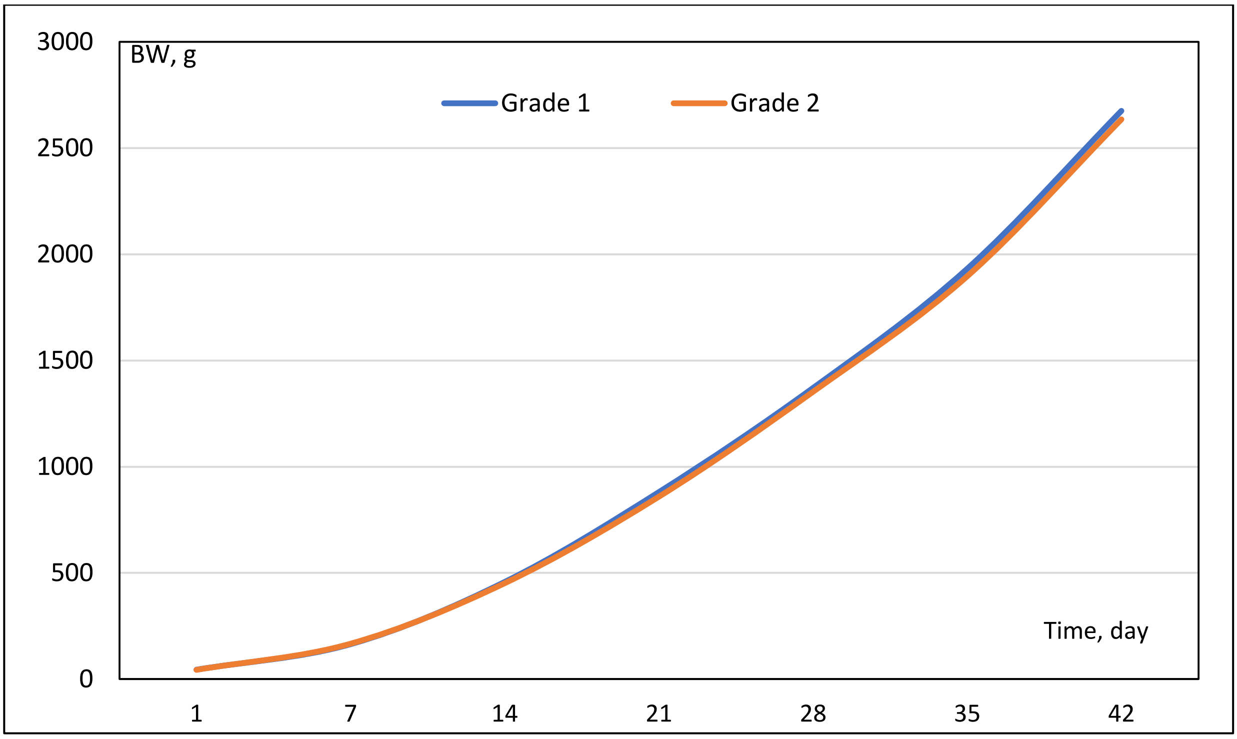

Figure 1. Gompertz growth curves of broiler chickens in different chick quality classes

Table 4. The slaughter-carcass characteristics of chickens from two different categories of chick quality

Chick Quality	CY	BP	LP	WP	AFP	EIOP
Grade 1	70.99	28.12	19.89	6.56	1.90	5.37
Grade 2	71.14	28.00	19.99	6.51	1.74	5.45
SEM	1.10	0.80	0.77	0.40	0.43	0.53
P Value	0.614	0.948	0.456	0.114	0.716	0.805

CY: Carcass yield, BP: Breast percentage, LP: Leg percentage, WP: Wing percentage, AFP: Abdominal fat percentage, EIOP: Edible inner organ percentage

Table 5. The pH and color characteristics of breast muscle of broiler chickens grouped according to chick quality

Chick Quality	pH_{15}	pH_U	L	a	b
Grade 1	6.46	5.79	51.26	3.81	4.98
Grade 2	6.51	5.83	52.21	3.57	4.57
SEM	0.23	0.18	0.98	0.38	0.41
P Value	0.784	0.485	0.741	0.814	0.111

Table 6. The meat quality characteristics of breast muscle of broiler chickens categorized by chick quality

Chick Quality	Thawing Loss (%)	Drip Loss (%)	Cooking Loss (%)	Water Holding Capacity (%)	Shear Force (kg)
Grade 1	2.01	2.01	21.32	74.86	2.14
Grade 2	1.94	1.92	21.88	74.45	2.07
SEM	0.08	0.05	1.18	0.82	0.12
P Value	0.721	0.856	0.888	0.524	0.511

Discussion

In the study, when all weekly body weight averages including hatching weight were taken into account, no differences were found between chick quality classes. Tona et al. (2004a) classified three broiler genotypes according to the Tona score method at one-day old in their study. At 41 days of age, the average live weight of chicks with a perfect score of 100 was between 6.29 and 8.05 % higher than that of chicks with the second-grade quality score.

It is thought that the inconsistency between the results of this report and those of the current study is due to the small sample size (12 chickens per replication and 48 chickens in total per genotype) and the failure to account for mortality rates. Willemsen et al. (2008) and Van de Ven et al. (2012) reported that the relationship between qualitative chick quality scores and post-hatch performance is not significant using the Tona score unless a significant percentage of second-grade chicks are included. Van de Ven et al. (2012) suggested that the efficacy of qualitative chick quality indicators for post-hatch performance can be questioned if poor quality chicks are not culled from the flock in the hatchery. In the current study, it was determined that the use of second-grade quality chicks in production did not cause a significant difference in live weight. In addition, there was no difference between the feed conversion ratios of broilers from different classes of chick quality. There is no study in the literature on the relationship between chick quality and feed efficiency. Some researchers have claimed that each of the methods for measuring chick quality-chick weight, chick length, Tona score, and Pasgar score-can predict chick's growth potential at one day of age (Hill, 2001; Tona et al., 2003; Wolanski et al., 2006; Molenaar et al., 2008; Mukhtar et al., 2013).

Although a strong correlation (r=068) was found between chick weight and length in this study, statistically insignificant and weak correlations (between 0.05 and 0.21; data not shown in table) were determined between the chick quality criteria and the body weight of broilers at 35 or 42 days. According to a recent study (Narinç and Aydemir 2021b), the heritability estimates of qualitative chick quality traits are quite low. The genetic and phenotypic correlations between qualitative chick quality traits and post-hatch performance traits were found insignificant by researchers. In their study, in which genetic parameter estimations for qualitative chick quality traits were performed for the first time in the scientific literature, researchers noted that the environmental factors for these traits were rather significant. Tona et al. (2005b) stated that differences in growth potential amongst chicks of the same quality indicate that other unknown factors impact growth performance. Thus, it can be predicted that these factors may have changed the physiology of the embryo by causing changes in gene expression. The present study's findings are consistent with those of Narinç and Aydemir (2021b) and Tona et al. (2005a).

Most of the studies (Tona et al., 2004a, Willemsen et al., 2008; Tona et al., 2005a) comparing chicks of different quality classes did not focus on survivability. In the present study, the mortality rates of second-grade quality chicks (23.33%) were significantly higher than those of first-grade quality chicks (1.67). In addition, this value is far greater than commercial production standards. When the birds were divided into two groups based on the length of the chick, which is one of the quantitative methods used to measure chick quality, the mortality rates were found to be 11.15 and 12.25%. When categorizing according to the weight of one-day-old chicks, a variation in mortality was detected. This demonstrates that low-viability chicks can be culled from a flock more efficiently with the Tona score method than with quantitative methods. In a study conducted by Van de Ven et al. (2012), it was determined that the cumulative mortality rate for chicks with second-grade quality was quite high. If chick culling is not implemented in systems where all chicks are included in the production process after hatching, such as the patio system, the mortality rate may exceed the standards. While the average mature weight parameter of the chickens in the first-grade chick quality group was 6924 g, it was determined as 6969 g in the second-grade group (P>0.05). These averages were found to be compatible with the averages (5797-6974 g) reported by Narinç et al. (2007), Topal and Bolukbasi (2008), Demuner et al. (2017), and Koushandeh et al. (2019). In addition, the β_0 parameter averages estimated in the current study were found to be higher than the averages (2691-3472 g) reported by Mignon-Grasteau et al. (2000), Roush et al. (2006), Norris et al. (2007), and Şekeroğlu et al. (2013). It is known that genetic or environmental manipulations carried out in some studies can change the shape of the growth curve without changing the body weight at the end of the experiment. However, in the current study, there were no statistical differences between broilers in different chick quality classes in terms of both end-of-trial body weights and Gompertz growth model parameters. In a study conducted by Narinç and Aydemir (2021b), it was determined that there were no relationships between the Tona score and the parameters, and the inflection point coordinates of the Gompertz growth model. The current study findings were consistent with the results reported by Narinç and Aydemir (2021b).

In the study, there were no statistical differences between different chick quality groups in terms of carcass yields and other slaughter-carcass characteristics of broiler chickens (all P>0.05). In a study performed by Narinç and Aydemir (2021b), it was found that Pasgar and Tona score values, which are qualitative chick quality assessment methods, lacked genetic and phenotypic correlations with carcass yield, ratios of breast, thigh, wing, and abdominal fat. The findings of the current study support the results of Narinç and Aydemir (2021b). Moreover, the same situation true for meat quality characteristics. All meat quality characteristics of broiler chickens from the first- and second-grade chick quality groups did not differ statistically significantly (all P>0.05). There is no study in the scientific literature that evaluates the relationships between the chick quality and the meat quality.

Conclusions

In numerous studies, the potential of chick quality, which is measured by qualitative and quantitative methods, to be a reliable predictor of subsequent performance of broilers has been evaluated. In this study, it was found that the correlations between chick quality and performance characteristics were quite weak. In addition, there were no differences in the performance characteristics of broilers categorized according to the chick quality. It has been determined that the Tona method for assessing the quality of chicks is an accurate predictor of viability. Due to the high mortality rate of broilers in the second-grade chick quality group, failure to cull is likely to increase the total flock mortality rate. It is not suggested to employ these birds in conventional broiler production, as ethical issues may develop if specific limits for conventional production under the applicable European Union legislation are surpassed. The use of broilers with low chick quality but high-performance features in alternative rearing systems when mortality rates are acceptable can be advised.

References

Alkan, S, Narinç, D, Karslı, T, Karabağ, K., Balcıoğlu, M. S. (2012). Effects of thermal manipulations during early and late embryogenesis on growth characteristics in Japanese quails (Coturnix cot. japonica). European Poultry Science, 76, 184–190.

Boerjan, M. (2002). Programs for single stage incubation and chick quality. Avian and Poultry Biology Reviews, 13, 237-238.

Decuypere, E., Tona, K., Bamelis, F., Careghi, C., Kemps, B., De Ketelaere, B., De Baerdemaker, J., Bruggeman, V. (2002). Broiler breeders and egg factors interacting with incubation conditions for optimal hatchability and chick quality. European Poultry Science, 66, 56-57.

Decuypere, E., Bruggeman, V. (2007). The endocrine interface of environmental and egg factors affecting chick quality. Poultry Science, 86, 1037-1042.

Demuner, L. F., Suckeveris, D., Muñoz, J. A., Caetano, V. C., Lima, C. G. D., Faria, D. E. D., Faria, D. E. D. (2017). Adjustment of growth models in broiler chickens. Pesquisa Agropecuária Brasileira, *52*, 1241-1252.

Hill, D. (2001). Chick length uniformity profiles as a field measurement of chick quality. Avian Poultry Biology Reviews, 12, 188.

Jiang, R. R., Zhao, G. P., Chen, J. L., Zheng, M. Q., Zhao, J. P., Li, P., Hu, J., Wen, J. (2011). Effect of dietary supplemental nicotinic acid on growth performance, carcass characteristics and meat quality in three genotypes of chicken. Journal of Animal Physiology and Animal Nutrition, 95(2), 137-145.

Koushandeh, A., Chamani, M., Yaghobfar, A., Sadeghi, A. A., Baneh, H. (2019). Comparison of the accuracy of nonlinear models and artificial neural network in the performance prediction of Ross 308 broiler chickens. Poultry Science Journal, *7*(2), 151-161.

Lourens, A., Van den Brand, H., Meijerhof, R., Kemp., B. (2005). Effect of eggshell temperature during incubation on embryo development, hatchability and posthatch development. Poultry Science, 84, 914-920.

Mignon-Grasteau, S., Piles, M., Varona, L., De Rochambeau, H., Poivey, J. P., Blasco, A., Beaumont, C. (2000). Genetic analysis of growth curve parameters for male and female chickens resulting from selection on shape of growth curve. Journal of Animal Science, 78(10), 2515-2524.

Molenaar, R., Reijrink, I. A. M., Meijerhof, R., Van den Brand, H. (2008). Relationship between hatchling length and weight on later productive performance in broilers. World's Poultry Science Journal, 64(4), 599-604.

Molenaar, R., Reijrink, I. A. M., Meijerhof, R., Van den Brand, H. (2008). Relationship between hatchling length and weight on later productive performance in broilers. World's Poultry Science Journal, 64(4), 599-604.

Muhammad, M., Muhammad, L. U., Mani, A. U., & Ambali, A. G. (2009). A survey of chick mortality at hatching in three selected hatcheries in Jos, Central Nigeria. International Journal of Poultry Science, 8, 656–659.

Mukhtar, N., Khan, S. H., & Anjum, M. S. (2013). Hatchling length is a potential chick quality parameter in meat type chickens. World's Poultry Science Journal, 69(4), 889-896.

Narinç, D., Aksoy, T., İlaslan Çürek, D., Karaman, E. 2007. Analyses of growth in broilers from different growth rate. Journal of Animal Research, 17:1–8.

Narinç, D., Aksoy, T., Karaman, E., Aygun, A., Firat, M. Z., Uslu, M. K. (2013). Japanese quail meat quality: Characteristics, heritabilities, and genetic correlations with some slaughter traits. Poultry Science, 92(7), 1735-1744.

Narinç, D., Karaman, E., Aksoy, T. (2014). Effects of slaughter age and mass selection on slaughter and carcass characteristics in 2 lines of Japanese quail. Poultry Science, 93(3), 762-769.

Narinç, D., Narinç, N. Ö., Aygün, A. (2017). Growth curve analyses in poultry science. World's Poultry Science Journal, 73(2), 395-408.

Narinç, D., Aydemir, E. (2021a). Chick quality: An overview of measurement techniques and influencing factors. World's Poultry Science Journal, 77(2), 313-329.

Narinç, D., Aydemir, E. (2021b). Genetic parameter estimates of chick quality, growth, and carcass characteristics in Japanese quail. Journal of the Hellenic Veterinary Medical Society, 72(4), 3363-3370.

Narinç, D., Genç, B. A. (2021). Genetic parameter estimates of fear, growth, and carcass characteristics in Japanese quail. Turkish Journal of Veterinary & Animal Sciences, 45(2), 272-280.

Norris, D., Ngambi, J. W., Benyi, K., Makgahlele, M. L., Shimelis, H. A., Nesamvuni, E. A. (2007). Analysis of growth curves of indigenous male Venda and Naked Neck chickens. South African Journal of Animal Science, 37(1), 21-26.

Northcutt, J. K., Buhr, R. J., Young, L. L., Lyon, C. E., Ware, G. O. (2001). Influence of age and postchill carcass aging duration on chicken breast fillet quality. Poultry Science, 80(6), 808-812.

Nowak, B., Pawlina, E., Ilska, K., Mucha, A., Kruszynski, W. (2019). Breeder line and age affects the occurrence of developmental defects, the number of culled one-day old broiler chicks and their body mass. Veterinární Medicína, 64(7), 323-333.

Reijrink, I. A. M., Berghmans, D., Meijerhof, R., Kemp, B., & Van den Brand, H. (2010). Influence of egg storage time and preincubation warming profile on embryonic development, hatchability, and chick quality. Poultry Science, 89(6), 1225-1238.

Roush, W. B., Dozier, W. A., Branton, S. L. (2006). Comparison of Gompertz and neural network models of broiler growth. Poultry Science, 85(4), 794-797.

Şekeroğlu, A., Tahtalı, Y., Sarıca, M., Gülay, M. Ş., Abacı, S. H., & Duman, M. (2013). Comparison of growth curves of broiler under different stocking densities by Gompertz model. The Journal of the Faculty of Veterinary Medicine, Kafkas University, 19, 669-672.

Tona, K., Bamelis, F., De Ketelaere, B., Bruggeman, V., Moraes, V. M. B., Buyse, J., Onagbesan, O., Decuypere, E. (2003). Effects of egg storage time on spread of hatch, chick quality, and chick juvenile growth. Poultry Science, 82(5), 736-741.

Tona, K., Onagbesan, O. M., Jego, Y., Kamers, B., Decuypere, E., & Bruggeman, V. (2004a). Comparison of embryo physiological parameters during incubation, chick quality, and growth performance of three lines of broiler breeders differing in genetic composition and growth rate. Poultry Science, 83(3), 507-513.

Tona, K., Onagbesan, O., De Ketelaere, B., Decuypere, E., & Bruggeman, V. (2004b). Effects of age of broiler breeders and egg storage on egg quality, hatchability, chick quality, chick weight, and chick posthatch growth to forty-two days. Journal of Applied Poultry Research, 13(1), 10-18.

Tona, K., Bruggeman, V., Onagbesan, O., Bamelis, F., Gbeassor, M., Mertens, K., & Decuypere, E. (2005a). Day-old chick quality: Relationship to hatching egg quality, adequate incubation practice and prediction of broiler performance. Avian and Poultry Biology Reviews, 16, 109-119.

Tona, K., Bruggeman, V., Onagbesan, O., Bamelis, F., Gbeassor, M., Mertens, K., & Decuypere, E. (2005b). Day-old chick quality: Relationship to hatching egg quality, adequate incubation practice and prediction of broiler performance. Avian and Poultry Biology Reviews, 16(2), 109-119.

Topal, M., & Bölükbaşı, Ş. C. (2008). Comparison of nonlinear growth curve models in broiler chickens. Journal of Applied Animal Research, 34(2), 149-152.

Van de Ven, L. J. F., Van Wagenberg, A. V., Uitdehaag, K. A., Koerkamp, P. G., Kemp, B., & Van den Brand, H. (2012). Significance of chick quality score in broiler production. Animal, 6(10), 1677-1683.

Willemsen, H., Everaert, N., Witters, A., De Smit, L., Debonne, M., Verschuere, F., Garain, P., Berckmans, D., Decuypere, E., & Bruggeman, V. (2008). Critical assessment of chick quality measurements as an indicator of posthatch performance. Poultry Science, 87(11), 2358-2366.

Wolanski, N. J., Renema, R. A., Robinson, F. E., Carney, V. L., & Fancher, B. I. (2006). Relationship between chick conformation and quality measures with early growth traits in males of eight selected pure or commercial broiler breeder strains. Poultry Science, 85(8), 1490-1497.