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# Effects of feed restriction on the occurrence of white striping and wooden breast myopathies, performance, carcass characteristics and some blood parameters in broiler chickens

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**Abstract:** This study was planned to determine the effects of feed restriction applied at different times and levels on the occurrence of white striping and wooden breast myopathies, performance, carcass characteristics and some blood parameters in broilers. In total, 600 male broilers were randomly placed to 5 groups with eight replicates. Control group was fed ad libitum throughout experimental period. T1 and T2 groups received feed as 80% and 70% of control group from 11 to 24 days of age, respectively. T3 and T4 groups received feed as 80% and 70% of control group from 25 to 39 days of age, respectively. T2, T3 and T4 groups had the lower mean values for feed intake and body weight gain from 0 to 49 days of age, final body weight, carcass weight, serum alanine aminotransferase (ALT) and lactate dehydrogenase (LDH) levels, compared to control group. T3 and T4 groups had lower dressing percentage, breast meat yield, serum aspartate aminotransferase (AST) and creatine kinase (CK) levels than control. T2, T3 and T4 groups had lower incidence for white striping and wooden breast myopathies than control. T3 and T4 groups had also the lower incidence for severe degree white striping and wooden breast myopathies than control. In conclusion, feed restriction to 70% of ad libitum intake between 11 and 24 days of age and feed restriction to 80% and 70% of ad libitum intake between 25 and 39 days of age may reduce the incidence and severeness of white striping and wooden breast myopathies, although there is some loss in performance traits. Feed restrictions to 80% and 70% levels of ad libitum intake between 25 and 39 days of age may be more effective in reducing these myopathies on pectoralis major muscle of broilers.

**Key words:** Broiler, feed restriction, white striping, wooden breast

## 1. Introduction

The growth performance of broiler chickens has considerably increased in recent years because of improvements in genetic, nutrition and management. The fast growth rate of broilers and higher food supply, however, has caused in some health issues, and increased fat accumulation in the body [1,2]. The increasing of growth rate and breast meat yield has also resulted in the occurrence of breast muscle myopathies such as white striping and wooden breast in broilers [3]. White striping is the formation of the white striations seen parallel to muscle fibers mainly in breast muscles [4,5]. Wooden breast is characterized by palpably firmness in breast fillets and causes to the occurrence of hard, rigid fillets. In case of a wooden breast myopathy, pale, expansive areas of considerable hardness, small hemorrhages, clear exudate, swelling, as well as white striations are noticeable [6,7].

It is known that the increase in serum ALT, AST and LDH levels may be related with liver or muscle damage. On the other hand, CK is a skeletal muscle specific enzyme and is used to distinguish whether the increase in ALT and AST levels is related to liver or muscle damage. [8,9]. Previous studies reported that these enzymes are associated with the presence of various myopathies [10–12].

White striations give a fatty appearance to the fillets, which negatively affects acceptance of these fillets by consumers [13,14]. Besides negatively affecting consumer choice, these myopathies may change functional and nutritional traits of meat [7,15,16]. Fillets affected by white striping and wooden breast myopathies are sold at low prices or used for further processed products and thus cause to substantial economic losses for poultry industry [5].

The exact reason and mechanism of white striping and wooden breast myopathies remains unknown. However, it has been reported that genotype, growth rate, sex and slaughter weight significantly affect the occurrence of these myopathies [14,17]. Previous studies showed that

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white striping and wooden breast myopathies are linked with high growth rate and breast meat yield [6,15,18,19]. Heavier broilers have a higher incidence of severe white striping and wooden breast [18–20]; males also have a higher incidence of these myopathies than females [20,21].

There are a few studies related to the effect of feed restriction on the occurrence of white striping and wooden breast myopathies in broiler chickens [10,21,22]. Trocino et al. [21] observed that feed restriction at the early period may increase the formation of white stripping myopathy in broiler breast muscles. However, Meloche et al. [10] stated that feed restriction to 95% of ad libitum consumption during entire production period led to a decrease in the degree of white striping and wooden breast myopathies. Livingston et al. [22] also showed that time-limited feeding may decrease these myopathies. However, the information about the effects of feed restriction at different times and different levels on white striping and wooden breast myopathies is limited.

For this reason, in this study it was investigated that the effect of feed restriction at different times and levels on the occurrence of white striping and wooden breast myopathies, performance, carcass characteristics and some serum biochemical parameters in broiler chickens.

## 2. Materials and methods

### 2.1. Animals and management

The study was carried out at the Poultry Unit of the Faculty of Veterinary Medicine, Aydın Adnan Menderes University, Turkey with approval of Ethics Committee of Aydın Adnan Menderes University (Approval No: 64583101/2016/188).

In total, 600 male broilers (Ross 308) were used as the material of the study. One-day old male broilers were purchased from a local hatchery (Egetav Tavukçuluk San. ve Tic. AŞ. İzmir, Turkey). Broilers were raised in floor pens having wood shavings of 6 to 8 cm depth as litter material. They were placed at stocking density of 10 birds per $m^2$. Each pen had 1 hanging feeder and 3 nipple drinkers. Experimental diets used for all broilers consisted of starter (3000 kcal/kg ME and 23% crude protein), grower (3100 kcal/kg ME and 21.5% crude protein), finisher (3200 kcal/kg ME and 19.5% crude protein) and withdrawal diet (3200 kcal/kg ME and 18.30% crude protein), which were used in the periods from 1 to 10, from 11 to 24, from 25 to 39 and from 40 to 49 days of age, respectively. Nutritional requirements were provided based on the standard recommendations of the breeder company for Ross 308 hybrids [23]. Water was available as free for all groups during entire experiment. Lighting period was continuous for the first week and then it was 18L: 6D. The temperature of the rooms was for 32 °C in the first 3 days; afterward, it was decreased 3 °C weekly until 21 days.

### 2.2. Treatments and experimental design

Six hundred 1-day-old broilers were wing-banded, weighed and then they were randomly placed to 5 treatments each of 120 broilers. Treatments had 8 replicate pens (15 broilers/pen). Broilers in control group had access to feed as free throughout the study. Broilers in treatment 1 (T1) and treatment 2 (T2) received feed as 80% and 70% of amount consumed by control group fed ad libitum from 11 to 24 days of age, respectively. Broilers in treatment 3 (T3) and treatment 4 (T4) received feed as 80% and 70% of amount consumed by control group from 25 to 39 days of age, respectively. Except for the duration of feed restrictions, all broiler chickens were fed ad libitum.

#### 2.2.1. Growth performance

Mortality was recorded daily. Broilers were weighted individually at hatching, 10, 24, 39 and 49 days of age. A balance sensitive to 0.1 g was used to weight the broilers at the beginning of the experiment and on the 10th day, and a balance sensitive to 1 g for subsequent weightings. Feed intake was measured daily on a pen basis and amounts of feed for T1, T2, T3 and T4 groups were determined as the percentage of amount consumed by the control group on the previous day. Feed consumption, weight gain, and feed conversion ratio (FCR) were recorded on pen basis. Cumulative mortality rate was calculated from 0 to 49 days of age.

### 2.3. Slaughter and carcass characteristics

Five birds from each pen (40 broilers per treatment) were selected at the age of 49 days. They were weighed individually after 12 h of fasting and then slaughtered to determine carcass characteristics, white striping and wooden breast myopathies in breast fillets. Broilers were processed by cutting the carotid artery and jugular vein, and afterwards, they were scalded for 2 min at 62 °C, defeathered and eviscerated**.** Carcass weight and abdominal fat weight was recorded. Breast, legs (thigh and drumstick together), wings and remainder parts were separated from each carcass. Subsequently, skinless and boneless breast muscles were removed and weighed. Abdominal fat pad was weighed by a balance sensitive to 0.1 g, carcass and carcass parts were weighed by a balance sensitive to 1 g. Dressing percentage was determined as percentage of preslaughter live weight, whereas the percentages of carcass cuts were determined as percentage of carcass weight.

### 2.4. Determination of white striping and wooden breast myopathies in breast muscles

The pectoralis major muscles of each broiler were examined macroscopically for white striping and wooden breast myopathies after skinless and boneless breast muscles were removed. The pectoralis major muscles were evaluated for white striping occurrence based on 3-point

scale according to Kuttappan et al. [13]. In detail, breast fillets without visual white striations were considered as normal (score 0). Fillets having white striations < 1-mm thick, parallel to muscle fibers were classified as moderate degree (score 1). Fillets having > 1-mm thick and very visible white striations on the fillet surface were classified as severe (score 2). Breast fillets were palpated and classified for wooden breast myopathy as following: score 0 was given to fillets without any hardness, score 1 was given when the hardness was mainly in cranial region and up to half of the total fillet surface are, and score 2 was given when the fillets had hardness throughout the fillet [10]. All fillets were scored by the same researcher.

#### 2.4.1. Blood sampling and analysis

A total of 5 mL blood samples were collected from jugular vein and carotid artery of slaughtered broilers (40 broilers from each group, 5 broilers from each pen) during slaughter. Blood samples were taken in biochemical tubes without anticoagulant. Blood samples were centrifuged at 2000 × g for 15 min at 4 °C and collected serum was stored at –20 °C until further analyses. Serum glucose, cholesterol, triglyceride, total protein, ALT, AST, LDH and CK levels were determined by an autoanalyzer (Ray Chemray 120) using commercial test kits.

### 2.5. Statistical analysis

Statistical analysis of data was done using SPSS software package version 22.0 [24]. Mortality rate and the incidence of different degrees of white striping and wooden breast myopathies were analyzed by using chi-square test [25]. Kruskal–Wallis test was used to analyze data of white striping and wooden breast myopathy scores, and Mann–Whitney U test was used for the significance control of differences between groups. The growth performance, carcass characteristics and blood parameters were analyzed by one-way analysis of variance. Duncan's multiple range test was used to find significant differences among treatment means [26].

## 3. Results

In the study, the mortality rate was found as 1.67%, 5%, 4.17%, 2.5% and 3.33% for control, T1, T2, T3 and T4 groups, respectively. Feed restriction did not significantly affect mortality rate.

Body weights of broilers at different growth periods are presented in Table 1. Body weight of broilers in T1 and T2 groups which received feed as 80% and 70% of control group, respectively from 11 to 24 days of age was lower ($p < 0.001$) compared with the other groups at 24 days of age. Body weight of broilers in T2 group also was lower ($p < 0.001$) than those in T1 group. At 39 days of age, broilers in T4 group had the lowest body weight, whereas those in control group had the highest ($p < 0.001$) body weight. Final body weight of T2, T3 and T4 groups were significantly lower ($p < 0.001$) than control group, whereas no statistically significant difference occurred between T1 and control groups.

Feed restriction significantly affected growth performance of broilers. Broilers in T1 and T2 groups had lower weight gain and feed consumption from 11 to 24 days of age, compared to those in the other groups. Broilers in T2 group had lower mean values than those in T1 group in terms of these traits ($p < 0.001$). Broilers in T3 and T4 groups had lower weight gain and feed consumption from

**Table 1.** Body weights of broilers at different growth periods.[1]

| Treatment[2] | n | Hatching weight | n | 10 days of age | n | 24 days of age | n | 39 days of age | n | 49 days of age |
|---|---|---|---|---|---|---|---|---|---|---|
| Control | 120 | 41.69 | 120 | 265.72 | 119 | 1234.76$^{a}$ | 119 | 2836.46$^{a}$ | 116 | 3819.93$^{a}$ |
| T1 | 120 | 41.56 | 119 | 263.82 | 118 | 1012.50$^{b}$ | 118 | 2739.77$^{b}$ | 118 | 3736.13$^{ab}$ |
| T2 | 120 | 41.82 | 120 | 259.08 | 119 | 895.15$^{c}$ | 117 | 2640.91$^{c}$ | 114 | 3678.68$^{b}$ |
| T3 | 120 | 42.01 | 120 | 266.06 | 119 | 1235.54$^{a}$ | 118 | 2464.36$^{d}$ | 115 | 3582.26$^{c}$ |
| T4 | 120 | 41.41 | 120 | 266.28 | 119 | 1225.51$^{a}$ | 117 | 2249.16$^{e}$ | 117 | 3527.09$^{c}$ |
| SEM[3] | | 0.14 | | 1.51 | | 7.69 | | 13.24 | | 15.13 |
| P | | 0.683 | | 0.528 | | < 0.001 | | < 0.001 | | < 0.001 |

[1]Values represents individual means of broilers for body weight at different growth periods.
[2]Control: Broilers in this group fed as ad libitum during entire experimental period. T1: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T2: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T3: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 25 to 39 days of age. T4: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 25 to 39 days of age. $^{a, b, c, d, e}$: Means having different superscript letter in the same column are significantly different ($p < 0.001$).
[3]SEM: pooled standard error of the mean.

25 to 39 days of age, compared to the other groups ($p < 0.001$). The mean values of these traits were lower in T4 group than T3 group. However, broilers in T4 group have a higher feed consumption and weight gain than the other groups from 40 to 49 days of age ($p < 0.05$). From 0 to 49 days of age, no significant differences were observed for weight gain and feed consumption between T1 and control groups. However, the lower mean values were obtained for T2, T3 and T4 groups in terms of these traits. The lowest mean values for feed intake and weight gain was observed in T3 and T4 groups ($p < 0.001$). There was no statistically significant difference between groups in terms of FCR from 0 to 49 days of age (Table 2).

Carcass characteristics of broilers in different groups are shown in Table 3. Dressing percentage and breast meat yield of broilers in T3 and T4 groups were significantly lower than those in control group. The percentage of abdominal fat pad was lower for T2, T3 and T4 groups, compared to control group ($p < 0.001$).

Some biochemical blood parameters of broilers in different groups are presented in Table 4. Serum glucose, cholesterol, triglyceride and total protein levels were not statistically different between the groups. However, the lower ($p < 0.05$) serum AST and CK levels were obtained for T3 and T4 groups, compared to control group. Serum ALT ($p < 0.01$) and LDH ($p < 0.05$) levels also were lower for T2, T3 and T4 groups than control group.

The incidence of white striping for broilers in different groups are shown in Table 5. The incidence of moderate degree white striping was not statistically different between the groups. However, the lower incidence of severe degree white striping was determined for T3 and T4 groups than control group ($p < 0.001$). Total white striping incidence for control group fed ad libitum was 97.5%, whereas, total white striping incidence for T1, T2, T3 and T4 groups were 85%, 80%, 60% and 52.5%, respectively.

Regarding the incidence of wooden breast myopathy, it was determined that feed restriction did not significantly

**Table 2.** Body weight gain, feed intake and feed conversion ratio of broilers at different growth periods.[1]

| Traits | Treatment[2] | | | | | SEM[3] | p |
|---|---|---|---|---|---|---|---|
| | Control | T1 | T2 | T3 | T4 | | |
| Body weight gain (g/bird) | | | | | | | |
| 0 to 10 days of age | 224.03 | 222.42 | 217.27 | 224.05 | 224.87 | 4.27 | 0.984 |
| 11 to 24 days of age | 970.29$^{a}$ | 748.75$^{b}$ | 635.66$^{c}$ | 966.98$^{a}$ | 958.41$^{a}$ | 23.50 | < 0.001 |
| 25 to 39 days of age | 1601.87$^{b}$ | 1727.13$^{a}$ | 1741.71$^{a}$ | 1225.99$^{c}$ | 1022.67$^{d}$ | 47.06 | < 0.001 |
| 40 to 49 days of age | 980.14$^{d}$ | 996.36$^{cd}$ | 1038.46$^{c}$ | 1118.75$^{b}$ | 1277.92$^{a}$ | 8.99 | < 0.001 |
| 0 to 49 daysof age | 3778.26$^{a}$ | 3694.63$^{ab}$ | 3636.91$^{b}$ | 3540.22$^{c}$ | 3485.68$^{c}$ | 15.11 | < 0.001 |
| Feed intake (g/bird) | | | | | | | |
| 0 to 10 days of age | 297.29 | 307.35 | 290.79 | 288.88 | 297.06 | 5.49 | 0.861 |
| 11 to 24 days of age | 1304.10$^{a}$ | 1051.50$^{b}$ | 919.87$^{c}$ | 1302.40$^{a}$ | 1294.69$^{a}$ | 28.55 | < 0.001 |
| 25 to 39 days of age | 2716.94$^{a}$ | 2785.33$^{a}$ | 2714.81$^{a}$ | 2198.46$^{b}$ | 1924.68$^{c}$ | 56.74 | < 0.001 |
| 40 to 49 days of age | 1947.36$^{b}$ | 1917.96$^{b}$ | 1898.28$^{b}$ | 1938.70$^{b}$ | 2125.80$^{a}$ | 24.92 | 0.020 |
| 0 to 49 daysof age | 6265.69$^{a}$ | 6062.15$^{ab}$ | 5823.76$^{bc}$ | 5728.45$^{c}$ | 5642.23$^{c}$ | 53.21 | < 0.001 |
| FCR[4] (g feed/g weight gain) | | | | | | | |
| 0 to 10 days of age | 1.33 | 1.40 | 1.33 | 1.30 | 1.32 | 0.02 | 0.444 |
| 11 to 24 days of age | 1.35$^{c}$ | 1.41$^{b}$ | 1.45$^{a}$ | 1.34$^{c}$ | 1.35$^{c}$ | 0.01 | < 0.001 |
| 25 to 39 days of age | 1.70$^{c}$ | 1.61$^{d}$ | 1.56$^{d}$ | 1.80$^{b}$ | 1.88$^{a}$ | 0.02 | < 0.001 |
| 40 to 49 days of age | 1.99$^{a}$ | 1.93$^{ab}$ | 1.83$^{bc}$ | 1.74$^{cd}$ | 1.67$^{d}$ | 0.03 | < 0.001 |
| 0 to 49 days of age | 1.66 | 1.64 | 1.60 | 1.62 | 1.62 | 0.01 | 0.274 |

[1]Values represent means of 8 replicate pens per treatment (15 broilers per pen). [2]Control: Broilers in this group fed as ad libitum during entire experimental period. T1: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T2: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T3: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 25 to 39 days of age. T4: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 25 to 39 days of age. [a, b, c, d]: Means having different superscript letter in the same row are significantly different ($p < 0.05$). [3]SEM: pooled standard error of the mean. [4]FCR: feed conversion ratio.

**Table 3.** Carcass characteristics of broiler chickens in different groups.

| Traits | Treatment[1] | | | | | SEM[4] | p |
|---|---|---|---|---|---|---|---|
| | Control (n = 40) | T1 (n = 40) | T2 (n = 40) | T3 (n = 40) | T4 (n = 40) | | |
| Carcass weight (g) | 2933.73[a] | 2864.70[ab] | 2785.03[b] | 2621.40[c] | 2584.38[c] | 16.47 | < 0.001 |
| Dressing percentage[2] (%) | 76.58[a] | 76.25[a] | 75.52[a] | 73.22[b] | 73.52[b] | 0.21 | < 0.001 |
| The percentages of carcass cuts[3] | | | | | | | |
| Breast meat | 33.60[a] | 33.11[ab] | 32.76[ab] | 32.15[b] | 31.94[b] | 0.19 | 0.028 |
| Leg | 34.03 | 34.25 | 34.73 | 34.92 | 35.00 | 0.14 | 0.114 |
| Wing | 9.77 | 9.87 | 9.98 | 10.14 | 10.02 | 0.06 | 0.415 |
| Abdominal fat pad | 2.04[a] | 1.97[ab] | 1.82[bc] | 1.71[c] | 1.66[c] | 0.03 | < 0.001 |
| Remaining carcass cuts | 20.57 | 20.78 | 20.67 | 21.04 | 21.32 | 0.17 | 0.674 |

[1]Control: Broilers in this group fed as ad libitum during entire experimental period. T1: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T2: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T3: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 25 to 39 days of age. T4: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 25 to 39 days of age.
[2]Dressing percentage = Carcass weight/preslaughter live weight × 100
[3]The percentages of carcass cuts = Weight of carcass cuts/carcass weight × 100
[a, b,c]: Means having different superscript letter in the same row are significantly different ($p < 0.05$). [4]SEM: pooled standard error of the mean.

**Table 4.** Some biochemical blood parameters of broilers in different groups.

| Traits | Treatment[1] | | | | | SEM[2] | p |
|---|---|---|---|---|---|---|---|
| | Control (n = 40) | T1 (n = 40) | T2 (n = 40) | T3 (n = 40) | T4 (n = 40) | | |
| Glucose (mg/dL) | 228.73 | 231.65 | 226.25 | 230.68 | 232.95 | 1.33 | 0.534 |
| Cholesterol (mg/dL) | 105.74 | 153.57 | 111.08 | 105.56 | 101.88 | 8.54 | 0.290 |
| Trigliserit (mg/dL) | 33.04 | 42.04 | 36.21 | 37.13 | 39.13 | 1.19 | 0.175 |
| Total protein (mg/dL) | 2.46 | 2.53 | 2.55 | 2.52 | 2.41 | 0.04 | 0.862 |
| AST (U/L) | 620.23[a] | 512.00[ab] | 566.04[ab] | 473.95[b] | 480.48[b] | 17.12 | 0.031 |
| ALT (U/L) | 6.30[a] | 5.58[ab] | 4.52[bc] | 4.43[bc] | 3.96[c] | 0.23 | 0.008 |
| CK (U/mL) | 51.39[a] | 44.51[ab] | 44.42[ab] | 31.06[b] | 33.21[b] | 2.25 | 0.019 |
| LDH (U/mL) | 2.66[a] | 2.32[ab] | 2.21[b] | 2.01[b] | 2.25[b] | 0.67 | 0.022 |

[1]Control: Broilers in this group fed as ad libitum during entire experimental period. T1: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T2: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T3: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 25 to 39 days of age. T4: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 25 to 39 days of age.
[a, b,c]: Means having different superscript letter in the same row are significantly different ($p < 0.05$). [2]SEM: pooled standard error of the mean.

affect the incidence of moderate degree wooden breast. However, incidence of severe degree wooden breast was lower in T3 and T4 groups, than the other groups ($p < 0.001$). The differences among T1, T2 and control groups were not statistically significant in terms of this trait. Total wooden breast incidence was found as 90% for broilers in control group, whereas it was 75%, 65%, 42.5% and 35%, for T1, T2, T3 and T4 groups, respectively (Table 6).

**Table 5.** The incidence of white striping for broilers in different groups.

| Treatment[1] | Scores of white striping | | | | | |
|---|---|---|---|---|---|---|
| | 0 | | 1 | | 2 | |
| | n | % | n | % | n | % |
| Control | 1 | 2.5[d] | 16 | 40.0 | 23 | 57.5[a] |
| T1 | 6 | 15.0[cd] | 17 | 42.5 | 17 | 42.5[a] |
| T2 | 8 | 20.0[bc] | 18 | 45.0 | 14 | 35.0[ab] |
| T3 | 16 | 40.0[ab] | 18 | 45.0 | 6 | 15.0[bc] |
| T4 | 19 | 47.5[a] | 16 | 40.0 | 5 | 12.5[c] |
| $X^2$ | | 29.067 | | 0.409 | | 26.211 |
| P | | < 0.001 | | 0.982 | | < 0.001 |

[1]Control: Broilers in this group fed as ad libitum during entire experimental period. T1: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T2: Broilers in this group received feed 70% of amount consumed by control group from 11 to 24 days of age. T3: Broilers in this group received feed 80% of amount consumed by control group from 25 to 39 days of age. T4: Broilers in this group received feed 70% of amount consumed by control group from 25 to 39 days of age.
[a, b, c, d]: Values having different superscript letter in the same column are significantly different ($p < 0.001$).
Score 0: normal (no white striping), score 1: moderate degree of white striping, score 2: severe degree of white striping.

**Table 6.** The incidence of wooden breast for broilers in different groups.

| Treatment[1] | Scores of wooden breast | | | | | |
|---|---|---|---|---|---|---|
| | 0 | | 1 | | 2 | |
| | n | % | n | % | n | % |
| Kontrol | 4 | 10.0[c] | 16 | 40.0 | 20 | 50.0[a] |
| T1 | 10 | 25.0[bc] | 16 | 40.0 | 14 | 35.0[a] |
| T2 | 14 | 35.0[b] | 14 | 35.0 | 12 | 30.0[a] |
| T3 | 23 | 57.5[a] | 14 | 35.0 | 3 | 7.5[b] |
| T4 | 26 | 65.0[a] | 11 | 27.5 | 3 | 7.5[b] |
| $X^2$ | | 34.970 | | 5.625 | | 28.222 |
| P | | < 0.001 | | 0.229 | | < 0.001 |

[1]Control: Broilers in this group fed as ad libitum during the entire experimental period. T1: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 11 to 24 days of age. T2: Broilers in this group received feed 70% of amount consumed by control group from 11 to 24 days of age. T3: Broilers in this group received feed 80% of consumed by control group from 25 to 39 days of age. T4: Broilers in this group received feed 70% of consumed by control group from 25 to 39 days of age.
[a, b, c]: Values having different superscript letter in the same column are significantly different ($p < 0.001$).
Score 0: normal (no wooden breast), score 1: moderate degree of wooden breast, score 2: severe degree of wooden breast.

In the study, the lower ($p < 0.001$) mean scores of white striping and wooden breast myopathies were obtained for T2, T3 and T4 groups than control group. The lowest mean scores of these myopathies were determined for T4 group in which broilers received feed as 70% of control group fed ad libitum from 25 to 39 days of age. No significant difference was observed between T3 and T4 groups (Table 7).

## 4. Discussion

In our study, body weight gain, feed intake and FCR from 0 to 10 days of age were not significantly different among treatments. However, from 11 to 24 days of age, body weight gain and feed intake were lower ($p < 0.001$), whereas FCR was higher ($p < 0.001$) for T1 and T2 groups. T2 group had also lower ($p < 0.001$) body weight gain and feed intake but has higher ($p < 0.001$) FCR than T1 group in this period. T4 group had the lowest ($p < 0.001$) body weight gain and feed intake, but the highest ($p < 0.001$) FCR from 25 to 39 days of age.. This finding is in line with previous studies reported that feed restriction negatively affected growth performance of broilers in restriction period [27–30].

In the study, broilers in T1 group had live weight similar to those in control group at 49 days of age. This result could be due to the fact that the broilers in T1 group showed a higher level body weight gain than those in control group, after restriction period. Similar to this study, Novel et al. [29] determined that broilers in group restricted to 75% of control group from 14 to 21 days of age have similar body weight with control group at the age of 42 days. However, Trocino at al. [21] reported that broilers received feed as 80% of control group fed ad libitum at 13 to 21 days of age have lower body weight at 46 days of age than those in control group. The differences between the studies could be due to differences in feed restriction time, feed restriction levels, slaughter age and also management conditions. It is known that the broilers exposed to early feed restriction show the fast body weight gain during ad libitum feeding period after restriction to compensate slow growth in restriction period. However, in this study, broilers in T2 group had lower ($p < 0.001$) body weight than those in control group at 49 days of age. This finding shows that feed restriction level applied to this group is too severe to compensate for the growth**.** In this study, the broilers in T3 and T4 groups had lower final live weight at 49 days of age than control group. These findings indicate that feed restriction time is important for the compensatory growth. Similar results were obtained by Boostani et al. [31].

In the study, feed restriction significantly affected carcass characteristics of broilers. Dressing percentage ($p < 0.001$) and breast meat yield ($p < 0.05$) in T3 and T4 groups were significantly lower than control group. This result may be due to the lower carcass and breast meat weights of broilers in T3 and T4 groups than those in control group. Similarly, Livingston et al. [22] determined that broilers in the group deprived of feed for 8 h daily between 8 to 42 days of age had lower breast meat yield and dressing percentage, compared to those in the group fed ad libitum throughout

**Table 7.** The mean scores of white striping and wooden breast myopathies in breast meats of broilers in different groups.

| Treatments[1] | n | WS myopathy score | | WB myopathy score | |
|---|---|---|---|---|---|
| | | $\bar{x}$ | $S_{\bar{x}}$ | $\bar{x}$ | $S_{\bar{x}}$ |
| Control | 40 | $1.55^{a}$ | 0.09 | $1.40^{a}$ | 0.10 |
| T1 | 40 | $1.28^{ab}$ | 0.11 | $1.10^{ab}$ | 0.12 |
| T2 | 40 | $1.15^{b}$ | 0.12 | $0.95^{b}$ | 0.13 |
| T3 | 40 | $0.75^{c}$ | 0.11 | $0.50^{c}$ | 0.10 |
| T4 | 40 | $0.65^{c}$ | 0.11 | $0.43^{c}$ | 0.10 |
| P | | < 0.001 | | < 0.001 | |

[1]Control: Broilers in this group fed as ad libitum during the entire experimental period. T1: Broilers in this group received feed 80% of amount consumed by
control group fed ad libitum from 11 to 24 days of age. T2: Broilers in this group received feed 70% of amount consumed by control group fed ad libitum from 11 to 24 days of age.
T3: Broilers in this group received feed 80% of amount consumed by control group fed ad libitum from 25 to 39 days of age. T4: Broilers in this group received feed
70% of amount consumed by control group fed ad libitum from 25 to 39 days of age. WS: white striping, WB: wooden breast.
[a, b, c]: Means having different superscript letter in the same column are significantly different ($p < 0.001$).

experiment. However, Poltowicz et al. [32] determined that feed restriction for 6 h daily from 3 to 4 weeks and from 4 to 5 had no significant effect on dressing percentage and breast meat yield, compared to control group. Some studies reported that feed restriction at an earlier stage of life in broilers give rise to fat deposition in the body in later growth periods [28,32,33]. However, in this study, it was determined that feed restriction to 80% of control group at 11 to 24 days of age did not significantly affect the percentage of abdominal fat pad; but feed restriction to 70% of control group from 11 to 24 days of age reduced the amount of abdominal fat ($p < 0.001$). The differences between the studies could be explained by differences in feed restriction level, duration, as well as feed restriction time. Zhan et al. [28] also stated that the first week of life in broilers is the critic stage for feed restriction and from the first day low level of feed restriction for a long time may stimulate metabolism programming, causing excessive fat accumulation in the body of broilers.

In this study, it was determined that broilers in T2, T3 and T4 groups had significantly lower serum ALT and LDH levels than broilers in control group. Serum AST and CK levels also were determined as lower for T3 and T4 groups than control. These results may explain that the incidence and degree of white striping and wooden breast myopathies were lower in these groups than control group. Similar to this study, Kuttappan et al. [9] also reported a rise in serum ALT, LDH AST and CK levels in broilers having breast meats with severe degree white striping.

In this study, feed restriction significantly affected the formation of white striping and wooden breast myopathies. T2, T3 and T4 groups had a higher ($p < 0.001$) rate of normal breast scored as 0 for both of these myopathies, compared with the control group. T3 and T4 groups had also lower ($p < 0.001$) incidence for severe degree white striping and wooden breast myopathies than control group. This result may be due to the fact that final live weight and breast meat yield of broilers in T3 and T4 groups were lower than those in control group. It has been reported that increasing of hypertrophy in breast muscles of fast growing broilers and decreasing of capillarization negatively affects muscle fiber metabolism and thus cause to white striping and wooden breast myopathies [4,6,34]. Similar to this study, some studies determined that the rate of severe degree white striping and wooden breast myopathies was higher in broilers having higher body weight [9,18,19]. On the other hand, Trocino et al. [21] reported that the incidence of white striping was higher in broilers received feed as 80% of control group fed ad libitum from 13 to 21 days of age than those in control group, but the difference between groups formed according to feeding program was not statistically significant. The authors explained that broilers in the group applied restriction had the faster growth rate during ad libitum feeding period after restriction and thus increased growth rate of breast muscle and damage in breast muscle, compared with broilers in control group. Unlike Trocino et al. [21], in this study, it was determined that broilers in T1 group had similar incidence of these myopathies to control group. Velleman et al. [35] stated that feed restriction applied during the first two weeks of life has adverse effects on pectoralis major muscle, and causes to increased necrose and fat deposition. The authors reported that earliest period after hatching is critical for growth and structure of breast muscles. However, in this study feed restriction was applied at a later time than their study.

In the study, white striping and wooden breast scores were determined as lower for T2, T3 and T4 groups, compared with control group. The lowest mean value in terms of this trait was obtained for T4 group. The difference between T3 and T4 groups was not statistically significant. This result indicates that the severity of these myopathies was lower in T3 and T4 groups than the other groups. Similar to this study, Meloche et al. [10] determined that white striping and wooden breast scores reduced with reduce in feed intake at 33, 43 and 50 days of age. In another study, Livingston et al. [22] also reported that the mean scores of these myopathies have lower in group feed restricted 8 h daily at 8 to 42 days of age than control group.

As a result, the high incidences of white striping and wooden breast myopathies were observed in this study. The broilers were slaughtered at 49 days of age and slaughter weights of broilers in groups were higher than 3500 g, which may have resulted in the occurrence of the high incidence of these myopathies. The feed restriction to 70% of ad libitum intake between 11 and 24 days of age, and feed restriction to 80% and 70% levels of ad libitum intake between 25 and 39 days of age significantly decreased the occurence and degree of white striping and wooden breast myopathies at 49 days of age, although there was some decrease in performance traits. Feed restriction to 80% and 70% levels of ad libitum intake between 25 and 39 days of had a greater effect on reduction of these myopathies in pectoralis major muscle of broilers. On the other hand, increasing of the feed restriction level from 80% to 70% of ad libitum in this period could not provide significant additional benefits for reducing the incidence and degree of these myopathies.

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