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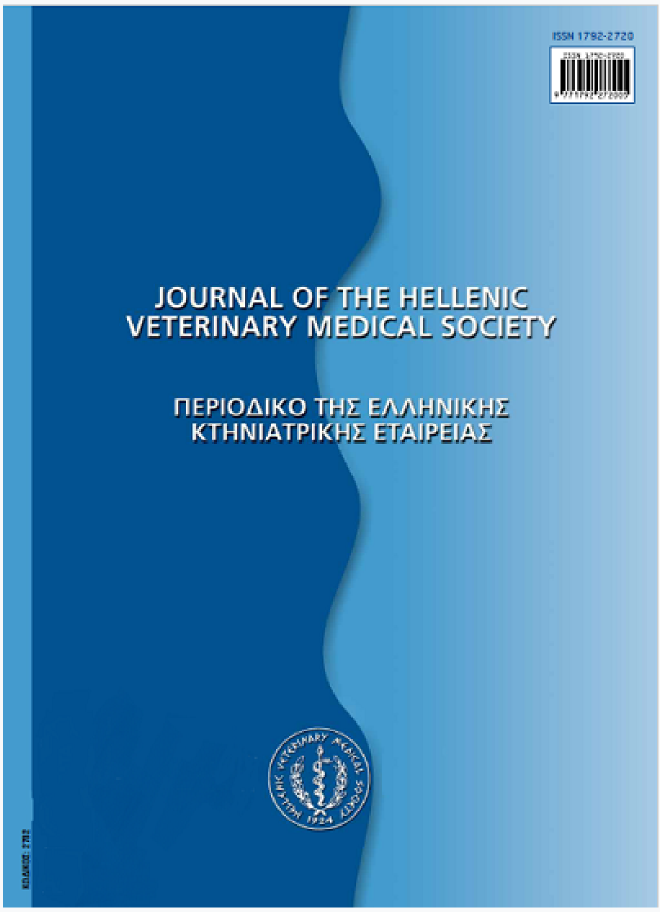

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Effects of intensity and duration of quantitative restriction of feed on broiler performance

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ABSTRACT. This study was carried out to evaluate the effects of physical feed restriction method with different intensity and duration on broiler performance. One hundred and fifty Ross-breed 308 male broiler chicks in a completely randomized design were divided into five experimental treatments. The treatments included physical limitations by 25% or 50% of recommended amount on feed of broilers in two periods of 7 or 14 days. One control group was used fed *ad libitum*. Each limitation's severity level was applied in τηρεε replications of 10 birds. All experimental treatments before and after the limitation period until slaughter (day 42) were fed *ad libitum*. The results showed that in total period broilers under the physical limitation of feed had significantly lower feed intake than controls ($P < 0.05$). In this research, methods and levels of physical restriction intensity and duration of feed had no significant effect on body weight for the whole experimental period. Methods and levels of food restriction severity and duration had significant effect on feed efficiency ($P < 0.05$).

Keywords: broiler, energy efficiency, feed efficiency, feed restriction, weight gain.

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INTRODUCTION

In recent decades, genetic modification, accurate determination of growing and maintenance needs, application of management and nutritional strategies for reduction of storage requirements, nutritional programs for optimal utilization of feed using oral enzyme, probiotics and prebiotics, are used to improve the efficiency of broiler production. In the last 30 years, average growth rate increases annually by approximately 40 grams and time required to reach market weight (1.8 kg) decreases by 0.75 days per year (Leeson et al., 1996; Golian and Salar Moeeni, 1999; Bedford and Partridge, 2000; Tumoa et al., 2002; Pourreza et al., 2004).

In recent years, restricted feed programs aiming at changing patterns of successful growth and thereby reducing storage requirements have been seriously considered. The purpose of food restriction is to encourage compensatory growth in broiler chickens in a particular stage of the rearing period that is expected to occur after the restriction period. In the rehabilitation period, chicks grow more rapidly to compensate for lost growth due to dietary restrictions (Summers et al., 1990; Bowes and Julian, 1998). Following the restricted feed program, the birds are fed a diet of high quality resulting in faster growth compared to the natural growth of the animal's age which is probably due to increased nutrient utilization; this phenomenon is called 'compensatory growth' (Pinchasov et al., 1993; Zubair and Leeson, 1994; Acar et al., 1995; Santoso et al., 1995; De Silva and Kalubowila, 2012; Butzen et al., 2013). Some researchers consider use of restricted feed programs and lighting programs as the key to reduce maintenance costs and to prevent metabolic abnormalities in modern strains (Jahanian et al., 1990; Fontana et al., 1992; Donald et al., 2000).

In one study, a diet containing 40 Kcal per day metabolisable energy in 2- or 4-week-old chickens failed to initiate compensatory growth at 9 weeks. However, in another study, researchers implemented the constraints of food for one week from 3 to 11 days; the lost growth was fully compensated when birds were 8 weeks old. Plavnik and Hurwitz (1991) found that aside from regimes with severe restriction, in other groups growth retardation caused by dietary restriction was offset and in diets with less intensity of restriction, even the body weight was slightly higher than the control group. The purpose of present research was to evaluate the effects of physical feed restriction method with different intensity and duration on broiler performance and to determine the most appropriate intensity and duration of feed restrictions.

MATERIALS AND METHODS

Experimental place

This experiment was performed at the Faculty of Agriculture, Islamic Azad University, Rasht Branch, Iran. The house had a dimension of 4×40 m with five ventilators, one strong ventilator with air discharge power of 1400 $mm^3\ h^{-1}$ and four other units with discharge power of 3500 $mm^3\ h^{-1}$. Prior to introduction of the birds, the house was cleaned and washed. All drinkers and feeders were also washed.

House environment

A heater was used to maintain appropriate temperature. In order to provide house moisture at least 55 to 65% in the early growing period, the floor was sprayed with water. A 43 Watt lamp installed at a height of 2.2 m from the floor was used as the light source. Lamps were placed in a row at a distance of 200 cm. Lighting program consisted of 23 h lighting and 1 hour darkness. This program was implemented from 1 to 42 days (end of the experiment).

Health programs

To maintain sanitation, drinkers were washed daily. The vaccination program was observed in all cases. Vaccine program was based on standard protocol of region including bronchitis, Newcastle B1, and Gambaro vaccines. To reduce stress associated with vaccination, 1:1000 multivitamin + electrolyte solution into drinking water was used for 24 h after the procedure. In addition to litter management for prevention

Table 1. Feed composition (%) at different experimental periods.

Ingredient	Starter	Grower	Finisher
Corn	46.09	50.09	48.88
Soybean meal (44% protein)	40.00	35.00	39.97
Fishmeal	3.00	3.00	-
Meatmeal	3.00	3.00	-
Oil	4.56	5.45	7.39
DL-methionine	0.29	0.23	0.17
L-tThreonine	0.30	-	-
Ca (% 22) – P (% 18) mixture	0.99	0.75	1.64
$CaCO_3$	0.98	0.76	1.00
K-bicarbonate	0.05	0.03	-
NaCl	0.37	0.37	0.37
Vitamin and mineral premix	0.60	0.50	0.50
Total	**100**	**100**	**100**

Table 2. Nutrient analysis of diets used during experimental periods.

	Feed type		
Nutrients	Starter	Grower	Finisher
Energy (ME) (kcal kg^{-1})	3200	3200	3200
Crude protein	23.0	20.0	20.0
Lysine (SID) (%)	1.41	1.26	1.22
Methionine (SID) (%)	0.67	0.59	0.50
Methinonie + Cystine (SID) (%)	1.05	0.94	0.85
Threonine (SID) (%)	1.98	0.87	0.85
Tryptophane (SID) (%)	0.30	0.27	0.28
Arginine (SID) (%)	1.68	1.54	1.51
Iso-leucine (SID) (%)	1.04	0.95	0.94
Valine (SID) (%)	1.60	1.07	1.03
Leucine (SID) (%)	1.99	1.87	1.82
Calcium (%)	1.05	0.90	0.85
Available phosphorus (%)	0.50	0.45	0.42
Sodium (%)	0.23	0.23	0.20
Potassium (%)	1.00	0.90	0.93
Chloride (%)	0.30	0.30	0.30
DCAB (mEq kg^{-1})	272.12	244.55	242.77
Choline (g kg^{-1})	1.48	1.37	1.37
Linoleic Acid (%)	1.21	1.27	1.24
Ether Extract (%)	6.84	7.87	9.22
Crude Fiber (%)	3.78	3.52	3.73

of coccidiosis, salinomycin (0.5 g kg^{-1}) was used from 21 d. Feed remaining in the feeder after each time was weighed; removal of feed was followed by thorough cleaning with a brush.

Experimental treatments

The experiment was carried out in five treatments and three replicates for each treatment. In total, 150 one-day-old chicks (male) of Ross-breed, strain 308, were divided into15 groups of 10 chicks each, so that mean bodyweights were similar in all groups. Chickens in land cages were raised in mass and under thesme conditions of light and ventilation. Growing conditions were similar in all treatments. Feeding program in the five treatments was as follows:

first treatment: intake as *ad libitum*
second treatment: feeding during days 8 to 14 50% of recommended feed
third treatment: feeding during days 8 to 21 50% of recommended feed
fourth treatment: feeding during days 8 to 14 75% of recommended feed
fifth treatment: feeding during days 8 to 21 75% of recommended feed

Nutritional requirements were based on NRC recommendations and Ross strain rearing catalogue. All chickens were fed *ad libitum* before and after completion of the restriction period in three periods of the starter period (1-21) days of old, grower period (21-35) days old and the finisher period (35-42) days old. In addition, all diets in each of the three rearing periods were formulated to contain the same raw energy and protein. Feed intake and bodyweight indices were weekly determined and recorded. Composition of diets used and nutrient contents of diets is shown in Tables 1 and 2.

Statistical design of experiment

For data analysis in this study, five treatments and three3 replications were studied in a completely randomized design using the general linear models (GLM). For comparison the mean of treatments together and with control group, Duncan test ($P < 0.05$) was used. The statistical model of the experiment was as follows:

$$Y_{ij} = \mu + T_i + e_{ij}$$

Y_{ij}=value of each observation, μ=average measured traits in the studied population, T_i=effect of ith treatment, e_{ij}=experimental error

Average daily feed intake

Feed intake for five chickens from each replicate on a weekly basis was calculated from reduction of remaining feed at the end of each week from feed distributed throughout each week. Digital scale for weighing feed with accuracy of ±1.0 g was used. To calculate the amount of food consumed per chicken per week, the below equation was used. If there were losses, amount of feed intake during the week depending on the number of live chickens was corrected.

$$\text{per chick in the relevant period (g)} = \frac{\text{feed remaining at the end of the week (g) -food provided the week (g)}}{\text{Number of live birds in the corresponding period}}$$

Number of live chicks at every day of the week was calculated by using the following relation:

live chicks = (number of casualties × number of days that the casualties were alive) + (days of period × number of live chicks at the finisher period)

Average feed consumption (g) per chick per experimental unit during the corresponding period = (average daily feed consumption per chick in the corresponding period × number of days in that period)

$$\text{weekly feed consumption per chick (g)} = \frac{\text{feed consumption during the week}}{\text{number of live chicks}}$$

Weight gain

To determine the average body weight, chicks were weighed at the end of each week, after fasting for four hours, in order to emptying gastrointestinal segments was weighted and average weight of each experimental unit and each group was calculated. Chicks of each replication were weighed individually.

weight gain of chicks per experimental unit in the corresponding period = (final weight during relevant period + weight loss) - starting weight

average weight gain among chicks per experimental unit during the corresponding period = average weight gain per piece in each experimental unit during the corresponding period × number of days

If there were dead chicks, weight gain was calculated by using the following formula:

$$\text{average weight gain of chicks per experimental unit during the corresponding period} = \frac{[(\text{final weight in period} + \text{weight loss}) - \text{starter weight}]}{\text{Number of live chicks}}$$

Average weight gain was calculated from the first week until the final week.
Average feed conversion ratio was calculated as average feed intake divided by weight gain .

$$\text{feed conversion ratio} = \frac{\text{consumption rate of each experimental unit}}{\text{weight gain of the unit in the period}}$$

Consumed metabolisable energy

Given the amount of energy in the diet and fitness by measuring it every week and the period with consumed feed and also its conversion ratio, consumed metabolisable energy was calculated.

Consumed protein

Given the amount of protein in the diet and fitness by measuring it every week and the period with consumed feed and also its conversion ratio, consumed protein was calculated.

Consumed metabolisable energy efficiency

Consumed metabolisable energy efficiency was calculated from Kilocalories of consumed energy divided by the average daily weight gain.

$$\text{consumed metabolisable energy efficiency} = \frac{\text{Kcal consumed per test unit during the period}}{\text{weight gain of the unit during the period}}$$

Consumed protein efficiency

Consumed protein efficiency was calculated by dividing the mean consumed protein by the average daily weight gain.

$$\text{Consumed protein efficiency} = \frac{\text{consumed amount of each experimental unit in the periods}}{\text{weight gain of the unit during the period}}$$

Economic calculations

Price of one kg of feed, cost of producing one kg of live bodyweight and income from sale of one kg of live broiler was calculated using the following formulas.

$$\text{Price of one kg feed for each treatment} = \frac{\text{X price} \times \text{X consume} + \text{Y price} \times \text{Y consume} + \text{Z price} \times \text{Z consume}}{\text{total feed intake}}$$

X: starter diet, Y: grower diet, Z: finisher diet,

feed costs per kg live broiler = FCR for each treatment × price of one kg of feed,

income of sales per live broiler = price of one kg of live weight - production costs of each live broiler

Production index

Production index was defined as final weight divided by the total period FCR × 100 (Poorghasemi et al., 2013).

$$\text{Production index} = \frac{\text{Final weight}}{\text{Total period FCR}} \times 100$$

Effect of intensity and duration of physical restriction on feed intake at various periods

Results of feed intake comparison between different treatments are in Table 3. Total period**:** the experiment results showed that there is significant difference between studied treatments for feed intake ($P < 0.01$). Meanwhile comparison of the averages showed that treatment 4 had the highest feed intake, followed by treatments 1, 2 and 5, whilst treatment 3 had the lowest feed intake.

Effect of intensity and duration of physical restriction on bodyweight at various periods

Results of body weight comparison between different treatments are in Table 4. Finisher period**:** there was no significant difference between treatments in body weight ($P > 0.05$). Averages showed that numerically treatment 4 resulted in the highest bodyweight followed by treatments 3, 2 and 5, whilst treatment 1 had the lowest body weight.

Effect of intensity and duration of physical restriction on weight gain at various periods

Results of weight gain comparison between different treatments are presented in Table 5. Total period**:** there was no significant difference between studied treatments for weight gain ($P > 0.05$).

Effect of intensity and duration of physical restriction on feed efficiency at various periods

Feed efficiency varied considerably between treatment groups in different periods; data are in Table 6.

Total period

The experiment results showed that there was no significant difference between studied treatments for feed efficiency ($P > 0.05$). Comparison of the averages showed that treatment 1 had numerically the highest feed efficiency, followed by treatments 5, 2 and 4, whilst treatment 3 had the lowest feed efficiency.

Effect of intensity and duration of physical restriction on consumed metabolisable energy at various periods

Metabolisable energy consumption varied between treatment groups in different periods; data are in Table 7. Total period**:** the experiment results showed that there were no significant differences between studied treatments for consumed metabolisable energy ($P > 0.05$).

Effect of intensity and duration of physical restriction on consumed protein at various periods

Results of consumed protein comparison between different treatments are in Table 8. There were significant differences between studied treatments and period on consumed protein ($P < 0.05$). Total period**:** treatments 4 and 1 resulted in highest protein consumption in comparison to that of treatments 2,3 and 5.

Effect of intensity and duration of physical restriction on consumed metabolisable energy efficiency at various periods

Consumed metabolisable energy efficiency varied significantly between different treatments and periods; results are detailed in Table 9. Total period: the experiment results showed that there was no significant difference between studied treatments for consumed metabolisable energy efficiency (P>0.05).

Effect of intensity and duration of physical restriction on consumed protein efficiency at various periods

Consumed protein efficiency differed significantly between different treatments; results are in Table 10.

Effect of intensity and duration of physical restriction on economical traits

Results of economical traits comparison between different treatments are presented in Table 11. No significant difference was detected in either production index, feed cost per Kg of live broiler, or live weight of broiler. However, significant differences were detected in the cost for live broiler, with the treatment 3 to result in the lowest cost for live chicken ($P < 0.01$).

DISCUSSION

Feed intake and the restriction period

By increasing the severity of restriction, feed intake was reduced. The feeding method also had an effect on feed intake; feed intake in chickens restricted to physical methods was less than those under full feeding. With increasing severity of physical restriction, feed intake was significantly reduced. Increasing restricted intensity from 25% to 50% did not cause significant difference. Generally, the amount of feed intake in birds is followed by received energy. Provision of low energy diets increases feed consumption. In other words, in order to maintain energy balance, birds offset energy deficiency in the feed by increasing consumption (Leeson and Summers, 1980). However, when dietary energy density is very low, it is almost impossible to offset the energy shortages by increasing consumption (Pourreza et al., 2004).

In connection with the response of chickens to dietary energy level, there are two theories. Some believe that broilers, like laying hens, set feed consumption according to the level of dietary energy which decreases with increasing level of dietary energy consumption (Susbilla et al., 1994). Others believe that broiler feed intake is based on their physical capacity and feeding of condensed diets does not have much effect on the consumption rate. Thus, consumption of dense diets lead to increased dietary energy retention in the adipose tissue (Pourreza et al., 2004). In other words, consumption and growth rate of broilers in a certain range of dietary energy levels is constant. Based on this, feed physical restriction program relies on the fact that broilers eat based on their maximum physical capacity. Control of feed intake is affected more by physical satiety than by the effects of specific nutrients (Mosier, 1989).

Feed intake in the starter, grower, finisher and total periods

Significant difference was observed between average consumption of chickens in starter period with different intensity and also between chickens restricted for different period with control group. At this period, the average daily consumption of chickens restricted by 50% and 7 days and 50% for 14 days physical restriction was less than control group. Plavnik and Hurwitz (1985a, 1988) stated that chickens restricted by physical methods had lower consumption in the period of their rehabilitation due to their smaller size and less requirements and also lower capacity of their digestive system.

In grower period, the average consumption of all restricted chickens was higher than controls, which is consistent with Palo et al., (1995) and Picard et al., (1999). In the finisher period, there was no significant difference between treatments and control. Leeson and Zubair (1997) found that after physical restriction pe-

Table 3. Comparison of feed intake among five studied treatments* (mean±se)

Total intake (g)	Finisher period intake (g)	Grower period intake (g)	Starter period intake (g)	6th week intake (g)	5th week intake (g)	4th week intake (g)	3rd week intake (g)	2nd week intake (g)	1st week intake (g)	Treatment
4442.0^{a}±27.2	1538.3^{a}±7.2	1903.8^{b}±7.8	991.0^{a}±6.4	1538.3^{a}±7.2	1045. 3^{b}±7.2	858.5^{b}±1.6	577.3^{b}±2.33	325.3^{a}±2.1	88.3^{ab}±2.0	1
4231.0^{b}±29.3	1540.7^{a}±16.7	1906.1^{b}±21.1	824.4^{ab}±7.8	1540.7^{a}±16.7	1037.6^{b}±20.8	868.4^{a}±0.9	579.8^{ab}±1.66	159.2^{c}±3.9	86.7^{b}±3.0	2
4007.3^{c}±11.8	1525.8^{a}±12.4	1944.1^{a}±5.5	537.7^{c}±4.9	1525.8^{a}±12.4	1083.3^{a}±7.6	858.7^{b}±1.6	284.8^{d}±1.30	161.6^{c}±2.0	91.3^{ab}±3.1	3
4449.6^{a}±10.3	1576.4^{a}±7.5	1954.7^{a}±2.7	785.6^{b}±6.5	1578.4^{a}±5.5	1091.3^{a}±3.4	863.4^{ab}±0.8	583.6^{a}±0.60	244.6^{b}±2.0	90.6^{ab}±1.3	4
4231.0^{b}±38.3	1540.8^{a}±33.1	1906.1^{ab}±5.5	761.7^{b}±4.3	1540.7^{a}±33.1	1086.6^{a}±7.2	846.0^{c}±2.7	425.2^{c}±1.60	241.1^{b}±2.6	95.3^{a}±1.6	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

Table 4. Comparison of body weight among five studied treatments* (mean±se)

Total weight (g)	Finisher period weight (g)	Grower period weight (g)	Starter period weight (g)	6th week weight (g)	5th week weight (g)	4th week weight (g)	3rd week weight (g)	2nd week weight (g)	1st week weight (g)	Treatment
2589.8^{a}±20.8	1909.3^{a}±14.2	865.3^{a}±12.4	2589.8^{a}±19.6	1909.3^{a}±14.2	1241.4^{a}±26.5	865.3^{a}±12.4	353.1^{a}±15.2	140.9^{a}±5.4	2589.8^{a}±20.8	1
2626.1^{a}±48.5	1856.0^{a}±19.2	742.7^{b}±18.3	2626.1^{a}±48.5	1856.0^{a}±19.2	1145.5^{b}±4.2	742.7^{b}±18.3	287.3^{a}±7.3	137.3^{a}±4.0	2626.1^{a}±48.5	2
2658.4^{a}±54.2	1795.5^{a}±50.6	666.8^{c}±5.0	2658.4^{a}±49.2	1795.5^{a}±50.6	1064.6^{b}±40.3	666.8^{c}±5.0	296.5^{a}±10.3	144.3^{a}±5.9	2658.4^{a}±54.2	3
2879.5^{a}±168.8	1895.7^{a}±71.3	755.8^{b}±14.7	2879.5^{a}±168.8	1895.7^{a}±71.3	1268.3^{a}±32.0	755.8^{b}±14.7	229.8^{a}±98.6	140.1^{a}±1.9	2879.5^{a}±168.8	4
2588.2^{a}±59.3	1844.6^{a}±22.3	739.5^{b}±16.4	2588.2^{a}±59.3	1844.6^{a}±22.3	1141.7^{b}±11.8	739.5^{b}±16.4	335.8^{a}±4.6	138.1^{a}±7.6	2588.2^{a}±59.3	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

Table 5. Comparison of weight gain among five studied treatments* (mean±se)

Total gain (g)	Finisher period gain (g)	Grower period gain (g)	Starter period gain (g)	6th week gain (g)	5th week gain (g)	4th week gain (g)	3rd week gain (g)	2nd week gain (g)	1st week gain (g)	Treatment
2530.8^{a}±54.2	678.4^{a}±14.3	1107.8^{a}±77.6	744.6^{a}±11.2	678.4^{a}±14.3	731.6^{a}±72.6	376.1^{b}±22.9	433.4^{a}±3.9	212.2^{a}±11.6	98.8^{a}±5.4	1
2516.5^{a}±49.9	769.7^{a}±57.3	1113.6^{a}±12.7	633.1^{b}±16.6	769.7^{ab}±57.3	711.3^{a}±21.2	402.2^{b}±21.9	387.6^{b}±9.8	150.1^{c}±5.0	95.3^{a}±4.0	2
2555.9^{a}±54.4	762.9^{a}±5.7	1128.7^{a}±53.2	564.4^{c}±4.4	862.9^{ab}±5.7	730.9^{a}±10.8	397.7^{b}±42.6	309.7^{d}±8.7	152.1^{c}±6.3	102.3^{a}±5.9	3
2765.7^{a}±177.4	983.9^{a}±111.9	1139.9^{a}±68.7	641.8^{b}±20.7	983.8^{a}±111.8	627.4^{a}±47.1	512.5^{a}±23.3	336.1^{cd}±8.6	186.6^{b}±3.3	98.1^{a}±1.9	4
2482.4^{a}±56.1	746.3^{a}±78.7	1084.7^{a}±28.5	651.6^{b}±18.7	746.3^{b}±78.7	703.1^{a}±12.9	381.2^{b}±17.1	360.2^{bc}±15.1	197.9^{ab}±1.1	93.4^{a}±7.9	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

Table 6. Comparison of feed efficiency among five studied treatments* (mean±se)

Total efficiency	Finisher period efficiency	Grower period efficiency	Starter period efficiency	6th week efficiency	5th week efficiency	4th week efficiency	3rd week efficiency	2nd week efficiency	1st week efficiency	Treatment
1.74^{a}±0.03	2.26^{a}±0.04	1.72^{a}±0.11	1.32^{b}±0.01	2.26^{a}±0.04	1.45^{a}±0.13	2.29^{a}±0.14	1.32^{b}±0.01	1.53^{a}±0.07	0.89^{a}±0.30	1
1.69^{a}±0.02	1.99^{ab}±0.16	1.70^{a}±0.00	1.30^{b}±0.02	2.01^{ab}±0.14	1.45^{a}±0.04	2.16^{a}±0.12	1.49^{a}±0.03	1.06^{c}±0.05	0.90^{a}±0.21	2
1.76^{a}±0.03	1.76^{ab}±0.02	1.72^{a}±0.08	0.94^{d}±0.00	1.76^{ab}±0.02	1.47^{a}±0.31	2.20^{a}±0.23	0.91^{c}±0.02	1.05^{c}±0.03	0.89^{a}±0.02	3
1.63^{a}±0.09	1.63^{b}±0.18	1.72^{a}±0.10	0.94^{a}±0.04	1.63^{b}±0.18	1.53^{a}±0.14	1.68^{b}±0.20	1.62^{a}±0.07	1.30^{b}±0.02	0.92^{a}±0.00	4
2.10^{a}±0.51	2.10^{ab}±0.24	1.77^{a}±0.44	1.16^{c}±0.02	2.10^{ab}±0.24	1.72^{a}±0.02	2.22^{a}±0.09	1.26^{b}±0.03	1.21^{bc}±0.03	1.02^{a}±0.07	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

Table 7. Comparison of consumed metabolisable energy among five studied treatments* (mean±se)

Total intake (Kcal)	Finisher period intake (Kcal)	Grower period intake (Kcal)	Starter period intake (Kcal)	6th week intake (Kcal)	5th week intake (Kcal)	4th week intake (Kcal)	3rd week intake (Kcal)	2nd week intake (Kcal)	1st week intake (Kcal)	Treatment
41859.1^{a}±42.6	49225.6^{a}±23.2	60921.2^{a}±25.0	31712.2^{a}±20.5	4922.6^{a}±23.2	3345.0^{b}±23.2	2747.2^{a}±5.1	1847.4^{b}±7.4	1047.7^{a}±11.3	282.6^{a}±6.4	1
36720.3^{a}±42.2	49301.3^{a}±28.2	60994.5^{a}±27.6	26424.5^{c}±25.7	4930.3^{a}±56.6	3320.5^{b}±66.7	2764.9^{a}±17.0	1855.4^{ab}±3.7	509.5^{c}±12.6	277.5^{a}±9.6	2
26247.4^{a}±38.5	48824.2^{a}±24.1	60218.9^{a}±18.2	17204.8^{e}±15.7	19741.2^{a}±14893.0	3467.0^{a}±24.2	2748.0^{a}±5.3	911.6^{d}±4.1	517.1^{c}±6.5	292.2^{a}±10.1	3
40057.9^{a}±30.9	50442.8^{a}±29.2	60256.2^{a}±17.2	29359.0^{b}±7.8	20033.8^{a}±14965.0	3492.2^{a}±11.1	2762.9^{a}±2.6	1866.6^{a}±0.6	782.7^{b}±6.5	523.4^{a}±237.0	4
35575.4^{a}±35.3	49304.7^{a}±27.1	61852.7^{a}±21.2	24407.9^{d}±13.9	4930.7^{a}±106.1	3478.5^{a}±23.5	2707.2^{b}±8.8	1360.8^{c}±5.1	771.7^{b}±8.3	305.0^{a}±5.4	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

Table 8. Comparison of consumed protein among five studied treatments* (mean±se)

Total intake (g)	Finisher period intake (g)	Grower period intake (g)	Starter period intake (g)	6th week intake (g)	5th week intake (g)	4th week intake (g)	3rd week intake (g)	2nd week intake (g)	1st week intake (g)	Treatment
916.3^{a}±3.7	307.6^{a}±1.4	380.7^{c}±1.5	227.9^{a}±1.4	307.6^{a}±1.4	209.0^{b}±1.4	171.7^{b}±0.3	132.7^{b}±0.5	74.8^{a}±0.5	20.3^{ab}±0.4	1
879.2^{b}±5.5	308.1^{a}±3.3	381.2^{bc}±4.2	189.8^{c}±1.8	308.1^{a}±3.3	207.5^{b}±4.1	173.6^{a}±0.1	133.3^{ab}±0.2	36.6^{c}±0.9	19.8^{b}±0.7	2
844.2^{b}±22.9	305.1^{a}±2.4	388.4^{ab}±1.2	123.6^{e}±1.1	305.1^{a}±2.4	216.6^{a}±1.5	171.7^{b}±0.3	65.5^{d}±0.1	37.1^{c}±0.4	21.0^{ab}±0.7	3
917.8^{a}±2.3	315.2^{a}±1.5	391.2^{a}±0.8	211.3^{b}±0.7	315.2^{a}±1.5	218.2^{a}±0.6	173.0^{a}±0.1	134.1^{a}±0.1	55.5^{b}±0.2	20.8^{ab}±0.2	4
870.6^{b}±6.3	308.2^{a}±6.6	386.6^{abc}±1.3	175.9^{d}±0.5	308.2^{a}±6.6	217.1^{a}±1.2	169.2^{c}±0.5	97.7^{c}±0.3	56.2^{b}±0.1	21.9^{a}±0.4	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

Table 9. Comparison of consumed metabolisable energy efficiency among five studied treatments* (mean±se)

Total efficiency	Finisher period efficiency	Grower period efficiency	Starter period efficiency	6th week efficiency	5th week efficiency	4th week efficiency	3rd week efficiency	2nd week efficiency	1st week efficiency	Treatment
5.6^{a}±0.1	7.2^{a}±0.1	5.5^{a}±0.3	4.2^{b}±0.0	7.2^{a}±0.1	4.6^{a}±0.4	7.3^{a}±0.4	4.2^{c}±0.5	4.9^{a}±0.2	2.8^{a}±0.0	1
5.4^{a}±08	7.1^{a}±0.5	5.4^{a}±0.0	4.1^{b}±0.0	7.1^{a}±0.5	4.6^{a}±0.1	6.9^{a}±0.4	4.7^{b}±0.1	3.3^{c}±0.1	2.9^{a}±0.0	2
5.0^{a}±0.1	5.6^{ab}±0.0	5.6^{a}±0.1	3.04^{d}±0.0	5.6^{ab}±0.0	4.7^{a}±0.0	7.0^{a}±0.7	2.9^{d}±0.0	3.4^{c}±0.1	2.8^{a}±0.0	3
5.1^{a}±0.3	5.2^{b}±0.5	5.5^{a}±0.3	4.5^{a}±0.1	5.2^{b}±0.5	5.6^{a}±0.4	5.3^{b}±0.2	5.2^{a}±0.2	4.1^{b}±0.0	2.9^{a}±0.0	4
5.4^{a}±0.1	6.7^{ab}±0.7	5.7^{a}±0.1	3.7^{c}±0.9	6.7^{ab}±0.7	4.9^{a}±0.1	7.1^{a}±0.3	4.0^{a}±0.1	3.9^{bc}±0.1	3.3^{a}±0.2	5

Table 10. Comparison of consumed protein efficiency among five studied treatments* (mean±se)

Total efficiency	Finisher period efficiency	Grower period efficiency	Starter period efficiency	6th week efficiency	5th week efficiency	4th week efficiency	3rd week efficiency	2nd week efficiency	1st week efficiency	Treatment
0.03^{a}±0.00	0.45^{a}±0.00	0.34^{a}±0.02	0.30^{b}±0.00	0.45^{a}±0.00	0.29^{a}±0.02	0.45^{a}±0.02	0.21^{a}±0.09	0.35^{a}±0.01	0.20^{a}±0.00	1
0.03^{ab}±0.00	0.43^{ab}±0.00	0.34^{a}±0.00	0.30^{b}±0.00	0.40^{ab}±0.02	0.29^{a}±0.00	0.43^{a}±0.02	0.03^{b}±0.00	0.24^{c}±0.01	0.20^{a}±0.00	2
0.03^{b}±0.00	0.35^{b}±0.00	0.34^{a}±0.01	0.21^{d}±0.00	0.35^{b}±0.00	0.29^{a}±0.00	0.44^{a}±0.04	0.02^{b}±0.00	0.24^{c}±0.00	0.20^{a}±0.00	3
0.03^{ab}±0.00	0.34^{b}±0.00	0.34^{a}±0.02	0.32^{a}±0.00	0.33^{b}±0.03	0.35^{a}±0.02	0.33^{b}±0.01	0.03^{b}±0.00	0.30^{b}±0.00	0.21^{a}±0.00	4
0.03^{ab}±0.00	0.42^{ab}±0.00	0.35^{a}±0.00	0.27^{c}±0.00	0.42^{ab}±0.04	0.30^{a}±0.00	0.44^{a}±0.19	0.02^{b}±0.00	0.28^{b}±0.00	0.23^{a}±0.01	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

Table 11. Comparison of other financial details among five studied treatments* (mean±se)

Bodyweight of chicks (g)	Cost of each live chick (in Rials)	Feed cost per kg live bodyweight (in Rials)	Production index	Treatment
2552.6^{a}±46.7	3216^{a}±13	1247^{a}±2	35303^{a}±668	1
2768.0^{a}±49.5	3087^{b}±12	1176^{a}±19	36967^{a}±1273	2
2540.0^{a}±113.7	2903^{c}±9	1072^{a}±9	40578^{a}±1852	3
2622.0^{a}±99.8	3228^{a}±7	1128^{a}±61	43014^{a}±5277	4
2790.0^{a}±32.1	3076^{b}±22	870^{a}±3	36803^{a}±1747	5

1: feeding *ad libitum*, 2: feeding during 8th-14th 50% restriction, 3: feeding during 8th-21st days 50% restriction, 4: feeding during 8th-14th days 25% restriction, 5: feeding during 8th-21st days 25% restriction

*Means in each column followed by the same letters are not significantly different at $P = 0.05$.

riod, chickens at 35 days of age had lower intake than control, but at 35 to 42 days old they showed equal intake with the group fed with complete diet.

In the total period, average consumption of restricted chickens was lower than controls with the reduction of 50% for 14 days to result the lowest feed consumption. This is consistent with the results of Yu et al. (1990), Griffiths et al. (1997) and Picard et al. (1999), who indicated that more restriction intensity and duration reduced total feed intake. Generally, during physical feed restriction period, growth rate decreases due to reduced feed intake. Consistent with growth, liver and gastrointestinal tract size also decreases (Oyawoye and Knieger, 1986; Ryan et al., 1993). Reduced size, decreased digestive capacity and probably decreased metabolism due to reduced liver size may be the reasons for reduced consumption of restricted chickens.

With increasing severity and duration of physical restriction, average consumption was smaller than in control group, so that all restricted treatments take less than the control group. The results obtained by Doyel and Leeson (1996) showed that method, intensity and duration of restrictions and rehabilitation period was effective in the intake amount of restricted animals in order to achieve control weight.

Weight gain and the feed restriction period

Comparison between chickens with same physical restriction and chickens with same age under full feeding in restriction period showed that chicks under the different restriction intensity had lower weight gain compared with controls. Also, comparison between chickens with same restriction to chickens with same age under full feeding showed that restricted chickens had lower weight gain compared with the controls. In a certain restriction period in physical method, weight gain in chickens was reduced with increasing restriction intensity, in a way that weight gain in chickens with 50% was less than chickens with 25% physical restriction. Growth rate was higher at early age and a greater share of food spending to growth, so, due to lack of adequate access to food, nutrients needed for growth were not adequately provided and, hence, growth rate in the restricted chickens was reduced. These results are consistent with those of Plavnik and Hurwitz (1985b), Yu et al. (1990), Jones and Farrel (1992) and Acar et al. (1995).

The results of this study showed that growth rate of chickens associated with low restriction severity and duration treatments is higher in the early period of rehabilitation period. However, chickens exposed to higher restriction intensity and duration treatment had higher growth rate in the finisher period and in the higher ages did not differ from the weight of control group. Similar results have been reported previously by several authors (Plavnik and Hurwitz, 1991; Jones and Farrel, 1992; Griffiths et al., 1997). However, our results are different than those of Leeson and Zubair (1997), Pinchasov and Jensen (1989), Yu et al. (1990), Palo et al. (1995) and Santoso (2001). This difference may be due to the strain types used, recreational time, and type of diet used in the rehabilitation period (the amount of metabolizable energy, protein), the method, intensity and duration of restriction. Many studies that failed to report complete compensatory growth had either a short rehabilitation period or the intensity and duration of feed restriction during the experimental period was so severe that broilers did not have enough time to compensate for weight loss (Leeson and Zubair, 1997).

In this study, the restriction period was in an extent that broilers had enough time to compensate growth that was missed during the restriction period. Effects of dietary restriction duration on weight gain in broilers at 21 days showed that by increasing the restriction duration, weight gain decreased in 21 days of age which is significantly lower than broilers fed with complete diet. In the fourth week, weight gain in broilers with 7 days feed restriction was higher than the controls. From fifth week onwards, the effect of restriction duration was not significant on weight gain in chicks at various levels of restriction duration. According to results of this study, chicks had the ability to compensate for the lost growth even in feed physical restriction of 14 days. These results are similar to those of Oyedeji and Atteh (2005) who report that food restriction period of 12 days was followed by complete compensatory growth. Also, our results are consistent with the study of Rinkon and Leeson (2002), who reached compensatory growth in 42 days old broilers with physical restriction, by 10% intensity from 5 days old for 5, 10, 15, 20 and 25 days.

Weight gain in the starter, grower, finisher and total periods

In this period, weight gain in chicks with 50% restriction was significantly lower than chicks fed with complete diet and weight gain of chicks restricted for 14 days was lower than in chicks restricted for 7 days. In the study of Jahanian et al. (1990), chicks with 25% restriction intensity for 3 days reached to the growth rate of chicks with complete diet only after 5 to 7 days of restriction. But weight gain in chicks with 25% restriction intensity for 6 and 9 days and chicks with 50% restriction for 3, 6 and 9 days was lower than controls. In this study also, the chicks of more treatment in the age 21 days had equal growth rate with control indicating that the growth rate of chicks in the early rehabilitation period was great.

In the finisher period, weight gain in restricted chicks was not significantly different than those fed complete diet. These results are not consistent with the studies of Jahanian (1990), Deaton (1995), Lee and Leeson (2001) and Teimouri et al. (2005). Feed restriction severity had significant effect on weight gain in the starter and grower period; increased feed restriction reduced growth rate of chickens in the starter period. In the way that daily weight gain under 50% restriction for 14 days was significantly smaller than of chickens with complete diet. Acar et al. (1995) and Lee and Leeson (2001) also showed that increasing the severity and duration of feed restriction, compensatory growth occurs in higher ages. Generally, gaining compensatory growth following a period of feed restriction may be affected by factors such as the onset age of dietary restriction, severity and duration of dietary restriction, sex and strain, duration of rehabilitation and diet quality in the rehabilitation period (Winick and Nobel, 1966; Zubair and Leeson, 1996). Leeson and Summers (1991), Plavnik and Hurwitz (1991), Jones and Farrel (1992), Zubair and Leeson (1994) and Teimouri et al. (2005) reported complete compensatory growth with milder restriction severity and duration. Plavnik and Hurwitz (1990) and Jones and Farrel (1992) reported complete compensatory growth with growing period over 56 days.

The results of this study showed that despite significant reduction in weight gain in chickens at the end of feed restriction, the difference in final weight between feed-restricted and control chickens was not significant. The results of this study showed that chickens of tested strain in a rearing period of 42 days showed complete compensatory growth even with 50% restriction severity for 14 days. Since in the finisher week and the total period growth rate of feed-restricted chickens in more sever and longer level was higher without significantly difference with chickens fed complete diet, it can be concluded that compensatory growth was delayed until the last days of rearing. The phenomenon of compensatory growth and the controlong physiological, nutritional, metabolic and endocrine factors are complex and still not fully understood (Oyedeji and Atteh, 2005).

Wilson and Osbourn (1960) and Mosier (1989) believed that compensatory growth was controlled by the central nervous system and hormones and claimed that an unknown regulator existed that is related to the animal's body size, which determines 'set point' of body size in relation to the age of animal, and sends a signal for shortage in growing to the hypothalamus until through increased production of growth hormone (GH) in pituitary. Energy to support the accelerated growth of rehabilitation period may be provided from the reduction of total maintenance energy requirements (Yu and Robinson, 1992) or reduction of basal metabolic rate (Zhong et al., 1995). McMurtry et al. (1988) stated that changes in growth rate involve efficient use of energy. Giachetto et al. (2003) in a study showed that Insulin-like factor I (IGF-I) increased in recreational period of restricted chicks. Another study showed that GH concentration in chickens during the period of food restriction was reduced and increased during rehabilitation period (Conzales et al., 1998; Buys et al., 1997).

Feed efficiency

To meet demands from the continuing increase in selection intensity for high growth rate, classical feed efficiency (digestibility, metabolism) has made enough progress; any further improvement in feed intake and efficiency should concern reduction of maintenance requirements of the birds. Reducing storage requirements and improved feed conversion is the aim of using physical feed restriction programs. Use of dietary restriction programs to reduce maintenance requirements described above is based on the assumption that using feed physical dietary restriction programs, growth curve could be converted to a more concave curve that cause size and weight of restricted chicks at each point of growth curve before reaching to the end point, to have large weight difference in comparison to chickens under complete diet. Given the lower weight of the chicks, the absolute amount of nutrients required for maintenance will decrease. Since with the occurrence of compensatory growth, restricted chicks reach at the same age the weight of chickens fed complete diet, it is assumed that more nutrients are spent towards growth, and better feed efficiency is achieved.

Feed efficiency and feed physical restriction

Despite increasing the conversion ratio index of all restricted chickens to the control group, the difference between the average conversion rate of chicks of severity and duration of physical restriction methods and controls was significant. A significant difference between chickens under different intensities of physical restriction was observed. Also there was significant difference between chickens under 50% or 25% feed restriction with various duration and controls. These data are consistent with results published in other studies showing that chickens fed restricted diet by 50% compared to *ad libitum* intake had double conversion ratio than chickens with complete diet at the finisher period (Acar et al., 1995; Leeson and Zubair, 1997; Lee and Leeson, 2001). Similarly, other studies have shown that at the end of restricted period the average conversion rate of chickens fed for 5 days with 50% of requirements was significantly higher than that of controls (Lee and Leeson, 2001; Teimouri et al., 2005). These observations could be explained through increased absorption of available amino acids (Gous et al., 1977) or via increased synthesis of digestive enzymes during the food restriction period (Nir et al., 1987). Pinchasov et al. (1993) showed that feeding regimens affect activity of proteolytic enzyme, so that trypsin activity in broilers under intermittent feeding increased compared to the chickens fed *ad libitum*. It was also reported that reducing the amount of feed increased fat digestibility in chickens (Kühn et al., 1996). Perhaps, the above mechanisms contributed to the relative improvement of feed conversion rate at the end of restriction period. It has to be stated that in the present study the best conversion ratio was achieved when chicks were fed by 50% restricted diet. Growth needs in the early period, especially in the first 2 weeks, are much higher than needs for maintenance. Thus, any nutritional deficiencies can lead to deterioration in feed conversion. Probably the body weight of chickens at 14 days of food restriction was reduced to an extent that continuing the trend of dietary restriction, chickens in the longer term triggered specific mechanisms, such as increased synthesis of digestive enzymes, especially proteolytic enzymes and fat digesters in the digestive tract, to optimally utilize their food (Newcombe and Summers, 1984; Pierre et al., 1995). According to Gous et al. (1977) utilization of nutrients, especially amino acids, may increase in the restricted chickens.

Feed efficiency in the starter, grower, finisher and total periods

Our results show that in the starter period, chickens subjected to treatment with 25% and 50% restriction intensity for 14 days had significantly higher conversion rate compared to chickens under complete diet. Moreover, we show that conversion rate of some treatments after the restriction and total period significantly improved compared to the control group which is consistent with the findings of others who showed that dietary restrictions in the early rearing period leads to improved feed conversion rate (McMurtry et al., 1988; Yu et al., 1990; Plavnik and Hurwitz, 1991; Zubair and Leeson, 1996; Lee and Leeson, 2001; Teimouri et al., 2005). Treatments did not affect total period feed efficiency, which is consistent with the studies published previously (Newcombe an Summers, 1984; Pinchasov and Jensen, 1989; Yu et al., 1990; Robinson et al., 1992, Jones and Farrel 1992).

Increasing restriction intensity in feed restriction period significantly reduced the average conversion rate of chickens compared to chickens with complete diet. Increasing the duration of feed restriction period, the chickens conversion rate in the grower and total period was improved, which is consistent with the results of Lee and Leeson (2001) and Oyedeji and Atteh (2005). Forsum et al. (1981) believed that physical restriction of feed leads to improved feed conversion rate by reducing the waste of metabolic energy (total heat production), basal metabolic rate and specific dynamic activity. McMurtry et al. (1988) stated that changes in growth composition or higher efficiency in use of energy and reduction in energy outflow, or a combination of these factors are involved in efficiency improvement in restricted chicks.

In the finisher and total period, despite higher numerical growth rate of restricted chicks, there was no significant difference between them and chicks fed with complete diet. Acar et al. (1995) and Lee and Leeson (2001) showed that with increasing intensity and duration of food restriction, compensatory growth is achieved in the higher age. Generally, realization of compensatory growth after a period of food restriction may be influenced by factors such as age for starting dietary restrictions, intensity and duration of the feed restriction period, sex and strain, duration of rehabilitation period and dietary quality in rehabilitation period (Winick and Nobel, 1966; Zubair and Leeson, 1996). Studies on the impact of physical feed restriction on poultry performance show that feed restriction is having positive effects. Deaton (1995) and Cristofori et al. (1997) showed that feed restriction had significant effects on feed intake, weight gain and feed conversion rate. The above results with the data on feed intake and weight gain in the fifth week of the present experiment we similar; however, we found no significant effect on feed conversion.

Julian et al. (1986) in their experiments found that physical restriction of feed improves feed conversion rate (FCR). In their experiments, they reported that food restriction of broiler chickens had no significant difference on the Production Index. Similarly, we did not find any difference in production inex but the cost of each live broiler was significantly reduced after restricted diet.

CONCLUDING REMARKS

Feed intake in chickens under physical restriction can be reduced significantly compared to complete-fed chickens during dietary restriction and total period. Average feed intake of chicks under 50% physical restriction was lower than chicks under 25% physical restrictions. Using different levels of restriction in dietary restriction had no significant effect on the weight gain chicks in the total period. Feed restriction could be a profitable choice for farmers, as marketable weight can be achieved using lower amounts of feed.

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CONFLICT OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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