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Performance and Changes in Body Composition of Broiler Chickens Depending on Feeding Regime and Sex

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ABSTRACT

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The differences in the performance, carcass parts, and internal organs of broiler chicken females and males fed *ad libitum* or restricted by 80 and 65% *ad libitum* were evaluated. Ross 308 males and females (2430 chickens) were fed *ad libitum* (ADL) or were restricted in days 8–14 of age by 80% ADL (R1) and 65% ADL (R2), respectively. Feed restriction depressed the live weight ($P \le 0.001$) in both sexes. Both sexes compensated for growth, and at the end of the fattening at 35 days, the restricted males (–3% R1 and –6% R2) and females (–3% R1 and –4% R2) were not significantly lighter than the ADL chickens. Feed intake was lower ($P \le 0.001$) in females than in males, and feed restriction and sex did not affect the feed conversion ratio. The growth of internal organs as early-developing tissues (heart, gizzard, liver) was less affected than the growth of late-developing tissues (breast, thigh, abdominal fat). Restricted males and females had more abdominal fat than the *ad libitum* chickens ($P \le 0.05$). Differences in allometric growth between males and females were in the liver, breast, and thigh. At the end of the experiment, restricted males had a higher weight of breast and thigh, whereas in females, the weights of both parts were similar to those of the ADL group. During the restriction period, the growth of internal organs is given priority compared to muscles, which was confirmed by allometric growth. Males showed a higher compensatory growth, including the growth of breasts and thighs.

Keywords: chicken; feed restriction; live weight; organ development; carcass composition

Over recent decades, feed restriction programmes have been applied in broiler chickens to reduce metabolic disorders and leg problems. Early feed restriction was first described by Plavnik and Hurwitz (1985). In this type of restriction, the diet of chickens is commonly restricted for the first two weeks of age, and then the depressed growth caused by limited feed intake is usually followed by compensatory growth in the realimentation period (Zubair and Leeson 1996; Govaerts et al. 2000, Tumova et al. 2002; Butzen et al. 2013; van der Klein et al. 2017). The occurrence of compensatory growth is accompanied by changes in the proportion of body parts. Most studies described illustrated differences in body composition at the end of the fattening period (Fontana et al. 1993; Saleh et al. 2005; Mohammadalipour et al. 2017); however, there is limited information about the developmental changes of body parts and organs. Govaerts et al. (2000) concluded that during feed restriction, the physical development of chickens gives priority to the development of the organs that are more important during early development, such as the stomach. Butzen et al. (2013)

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stated that internal organs recovered more quickly than other parts. The growth of broiler chickens is affected by sex, which was found to be a factor that also influences body weight recovery after feed restriction (Tumova et al. 2002; Butzen et al. 2013). In addition, van der Klein et al. (2017) observed that allometric growth curves for all body parts differed between males and females. The literature shows limited data on the effect of feed restriction on body parts development of chicken males and females. Therefore, the aim of this study was to evaluate differences in carcass parts and internal organ development in broiler chicken females and males fed *ad libitum* or restricted (80 and 65% *ad libitum*).

MATERIAL AND METHODS

In the experiment, 2430 one-day-old Ross 308 chickens were wing banded and assigned to 18 floor pens (135 chickens per pen, 16 birds per m^2, males and females were housed separately). Chickens were split into six groups, with 3 replicates per group. *Ad libitum* group (ADL) was fed *ad libitum* during the whole experiment, group R1 was restricted in days 8–14 of age and fed 80% *ad libitum*, and group R2 was restricted at the same age and fed 65% *ad libitum*. The same experimental design was applied in males and females. The amount of feed for restricted groups was calculated daily based on the feed intake of *ad libitum* groups. Birds in restricted groups before and after feed restriction were fed *ad libitum*. During the entire experiment, chickens were watered *ad libitum*. Chickens were fattened until 35 days of age and received a commercial type of feed mixture. The starter diet was fed until 14 days of age, the grower diet was fed in days 15–28, and the finisher diet was fed until 35 days of age. The composition of feed mixtures is given in Table 1. In feed mixtures, dry matter, crude protein, crude fat, and crude fibre were determined by the methods of AOAC International (1995, 2005) and were described in detail by Skrivanova et al. (2017). The environmental conditions were maintained in accordance with the chickens' requirements. The lighting regime consisted of 23 h light in days 1–14 and 19 h light in days 15–35 of age. The experiment was approved by the Ethics Committee of the Central Commission for Animal Welfare at the Ministry of Agriculture of the Czech Republic.

The chickens were individually weighed from the first day of age in a week interval; feed consumption was recorded weekly for each pen. Records were used for the calculation of daily feed intake (FI) and the feed conversion ratio (FCR). Mortality was evaluated in a group over the entire experiment. At the ages of 14, 21, 28, and 35 days, 12 birds from each group (4 birds per pen) were randomly selected for carcass analysis. Birds were slaughtered in the experimental slaughterhouse of the International Poultry Testing Station Ustrasice by electrical stunning and bleeding from the jugular vein. Chickens were slaughtered at similar weights at the given age to detect the differences between feeding regimes and the sexes. Immediately after slaughtering, chickens were eviscerated, and their internal organs (gizzard, heart, and liver) were

Table 1. Composition and analysed nutrient content in the experimental feed mixtures (g/kg)

Component	Starter	Grower	Finisher
Wheat	382.7	467.5	529.0
Corn	200.0	150.0	120.0
Soybean meal	320.0	280.0	250.0
Fish meal	20		
Rapeseed oil	40.0	60.0	65.0
L-Lysine	2.0	2.8	1.4
L-Threonine	0.6	1.1	0.5
DL-Methionine	1.0	1.1	0.5
Limestone	12.3	15.0	13.6
Salt	2.2	2.5	3.0
Monocalcium phopshate	13.2	13.5	11.0
Na_2CO_3	1.0	1.5	1.0
Vitamin premix[1]	5.0	5.0	5.0
Analysed content of nutrients			
Dry matter	906.4	899.4	907.3
Crude protein	233.9	208.8	199.8
Crude fibre	28.2	31.6	27.6
Crude fat	63.5	79.9	82.9
AME_N	12.7	12.6	13.2

AME_N = apparent metabolizable energy (MJ)

[1]vitamin-mineral premix provided per kg of diet: retinyl acetate 3.6 mg, cholecalciferol 13 μg, α-tocopherol acetate 30 mg, menadione 3 mg, thiamine 3 mg, riboflavin 5 mg, pyridoxine 4 mg, cyanocobalamin 40 μg, niacin 25 mg, calcium pantothenate 12 mg, biotin 0.15 mg, folic acid 1.5 mg, choline chloride 250 mg, copper 12 mg, iron 50 mg, iodine 1 mg, manganese 80 mg, zinc 60 mg, selenium 0.3 mg

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weighed. After evisceration, carcasses were chilled overnight at 4°C, and then carcass weight, breast weight, thigh weight, and abdominal fat weight were measured. The weights of organs, carcass, and carcass cuts were used for the calculation of growth. The allometric growth was calculated using the formula of Huxley and Teissier (1936):

$$y = b \times x^k$$

where:
y = weight of the organ or carcass part
b = constant (origin index)
x = live weight
k = allometric growth constant

Individual data of body weight and feed consumption were processed by two-way analysis of variance, with sex and group as the main factors, using the ANOVA procedure of the SAS 9.4 for Windows, 2013. The carcass composition and the allometric growth of organs were evaluated by three-way analysis on the interaction of sex, group, and age. The statistically significant differences ($P < 0.05$) are indicated by different superscripts.

RESULTS AND DISCUSSION

The results of growth (Figure 1) show significant differences between males and females during the entire experiment. Feed restriction depressed live weight ($P \leq 0.001$) in both sexes, with a higher reduction in males. At the end of feed restriction at 14 days of age, the live weight of restricted males in group R1 fed 80% *ad libitum* reached 73% of the live weight of the ADL males and 69% of the live weight of the group R2 males fed 65% *ad libitum*. A similar trend was found in females whose live weight in R1 reached 81% of that in the ADL group, and in R2 reached 78% of that in the ADL group. Restricted chickens had a significantly lower live weight until the end of the fattening period at 35 days than the ADL ones. Restricted males showed a lower final live weight of approximately −3% in R1 and −6% in R2, whereas in females, lower final live weights were approximately −3% in R1 and −4% in R2. These results are in accord with the findings of Lippens et al. (2000). In contrast, Zhan et al. (2007) and Butzen et al. (2013) observed that restricted chickens recovered their live weight. Data of the present study show that in males the feed restriction caused a higher depression of growth; however, in the realimentation period, restricted males of both groups managed to overcome the growth depression better than the restricted females, which corresponds with the previous studies (Plavnik and Hurwitz 1991; Tumova et al. 2002; van der Klein et al. 2017).

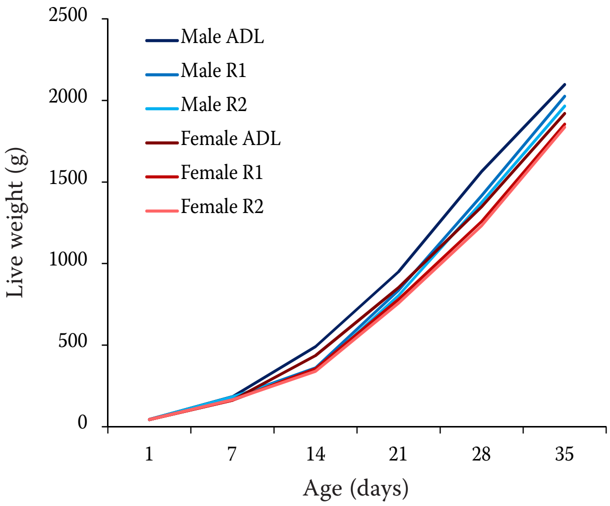

Figure 1. Live weight of broiler chickens in relation to feeding regime and sex

The effect of feed restriction on feed consumption and mortality is presented in Table 2. As expected, FI was lower ($P \leq 0.001$) in females than in males. Restricted chickens consumed less feed

Table 2. Feed consumption and mortality during the entire experiment (1–35 days of age)

Sex	Group	Feed intake (g/bird)	Feed conversion ratio (kg/kg)	Mortality (%)
	ADL	105.6	1.96	8.55
Males	R1	99.1	1.87	6.50
	R2	97.0	1.88	4.85
	ADL	90.9	1.82	5.85
Females	R1	88.4	1.82	3.20
	R2	89.2	1.83	1.80
RMSE		2.84	0.18	
Significance				
Sex		0.001	ns	
Group		0.05	ns	
Sex × group		ns	ns	

RMSE = root mean square error, ADL = *ad libitum* feeding, R1 = feeding 80% *ad libitum* in days 8–14 of age, R2 = feeding 65% *ad libitum* in days 8–14 of age, ns = not significant

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than the ADL chickens ($P \leq 0.05$), without the effect of intensity of feed restriction. Lower FI of restricted chickens is assumed to be related to lower maintenance requirements during feed restriction and may support compensatory growth in the realimentation period. Lower FI can result in better FCR. However, in the present study, FCR was not affected by the group or sex of chickens and is in agreement with Tumova et al. (2002), Butzen et al. (2013), and van der Klein (2017). Mortality was lower in the female restricted chickens and decreased with the intensity of restriction. In the present study, lower mortality of restricted chickens was related to a lower incidence of the "sudden death syndrome", which is also described by Lippens et al. (2000).

The weight of internal organs (Table 3) was not affected by the interaction of sex, group, and age. The heart weight was significantly higher in males, and in both sexes, it increased with age ($P \leq 0.001$). Regarding the feeding regime, a significant effect was observed at the end of feed restriction (at 14 days of age), the heart weight was higher in restricted males, but there was no effect on the heart weight of females. A higher intensity of feed restriction in males increased the heart weight as compared to ADL chickens (+2.5 and +5% in the R1 and R2 groups, respectively). A higher heart weight at the end of feed restriction was considered to be explained by the results of a study in sheep conducted by Santos et al. (2018), in which the greater weight of the heart in restricted lambs could have been caused by an impairment of mitochondrial metabolism caused by the lack of nutrients during early life. Similarly, different effects of feed restriction and its intensity in males and females on heart weight occurred at the end of the fattening period. In restricted males, the heart weight was higher (+8 and +3%), but in R1 group females, with a lower intensity of feed restriction, the measurement was lower by –6%, while in R2 group females, the measurement was higher by +12%. Mohammadalipour et al. (2017) suggested that the higher heart mass of restricted chickens increased oxygen supply for a higher metabolic rate, which was assumed to be the case of males. In Table 3, gizzard weight was lower ($P \leq 0.001$) in restricted chickens, which is in accord with Wang et al. (2017), who observed a lower gizzard proportion in protein-restricted ducks. The lower gizzard weight of restricted chickens might decrease the FI of these groups; therefore, it could be assumed that the compensatory growth of restricted chickens was supported by the improved digestibility of nutrients. Liver weight was higher in males ($P \leq 0.001$) and increased with advancing age ($P \leq 0.001$). However, the feeding regime did not affect liver weight and corresponds with Susbilla et al. (1994) and Mohammadalipour et al.

Table 3. Slaughter weight and weight of internal organs (g)

Sex	Group	Age	Weight			
			slaughter	heart	gizzard	liver
Male	ADL	14	375^{g}	4.75	11.2	13.1
		21	819^{e}	5.00	13.4	22.5
		28	1436^{c}	7.57	19.2	37.8
		35	1948^{b}	11.51	25.7	54.3
	R1	14	376^{g}	4.87	11.2	11.9
		21	786^{f}	5.00	16.9	23.7
		28	1418^{c}	7.54	21.9	34.2
		35	2164^{a}	12.51	25.0	53.4
	R2	14	370^{g}	5.00	11.2	11.25
		21	765^{f}	5.00	16.2	23.1
		28	1421^{c}	8.16	19.0	36.0
		35	1962^{b}	11.91	23.8	56.1
Female	ADL	14	385^{g}	4.52	9.4	10.6
		21	775^{f}	5.00	15.0	23.1
		28	1287^{d}	7.25	15.5	32.7
		35	1901^{b}	10.09	25.8	42.0
	R1	14	383^{g}	4.52	11.2	10.0
		21	768^{f}	5.00	16.2	24.3
		28	1246^{d}	6.31	18.9	32.0
		35	1917^{b}	9.49	21.7	40.9
	R2	14	368^{g}	4.52	11.2	9.4
		21	769^{f}	6.25	17.0	23.7
		28	1288^{d}	7.24	17.5	31.3
		35	1913^{b}	11.31	25.3	48.1
RMSE			43.5	1.29	3.7	4.25
Significance						
Sex			0.001	0.001	ns	0.001
Group			0.001	0.05	0.001	ns
Age			0.001	0.001	ns	0.001
Sex × group × age			0.001	ns	ns	ns

RMSE = root mean square error, ADL = *ad libitum* feeding, R1 = feeding 80% *ad libitum* in days 8–14 of age, R2 = feeding 65% *ad libitum* in days 8–14 of age

$^{a-g}$statistically significant differences ($P \leq 0.05$) within columns are indicated by different superscripts, ns = not significant

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(2017). Govaerts et al. (2000) observed a significant interaction between feeding regime and age, which resulted in a higher liver proportion after feed restriction compared to chickens fed *ad libitum*; however, differences were not detected in the realimentation period. The discrepancy between studies may be due to differences in the intensity of feed restriction and corresponds with the finding of Govaerts et al. (2000), which is that less severe restriction and maintenance do not have to be sustained by liver breakdown.

Feed restriction also modifies the body composition (Table 4). Breast weight was affected by the feeding regime ($P \leq 0.05$), age ($P \leq 0.001$), and the interaction of sex, group, and age ($P \leq 0.001$). The interaction shows that, after feed restriction, breast weight was higher in restricted males (+9% in R1 and +3% in R2) but lower in females (–7% in R1 and –19% in R2). At the end of the experiment, breast weight in restricted males was higher (+27% for R1 and +4% for R2), whereas in restricted females, breast weight was higher in R1 (+2%) but negligibly lower in R2 (–1%). Significant differences between the groups were observed only at the end of the experiment. These results indicate that less intensive restriction had a positive effect on breast growth, and at 35 days of age, males and females in R1 had significantly higher breast weight than ADL chickens. Govaerts et al. (2000), Lippens et al. (2000), and Butzen et al. (2013) did not find significant differences in the proportional breast weight based on the feeding regime. Differences between the present study and the literature can be related to different methods of feed restriction. The significant effects of sex, group, age and their interaction were observed in thigh weight. Although there were no significant differences between groups at 14, 21, and 28 days of age, at 35 days the significantly highest thigh weight was in R1 males, whereas in other groups thigh weight did not differ. Similarly, Lippens et al. (2000) observed a higher proportion of thighs in chickens fed 80% *ad libitum.*

The weight of abdominal fat was not affected by the sex of chickens, which is in contrast with the findings of Lippens et al. (2000) and van der Klein et al. (2017). de Souza Khatlab et al. (2018) revealed that a higher fat content in females is related to a higher expression of the fatty acid synthase gene. As expected, abdominal fat weight significantly increased with advancing age. Restricted males and females had a higher ($P \leq 0.05$) abdominal fat weight than ADL chickens, which is similar to the findings of Lippens et al. (2000). The effect of feed restriction on abdominal fat content is not clear, which was also proven in the literature, where we can find that the measurement of abdominal fat weight was not affected by the feeding regime (Susbilla et al. 1994;

Table 4. Weight and carcass components (g)

Sex	Group	Age (days)	Weight			
			carcass	breast	thigh	abdominal fat
Male	ADL	14	217	42.5^{f}	40.0^{e}	1.9
		21	514	121^{e}	92.5^{d}	7.9
		28	929	237^{d}	185^{c}	14.4
		35	1294	323^{c}	278^{b}	23.5
	R1	14	223	46.2^{f}	41.2^{e}	3.7
		21	494	111^{e}	97.5^{d}	8.9
		28	891	219^{d}	150^{c}	14.7
		35	1607	410^{a}	320^{a}	31.0
	R2	14	223	43.7^{f}	40.0^{e}	3.5
		21	460	96.8^{e}	90.0^{d}	9.4
		28	894	228^{d}	186^{c}	15.2
		35	1328	335^{bc}	284^{b}	26.8
Female	ADL	14	230	51.8^{f}	38.7^{e}	3.4
		21	489	117^{e}	92.5^{d}	6.1
		28	859	241^{d}	167^{c}	15.5
		35	1313	349^{b}	266^{b}	28.7
	R1	14	230	48.1^{f}	38.7^{e}	3.9
		21	491	104^{e}	92.5^{d}	8.9
		28	839	223^{d}	168^{c}	15.6
		35	1471	355^{b}	270^{b}	30.4
	R2	14	223	41.8^{f}	37.5^{e}	3.6
		21	493	109^{e}	98.2^{d}	18.9
		28	859	222^{d}	174^{c}	21.2
		35	1333	346^{b}	276^{b}	30.7
RMSE			111	22	14	0.11
Significance						
Sex			ns	ns	0.001	ns
Group			0.05	0.05	0.05	0.05
Age			0.001	0.001	0.001	0.001
Sex ×group × age			ns	0.001	0.05	ns

RMSE = root mean square error, ADL = *ad libitum* feeding, R1 = feeding 80% *ad libitum* in days 8–14 of age, R2 = feeding 65% *ad libitum* in days 8–14 of age

$^{a-f}$statistically significant differences ($P \leq 0.05$) within columns are indicated by different superscripts, ns = not significant

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Lippens et al. 2009) or was lower (Wijtten et al. 2010; van der Klein et al. 2017). The discrepancies among studies may be associated with restriction type and intensity, and more research is needed.

The allometric growth coefficient of internal organs and carcass parts is given in Table 5. Internal organs are assumed to be early maturing, which confirm lower coefficients of growth allometry than in heart, gizzard, and liver; this is in line with the results of Govaerts et al. (2000) and van der Klein et al. (2017). The heart allometric growth of restricted males and females was negligibly higher in the first week of the realimentation period compared to the ADL chickens. However, in the second week of realimentation it was lower ($P \leq 0.05$) than in the ADL chickens. Slow allometry growth of the heart continued in the last week of the experiment and the differences between restricted and *ad libitum* groups were not significant. A similar trend in heart growth was observed by van der Klein et al. (2017). Development of the gizzard was positively affected by feed restriction, and coefficients of allometry were lower in restricted groups and significantly lower in the last week of the fattening period. Liver allometric growth indicates that in the first week after feed restriction, coefficients of allometry were lower in females ($P \leq 0.001$) than in males and in restricted groups ($P \leq 0.001$) than in ADL chickens. At 35 days of age, higher coefficients were observed in males ($P \leq 0.001$) and ADL chickens ($P \leq 0.05$). van der Klein et al. (2017) observed similar trends in the allometric growth of the liver. The liver plays an important role in lipogenesis, and a larger liver weight may indicate higher hepatic activity, which may lead to a higher fat deposition; therefore, the higher abdominal fat weight of restricted chickens in the present study could be a result of this metabolism level.

Coefficients of allometry of the breast, thigh, and abdominal fat were higher than 1 and pointed

Table 5. Coefficients of growth allometry

Measurement	Age (days)	Male			Female			RMSE	Significance		
		ADL	R1	R2	ADL	R1	R2		sex	group	sex × group
Carcass	21	1.11^{a}	1.08^{b}	1.04^{c}	1.09^{ab}	1.08^{b}	1.07^{b}	0.06	ns	ns	0.05
	28	1.05	1.00	1.07	1.11	1.07	1.07	0.08	ns	ns	ns
	35	1.09	1.34	1.22	1.08	1.31	1.11	0.09	ns	0.05	ns
Heart	21	0.26	0.30	0.37	0.31	0.32	0.55	0.02	ns	ns	ns
	28	0.93	0.65	0.65	0.83	0.43	0.70	0.03	ns	0.05	ns
	35	1.41	1.21	1.18	1.11	0.99	1.14	0.03	ns	ns	ns
Gizzard	21	0.50	0.64	0.65	0.78	0.62	0.74	0.03	ns	ns	ns
	28	0.78	0.55	0.52	0.70	0.40	0.68	0.03	ns	ns	ns
	35	0.95	0.52	0.88	1.32	0.50	1.04	0.03	ns	0.05	ns
Liver	21	0.68	0.96	1.16	1.11	1.27	1.28	0.04	0.001	0.001	ns
	28	0.94	0.62	0.72	0.70	0.55	0.54	0.03	ns	ns	ns
	35	1.37	1.02	1.36	0.65	0.59	1.11	0.04	0.001	0.05	ns
Breast	21	1.35	1.18	1.09	1.16	1.11	1.27	0.02	ns	ns	ns
	28	1.21	1.17	1.39	1.42	1.52	1.42	0.02	0.001	ns	ns
	35	1.02	1.52	1.17	0.95	1.11	1.09	0.04	ns	ns	ns
Thigh	21	1.14	1.17	1.13	1.24	1.25	1.28	0.02	0.05	ns	ns
	28	1.13	1.13	1.17	1.17	1.17	1.15	0.02	ns	ns	ns
	35	1.31	1.26	1.31	1.18	1.17	1.60	0.03	ns	ns	ns
Abdominal fat	21	1.92	1.61	1.31	1.26	1.40	1.16	0.01	ns	ns	ns
	28	1.61	1.57	1.14	1.21	1.52	1.14	0.01	ns	ns	ns
	35	1.21	1.97	1.64	1.97	1.60	1.21	0.01	ns	ns	ns

RMSE = root mean square error, ADL = *ad libitum* feeding, R1 = feeding 80% *ad libitum* in days 8–14 of age, R2 = feeding 65% *ad libitum* in days 8–14 of age

[a–c]statistically significant differences ($P \leq 0.05$) within rows are indicated by different superscripts, ns = not significant

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to their late maturing. Breast growth was lower in females and significantly lower in the second week after restriction. On the other hand, the feeding regime did not affect breast allometric growth. Similarly, Govaerts et al. (2000) stated that differences in the growth of the breasts of ADL and restricted chickens disappeared at slaughter age. However, van der Klein et al. (2017) observed that the allometric growth curve of the breast muscle was shifted further upward in females than in males. The thigh allometry coefficient was significantly higher only in females in the first week after restriction. In the rest of the experiment, neither sex nor the feeding regime affected the parameter which corresponds with Govaerts et al. (2000) and van der Klein et al. (2017). No significant effect of sex or feeding regime was observed in the allometric coefficient of abdominal fat, which corroborates with Govaerts et al. (2000); however, van der Klein et al. (2017) observed that the allometric growth curve was significantly different between males and females, and markedly lower in restricted groups. Higher allometry coefficients of the abdominal fat compared to the breast or thigh coefficients indicate that the abdominal fat is a very late maturing tissue. Numerically lower coefficients of the abdominal fat allometry of restricted groups indicate higher lipogenesis related to higher fat deposition in these groups in the present study.

To sum up, the results indicate that feed restriction at 80 and 65% *ad libitum* impaired growth and feed intake; however, it reduced the mortality of the chickens. During the restriction period, growth of internal organs is given priority compared to muscle growth, which was confirmed by the allometric growth. Males showed a higher compensatory growth, including the growth of breasts and thighs. On the other hand, restricted chickens showed a higher content of abdominal fat, which was assumed to be a result of higher lipogenesis in the liver. The results of the present study confirmed some of the data found in the literature, but some processes are still unclear, and more research is needed.

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