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A comparative study on the effect of quantitative feed restriction in males and females of broiler chickens, rabbits and nutrias. I. Performance and carcass composition

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Abstract: The aim of the study was to compare the effects of feed restriction on the growth performance and carcass composition of chicken, rabbit and nutria males and females. Feed restriction was applied at a rate of 70% *ad libitum* from 14 to 21 days of age in chickens, 70% *ad libitum* from 42 to 49 days of age in rabbits, and 70% *ad libitum* from 12 to 15 weeks of age in nutrias. Animals were fed *ad libitum* prior to and following restriction. Carcass composition was evaluated at common slaughter ages, i.e., 31 days in chickens, 70 days in rabbits, and eight months in nutrias. The results showed stronger effects of feed restriction, sex, and their interaction in broiler chickens than in rabbits and nutrias. In chickens, feed restriction increased the sex differences in final body weight, which were associated with interaction of feed restriction and sex ($P = 0.009$). Feed restriction as a fixed factor significantly affected growth and feed conversion in chickens and it was with no effect in rabbits and nutrias. The effect of feed restriction on carcass composition was negligible in all selected species. With respect to sex, significant differences were observed in chickens in final body weight, daily weight gain, dressing out percentage and breast percentage, in rabbits in loin percentage, and in nutrias in growth and perirenal fat percentage. Results of the study indicated that interactions of feed restriction and sex in growth might be associated with a short realimentation period.

Keywords: species; sex; growth; carcass yield

Meat production efficiency has been related to growth intensity, feed consumption, mortality, carcass yield, and meat quality. Feed restriction (FR) can be an effective method to reduce economic losses by reducing the incidence of metabolic disorders and mortality in fast-growing

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broiler chickens (Mohammadalipour et al. 2017; Tumova et al. 2019), rabbits (Gidenne et al. 2012; Birolo et al. 2016), and pigs (Le Floc'h et al. 2014). It was reported that FR resulted in a similar or better feed conversion ratio in several species, including broiler chickens (van der Klein et al. 2017; Tumova and Chodova 2018; Lunedo et al. 2019), rabbits (Gidenne et al. 2012; Tumova et al. 2016; Chodova et al. 2019; Crespo et al. 2020), and turkeys (Tumova et al. 2002). However, inconsistent data have been published on growth parameters. Previous studies confirmed compensatory growth following FR in chickens (Tumova et al. 2002; van der Klein et al. 2017; Lunedo et al. 2019), rabbits (Tumova et al. 2002; Gidenne et al. 2012; Crespo et al. 2020), and nutrias (Tumova et al. 2021a). However, other studies reported growth retardation due to FR in chickens (Tumova and Chodova 2018; Gratta et al. 2019), rabbits (Tumova et al. 2016), turkeys (Tumova et al. 2002), lambs (Santos et al. 2018), and pigs (Carco et al. 2018). With respect to carcass composition, Tumova et al. (2019) observed no significant effect of FR on dressing out percentage (DOP) and thigh percentage; meanwhile, breast yield was lower and abdominal fat yield was higher in restricted chickens. Gratta et al. (2019) stated that late-restricted (from 27 to 37 days of age) chickens had a significantly lower carcass weight and breast proportion, while early-restricted (from 13 to 23 days of age) chickens had an intermediate carcass weight and breast percentage compared to those of *ad libitum* fed chickens. In rabbits, Birolo et al. (2016; 2020a), Alabiso et al. (2017), and Chodova et al. (2019) did not observe a significant effect of FR on carcass composition, while Gidenne et al. (2012), Chodova et al. (2016) and Birolo et al. (2020b) observed lower DOP in restricted rabbits. In our recent experiment with nutrias, FR increased the hind part and perirenal fat percentage (Tumova et al. 2021a).

Sexual dimorphism encompasses growth, feed consumption and carcass yield. However, the degree of divergence between sexes varies considerably among species (Baeza et al. 2001). van der Heide et al. (2016) observed in a sex specific model a high genetic correlation for the growth of males and females in broiler chickens (0.86–0.94), cattle (0.68–0.84), and pigs (0.86–0.93). Muscovy drakes are almost double the size of females (Baeza et al. 2001). In contrast to the differences in the growth of turkey males and females, the thighs and breasts developed at the same rate (Tumova et al. 2020). In nutrias, the difference between males and females in live body weight at eight months was 24–26% (Tumova et al. 2021b). Conversely, rabbits showed low sexual dimorphism in live body weight at early ages but females had a higher proportion of the *longissimus lumborum* (LL) muscle (Trocino et al. 2015).

It could be hypothesized that the variability in body weight between males and females might be related to the effect of FR on growth performance and carcass yield. Therefore, the objective of the present study was to compare the effects of quantitative FR on the growth, feed consumption and carcass composition of broiler chicken, rabbit, and nutria species with different degrees of sexual dimorphism and to evaluate the interaction of feeding regime and sex using similar methods of FR in these selected animal species.

MATERIAL AND METHODS

All experiments were approved by the Ethics Committee of the Central Commission for Animal Welfare at the Ministry of Agriculture of the Czech Republic for feeding tests. The experimental conditions agreed with the principles laid down in EC Directive 86/609/EEC regarding the protection of animals used for experimental and other scientific purposes. The experiment with broiler chickens was performed at the Ústrašice International Testing Station (Tábor, Czech Republic), with rabbits in the experimental unit of the Institute of Animal Science (Prague, Czech Republic), and with nutrias at the Central Institute for Supervising and Testing in Agriculture at Havlíčkův Brod (Havlíčkův Brod, Czech Republic).

Animals and experimental design

In the present study in all experiments, 70% of *ad libitum* feeding was applied in the restriction period. The length of the restriction period was adapted to each selected animal species. In all experiments, the amount of feed for restricted groups was calculated daily based on feed intake of the *ad libitum* groups. Animals in restricted groups were fed *ad libitum* before and after FR. Water was available *ad libitum* throughout the experiment.

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The broiler chicken experiment was carried out with 240 males and 240 females of the fast-growing hybrid Ross 308. One-day-old chickens after weighing and wing banding were randomly split into 12 littered pens (40 birds in one pen, 14 birds per m^2). The experimental design was a 2 × 2 factorial design, with two sexes and two types of feeding regime, namely, *ad libitum* (AL) throughout the experiment and quantitative feed restriction (FR) between 14 and 21 days of age. Each group had three replicates. During the restriction period, chickens received 70% of the amount of feed consumed by the *ad libitum* group. The experiment was finished at 31 days of age when chickens reached a live body weight of approximately 2 000 g. During the experimental period, chicks were fed the starter diet from one to 14 days, the grower diet from 15 to 25 days, and the finisher diet from 26 to 31 days. The composition of feed mixtures is given in Table 1. The environmental conditions were described in detail in Tumova et al. (2021c). For the purpose of the present study, data of performance and abdominal fat percentage were statistically analysed separately to detect the interaction of FR and sex (Table 2), which were not analysed in the previous study.

The rabbit experiment was carried out with 120 males and females (1 : 1 ratio) of the Hyplus hybrid. Rabbits were weaned at 30 days of age, and after weaning, they were allocated to 24 collective wire net cages (five rabbits per cage, 0.80 × 0.60 × 0.45 cm, 0.12 m^2 per rabbit) and randomly divided into four groups: AL males (30 rabbits per group, six cages), AL females (30 rabbits per

Table 1. Chemical composition of the experimental diets as fed basis (g/kg)

Item	Broiler chickens			Rabbits	Nutrias
	starter	grower	finisher		
Dry matter	872	887	893	912	907
Crude protein	223	201	179	174	206
Crude fat	52.1	54.2	72.6	30.0	38.7
aNDFom	–	–	–	392	331
ADFom	–	–	–	221	201
Metabolizable energy (MJ)	12.5	12.9	13.5	9.6	9.8

ADFom = acid detergent fibre expressed exclusive of residual ash; aNDFom = neutral detergent fibre expressed exclusive of residual ash

Table 2. Performance and carcass composition of *ad libitum* and restricted chicken males and females

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
Final weight (g)	2 073^{a*}	1 935^{b*}	1 870^{c*}	1 624^{d*}	12.780	< 0.001	< 0.001	0.009
DWG (g)	63.3^{a*}	58.9^{b*}	56.9^{b*}	49.3^{c*}	0.402	< 0.001	< 0.001	0.009
FCR (kg)	1.54*	1.55*	1.57*	1.59*	0.007	0.016	0.230	0.675
Slaughter weight (g)	2 037	2 000	2 039	1 916	9.256	< 0.001	< 0.001	< 0.001
Carcass weight (g)	1 359	1 363	1 359	1 303	7.942	0.045	0.079	0.043
DOP (%)	66.7	68.1	66.7	68.4	0.355	0.924	0.047	0.953
Percentages of parts from the carcass weight (%)								
Breast	34.3	30.1	32.1	30.0	0.451	0.089	< 0.001	0.603
Thigh	31.8	32.9	32.6	32.5	0.204	0.952	0.746	0.242
Abdominal fat	1.50*	1.61*	1.46*	2.06*	0.101	0.309	0.080	0.212

AL = *ad libitum*; DOP = dressing out percentage; DWG = daily weight gain; FCR = feed conversion ratio; FR = feed restriction

^{a,b,c,d}Means with different superscripts are significantly different

*Data published by Tumova et al. (2021b)

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group, six cages), restricted males (30 rabbits per group, six cages), and restricted females (30 rabbits per group, six cages). The experimental design was a 2 × 2 factorial design, with two sexes and two types of feeding regimes. Feed restriction was applied between 42 and 49 days of age, and rabbits received 70% of the *ad libitum* feeding. The feed mixture chemical composition is shown in Table 1, and environmental conditions were the same as those described in detail in Chodova et al. (2019). The experiment was finished at the age of 70 days.

The nutria experiment was carried out with 120 nutrias (60 males and 60 females) of the standard colour type under the same conditions as described in our recent study (Tumova et al. 2021b). After weaning and weighing, the nutrias were randomly placed into 12 pens (two sexes × two feeding regimes × three replicates), with 10 nutrias per pen. The experimental design was a 2 × 2 factorial design, with two sexes and two types of feeding regimes. The AL males and females were fed *ad libitum* throughout the experiment until eight months of age, and restricted nutrias were restricted in the 3rd month of age for four weeks (12th–15th week of age) and received 70% of the *ad libitum* feeding. Table 1 describes the feed chemical composition.

Growth performance

During all experiments, animals were individually weighed. Body weight in grams was measured weekly in chickens and rabbits and monthly in nutrias. The growth of the animals was evaluated by calculating the daily weight gain (DWG) from individual weighing. Feed consumption was measured daily per pen or cage, and mortality was recorded daily.

Carcass analyses

In all experiments, animals were fasted for 12 h before slaughtering. Animals were slaughtered by electrical stunning and bleeding from the jugular vein. Carcass dissection was evaluated in cold carcasses after chilling for 24 h at 4 °C. After chilling, the carcass weight was measured, and then the carcass analysis was carried out by a method described by Chodova et al. (2021).

Carcass dissection of the chickens was performed at the end of the fattening period at 31 days of age, when chickens came to an approximate weight of 2 000 g. Twelve birds from each group (four birds per pen) were selected to determine carcass composition. After stunning and bleeding, the chickens were plucked and eviscerated. During the carcass analysis, carcass weight, internal organs weight, breast weight with skin, thigh weight including skin, and abdominal fat (AF) weight were recorded. The breasts were cut from the shoulder joint and sternum, and the thighs (upper thigh and drumstick) were cut at the hip joint. The weights of the carcass and carcass cuts were used to calculate the proportion in the whole carcass. The DOP was calculated using the following formula: (carcass weight/slaughter weight) × 100.

Rabbits for carcass analysis were slaughtered at 70 days of age. The dissection of 12 rabbits per group (two rabbits per cage) followed the method of Zapletal et al. (2020). Carcass weight, DOP, loin, hind legs, and perirenal fat were recorded. The percentage of carcass parts was calculated relative to the whole carcass. The DOP was calculated by dividing the carcass weight by the live body weight.

A total of 36 nutrias (nine from each group, three per replicate) at eight months of age were used for carcass analysis. Nutrias selected for carcass dissection were close to the average weight of each group. Carcass analysis was performed according to Tumova et al. (2021a). The DOP was calculated from the cold carcass weight divided by the live weight and multiplied by 100. The carcass was cut to separate the hind part and then the loin and hind legs. The weights of each part and perirenal fat were used to calculate the percentage in the chilled carcass.

Statistical analysis

Data were statistically analysed by two-way ANOVA (GLM procedure) in SAS software v9.4. (SAS Institute, Inc., Cary, NC, USA). Feeding regime, sex, and their interaction were included as fixed effects, and pen or cage was included as a random effect. The pen or cage was used as an experimental unit for growth performance, and the individual chicken, rabbit, and nutria represented the experimental unit for carcass composition. The differences between groups in final body weight

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and DWG were tested by the Sheffe test and for FCR and carcass composition Duncan's test was used. Significance was considered at the $P < 0.05$ level.

RESULTS

Growth performance

Results of the performance and carcass composition of broiler chickens, rabbits, and nutrias are given in Tables 2–4. In broiler chickens (Table 2), an interaction between FR and sex was found for final live body weight and DWG ($P = 0.009$). This significant interaction shows that FR increased the sex differences in final body weight from 7% to 13%. In restricted chicken males and females, compensatory growth was not detected, and final body weight was lower in males by 10% and in females by 16% than in the AL chickens. A similar tendency was observed in DWG. However, restricted rabbit (Table 3) and nutria (Table 4) males and females compensated for final body weight. With respect to the effect of the main factors in the present study, in chickens, FR significantly decreased final body weight and DWG and increased FCR. Significant sex differences in final body weight and DWG were observed in chickens and nutrias.

Table 3. Performance and carcass composition of *ad libitum* and restricted rabbit males and females

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
Final weight (g)	2 686	2 614	2 744	2 651	27.908	0.400	0.142	0.848
DWG (g)	45.6	42.8	46.1	44.6	0.587	0.297	0.070	0.583
FCR (kg)	3.23	3.27	3.19	3.24	0.035	0.558	0.423	0.287
Slaughter weight (g)	2 781	2 834	2 757	2 745	23.548	0.254	0.671	0.495
Carcass weight (g)	1 450	1 477	1 453	1 401	14.315	0.199	0.669	0.166
DOP (%)	60.3	60.4	61.6	60.0	0.299	0.486	0.324	0.127
Percentages of parts from the carcass weight (%)								
Loin	16.3	18.6	17.1	17.9	0.278	0.811	0.003	0.109
Hind legs	30.7	31.4	30.3	30.2	0.192	0.029	0.450	0.318
Perirenal fat	1.86[b]	2.32[a]	2.20[a]	1.99[b]	0.080	0.996	0.425	0.040

AL = *ad libitum*; DOP = dressing out percentage; DWG = daily weight gain; FCR = feed conversion ratio; FR = feed restriction

[a,b]Means with different superscripts are significantly different

Table 4. Performance and carcass composition of *ad libitum* and restricted nutria males and females

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
Final weight (g)	5 704	4 799	5 312	4 469	134.136	0.133	0.005	0.937
DWG (g)	28.4	23.9	24.7	21.1	0.849	0.121	0.022	0.560
FCR (kg)	5.9	5.6	5.7	5.8	0.162	0.952	0.689	0.600
Slaughter weight (g)	5 697	4 893	5 072	4 803	121.323	0.097	0.009	0.202
Carcass weight without head (g)	3 085	2 522	2 672	2 425	80.781	0.061	0.002	0.229
DOP (%)	54.0	51.7	52.8	50.5	0.659	0.344	0.074	0.995
Percentages of parts from the carcass weight without head								
Loin	5.86	5.98	6.48	6.07	0.098	0.077	0.642	0.174
Hind legs	22.9	21.3	22.2	23.0	0.333	0.416	0.595	0.077
Perirenal fat	1.13	1.39	0.97	1.14	0.077	0.630	0.032	0.555

AL = *ad libitum*; DOP = dressing out percentage; DWG = daily weight gain; FCR = feed conversion ratio; FR = feed restriction

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Carcass composition

Regarding carcass characteristics, a significant interaction between FR and sex was observed for chicken slaughter weight and carcass weight (Table 2) and for perirenal fat percentage in rabbits (Table 3). In chickens, slaughter weight ($P < 0.001$) and carcass weight ($P = 0.043$) were lower in restricted females than in restricted males. In rabbits, the perirenal fat percentage was lower in AL males and restricted females than in the other groups ($P = 0.040$). Regarding the fixed effects, FR decreased slaughter weight ($P < 0.001$) and carcass weight ($P = 0.045$) in chickens. Conversely, a stronger impact of sex was observed for carcass composition. In chickens, females had a lower slaughter weight ($P < 0.001$) and breast percentage ($P < 0.001$) and a higher DOP ($P = 0.027$) than males. In rabbits, males showed a significantly lower loin percentage than females. In nutrias, males had a higher slaughter weight ($P = 0.009$) and carcass weight ($P = 0.002$) and lower perirenal fat ($P = 0.022$) than females (Table 4).

DISCUSSION

Growth performance

The growth of restricted animals is accompanied by compensatory growth during the realimentation period. In the present study, restricted chicken males and females reached a significantly lower final body weight than AL chickens. The lack of compensatory growth of restricted chickens might be related to the short realimentation period. Moreover, from a physiological point of view, it was illustrated that immediately after finishing the FR period, feed intake was decreased because the capacity of the gastrointestinal tract became limited, resulting in the incomplete consumption of the amount of feed provided and thus growth retardation (Rodrigues and Choct 2018). The significant interaction between FR and sex for final body weight and DWG in chickens of the present study led to an increase in the differences between sexes, with differences of 7% and 13% for AL and restricted groups, respectively. These differences indicate higher growth depression in females than in males and that females were more sensitive to FR than males. This result was confirmed by the DWG data, which showed a decrease of 10% in males and 16% in females. Different responses of chicken males and females to FR correspond with the observations of Plavnik and Hurwitz (1991) and Tumova et al. (2002), who illustrated that chicken males had a greater ability to exhibit compensatory growth after FR than females, which is frequently explained by the faster growth rate observed in males. In the present study, the differences between sexes were underlined by a short realimentation period. Lower DWG impaired the FCR of restricted chickens, presumably due to a lack of compensatory growth, which is accompanied by a lower basal metabolism and thus better FCR (Shabani et al. 2015). However, rabbits and nutrias of the present study compensated for growth depression after passing the restricted period. Thus, no significant differences were detected in final body weight or DWG. In rabbits, none of the performance characteristics was affected by FR, sex, or their interaction, which might be associated with the lack of sexual dimorphism. These results are in accordance with those of Tumova et al. (2002), Gidenne et al. (2012), and Crespo et al. (2020). Conversely, in nutrias, growth performance characteristics of the present study were significantly affected by sex, where females showed a 16% lower final body weight and DWG than males. Growth intensity in the AL and restricted nutria groups was affected similarly in both sexes and corresponds with our recent results (Tumova et al. 2021b).

Carcass composition

Compensatory growth and final body weight might affect slaughter and carcass characteristics. In chickens of the present study, a significant interaction between FR and sex was observed for slaughter and carcass weights, which was mainly related to live body weight, and these results are in agreement with the findings of Shabani et al. (2015) and Tumova and Chodova (2018). Additionally, both measurements were significantly lower in restricted chickens than in AL chickens (Table 2). These results are in harmony with those of Livingston et al. (2019), who proved that restricted chickens had lower body and hot carcass weights than AL-fed chickens. With respect to the effect of sex as the main factor, chicken females had a significantly lower slaughter weight and breast percentage and higher DOP, which reflect the lower growth of females. Velleman et al. (2014), in line with van der Klein et al. (2017), reported

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that FR during the third week of age reduced breast muscle gain as a result of a short recovery time after feed restriction. However, the higher DOP in females of the present study might be related to lower gastrointestinal weight, as reported by van der Klein et al. (2017), who observed reduced gastrointestinal development after FR in females. The effects of feeding regime, sex, and their interaction on carcass characteristics in rabbits were negligible, which corresponds with the findings of Birolo et al. (2016; 2020a), Alabiso et al. (2017), and Chodova et al. (2019). The interaction of FR and sex in rabbits of the present study was observed in perirenal fat with the highest values in AL females and the lowest in AL males. However, the trait was not affected by sex as a fixed effect, which corresponds with Zapletal et al. (2020). In rabbits, perirenal fat is in relation to total dissectible fat (Dalle Zotte et al. 2020). In nutrias of the present study, sex was the only factor affecting the carcass weight and perirenal fat percentage, which might be assumed to be a result of sexual dimorphism. These results are consistent with those reported by Cabrera et al. (2007), who postulated that carcass composition is not dependent on sex in nutrias.

CONCLUSION

The results of the present study show similar effects of FR on the performance of rabbits and nutrias, whereas in chickens, the interaction between FR and sex played an important role. In spite of the different degree of sexual dimorphism of the evaluated species, the interactions in carcass composition were not important. Feed restriction as the main factor affected chicken growth and carcass composition. As expected, the effect of sex as a fixed factor was important in chickens and nutrias, which have a higher degree of sexual dimorphism.

Conflict of interest

The authors declare no conflict of interest.

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