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A comparative study on the effect of quantitative feed restriction in males and females of broiler chickens, rabbits and nutrias. II. Meat quality

Eva Tůmová[1], Darina Chodová[1], Zdeněk Volek[2], Tarek A. Ebeid[3,4], Mohamed Ketta[1], Věra Skřivanová[2]*

[1]*Department of Animal Science, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague-Suchdol, Czech Republic*
[2]*Institute of Animal Science, Prague-Uhříněves, Czech Republic*
[3]*Department of Poultry Production, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, Egypt*
[4]*Department of Animal Production and Breeding, College of Agriculture and Veterinary Medicine, Qassim University, Buraydah, Saudi Arabia*

**Corresponding author: chodova@af.czu.cz*

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Abstract: The objective of the study was to evaluate the effects of feed restriction and sex on the physical, chemical and histochemical parameters of meat quality in chickens, rabbits and nutrias. 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. The results showed stronger effects of feed restriction, sex, and their interaction on the meat quality of broiler chickens than in rabbits and nutrias. The effect of feed restriction, sex and their interaction were mainly observed in the nutritional value of meat, while physical measurements of meat were negligibly affected. The interaction between feed restriction and sex affected the cross-sectional area of muscle fibre only in rabbits and nutrias. The data indicated the relationships between compensatory growth, muscle fibre distribution, and nutritional value of meat.

Keywords: species; sex; feed restriction; physical and chemical meat quality; muscle fibres

The environmental and nutritional interactions are important in animal husbandry (Migdal et al. 2019). Among feeding strategies, feed restriction (FR) plays an important role in a reduction of metabolic disorders and might improve the production economics by decreasing the mortality. FR can be applied in various animal species and practically it has mainly been used in broiler chickens and rabbits. The effect of FR on performance has been described in broiler chickens (van der Klein et al. 2017; Tumova et al. 2021a), rabbits (Gidenne et al. 2012; Chodova et al. 2019; Crespo et al. 2020),

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pigs (Le Floc'h et al. 2014), lambs (Santos et al. 2018) and recently in nutrias (Tumova et al. 2021b). Sex differences in growth vary among the animal species. 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). Relatively large differences in live weight at eight months of age were shown by nutrias, approximately 24–26% (Tumova et al. 2017), whereas in rabbits sexual dimorphism in live weight at an early age is very low (Trocino et al. 2015a; Zapletal et al. 2020). The variability in live weight of males and females leads to differences in meat quality.

Meat quality is important for consumers and feeding strategy can provide further enrichment (Dalle Zotte et al. 2020). A minor effect of FR on physical meat quality characteristics has been described in chickens (Gratta et al. 2019), rabbits (Gidenne et al. 2012; Chodova et al. 2019) and cattle (Keady et al. 2017). Inconsistent data were documented for the meat nutritional value in rabbits. Alabiso et al. (2017) found no significant effect of FR on meat chemical composition. However, Birolo et al. (2016) observed higher dry matter and fat, while Crespo et al. (2020) noted lower dry matter and fat and a higher crude protein content in restricted rabbits. Similarly, inconsistent data have been published on muscle fibre characteristics, which are associated with biochemical characteristics. Gondret et al. (2000) and Chodova et al. (2019) illustrated that FR had no significant effect on muscle fibre characteristics. On the other hand, Dalle Zotte et al. (2005a) and Chodova et al. (2016) observed a higher proportion of type IIB fibres in restricted rabbits. Dalle Zotte et al. (2005a) noted a larger cross-sectional area (CSA) of all types of muscle fibres, whereas Chodova et al. (2019) recognized a smaller CSA in early weaned rabbits subjected to stronger FR. The inconsistent findings of the effect of FR on variable parameters of meat characteristics might be attributed to interactions with other factors, such as genotype, age, or sex. For example, Trocino et al. (2015a) observed the lower meat redness (a*) index and cooking loss in females compared to males. However, Dalle Zotte et al. (2016) found no significant effect of sex on meat chemical composition (except fatty acid composition) in rabbits.

It is assumed that the differences in body weight between males and females are associated with meat quality and muscle fibre characteristics. Thus, the results of FR can be contradictory due to the interactions of environmental factors, genotype or sex. Therefore, the objective of the present study was to evaluate the effects of quantitative FR on the physical and chemical parameters of meat quality, and muscle fibre characteristics of broiler chickens, rabbits, and nutrias with different degrees of sexual dimorphism.

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 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 Havlíčkův Brod (Czech Republic).

Experimental design

The methodology of the experiment was described by Tumova et al. (2022). Briefly, all experiments were designed as two factorials with two sexes and two types of feeding regimes, *ad libitum* throughout the whole experiment (AL) and quantitative feed restriction. In broiler chickens, feed restriction was applied between 14 and 21 days of age (FR), and during the restriction period chickens received 70% of the amount of feed consumed by the *ad libitum* group. The experiment lasted until the age of 31 days and live body weight of approximately 2 000 g. Rabbits were restricted between 42 and 49 days of age, and received 70% of the *ad libitum* feeding. The experiment was finished at the age of 70 days. In restricted nutria males and females, feed restriction was used in the 3rd month of age for four weeks (12th–15th week of age) and the animals received 70% of the *ad libitum* feeding. The end of the experiment was at eight months of age. After the fattening period, carcass dissection was performed on 12 chickens, 12 rabbits and nine nutrias from each group.

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Meat physical analyses

The carcass cuts from the carcass analysis were used for meat quality assessment. The pH in chickens was measured in breast muscle (the right *pectoralis major* muscle, PM) and in rabbits and nutrias on the right side of the loin (*musculus longissimus lumborum*) 24 h *post mortem* with a Jenway pH meter (Jenway, Essex, UK) with a glass probe introduced 1 cm deep. The pH meter was calibrated prior to measurement using commercial pH 4, pH 7, and pH 9 buffer solution standards (Penta, Prague, Czech Republic) at room temperature. Meat colour was measured with a Minolta SpectraMagic^{TM} NX analyzer (Konica Minolta Sensing, Inc., Osaka, Japan) with a CIEL*a*b* system (CIE, Commission Internationale de l'Eclairage, 1976) using the SAV measurement area (3 mm), observation at 10 degrees, and D65 illuminant. Three measurements per sample distributed on the muscle cross-section surface were taken after 30 min of air exposure to allow blooming. The cooking loss was determined on the right side of the breast in chickens and on the right side of the loin in rabbits. The samples were weighed, packed in plastic zip bags, and heated in a GFL 1013 water bath (Gesellschaft für Labortechnik, Burgwedel, Germany) of a temperature of 80 °C to a sample core temperature of 80 °C. The core temperature was controlled using a DT-1 digital thermometer (Termoprodukt, Bielawa, Poland). Subsequently, the samples were depacked and cooled to room temperature; the remaining liquid was aspirated with a paper towel, and the samples were weighed to determine the weight after cooking. The drip loss was determined on the right side of chicken breast and right side of rabbit loin by calculating the difference between the weight at the time of slaughter analysis and that after storage for 24 h at 4 °C. The cooking loss was calculated using the weights of the raw and cooked samples. Meat tenderness was detected in the right breast muscle in chickens and the right side of loin in rabbits by the Warner-Bratzler method. Samples (2 × 1 cm) of cooled meat were cut perpendicularly to the muscle fibres using an Instron texture analyzer (Instron Model 3342, Norwood, MA, USA) with a Warner-Bratzler shear blade containing a triangular hole to determine the maximum shear force (F_{max}) with a load cell of 20 N, a crosshead speed of 100 mm/min, and a sampling rate of 20 points/s. The drip loss, cooking loss, and F_{max} were not determined in nutrias.

Meat chemical analysis

The meat chemical composition was determined in the left chicken breast muscle and the left side of loin of rabbits and nutrias using methods of AOAC (2005). Prior to analyses, the samples were vacuum-packed, frozen at –20 °C and stored for approximately two months until the start of analysis. Twenty-four hours before analysis, the samples were thawed inside their vacuum bags at +4 °C. Dry matter was determined by oven drying at 105 °C (Method 934.01), and ether extract was determined by extraction with petroleum ether in a Soxtec 1043 apparatus (FOSS Tecator AB, Höganäs, Sweden; Method 920.39). Protein content was determined using a Kjeltec Auto 1030 Analyzer (FOSS Tecator AB, Höganäs, Sweden; Method 954.01). Ash content was determined according to Method 920.153, and hydroxyproline (HPR) was determined by acid hydrolysis according to Diemar (1963). Meat cholesterol content was analysed in chickens and nutrias. The samples were saponified with potassium hydroxide in ethanolic solution, and cholesterol was extracted with *n*-hexane. Cholesterol content was detected by a gas chromatographic method using a Perkin Elmer 5000 apparatus (Perkin Elmer Inc., Wellesley, MA, USA). The total cholesterol content was calculated based on an external standard technique from a standard curve of peak area versus concentration. The cholesterol content was not determined in rabbits. The energy value of meat was calculated using an equation based on the protein and fat contents in meat: energy value (MJ/kg) = [(16.74 × protein content) + (37.66 × fat content)]/1 000.

Determination of muscle fibre characteristics

Histochemical analysis of the muscle fibre characteristics was performed in the *biceps femoris* (BF) muscles. Samples were collected immediately after slaughter and frozen in 2-methylbutane with liquid nitrogen (–156 °C). Six cross-sections (12 µm) of each sample were obtained from entire blocks (0.5 × 0.5 × 1.5 cm) using a Leica CM 1850 cryostat (Leica Microsystems Nussloch GmbH, Nussloch, Germany) at –20 °C and treated with myofibrillar ATPase stain after successive preincubations in alkaline buffer (Brooke and Kaiser

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1970). After staining, the samples were fixed and captured using a Nikon Eclipse E200 microscope with a DS-Fi1 camera (Nikon, Tokyo, Japan). An image analysis system, NIS Elements AR v3.1 software (Nikon, Tokyo, Japan), was used to examine the stained sections. For analysis of each sample, the muscle fibre from an area of 1 mm^2 was evaluated. The fibres were classified as type I (red, slow-twitch oxidative fibres), type IIA (red, fast-twitch oxido-glycolytic fibres), or type IIB (white, fast glycolytic fibres) according to the nomenclature of Brooke and Kaiser (1970). For each muscle fibre type, the percentage and the mean (μm^2) were determined using NIS Elements AR v3.1 software (Nikon, Tokyo, Japan).

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. The individual chicken, rabbit, and nutria represented the experimental unit for physical, chemical, and histochemical measurements. The differences between groups in meat quality parameters were tested by Duncan's test. Significance was considered at the P < 0.05 level.

RESULTS

Physical properties of meat

Physical characteristics of meat were less affected by the evaluated factors than chemical composition (Tables 1–3). The interaction between FR and sex affected the redness (a*) of chicken breast (P = 0.038). The highest a* value was detected in restricted females, and the lowest a* value was observed in AL females (Table 1). In nutrias, a significant interaction between FR and sex was observed for loin lightness (L*) (Table 3), when the lightest meat was noted in AL females and the darkest meat was noted in restricted females (P = 0.034). Regarding the influence of the main factors in the present study, FR increased meat pH (P < 0.001) and the L* value (P < 0.001) and decreased the a* value (P < 0.001) in nutrias (Table 3), while F_{max} decreased in rabbits (P < 0.001) (Table 2). In relation to the effect of sex, females had a higher F_{max} than males in rabbits (P = 0.042) (Table 2).

Chemical composition of meat

The nutritional value of meat was affected by the interaction between FR and sex in all studied animal species, with a stronger effect in chickens

Table 1. Physical and chemical meat characteristics of *ad libitum* and restricted chickens

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
pH	5.88	5.85	5.87	6.11	0.072	0.392	0.454	0.353
Lightness	49.3	50.1	50.3	49.9	0.451	0.683	0.796	0.565
Redness	–0.84^{bc}	–1.32^{a}	–0.96^{b}	–0.72^{c}	0.088	0.169	0.484	0.038
Yellowness	5.77	5.04	5.82	6.07	0.197	0.175	0.545	0.217
Drip loss (%)	0.47	0.47	0.53	0.43	0.035	0.898	0.479	0.522
Cooking loss (%)	26.3	26.0	26.3	24.8	0.369	0.424	0.214	0.437
F_{max} (N)	15.3	15.1	11.5	12.0	1.062	0.114	0.951	0.881
Dry matter (g/kg)	253.4^{a}	246.8^{bc}	244.5^{c}	248.8^{b}	1.02	0.064	0.532	0.005
Crude protein (g/kg)	224.3^{a}	214.6^{c}	210.1^{d}	221.8^{b}	1.26	0.064	0.592	< 0.001
Ether extract (g/kg)	10.6	7.0	7.9	5.9	0.47	0.018	< 0.001	0.330
Ash (g/kg)	11.6	11.8	11.3	11.9	0.07	0.569	0.018	0.184
HPR (g/kg)	0.51	0.45	0.53	0.41	0.01	0.559	< 0.001	0.068
Cholesterol (mg/kg)	438.9	412.6	416.7	400.9	16.4	0.621	0.539	0.878
Enegetic value (MJ/kg)	4.15^{a}	3.86^{c}	3.81^{c}	3.93^{b}	0.032	< 0.001	0.016	< 0.001

AL = *ad libitum*; F_{max} = maximum shear force; FR = feed restriction; HPR = hydroxyproline

$^{a–d}$Within a row, means with different superscripts are significantly different

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Table 2. Physical and chemical meat characteristics of *ad libitum* and restricted rabbits

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
pH	5.72	5.69	5.68	5.70	0.011	0.501	0.915	0.417
Lightness	52.2	46.6	49.7	53.6	1.819	0.549	0.819	0.218
Redness	0.63	–0.07	–0.96	–1.26	0.309	0.024	0.390	0.722
Yellowness	8.70	7.53	6.72	6.94	0.397	0.113	0.548	0.384
Drip loss (%)	3.96	4.46	4.09	4.64	0.102	0.407	0.102	0.912
Cooking loss (%)	29.6	30.6	29.9	29.8	0.209	0.539	0.348	0.222
F_{max} (N)	21.0	23.9	25.2	26.1	0.480	0.001	0.042	0.247
Dry matter (g/kg)	246.9[c]	251.3[b]	254.5[a]	251.3[b]	0.83	0.012	0.654	0.009
Crude protein (g/kg)	215.5	217.4	218.3	217.6	0.64	0.258	0.634	0.339
Ether extract (g/kg)	12.5	14.5	17.1	14.4	0.75	0.137	0.807	0.112
Ash (g/kg)	11.9	11.9	12.1	12.0	0.04	0.455	0.825	0.845
HPR (g/kg)	1.25	1.29	1.28	1.24	0.03	0.916	0.987	0.490
Cholesterol (mg/kg)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Enegetic value (MJ/kg)	4.08[c]	4.18[b]	4.29[a]	4.18[b]	0.03	0.039	0.955	0.037

AL = *ad libitum*; F_{max} = maximum shear force; FR = feed restriction; HPR = hydroxyproline; n.d. = not determined
[a–c]Within a row, means with different superscripts are significantly different

Table 3. Physical and chemical meat characteristics of *ad libitum* and restricted nutrias

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
pH	5.79	5.83	6.05	5.98	0.027	< 0.001	0.363	0.267
Lightness	42.2[c]	35.5[d]	47.8[b]	51.8[a]	1.462	< 0.001	0.851	0.034
Redness	10.6	7.5	4.6	3.9	0.614	< 0.001	0.129	0.227
Yellowness	13.6	11.2	12.4	12.0	0.402	0.814	0.190	0.240
Drip loss (%)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cooking loss (%)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
F_{max} (N)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Dry matter (g/kg)	252.9	254.0	249.9	260.7	1.46	0.477	0.032	0.074
Crude protein (g/kg)	198.2[a]	194.3[b]	194.8[b]	197.3[ab]	0.61	0.876	0.521	0.008
Ether extract (g/kg)	27.4	32.2	28.7	32.3	1.65	0.308	0.042	0.528
Ash (g/kg)	10.9	10.9	10.7	10.5	0.07	0.019	0.861	0.380
HPR (g/kg)	1.07	0.98	1.06	1.14	0.02	0.103	0.935	0.058
Cholesterol (mg/kg)	485.1	533.2	421.4	491.5	12.5	0.016	0.008	0.587
Enegetic value (MJ/kg)	4.34	4.46	4.34	4.71	0.06	0.287	0.380	0.266

AL = *ad libitum*; F_{max} = maximum shear force; FR = feed restriction; HPR = hydroxyproline; n.d. = not determined
[a–d]Within a row, means with different superscripts are significantly different

(Tables 1–3). In chickens, the highest dry matter (P = 0.005) and crude protein (P < 0.001) were obtained in AL males, and the lowest were obtained in restricted males. The highest energy value was detected in AL males, and the lowest was detected in both AL females and restricted males (P < 0.001) (Table 1). In rabbits, AL males had the lowest dry matter (P = 0.009) and energy value (P = 0.003), whereas the restricted males had the highest values (Table 2). In nutrias, the highest crude protein was noted in AL males, and the lowest was noted in AL females and restricted males (P = 0.008) (Table 3). Regarding the effects of main factors, FR decreased the ether extract (P = 0.018) and energy

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value (P < 0.001) in chickens (Table 1), increased the dry matter (P = 0.012) and energy value (P = 0.039) in rabbits (Table 2), and decreased the ash (P = 0.019) and cholesterol (P = 0.016) contents in nutrias (Table 3). Regarding the effect of sex, the nutritional value of meat was not affected in rabbits (Table 2), while in chickens, females had a significantly lower ether extract, hydroxyproline content, and energy value and a higher ash content than males (Table 1). In nutrias, males had lower dry matter (P = 0.032), ether extract (P = 0.042), and cholesterol (P = 0.008) values than females (Table 3).

Histochemical measurements of muscle fibres

The interaction between FR and sex affected only the CSA of rabbits and nutrias. In rabbits, the CSA of type I fibres was the highest in restricted males and the lowest in AL males (P = 0.031) (Table 4). In nutrias, the CSA was affected in type I and type IIB fibres (Table 5). Fibres of type I are red and oxidative, and the highest CSA was detected in restricted females (P = 0.018). In contrast, fibres of type IIB are white and glycolytic, and the largest size was detected in AL males, while the lowest size was revealed in restricted males (P < 0.001). In chickens, the fixed factor FR had a negligible effect on muscle fibre measurements and it only decreased the number (P = 0.030) and CSA of type IIB fibres (P < 0.001) (Table 6), while in rabbits, FR significantly lowered the number and percentage of type I muscle fibres and increased the percentage and CSA of type IIB fibres (Table 4). In contrast to the pattern in rabbits, a significant effect of FR was observed in nutrias, when FR significantly increased the number and percentage of type I fibres and reduced the percentage and CSA of type IIB fibres (Table 5). With respect to the effect of sex as a fixed factor, chicken males had a significantly higher number of type I and IIB fibres and a lower CSA of fibres of type IIB than females (Table 6). Similarly, rabbit males had a lower CSA of type IIB fibres (Table 4).

DISCUSSION

Physical properties of meat

The effects of FR, sex, and their interaction on physical measurements of meat quality were minor in all investigated species. Only in chickens did FR increase meat redness, which might be associated with a tendency for increased red muscle fibres in restricted females and their lower growth, as reported by Keady et al. (2017). Conversely, in nutrias, the interaction between FR and sex increased the meat darkness of restricted females, which is in contrast to our recent results (Tumova et al. 2021b), indicating that meat physical measurements were not affected by FR. The contrasting

Table 4. Muscle fiber characteristics of *ad libitum* and restricted rabbits in *biceps femoris*

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
Number (pieces per 1 mm^2)								
Type I	30.7	26.7	15.3	16.0	2.140	0.001	0.638	0.512
Type IIA	12.7	11.3	12.0	12.0	0.963	1.000	0.749	0.749
Type IIB	266.7	230.0	251.3	219.3	8.648	0.443	0.052	0.890
Percentage of total fibres (%)								
Type I	10.0	10.0	5.8	6.5	0.746	0.009	0.803	0.831
Type IIA	4.2	4.4	4.4	4.9	0.374	0.669	0.704	0.861
Type IIB	85.8	85.6	89.8	88.7	0.852	0.045	0.698	0.795
Cross sectional area (μm^2)								
Type I	2 470^b	2 726^{ab}	2 948^a	2 617^{ab}	65.175	0.173	0.779	0.031
Type IIA	1 678	1 574	1 698	1 670	62.516	0.653	0.607	0.769
Type IIB	2 789	3 307	3 073	3 370	33.498	0.009	< 0.001	0.094

AL = *ad libitum*; FR = feed restriction

^{a,b}Within a row, means with different superscripts are significantly different

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Table 5. Muscle fiber characteristics of *ad libitum* and restricted nutrias in *biceps femoris*

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
Number (pieces per 1 mm^2)								
Type I	14.0	24.7	40.3	43.0	4.469	0.011	0.414	0.622
Type IIA	7.3	11.3	9.2	8.0	1.218	0.769	0.581	0.318
Type IIB	156.7	202.7	145.0	165.3	12.307	0.331	0.192	0.607
Percentage of total fibres (%)								
Type I	7.8	10.7	21.0	19.3	1.609	< 0.001	0.806	0.338
Type IIA	4.4	5.1	4.6	4.6	0.654	0.910	0.823	0.782
Type IIB	87.8	84.1	74.3	76.2	1.808	0.002	0.763	0.369
Cross sectional area (μm^2)								
Type I	1 874^{ab}	1 774^{b}	1 737^{b}	2 279^{a}	60.048	0.174	0.103	0.018
Type IIA	2 067	2 137	1 581	2 376	116.257	0.593	0.064	0.119
Type IIB	4 254^{a}	3 563^{bc}	3 428^{c}	3 770^{b}	48.878	< 0.001	0.060	< 0.001

AL = *ad libitum*; FR = feed restriction

$^{a–c}$Within a row, means with different superscripts are significantly different

Table 6. Muscle fiber characteristics of *ad libitum* and restricted chickens in *biceps femoris*

Characteristic	AL		FR		SEM	Significance		
	male	female	male	female		FR	sex	FR × sex
Number (pieces per 1 mm^2)								
Type I	18.2	10.0	29.3	12.0	3.110	0.286	0.044	0.456
Type IIA	13.8	9.3	12.7	16.0	1.793	0.467	0.884	0.311
Type IIB	368.0	302.6	430.7	363.3	15.710	0.042	0.030	0.973
Percentage of total fibres (%)								
Type I	4.7	3.4	6.3	3.0	0.712	0.689	0.123	0.497
Type IIA	3.7	3.1	2.7	4.3	0.506	0.915	0.650	0.321
Type IIB	91.6	93.5	91.0	92.7	1.003	0.745	0.397	0.970
Cross sectional area (μm^2)								
Type I	1 233	1 407	1 200	1 079	52.449	0.128	0.823	0.211
Type IIA	1 560	1 749	1 591	1 779	70.263	0.838	0.205	0.995
Type IIB	1 896	2 372	1 599	1982	20.915	< 0.001	< 0.001	0.267

AL = *ad libitum*; FR = feed restriction

results of these studies in nutrias might be related to the method of restriction and age.

Chemical composition of meat

Although FR and sex had negligible effects on physical measurements of meat, they had a stronger impact on the nutritional value of meat. An interaction between FR and sex was observed for meat dry matter and energy in chickens and rabbits and for meat crude protein in chickens and nutrias. However, a comparison between species revealed opposite effects in the two species. A different reaction of each species indicates the importance of sexual dimorphism and their response to FR. Compared to our recent experimental results in nutrias (Tumova et al. 2021b), the results are contrasting, and this inconsistency might be attributed to the method of FR, the period of FR, or the age of the animal. However, no comparable data are available in chickens and rabbits. Regarding the individual fixed factors considered in the present study, sex affected chemical compo-

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sition of meat in both chickens and nutrias, as these species possess higher levels of sexual dimorphism than rabbits. The meat contents of fat and HPR in chicken females were lower than those in males. Similarly, the meat fat content in nutria females was lower than that in males. These results are in contrast with those of Baeza et al. (2010), who observed higher fatness in female chickens than in male ones. The opposite result obtained in the present study might be associated with FR, which had a stronger negative impact on muscle growth and development, reduced fat and collagen, and tended to reduce cholesterol deposition in muscles. This assumption agrees with the finding of Englmaierova et al. (2021) that FR minimized breast meat cholesterol content and tended to decrease breast fat content in medium-growing chickens. It was reported that lipid deposition is regulated by the nutritional status and might be related to a reduction of the activity of the enzymes involved in biosynthesis (Crespo et al. 2020). Both contrasting results indicate the importance of the interaction between FR and sex in determining chemical composition of meat.

Histochemical measurements of muscle fibres

The effects of FR, sex, and their interaction on muscle fibre characteristics were evaluated in BF muscle, which is an oxidative-glycolytic muscle containing fibres of type I (oxidative), type IIA (oxidative-glycolytic), and IIB (glycolytic), in comparison with PM or *longissimus lumborum* muscle (LL), which have minimal contents of type I and IIA fibres. However, the literature dealing with chickens shows data on PM in relation to the sensitivity to muscle defects (Velleman et al. 2014; Trocino et al. 2015b; Gratta et al. 2019), and in rabbits in relation to LL (Dalle Zotte et al. 2005b; Chodova et al. 2019). Powell et al. (2014) inferred different effects of FR on PM and BF fibre metabolism in their results. In the present study, muscle fibre distribution was significantly affected by FR in rabbits and nutrias, with opposite effects. Recently, Englmaierova et al. (2021) found that FR increased the number and decreased the area and diameter of muscle fibres in medium-growing chickens. However, in fast-growing chickens Chodova et al. (2021a) observed that the low protein diet did not affect the density of muscle fibres and increased the CSA. In rabbits of the present study, FR increased glycolytic fibres of type IIB, whereas in nutrias it increased oxidative fibres of type I, which is coincident with the findings of Dalle Zotte et al. (2005a) that compensatory growth (detected in rabbits but not in nutrias) enhanced glycolytic energy metabolism and resulted in lower oxidative energy metabolism in muscle. Additionally, changes in the muscle fibre distribution to glycolytic metabolism lead to lipid accumulation in muscles (Powel et al. 2014) and might explain changes in the chemical composition of muscles. The absence of the effect of FR on muscle fibre distribution in chickens might be related to the time of FR in the present study because Velleman et al. (2014) showed that morphological changes observed after FR in the 1st week of age were eliminated by moving the restriction to the 2nd week of age. At the level of gene expression, early FR (from 13 to 23 days of age) and late FR (from 27 to 37 days of age) reduced the expression of calsequestrin and vascular endothelial growth factor mRNA, which are involved in stimulating the proliferation and differentiation of muscle fibres, leading to a reduction in the rates and degrees of myopathies in PM muscle in broiler chickens (Gratta et al. 2019). In chickens of the present study, muscle fibre distribution was affected by sex, and this effect might be associated with differences in slaughter weight. The distribution of fibres closely correlates with the CSA and the dominant type of fibres (type IIB). The number of type IIB fibres was significantly higher in chicken males than in females and associated with the lower CSA in the former group. Conversely, in rabbits and nutrias, the interaction between FR and sex for the CSA explained that this effect in fibres of type I was related with the significantly higher CSA in restricted rabbit males and nutria females. In nutrias, the interaction between FR and sex affected fibres of type IIB, with the largest size in AL males. Regarding the effect of FR as a main factor on the CSA, fibres of type IIB were negatively affected in chickens and nutrias and positively affected in rabbits. It might be assumed that these changes in the CSA are associated with the compensatory growth detected in rabbits and suggested in nutrias but lacking in chickens. With respect to the effect of sex as a main factor, the lower CSA of type IIB fibres was detected in rabbit females and chicken males, which reflected the higher density

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of these fibres in rabbit females and chicken males. In contrast, the sex in chickens had no influence on muscle fibre characteristics (Chodova et al. 2021b).

CONCLUSION

The significant effects of the interaction between FR and sex on meat quality parameters are more important when the animals do not show any compensatory growth. Effects of FR, sex, and their interaction were mainly observed in the nutritional value of meat, while physical measurements of meat were negligibly affected. Feed restriction was a main factor affecting muscle fibre parameters in rabbits and nutrias. As expected, the effect of sex as a fixed factor was important in chickens and nutrias, which have a higher degree of sexual dimorphism. However, more research is still needed to understand the mechanisms underlying the effects of FR on meat quality.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Alabiso M, Di Grigoli A, Mazza F, Maniaci G, Vitale F, Bonanno A. A 3-week feed restriction after weaning as an alternative to a medicated diet: Effects on growth, health, carcass and meat traits of rabbits of two genotypes. Animal. 2017 Sep;11(9):1608-16.

AOAC – Association of Official Analytic Chemists. Official methods of analysis. 18th ed. Maryland, USA: Association of Official Analytical Chemists; 2005.

Baeza E, Chartrin P, Meteau K, Bordeau T, Juin H, Le Bihan-Duval E, Lessire M, Berri C. Effect of sex and genotype on carcase composition and nutritional characteristics of chicken meat. Br Poult Sci. 2010 Aug 2;51(8):344-53.

Birolo M, Trocino A, Zuffellato A, Xiccato G. Effect of feed restriction programs and slaughter age on digestive efficiency, growth performance and body composition of growing rabbits. Anim Feed Sci Technol. 2016 Dec 1; 222(12):194-203.

Brooke MH, Kaiser K. Muscle fiber types: How many and what kind? Arch Neurol. 1970 Oct 1;23(4):369-79.

Chodova D, Tumova E, Volek Z, Skrivanova V, Vlckova J. The effect of one-week intensive feed restriction and age on the carcass composition and meat quality of growing rabbits. Czech J Anim Sci. 2016 Apr;61(4):151-8.

Chodova D, Tumova E, Volek Z. The effect of limited feed intake on carcase yield and meat quality in early weaned rabbits. Ital J Anim Sci. 2019 Jan;18(1):381-8.

Chodova D, Tumova E, Ketta M. The response of fast-, medium- and slow-growing chickens to a low protein diet. Czech J Anim Sci. 2021a Mar 2;66(3):97-105.

Chodova D, Tumova E, Ketta M, Skrivanova V. Breast meat quality in males and females of fast-, medium- and slow-growing chickens fed diets of 2 protein levels. Poult Sci. 2021b Apr 1;100(4): 9 p.

Crespo R, Alfonso C, del Barrio AS, Garcia-Ruiz AI, Marco M, Nicodemus N. Effect of feed restriction on performance, carcass yield and nitrogen and energy balance in growing rabbits. Livest Sci. 2020 Nov;241(11):104278.

Dalle Zotte A, Remignon H, Ouhayoun J. Effect of feed rationing during post-weaning growth on meat quality, muscle energy metabolism and fibre properties of Biceps femoris muscle in the rabbit. Meat Sci. 2005a Jun 1;70(6):301-6.

Dalle Zotte A, Remignon H, Chiericato GM. Influence of maternal feed rationing on metabolic and contractile properties of Longissimus lumborum muscle fibres in the rabbit offspring. Meat Sci. 2005b Aug 1;70(8):573-7.

Dalle Zotte A, Cullere M, Alberghini L, Catellani P, Paci G. Proximate composition, fatty acid profile, and heme iron and cholesterol content of rabbit meat as affected by sire breed, season, parity order, and gender in an organic production system. Czech J Anim Sci. 2016 Sep 27;61 (9):383-90.

Dalle Zotte A, Cullere M, Gleeson E, Cossu ME. Animal fat and vitamin E in rabbit diets: Total tract apparent digestibility, growth performance, carcass and meat quality traits. Czech J Anim Sci. 2020 Oct 27;65(10):380-8.

Diemar W. Laboratoriembuch fur den Lebensmittelchemiker [Laboratory manual for food chemists]. Dresden: Theodor Steinkopf Verlag; 1963. German.

Englmaierova M, Skrivan M, Taubner T, Skrivanova V, Cermak L. Effect of housing system and feed restriction on meat quality of medium-growing chickens. Poult Sci. 2021 Aug;100(8): 8 p.

Gidenne T, Combes S, Fortun-Lamothe L. Feed intake limitation strategies for the growing rabbit: Effect on feeding behaviour, welfare, performance, digestive physiology and health: A review. Animal. 2012 Sep;6(9):1407-19.

Gondret F, Lebas F, Bonneau M. Restricted feed intake during fattening reduces intramuscular lipid deposition without modifying muscle fiber characteristics in rabbits. J Nutr. 2000 Feb 1;130(2):228-33.

Gratta F, Birolo M, Sacchetto R, Radaelli G, Xiccato G, Ballarin C, Bertotto D, Piccirillo A, Petracci M, Maertens L,

https://doi.org/10.17221/186/2021-CJAS

Trocino A. Effect of feed restriction timing on live performance, breast myopathy occurrence, and muscle fiber degeneration in 2 broiler chicken genetic lines. Poult Sci. 2019 Nov 1;98(11):5465-76.

Keady SM, Waters SM, Hamill RM, Dunne PG, Keane MG, Richardson RI, Kenny DA, Moloney AP. Compensatory growth in crossbred Aberdeen Angus and Belgian Blue steers: Effects on the colour, shear force and sensory characteristics of longissimus muscle. Meat Sci. 2017 Mar 1; 125(3):128-36.

Le Floc'h N, Knudsen C, Gidenne T, Montagne L, Merlot E, Zemb O. Impact of feed restriction on health, digestion and faecal microbiota of growing pigs housed in good or poor hygiene conditions. Animal. 2014 Jun 25;8(10):1632-42.

Migdal L, Palka S, Kmiecik M, Derewicka O. Association of polymorphisms in the GH and GHR genes with growth and carcass traits in rabbits (Oryctolagus cuniculus). Czech J Anim Sci. 2019 Jun 18;64(6):255-64.

Powell DJ, McFarland DC, Cowieson AJ, Muir WI, Velleman SG. The effect of nutritional status on myogenic gene expression of satellite cells derived from different muscle types. Poult Sci. 2014 Sep 1;93(9):2278-88.

Santos A, Valdes C, Giradez FJ, Lopez S, France J, Frutos J, Fernandez M, Andres S. Feed efficiency and the liver proteome of fattening lambs are modified by feed restriction during the suckling period. Animal. 2018 Sep;12 (9):1838-46.

Trocino A, Filiou E, Tazzoli M, Birolo M, Zuffellato A, Xiccato G. Effects of floor type, stocking density, slaughter age and gender on productive and qualitative traits of rabbits reared in collective pens. Animal. 2015a Jan 1; 9(5):855-61.

Trocino A, Piccirillo A, Birolo M, Radaelli G, Bertotto D, Filiou E, Petracci M, Xiccato G. Effect of genotype, gender and feed restriction on growth, meat quality and the occurrence of white striping and wooden breast in broiler chickens. Poult Sci. 2015b Dec 1;94(12):2996-3004.

Tumova E, Chodova D, Vlckova J, Nemecek T, Uhlirova L, Skrivanova V. Age-related changes in the carcass yield and meat quality of male and female nutrias (Myocastor coypus) under intensive production system. Meat Sci. 2017 Nov 1;133(11):51-5.

Tumova E, Chodova D, Skrivanova E, Lalouckova K, Subrtova-Salmonova K, Ketta M, Machander V, Cotozzolo E. Research note: The effects of genotype, sex, and feeding regime on performance, carcasses characteristic, and microbiota in chickens. Poult Sci. 2021a Feb 1;100(2):760-4.

Tumova E, Chodova D, Volek Z, Ketta M. The effect of feed restriction, sex and age on the carcass composition and meat quality of nutrias (Myocastor coypus). Meat Sci. 2021b Jul 10;182(12): 6 p.

Tumova E, Chodova D, Volek Z, Ebeid TA, Ketta M, Skrivanova V. A comparative study on the effect of quantitative feed restriction in males and females of broiler chicken, rabbits and nutrias. I. Performance and carcass composition. Czech J Anim Sci. Forthcoming 2022.

van der Heide EMM, Lourenco DAL, Chen CI, Herring WO, Sapp RL, Moser DW, Tsuruta S, Masuda Y, Duero BJ, Misztal I. Sexual dimorphism in livestock species selected for economically important traits. J Anim Sci. 2016 Sep 1; 94(9):3684-92.

van der Klein SAS, Silva FA, Kwakkel RP, Zuidhof MJ. The effect of quantitative feed restriction on allometric growth in broilers. Poultry Sci. 2017 Jan 1;96(1):118-26.

Velleman SG, Coy CS, Emmerson DA. Effect of the timing of posthatch feed restrictions on the deposition of fat during broiler breast muscle development. Poult Sci. 2014 Oct 1;93(10):2622-7.

Zapletal D, Jakesova P, Zakova E, Simek V, Strakova E. Growth performance, mortality and body and carcass characteristics of rabbit fatteners related to crossbreeding of Mecklenburger Schecke sires with dam line of HYLA rabbits. Czech J Anim Sci. 2020 Sep 30;65(9):337-45.

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