Effect of housing system and genotype on rabbit meat quality

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ABSTRACT: The effect of the housing system on the carcass characteristics, physical parameters of meat quality, fatty acid composition, and muscle fibre characteristics was studied in some Czech breeds. Ninety-six rabbits from seven different breeds of Czech genetic resources (Moravian Blue, Czech White, Czech Solver, Czech Spotted, Moravian White of Brown Eye, Czech Gold, and Czech Black Guard Hair) and one rabbit commercial hybrid (Hyplus), kept in two housing systems: intensive system (wire-net cages) or alternative (straw-bedded pen), were slaughtered at the age of 91 days. Alternatively housed rabbits had lower weight at slaughter, lower weight of loin, of hind legs meat, and of renal fat than rabbits from cages. The interactions between housing system and genotype were reflected significantly in pH value, and lightness and yellowness of *biceps femoris*. The highest ($P \leq 0.047$) pH was observed in Hyplus (6.68) from cages, while the lowest value was noted in Moravian White of Brown Eye (6.26). The significantly ($P \leq 0.010$) lightest meat was detected in Czech Solver (60.93) and the darkest in Czech Gold (47.81). Alternatively reared rabbits showed significantly ($P \leq 0.001$) lower monounsaturated fatty acids (MUFA) (26.63%) and higher ($P \leq 0.001$) polyunsaturated fatty acids (PUFA) (36.73%) contents than rabbits from cages (36.94% MUFA and 26.23% PUFA). The alternatively housed group had also higher n-3 and n-6 PUFA contents and higher PUFA : SFA ratio than the intensively housed one. Significant interactions ($P \leq 0.001$) were observed in cross sectional area (CSA), diameter, and perimeter of muscle fibres of type I. The largest ($P \leq 0.001$) CSA of type I muscle fibre had Czech Black Guard Hair from cages (2573.1 μm^2), while in pens this breed exhibited the smallest CSA (1219.6 μm^2), diameter (38.68 μm), and perimeter (130.2 μm). Fibre type distribution was not affected by any of the monitored parameters. The effect of interactions of the housing system and genotype was manifested mainly in physical and muscle fibre characteristics.

Keywords: breed; carcass traits; fatty acids; muscle fibre characteristics

The intensive housing system for rabbits is based on group wire cages, which are located inside buildings (Hernández and Gondret, 2006). However, with the increasing customer demand for high quality animal products (Keskin et al., 2012) mainly home-made products or meat from alternative rearing systems complying with the conditions of welfare become still more required.

The housing system is one of the factors, which moderately affect rabbit carcass and meat quality (Dal Bosco et al., 2000; 2002; Dalle Zotte, 2002). Because of higher locomotory activity, pen housed rabbits have lower slaughter weight than those housed in cages (Maertens and Van Herck, 2000; Lambertini et al., 2001; Metzger et al., 2003; Combes et al., 2010). Also dressing percentage as one of the most important characteristics is significantly higher in caged rabbits (Dal Bosco et al., 2002; Metzger et al., 2003; Lazzaroni et al., 2009a; Combes et al., 2010). In the pen housed rabbits, only the weight of the hind part was higher, the other carcass characteristics were not affected by the housing system (Metzger et al., 2003; Lazzaroni et al., 2009a).

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Similarly as live weight, parameters of meat quality can also be affected by the housing system. Rabbit meat is easily digestible and has a very high nutritional value. It is high in protein, low in fat, low in cholesterol – approximately 59 mg/100 g muscle (Gondret et al., 1998) and also the n-3/n-6 polyunsaturated fatty acids ratio is low (Hernández and Gondret, 2006; Cavani et al., 2009). Fats in rabbit meat contain about 36.9% saturated fatty acids (SFA) (Hernández, 2008), around 60% unsaturated fatty acids and polyunsaturated fatty acids (PUFA), and roughly 32.5% fatty acids (FA) in total (Dalle Zotte and Szendrö, 2011). Volek et al. (2012) stated that rabbits reared at the lower stocking density yielded hind leg meat with the lower content of medium-chain fatty acids. Housing system influenced physical characteristics of meat – pH (Dal Bosco et al., 2000, 2002) and colour of meat (Dal Bosco et al., 2002; Dalle Zotte et al. 2009; Combes et al., 2010). As mentioned above, many authors studied the influence of housing system on performance, meat quality, and other parameters in hybrids, but only few authors examined this effect in local rabbit breeds. According to D'Agata et al. (2009) and Lazzaroni et al. (2009a), Italian local breeds had higher dressing out percentage in cage or indoor housing system than in pens or outdoor system. However, these authors show contradictory results of meat characteristics. The present study is the first study which investigates the effect of the housing system on meat quality characteristics, especially on muscle fibre parameters in Czech local rabbit breeds. Consequently, the aim of this study was to evaluate the effect of the two housing systems and genotype on slaughter parameters, physical traits of meat, muscle fibre characteristics, and fatty acids composition.

MATERIAL AND METHODS

A total of 96 rabbits (n = 6) of eight different genotypes housed in two systems were included in the experiment. The following Czech rabbit genetic resources were represented: giant breed Moravian Blue (MB), medium breeds Czech White (CW), Czech Spotted (CS), Czech Solver (CSo), Moravian White of Brown Eye (MW), small breeds Czech Black Guard Hair (CB), Czech Gold (CG), and a commercial hybrid Hyplus (PS 19 × PS 39). Pure breed characteristics were described by Tůmová et al. (2011). Rabbits were weaned at 42 days of age, housed in two different housing systems. In intensive system, rabbits were housed in collective wire net cages Kovobel D-VK-72 (Kovobel, Domažlice, Czech Republic) with the density of 1 rabbit per 0.09 m^2 (2 rabbits per cage). In alternative system, rabbits were housed in straw-bedded pens with the same density of 1 rabbit per 0.09 m^2 (10 rabbits per pen). Environmental conditions in both housings were the following: temperature 16–17°C, relative humidity 65%, lightening period 12 h light : 12 h darkness. Rabbits in both housing systems were fed *ad libitum* by commercial pelleted diet with the following nutrient content: crude protein 184 g/kg, crude fibre 169 g/kg, starch 117 g/kg, and fat 36.8 g/kg and had *ad libitum* access to water.

Rabbits were selected for slaughter and meat quality presented on average weight of each genotype and housing system at the age of 91 days. The method of slaughter measurement was in accord with Blasco and Ouhayoun (1996). Slaughtered rabbits were bled, and the skin, genitals, bladder, gastrointestinal tract, and distal portion of the legs were removed. Carcasses without thoracic cage organs, liver, kidneys, perirenal fat, but including head were weighed immediately to acquire the hot carcass weight for dressing-out percentage. Dressing out percentage was calculated by dividing the value of hot carcass weight by the value of live weight at 91 days of age. Then, the carcass was cut between the last thoracic and first lumbar vertebra, following the prolongation of the 12th rib when cutting the thoracic wall to determine hind part, section between the 6th and 7th lumbar vertebra, cutting the abdominal wall transversely to the vertebral column to determine loin, and then separation of hind legs and hind leg meat. Subsequently, the hind legs were used to determine meat quality characteristics. The pH value was measured 45 min *post mortem* using calibrated pH meter WTW pH 330i (WTW, Weilheim, Germany) with glass core probe, which was introduced 1 cm deep into the *biceps femoris* muscle. Colour characteristics L^* (lightness), a^* (redness), and b^* (yellowness) were determined 45 min *post mortem* on the cross section of *biceps femoris* muscle using a spectrophotometer Minolta SpectraMagic™ NX (Konica Minolta Sensing Inc., Osaka, Japan). Samples of *biceps femoris* muscle were taken from slaughtered rabbit for determination of histochemical parameters. Samples were frozen in 2-methylbutane cooled by liquid nitrogen (–156°C) and then stored at –80°C until analysis. Cross-sections (12 μm) were cut with

a cryostat Leica CM1850 (Leica Microsystems Nussloch GmbH, Nussloch, Germany) at –20°C. Subsequently, staining for myofibrillar ATPase was performed after preincubation in alkaline buffer according to methodology by Brooke and Kaiser (1970). Fibres were typed according to the nomenclature of previous authors as type I and II. Characteristics of muscle fibres (fibre cross sectional area, diameter, perimeter, circularity) were determined using NIS Elements AR software (Version 3.1, 1991). Subsequently the fibre type distribution was calculated.

A homogeneous mixture of deboned hind leg meat of each rabbit was analyzed for fatty acid composition after chloroform-methanol extraction of total lipids (Folch et al., 1957) by gas chromatography (Hewlett-Packard 6890; Agilent Technologies, Inc., Wilmington, USA) equipped with a programmed 60 m DB-23 capillary column (150–230°C) and flame-ionization detector. Alkaline *trans*-methylation of FA was performed as described by Raes et al. (2003). 1 µl samples of FAME in hexane were injected at a 1 : 40 split ratio. The separation conditions were as follows: initial temperature of 60°C held for 7 min was followed by temperature increase to 110°C at the rate of 20°C/min held for 4 min, by increase to 120°C at the rate of 10°C/min held for 4 min, by increase at the rate of 15°C/min to 170°C, of 2°C/min to 210°C, held for 13.5 min, and by final temperature increase to 230°C at the rate of 40°C/min and held for 7 min. Fatty acids were identified according to retention times corresponding to standards.

Data were processed by Two-Way Analysis of Variance (ANOVA) (interaction of housing system and genotype) using the GLM procedure of SAS (Statistical Analysis System, Version 9.2, 2003). The significance of differences between groups was tested by the Duncan test. The value of $P \leq 0.05$ was considered significant for all measurements.

RESULTS AND DISCUSSION

Results of live weight and slaughter characteristics are shown in Table 1. No interaction between housing system and genotype was detected in any carcass traits. Slaughter weight was significantly ($P \leq 0.003$) affected by housing system. Higher live weight was detected in caged rabbits (2416 g) than in rabbits on litter (2202 g). Likewise, Lambertini et al. (2001), Dal Bosco et al. (2002), and Metzger et al. (2003) observed similar results of slaughter weight between intensive and alternative housing system. According to Princz et al. (2008), the lower weight of pen housed rabbits could be attributed to the higher locomotory activity, but in the present study, the housing area was the same in both systems. Slaughter weight of rabbit genotypes corresponded with size of different breeds. The highest slaughter weight was detected in the giant breed MB in both systems, on the other hand, the lowest in the small breed CB kept on litter. In contrast, for example in the CW the largest differences in live weight were associated with the cage and litter housing system, while in CS or Hyplus rabbits no variances in live weight due to various housing systems were registered. Slaughter weight of the commercial hybrid at slaughter age was lower compared to MB and CW. However, Metzger et al. (2006) reported significantly higher body weight at slaughter in hybrid rabbits Hycole and Zika compared to purebred Panon White.

Dressing out percentage was significantly ($P \leq 0.033$) affected by housing system. Rabbits housed in cages had higher dressing out percentage (54.06%) than those from litter system (52.70%). Dal Bosco et al. (2002), Metzger et al. (2003), D'Agata et al. (2009), and Lazzaroni et al. (2009a) observed similar results. In contrary, Dalle Zotte et al. (2009), Combes et al. (2010), and Daszkiewicz et al. (2012) did not note significant differences in dressing out percentage between housing systems. In our study, a significant ($P \leq 0.006$) effect of genotype on dressing out percentage was found out. The highest dressing out percentage was observed in CG, while the lowest was observed in Hyplus. These results are in agreement with our previous study with rabbit genetic resources (Tůmová et al., 2012) where the highest dressing out percentage was detected in CG and the lowest was detected in Hyplus rabbits. Dalle Zotte and Ouhayoun (1998) and Pla et al. (1998) stated that smaller sized breeds have higher dressing out percentage, which is affected by slaughter maturity.

No significant differences between housing systems were manifested in hind part weight. These results are in contrast with Pla (2008), who registered significantly higher hind part weight in organic rabbits than in the conventionally reared ones. On the other hand, Daszkiewicz et al. (2012) observed significantly higher hind part weight in the intensive rather than in the extensive production system. Differences between the presented results and contrast data in literature might be affected by the type of housing and

Table 1. Carcass traits of intensively and alternatively housed rabbits of different genotypes

Genotype	Housing	Slaughter characteristics (g)							
		live weight	DOP (%)	skin	hind part	loin	hind leg	hind leg meat	perirenal fat
Cage		2416[a]	54.06[a]	399.8[a]	668.1	259.8[a]	408.6	322.8[a]	27.0[a]
Litter		2202[b]	52.70[b]	349.1[b]	633.0	188.4[b]	390.5	264.4[b]	10.8[b]
RMSE		521.09	2.92	88.05	155.84	56.95	96.64	76.36	11.0
MB	cage	3217	54.55	535.8	888.3	338.3	549.2	430.0	34.2
	litter	3092	53.64	488.8	915.4	270.4	549.6	378.4	15.2
CS	cage	2190	54.42	365.0	591.7	250.8	341.7	276.7	35.0
	litter	2156	52.07	355.1	620.8	198.2	375.1	264.7	12.4
CSo	cage	2024	54.70	358.0	560.0	203.0	358.0	284.0	22.0
	litter	1770	53.88	304.5	508.0	144.0	322.5	231.0	7.1
CW	cage	2804	55.39	467.0	810.0	291.0	519.0	402.0	24.0
	litter	2313	52.31	384.0	642.7	166.3	414.0	283.3	14.0
MW	cage	2520	50.37	346.7	626.7	246.7	381.7	306.7	23.3
	litter	2222	53.15	332.7	631.0	182.7	396.0	277.3	9.8
CG	cage	1933	56.24	332.5	576.2	241.7	335.8	270.0	30.8
	litter	1696	55.43	245.2	517.6	156.2	323.2	229.2	12.0
CB	cage	2000	52.64	375.0	530.0	206.7	323.3	263.3	13.3
	litter	1670	51.57	281.5	457.8	134.0	284.0	198.0	5.4
Hy+	cage	2482	51.93	383.3	677.5	262.5	414.2	318.3	23.3
	litter	2424	50.04	363.2	683.5	201.8	429.3	232.8	6.5
RMSE		60.63	2.68	10.45	17.99	7.73	11.13	9.33	1.57
Significance									
Housing system		0.003	0.033	< 0.001	0.120	< 0.001	0.177	< 0.001	< 0.001
Genotype		< 0.001	0.006	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.067
Housing × genotype		0.752	0.642	0.590	0.409	0.757	0.286	0.545	0.844

RMSE = root mean square error, DOP = dressing out percentage, MB = Moravian Blue, CS = Czech Spotted, CSo = Czech Solver, CW = Czech White, MW = Moravian White of Brown Eye, CG = Czech Gold, CB = Czech Black Guard Hair, HY+ = Hyplus
[a,b]$P \leq 0.05$

variable genotypes which were used in the studies. In addition, in our experiment, the same floor area was used in both housings. The weight of hind part corresponded with the size of breeds. The highest ($P \leq 0.001$) weight of hind part was noted in the giant breed MB (915.4 g) and the lowest was noted in CB, which is a small breed (457.8 g). In contrast, Pla (1996) did not show considerable differences in this characteristic between breeds of large and medium body size.

The significantly ($P \leq 0.001$) highest loin weight was detected in caged rabbits (259.8 g) compared to those on litter (188.4 g). In contrary, Pla (2008) found out higher loin weight in organically produced rabbits compared to those produced under intensive housing system. The loin weight was significantly ($P \leq 0.001$) influenced also by genotype. The highest loin weight exhibited the heaviest genotypes, MB and CW. These genotypes had a higher loin weight compared to the hybrid rabbit Hyplus. The lowest weight of this part showed CSo, which accords with the results by Metzger et al. (2006) or Paci et al. (2012a) who found higher loin in the local breeds than in the commercial hybrid.

As shown in Table 1, the significantly ($P \leq 0.001$) highest hind leg meat weight was measured in rabbits from intensive housing system. These results are in contrast with Pla (2008), who stated higher hind leg meat weight in organically produced rabbits than in caged ones. The hind leg weight was significantly ($P \leq 0.001$) related to genotype. The lowest weight of hind leg meat had CB, while the highest displayed MB and CW, whose hind leg meat weight was higher than that of Hyplus.

Table 2. Effect of housing system and genotype on pH value and colour parameters of *biceps femoris*

Genotype	Housing	pH	Colour		
			*L**	*a**	*b**
Cage system		6.55^{a}	54.37	–1.37^{a}	7.66^{b}
Litter		6.39^{b}	54.66	–2.77^{b}	9.01^{a}
RMSE		0.17	4.53	0.95	2.07
MB	cage	6.62^{ab}	53.18^{d}	–1.88	7.14^{bc}
	litter	6.29^{e}	58.02$^{a–c}$	–3.24	9.18^{b}
CS	cage	6.61$^{a–c}$	55.81$^{a–d}$	–2.06	8.40^{bc}
	litter	6.39^{de}	53.26^{d}	–2.76	8.46^{bc}
CSo	cage	6.46$^{b–e}$	52.65^{de}	–1.11	8.30^{bc}
	litter	6.33^{de}	60.93^{a}	–2.00	12.47^{a}
CW	cage	6.57$^{a–d}$	54.42$^{b–d}$	–0.71	7.53^{bc}
	litter	6.32^{e}	59.96^{ab}	–1.68	13.44^{a}
MW	cage	6.66^{ab}	58.81$^{a–c}$	–1.61	7.78^{bc}
	litter	6.26^{e}	55.71$^{a–d}$	–3.73	8.54^{bc}
CG	cage	6.36^{e}	51.89^{de}	–1.29	7.39^{bc}
	litter	6.41$^{c–e}$	47.81^{e}	–2.45	6.80^{c}
CB	cage	6.45$^{a–e}$	55.25$^{a–d}$	–1.80	8.27^{bc}
	litter	6.50$^{a–e}$	55.16$^{a–d}$	–2.82	9.28^{b}
Hy+	cage	6.68^{a}	55.32$^{a–d}$	–0.67	6.90^{c}
	litter	6.61$^{a–c}$	53.75^{cd}	–3.04	7.86^{bc}
RMSE		0.16	3.86	0.89	1.77
Significance					
Housing system		< 0.001	0.749	< 0.001	0.002
Genotype		0.039	0.009	0.020	0.016
Housing × genotype		0.047	0.010	0.419	0.007

RMSE = root mean square error, MB = Moravian Blue, CS = Czech Spotted, CSo = Czech Solver, CW = Czech White, MW = Moravian White of Brown Eye, CG = Czech Gold, CB = Czech Black Guard Hair, HY+ = Hyplus

*L** = lightness, *a** = redness, *b** = yellowness

$^{a–e}P \leq 0.05$

Also Metzger et al. (2006) detected higher hind leg weight in Panon White than in broiler rabbits.

Perirenal fat was significantly ($P \leq 0.001$) affected only by housing system. Lower weight of perirenal fat had rabbits housed on litter. Similar results were documented by Pla (2008) and Lazzaroni et al. (2009a) who stated that the lower perirenal fat might be related to higher activity of rabbits housed in pens. However, it seems that locomotory activity did not affect the amount of perirenal fat in the present case, because the housing area of both systems was the same. Lower amount of perirenal fat could be caused by the lower feed and energy intake due to the consumption of litter material, which can significantly impact renal fat deposition (Metzger et al., 2003).

Physical indicators of meat quality are shown in Table 2. Interactions between housing system and genotype reflected in pH value of *biceps femoris* were registered. The highest significant ($P \leq 0.047$) pH was recorded in Hyplus rabbits in intensive housing system (6.68), on the other hand, the lowest value of pH was noted in MW (6.26) from alternative housing system. There is a lack of data about interaction of genotype and housing system in literature and interactions might have been influenced by differences in muscle fibre composition or glycolytic potential of genotype in different housing systems. Rabbits from cage system had significantly higher ($P \leq 0.001$) pH value (6.55) than rabbits from litter (6.39) and this is consistent with Lazzaroni et al. (2009a) who measured pH in rabbits 1 h *post mortem*. Dal Bosco et al. (2002), Pla (2008), and Dalle Zotte et al. (2009) measured ultimate pH 24 h *post mortem* (pH_u) and they stated significantly

Table 3. Effect of housing system and genotype on hind leg meat FA profile (% of total FA)

Genotype	Housing	SFA	MUFA	PUFA	PUFA n-3	PUFA n-6	PUFA n-6 : n-3	PUFA : SFA
Cage system		36.18	36.94[a]	26.23[b]	3.11[b]	23.12[b]	7.60	0.73[b]
Litter		36.28	26.63[b]	36.73[a]	4.38[a]	32.34[a]	7.58	1.02[a]
RMSE		1.67	2.63	3.66	0.70	3.25	1.26	0.13
MB	cage	35.20	37.33	26.78	3.32	23.45	7.20	0.76
	litter	36.78	28.03	34.87	4.51	30.36	7.09	0.96
CS	cage	37.51	38.85	23.03	2.94	20.10	7.09	0.62
	litter	38.05	29.36	32.09	3.32	28.77	8.66	0.84
CSo	cage	36.55	39.40	23.44	2.83	20.61	7.32	0.65
	litter	37.54	26.83	35.28	3.89	31.39	8.27	0.94
CW	cage	36.01	36.27	26.99	3.22	23.77	7.47	0.76
	litter	35.20	26.81	37.71	4.23	33.48	7.94	1.07
MW	cage	36.23	36.67	26.42	2.85	23.57	8.43	0.73
	litter	35.77	26.22	37.65	3.93	33.72	8.68	1.06
CG	cage	36.14	35.15	28.30	2.93	25.10	8.76	0.78
	litter	34.74	24.42	40.48	4.63	35.85	7.77	1.17
CB	cage	35.61	34.89	28.93	3.68	25.26	6.99	0.82
	litter	36.21	26.06	37.39	5.00	32.39	6.49	1.04
RMSE		1.59	2.37	3.23	1.59	2.85	1.10	0.12
Significance								
Housing system		0.783	< 0.001	< 0.001	< 0.001	< 0.001	0.944	< 0.001
Genotype		0.068	0.002	< 0.001	< 0.001	< 0.001	0.001	0.002
Housing × genotype		0.397	0.678	0.621	0.502	0.520	0.197	0.525

RMSE = root mean square error, MB = Moravian Blue, CS = Czech Spotted, CSo = Czech Solver, CW = Czech White, MW = Moravian White of Brown Eye, CG = Czech Gold, CB = Czech Black Guard Hair, HY+ = Hyplus, FA = fatty acids, SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids

SFA: C14:0, C15:0, C16:0, C17:0, C18:0, C20:0

MUFA: C14:1, C16:1 n-7, C18:1, C20:1 n-9, C22:1 n-9

PUFA: C18:2 n-6, C 18:3 n-6, C18:3 n-3, C20:2 n-6, C20:3 n-6, C20:4 n-6, C20:3 n-3, C20:5 n-3, C22:2 n-6, C22:4 n-6, C22:5 n-3, C22:6 n-3

PUFA n-3: C18:3 n-3, C20:3 n-3, C 20:5 n-3, C22:5 n-3, C22:6 n-3

PUFA n-6: C18:2 n-6, C18:3 n-6, C20:2 n-6, C20:3 n-6, C20:4 n-6, C22:2 n-6, C22:4 n-6

[a,b]$P \leq 0.05$

higher pH_u in rabbits from cages than from pens. However, our results are in contrast with those of Lambertini et al. (2001) and Metzger et al. (2003), who did not show differences between rabbits from different housing systems in pH_{45} or pH_u of *longissimus lumborum*, respectively. The pH ($P \leq 0.039$) was also significantly affected by genotype, with higher values in Hyplus rabbits. This is consistent with Paci et al. (2012b), who determined higher pH_{45} in a commercial hybrid than in the Italian local population of rabbits. Differences in pH_u between lines selected for variable traits were described by Hulot and Ouhayoun (1999) or Hernández and Gondret (2006). However, Paci et al. (2012a) did not determine differences in pH_u between local and hybrid rabbits.

Meat colour is a very important characteristic of meat quality directly influencing the consumers' choice. Meat colour is affected by myoglobin content, which differs mainly with fibre type distribution in muscle. In meat colour characteristics, interactions were observed in L^* (lightness) and b^* (yellowness) parameters of *biceps femoris*. The significantly lightest colour of *biceps femoris* was observed in CSo (60.93), the lowest in CG (47.81), both breeds kept on litter. The highest yellowness was measured in CW (13.44) kept on litter, while the lowest yellowness was detected in CG (6.80)

Table 4. Effect of housing system and genotype on muscle fibre characteristics of *biceps femoris*

Genotype	Housing	Muscle fibre characteristics									
		cross sectional area (μm^2)		diameter (μm)		perimeter (μm)		circularity		fibre type distribution (%)	
Muscle fibre type		I	II	I	II	I	II	I	II	I	II
Cage system		1946.1	2680.3^{a}	48.89	56.63^{a}	168.58	215.86^{a}	0.85	0.68^{b}	6.88	93.12
Litter		1896.1	1577.8^{b}	48.25	42.95^{b}	167.14	156.84^{b}	0.84	0.76^{a}	5.81	94.19
RMSE		734.9	1428.3	9.05	14.26	31.11	81.42	0.08	0.16	3.29	3.29
MB	cage	1682.8$^{c–e}$	2675.5	45.60$^{c–e}$	56.49	159.6^{cd}	216.7	0.82	0.74	4.60	95.40
	litter	2606.4^{ab}	1805.1	56.93^{ab}	46.37	199.0^{a}	173.8	0.81	0.72	6.32	93.68
CS	cage	2044.2^{bc}	2921.1	50.65^{bc}	59.74	181.3^{ab}	249.3	0.79	0.70	6.26	93.74
	litter	1929.3$^{b–e}$	1469.1	48.80^{bc}	41.06	170.0^{bc}	149.8	0.83	0.76	4.92	95.08
CSo	cage	1945.5^{cd}	3258.4	49.07^{bc}	62.96	169.9^{bc}	251.4	0.84	0.68	7.92	92.08
	litter	2144.9$^{a–e}$	1573.2	51.99$^{a–e}$	43.46	177.3$^{a–d}$	161.5	0.85	0.74	6.59	93.41
CW	cage	1865.3$^{b–e}$	2678.6	48.16$^{b–e}$	56.25	158.3$^{b–e}$	209.3	0.91	0.76	9.59	90.41
	litter	2186.1$^{a–e}$	1599.1	52.08$^{a–d}$	43.54	175.5$^{a–c}$	158.6	0.87	0.77	8.60	91.40
MW	cage	1685.6^{de}	2506.9	45.94$^{c–e}$	55.15	164.5$^{b–d}$	208.9	0.83	0.58	7.10	92.90
	litter	1541.1$^{c–e}$	1533.3	43.85$^{c–e}$	43.01	150.4$^{b–e}$	155.6	0.84	0.77	4.59	95.41
CG	cage	2023.2^{bc}	2784.2	49.62^{bc}	57.38	194.5^{a}	255.9	0.88	0.64	6.98	93.02
	litter	1623.8$^{c–e}$	1461.2	44.95$^{c–e}$	41.24	156.0$^{b–e}$	150.3	0.83	0.76	4.84	95.16
CB	cage	2573.1^{a}	2425.2	56.19^{a}	53.78	195.0^{a}	190.2	0.84	0.70	7.78	92.22
	litter	1219.6^{e}	1196.5	38.68^{e}	37.20	130.2^{e}	132.2	0.87	0.80	4.88	95.12
Hy+	cage	1458.1^{e}	2257.0	42.62^{de}	52.15	144.1^{de}	193.1	0.86	0.73	6.89	93.11
	litter	2239.2$^{a–c}$	1983.8	52.99$^{a–c}$	48.61	182.2$^{a–c}$	176.6	0.84	0.76	7.39	92.61
RMSE		678.6	1400.9	8.33	13.93	25.18	78.07	0.07	0.15	3.43	3.43
Significance											
Housing system		0.685	< 0.001	0.671	< 0.001	0.769	< 0.001	0.372	< 0.001	0.188	0.188
Genotype		< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.657	0.657
Housing × genotype		< 0.001	0.563	< 0.001	0.224	< 0.001	0.142	0.551	0.268	0.867	0.867

RMSE = root mean square error, MB = Moravian Blue, CS = Czech Spotted, CSo = Czech Solver, CW = Czech White, MW = Moravian White of Brown Eye, CG = Czech Gold, CB = Czech Black Guard Hair, HY+ = Hyplus

$^{a–e}P \leq 0.05$

kept also on litter and in caged Hyplus (6.90). There were no significant differences between cage system and litter as concerns lightness, but yellowness was significantly ($P \leq 0.002$) higher in rabbits housed on litter. Concordantly, Lambertini et al. (2001), Pla (2008), Dalle Zotte et al. (2009), Lazzaroni et al. (2009a), Combes et al. (2010), and Daszkiewicz et al. (2012) did not find differences in meat colour measured 24 or 48 h *post mortem* between pen and cage housed rabbits. Meat colour characteristics were significantly affected by genotype ($P \leq 0.009$, $P \leq 0.020$, $P \leq 0.018$ for L^*, a^*, b^*, respectively). The highest ($P \leq 0.009$) lightness of *biceps femoris* had CW and MW, while the lowest CG rabbits. The Hyplus rabbits had average values of lightness comparable to those of local breeds. In comparison, Paci et al. (2012a) reported significantly higher L^* value in Hyplus than in a local breed. However, Szulc et al. (2012) did not find differences between purebreed and crossbreed in pigs.

FA profile of hind leg meat (Table 3) was influenced by the interaction between genotype and housing system. The SFA content was not affected by selected factors, which is consistent with findings of Lazzaroni et al. (2009b), who detected similar SFA content in *longissimus lumborum* muscle of animals from cages and littered pens. On the other hand, Pla (2008) found higher SFA in conventionally compared to organically produced rabbits. Dalle Zotte et al. (2009) detected higher SFA in pen-reared than in caged animals. The meat of rabbits reared in cages had significantly higher ($P \leq 0.001$) monounsaturated fatty acids (MUFA) and lower PUFA contents than that of animals housed on litter. Similar results observed also Dal Bosco et al. (2002), Pla (2008), and Lazzaroni et al. (2009b). Small breeds (CG and CB) had lower MUFA ($P \leq 0.002$) and higher PUFA ($P \leq 0.001$) contents than the medium and giant breeds. Higher ($P \leq 0.001$) contents of n-3 and n-6 PUFA were found in rabbits housed on litter, which agrees with the findings of Pla (2008) and Lazzaroni et al. (2009b). The n-6/n-3 ratio was the same in caged animals as well as in those kept on litter. Likewise, Dalle Zotte et al. (2009) did not find significant differences among various housing systems. In agreement with Lazzaroni et al. (2009b), alternatively reared rabbits had also higher ($P \leq 0.001$) PUFA : SFA ratio than rabbits from the cage system. Higher PUFA : SFA ratio indicates a better quality of meat. The variances in fatty acid profile in rabbits from different housing systems could be due to lower renal fat in rabbits housed on litter because the amount of fat affects meat fatty acid composition, with increasing fatness the levels of SFA and MUFA go up faster than does the content of PUFA, which declines depending on the changes of the PUFA : SFA ratio (De Smet et al., 2004).

Muscle fibre parameters of *biceps femoris* are shown in Table 4. A significant ($P \leq 0.001$) interaction was found in cross sectional area (CSA) in muscle fibres of type I. The highest CSA was recorded in CB from cage system (2573.1 μm^2) while the lowest CSA (1219.6 μm^2) in animals kept on litter. Contrary, there were no interactions between housing system and genotype in muscle fibres of type II. However, this parameter was significantly ($P \leq 0.001$) affected by housing system. Rabbits from cages had higher CSA of type I muscle fibres (2680.3 μm^2) than rabbits from litter (1577.8 μm^2). In caged animals, muscle fibres of type II had larger CSA compared to fibres of type I, while in animals on litter the values were opposite. This is consistent with Gondret et al. (2002) and Dalle Zotte et al. (2005), who detected larger CSA in muscle fibres of type II than of type I. Volek et al. (2012) found that rabbits kept at the lower stocking density had significantly smaller CSA of type I fibres compared to rabbits kept at the higher stocking density. CSA of both types of muscle fibres were affected ($P \leq 0.001$) by genotype. The largest CSA were measured in MB for both types of muscle fibres, while the smallest areas were identified in MW for type I and in CB for type II. Contradictory to our results, Bianospino et al. (2008) did not reveal differences between genetic groups, although the values of CSA were numerically higher in the crossbred rabbits than in the straightbred ones. A smaller area of muscle fibres is generally found in smaller rabbit breeds and it can be associated with higher meat tenderness. For example, Gondret et al. (2002) or Choi et al. (2013) concluded that increase of the muscle fibres CSA is correlated with live weight. Likewise, Larzul et al. (2005) and Lefaucher (2010) stated that the increasing size of muscle fibres is due to selection of rabbits for growth and live weight.

Significant ($P \leq 0.001$) interactions between the housing system and genotype were discovered as concerns diameter and perimeter of type I muscle fibres. The largest diameter and perimeter had MB housed on litter (diameter 56.93 μm, perimeter 199 μm), while the smallest diameter (38.68 μm) and perimeter (130.2 μm) was in CB also from litter system. In the present study, housing system did

not affect diameter and perimeter of type I muscle fibres. However, in fibres of type II a significantly larger diameter ($P \leq 0.001$) and perimeter ($P \leq 0.001$) were detected in rabbits kept in cages. Diameter and perimeter are two characteristics describing muscle fibres. The size of muscle fibres is determined by the diameter, perimeter, and cross sectional area. With increasing diameter or perimeter the number of muscle fibres decreases. Generally, muscle fibres of type I have smaller diameter compared to type II.

The fibre type distribution was not affected by any of the monitored parameters. Caged rabbits had insignificantly higher share of type I muscle fibres than of type II muscle fibres if compared to rabbits from litter system. Ouhayoun (1998) stated that the greater locomotory behaviour of alternatively housed rabbits should enhance oxidative metabolism. Volek et al. (2012) detected a significant impact of the stocking density on muscle fibre distribution with lower percentage of type II fibres and higher percentage of type I fibres exhibited by rabbits reared at lower stocking density. However, in the current study stocking density was the same and the effect of housing was not determined.

CONCLUSION

Finally, it can be concluded that alternative housing system resulted in lower slaughter weight, weight of carcass parts except hind part and hind legs. Significant interactions between housing system and genotype were reflected in pH value, and lightness and yellowness of *biceps femoris*. Meat of alternatively reared rabbits had lower MUFA and higher PUFA content compared with that of caged animals. Significant interactions were detected in histological characteristics of type I muscle fibres, while fibres of type II were affected either by genotype or the housing system. Rabbits from cage housing system had significantly larger cross sectional area of type II muscle fibres, whereas fibre type distribution was not affected by any of the classification parameters.

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