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Growth performance, carcass characteristics, and selected meat quality traits of two strains of Pekin duck reared in intensive vs semi-intensive housing systems

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A B S T R A C T

Selection of optimal hybrid of Pekin duck and housing system could improve yield and quality of duck meat. The aim of this study was to investigate the effects of two rearing systems (intensive vs semi-intensive housing) on growth performance, carcass quality, and selected physical meat quality traits of two commercial strains of Pekin ducks. The study was performed on 240 one-day-old Pekin ducklings of two different strains (120 ducklings of STAR 53 medium hybrid and 120 ducklings of SM3 heavy hybrid) during a 49-day period. Half the birds (120) were reared in a complete confinement system on a floor (intensive system), while the remaining 120 ducks had access to land outside (semi-intensive system). Growth performance of ducks was determined by BW, weight gain, feed intake, and feed conversion ratio (**FCR**), carcass quality by dressing percentage, percentage of basic cuts in carcasses, and content of various tissues in basic cuts, while meat quality was determined by pH, drip loss, cooking loss, Warner-Bratzler shear force, and color (L*, a*, and b*) values. At the end of the study, SM3 heavy hybrid and STAR 53 hybrid Pekin ducks achieved similar BWs. Higher final BW and lower overall FCR were found in ducks reared in the intensive system than in ducks kept in the semi-intensive system. Higher dressing percentage, weight and percentage of breast, but also a lower percentage of back with pelvis in the carcasses were determined in SM3 hybrid ducks than in STAR 53 hybrid ducks. The strain of duck did not affect meat pH, drip loss, or L* color value. Moreover, housing system affected the physical meat quality of the ducks, since breasts from ducks reared in the semi-intensive system had higher initial meat pH, higher percentage of EZ-drip loss and cooking loss, and higher L*, a*, and b* values than did breasts from intensively-reared ducks. In conclusion, SM3 ducks were more suited for broiler production due to their better carcass quality than STAR 53 ducks. Furthermore, ducks reared in the intensive system had better growth performance results and better physical meat quality traits than did ducks from the semi-intensive system.

Implications

Production of duck meat is mainly based on commercial strains of Pekin duck that vary in growth performance, carcass conformation, and meat quality. Furthermore, large differences exist in their housing conditions that affect welfare, growth, and carcass characteristics. This study showed Pekin duck SM3 hybrid had a better carcass quality than the STAR 53 hybrid. Moreover, ducks reared in intensive housing had better growth performance and improved physical meat quality than ducks from the semi-intensive housing system. These results can contribute to selection of the optimal hybrid of Pekin duck and housing system to improve the yield and quality of duck meat.

Introduction

Duck meat is of increasing importance in human nutrition worldwide due to its high nutritive value. Compared to broiler meat, duck meat contains higher percentages of protein and ash, lower percentages of fat and water, and a higher content of red muscle fiber in breast meat (Ali et al., 2007). Moreover, duck meat is a good source of polyunsaturated fatty acids and has a favorable amino acid profile (Woloszyn et al., 2006; Ali et al., 2007).

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World production of duck meat was 4 464 925 t in 2018. Asia accounted for 83% (3 705 427 t), Europe for 11.7% (520 456 t), and other parts of the world for 5.3% of the total production of duck meat. The largest duck meat producing country in 2018 was China (3 015 003 t). Duck meat is mainly obtained from Pekin ducks in Asia and north and central Europe and to a lesser extent from Muscovy and mallard ducks (France and Italy). In Europe, large duck meat producing countries are France (246 209 t), Hungary (93 622 t), and Germany (37 058 t) (Food and Agriculture Organization [FAO], 2018).

Meat-producing duck strains grow fast due to genetic selection, efficient housing systems, and excellent nutrition (Adeola, 2003). Several strains of Pekin duck are commonly used in commercial meat production due to their high growth rates, good feed conversion rates, desirable body conformation, and high dressing percentages (Biesiada-Drzazga, 2012). Growth performance and meat quality of commercial Pekin duck strains have been investigated in many studies (Kwon et al., 2014; Kokoszynski et al., 2015; Kokoszynski et al., 2019b; Kokoszynski et al., 2019c). Pekin ducks are subjected to slaughter between 6 and 8 weeks of age, when they have completed their rapid growth and weigh approximately 3.5 kg (Kokoszynski et al., 2019a). However, selection for fast growth and high meat yield can adversely impact the meat quality (Kwon et al., 2014).

Since production of duck meat has become more intensive in recent decades, appropriate production systems have to be developed in order to provide suitable animal welfare conditions and produce good quality meat (Chen et al., 2015). Various duck production systems have been used that differ in floor type, stocking density, outdoor access, access to water for swimming, light regime, and drinker systems and affect animal welfare, growth performance, and carcass and meat quality (Onbasilar and Yalcin, 2018). Pekin ducks have a high susceptibility to environmental stress, as affected by housing conditions (Faure et al., 2003). Moreover, high stocking density reduces the growth performance, health, and welfare of Pekin ducks (Xie et al., 2014). Therefore, the aim of this study was to investigate effects of two rearing systems (intensive vs semi-intensive housing) on growth performance, carcass quality, and selected physical meat quality traits of two commercial strains of Pekin ducks (STAR 53 medium hybrid vs SM3 heavy hybrid).

Material and methods

Animals, housing, experimental diets, and study duration

The study was performed over 49 days on 240 one-day-old Pekin ducklings of two strains: 120 STAR 53 medium hybrid ducklings hatched from parents imported from the French company, Grimaud Frères, and 120 SM3 heavy hybrid ducklings hatched from parents imported from Cherry Valley Farms Ltd. (Great Britain). One-day-old ducklings were placed in cardboard boxes for two weeks and then marked with individually numbered leg rings and randomly assigned to one of two different housing systems (intensive vs semi-intensive). The ducklings from both strains were divided randomly in two groups that were split between the two housing systems, so each system contained 60 of the 120 STAR 53 medium hybrid ducklings and 60 SM3 heavy hybrid ducklings. Half the birds (120) were reared in a complete confinement system on a floor (stocking density = 0.15 m^2/head), while the other half (120) of the ducks had access to land outside (stocking density = 0.38 m^2/head). The study was conducted during April and May, when the average daily temperature was 14.7 °C. From the beginning of the study, ducklings were housed at 33 °C and then room temperature was gradually decreased by 3 °C each week until the final temperature of 22 °C was reached in the complete confinement housing system. After the fourth week of the trial, housing buildings were not heated anymore. In the semi-intensive housing system that enabled access to land outside, birds were kept enclosed in a barn during the night. Ducklings were not identified by sex at any time during the study, so we assumed an approximately equal ratio of males and females was distributed in the experimental groups. Considering the differences in duck strain (STAR 53 medium hybrid vs SM3 heavy hybrid) and rearing system (intensive vs semi-intensive), four experimental groups were formed, each containing 60 animals. Within these groups, birds were divided into six subgroups having 10 animals per pen. Pen floors were covered with straw, and birds were provided with fresh drinking water and feed *ad libitum*. Uneaten feed was removed at the end of each day and replaced with fresh feed. From the start of the study, animals were fed with the same diets that were formulated to meet the maintenance and growth requirements of animals (National Research Council [NRC], 1994) (Table 1). Diets fed from days 1 to 49 were starter (days 1–21), grower (days 22–35), and finisher (days 36–49).

Feedstuff composition

All components of the diets were analyzed for DM (ISO 6496, 1999b), CP (ISO 5983-1, 2005), crude fat (ISO 6492, 1999a), crude fiber (ISO 6865, 2000), calcium (ISO 6490-1, 1985), and phosphorus (ISO 6491, 1998) (Table 1). Percentages of lysine, methionine, and methionine + cysteine in diets were calculated based on their contents in feed materials and contents of supplemented DL-methionine and L-lysine (Sinovec and Ševković, 1995).

Growth performance

Growth performance of the ducks was assessed by recording BW, weight gain, feed consumption, and feed conversion ratio (**FCR**) during the study. Body weight was measured weekly (days 1, 7, 14, 21, 28, 35, 42, and 49), and weekly weight gain was calculated. Feed consumed on a per pen basis was recorded daily. Feed conversion ratio was calculated as the amount of feed consumed per unit of BW gain.

Table 1
Ingredients and chemical composition of diets for STAR 53 medium (STAR 53) and SM3 heavy (SM3) hybrids of Pekin ducks.

Ingredient (g/kg as-fed)	Starter (1–21 days)	Grower (22–35 days)	Finisher (36–49 days)
Maize	606	608	633
Soybean meal 46%	310	180	170
Sunflower meal	30.0	60.0	50.0
Yeast	20.0	30.0	20.0
Mono-calcium phosphate	21.5	20.0	20.0
Wheat feed flour	–	50.0	35.0
Full-fat soybean meal	–	40.0	60.0
Vitamin-mineral premix[1]	10.0	10.0	10.0
DL-methionine	1.20	0.80	0.80
L-lysine	1.30	0.90	0.90
Chemical composition (g/kg as-fed)			
DM	883	884	883
CP	213	187	179
Crude fat	28.6	38.0	41.4
Crude fiber	40.1	43.7	41.0
Calcium	8.90	10.0	9.70
Phosphorus	6.40	7.00	6.30
Calculated composition (g/kg as-fed)			
Lysine	13.50	11.7	9.90
Methionine	5.70	5.60	4.20
Methionine + cysteine	9.00	8.50	7.10

[1] Vitamin-mineral premix (per kg of diet): vitamin A (retinyl acetate), 10,000 IU; vitamin D3 (cholecalciferol), 4000 IU; vitamin E (a-tocopherol), 20 mg; vitamin K3 (menadione), 3 mg; vitamin B1 (thiamine), 2.2 mg; vitamin B2 (riboflavin), 8 mg; vitamin B3 (niacin), 65 mg; vitamin B5 (calcium pantotenate), 25 mg; vitamin B6 (pyridoxine), 5 mg; vitamin B7 (biotin), 0.3 mg; vitamin B9 (folic acid), 1.5 mg; vitamin B12 (cyanocobalamin), 0.02 mg; iron ($FeSO_4$), 80 mg; copper ($CuSO_4$), 8 mg; manganese ($MnSO_4$), 60 mg; zinc ($ZnSO_4$), 40 mg; iodine (KI), 0.33 mg.

Carcass quality

Feed was withdrawn 12 h before transport, while ducks' access to drinking water remained unrestricted. At the end of the study, animals were weighed before transport. Subsequently, animals were transported in plastic cages to the slaughterhouse and then individually weighed to calculate the percentage of weight loss during transport. In the slaughterhouse, ducks were electrically stunned and immediately slaughtered by severance of the jugular veins. Animals were processed following standard industrial techniques, and hot carcass weight was measured to calculate dressing percentage on hot carcass weight. During the first 24 h post mortem, carcasses were stored in a ventilated cold room at 2 °C, measured at 24 h post mortem to obtain cold carcass weight, and subsequently butchered into basic cuts (breast, drumsticks with thighs, wings, neck and back with pelvis). The basic cuts were weighed and their percentage of total cold carcass weight was calculated. Moreover, breasts and drumsticks with thighs were dissected into meat, bone, and skin with subcutaneous fat, which were then weighed to enable calculation of their percentages in each of these two meat cuts.

Physical meat quality traits

In all carcasses, physical meat quality traits (pH, EZ-drip loss, cooking loss, and Warner-Bratzler shear force (WBSF)) were determined in breast meat, while instrumental color was determined in breast meat and in thigh meat. pH was measured 45 min (pH_{45min}) and 24 h (pH_{24h}) post mortem on the cranial part of the *Pectoralis superficialis* muscle using a pH-meter Testo 205 (Germany). Before and during pH determinations, the pH-meter was calibrated with pH 4.00 and 7.00 phosphate buffer. After measuring pH_{24h}, carcasses were butchered into basic cuts to determine carcass characteristics, and after dissection, breast meat and thigh meat were used for measuring other physical meat quality traits. First, instrumental color (CIE L*a*b*) was determined in meat samples from breasts (*Pectoralis superficialis* muscle) and thighs (*Iliotibialis* muscle) at 24 h post mortem, after approximately 15 min of blooming time. L*, a*, and b* values were determined using a Minolta chroma meter CR-400 (Minolta Co., Ltd., Osaka, Japan) utilizing a 65 light source and a 2° observer. Furthermore, drip loss in meat samples from the medial part of *Pectoralis superficialis* muscle was measured using the EZ-drip loss method (Rassmussen and Andersson, 1996). For this, each meat sample was weighed and stored for 24 h at 4 °C in a container. After storage, meat samples were reweighed, and the percentage of drip loss was calculated. Cooking loss was then determined in meat from the medial part of breast (*Pectoralis superficialis* muscle) after weighing meat samples before cooking and then after 30 min of cooking followed by 30 min of cooling at room temperature. Cooking loss was expressed as the percentage difference in meat weight after cooking, where weight before cooking was taken as 100%. WBSF was measured in the cooked meat samples that were cooled to room temperature (described immediately above) and then sheared perpendicular to the longitudinal orientation by TA-XT Plus Texture Analyzer (Stable Micro Systems, Surrey, UK). A TA-7 Warner-Bratzler shear type blade was used. The maximum force measured to cut the heat-treated meat was expressed in newtons.

Statistical analysis

Statistical analysis of the results was conducted with GraphPad Prism software version 8.00 for Windows (GraphPad Software, San Diego, CA, USA, www.graphpad.com). Pen was the experimental unit for for feed intake and FCR. The single animal was the statistical unit for data regarding BW, weight gain, carcass characteristics, and physical meat traits. Two-way ANOVA with Tukey's multiple comparison test was performed to test the effect of duck strain (STAR 53 medium hybrid vs SM3 heavy hybrid) and housing system (intensive vs semi-intensive) as the main effects and their interactions on growth performance, carcass quality, and meat quality of ducks. Repeated measures ANOVA was applied for time-dependent variables, BW, weight gain, feed intake, and FCR, where the measurements were conducted on the same animal but at different times. Duck strain, housing system, and duck strain × housing system interaction were considered as fixed effects and observation session as repeated option. All parameters were described by means and SEMs. Values of $P < 0.05$ were considered significant.

Results

Growth performance

The effects of duck strain (STAR 53 medium hybrid vs SM3 heavy hybrid) and housing system (intensive vs semi-intensive), as well as their interactions on growth performance of ducks, are presented in Table 2. At the beginning of the study, STAR 53 ducklings had lower BW ($P < 0.01$) than SM3 ducklings, while the opposite was observed on days 14 and 28 of the study ($P < 0.05$). Similar to the BW, higher weight gain ($P < 0.01$) was measured in STAR 53 than in SM3 ducks in weeks 2 and 4 of the study. Contrary to that, in the second half of the study, during weeks 5 and 7, SM3 ducks had higher weight gain ($P < 0.001$) than STAR 53 ducks. Higher feed intake ($P < 0.05$) was recorded in SM3 ducks than in STAR 53 ducks during week 5 of the study. However, duck strain had no influence on FCR.

Rearing conditions affected the growth performance of the ducks. At the end of the study, lower live weight ($P < 0.05$) was achieved in ducks reared in the semi-intensive housing system than in ducks from the intensive housing system. Furthermore, housing system had an impact on weight gain from weeks 4 to 7 of the study. Higher weight gain ($P < 0.05$) was observed in ducks reared in the intensive than in those in the semi-intensive system during weeks 4, 6, and 7, while the opposite was found during week 5 of the study. Housing system had no influence on feed intake, but it did affect FCR, since higher FCR ($P < 0.05$) was found in birds with access to land outside than in birds reared in the complete confinement system during week 6 and at the end of the study. Significant interactions between duck strain and housing system were detected for weight gain in weeks 3, 4, 5, 6, and 7 and for feed intake and FCR during week 7 of the study. STAR 53 ducks raised in the intensive system had higher weight gain ($P < 0.001$) than STAR 53 ducks raised in the semi-intensive system and SM3 ducks raised in the intensive system during week 3. The highest weight gains ($P < 0.001$) were observed in SM3 ducks raised in semi-intensive conditions during week 5, in STAR 53 ducks from intensive housing during week 6, and in SM3 ducks raised in the intensive system during week 7. The lowest weight gain ($P < 0.001$) was seen in SM3 ducks raised in semi-intensive housing during week 4. In week 7, lower feed intake and FCR ($P < 0.01$) were observed in intensively raised STAR 53 ducks and semi-intensively raised SM3 ducks than in the other two experimental groups.

Carcass quality

Table 3 shows the effects of duck strain (STAR 53 medium hybrid vs SM3 heavy hybrid), rearing conditions (intensive vs semi-intensive), and their interactions on carcass quality parameters in ducks. Duck strain affected the percentage of weight loss during the transport from farm to slaughterhouse, as higher transport loss ($P < 0.05$) was determined in SM3 ducks than in STAR 53 ducks. Higher dressing percentage ($P < 0.05$) was found in SM3 ducks than in STAR 53 ducks. Higher weight and percentage of breasts and lower percentage of drumsticks with thighs in the carcasses ($P < 0.01$) was found in SM3 ducks than in STAR 53 ducks. Moreover, a lower percentage ($P < 0.001$) of less valuable parts (back with pelvis) was found in SM3 than in STAR 53 ducks. The percentage of meat in breast was higher ($P < 0.001$), while the percentages of bone and skin with subcutaneous fat in breast were lower ($P < 0.001$) in SM3 ducks than in STAR 53 ducks.

Table 2
Growth performance of duck strains, STAR 53 medium (STAR 53) and SM3 heavy (SM3) hybrids of Pekin ducks, reared in two different housing systems (intensive vs semi-intensive).

	Experimental group				SEM	*P*-value		
	STAR 53[1]		SM3					
	Intensive system[2]	Semi-intensive system	Intensive system	Semi-intensive system		S	H	S×H
BW (g) ($n = 60$ birds per group)								
Day 1	56.9^{a}	57.5^{ab}	58.2^{ab}	58.9^{b}	1.00	**	ns	ns
Day 7	216	216	215	210	6.41	ns	ns	ns
Day 14	567	564	554	530	20.5	*	ns	ns
Day 21	1187	1132	1111	1122	47.8	ns	ns	ns
Day 28	1777^{a}	1710^{ab}	1693^{ab}	1643^{b}	69.5	*	ns	ns
Day 35	2392	2312	2341	2371	93.9	ns	ns	ns
Day 42	2890	2733	2793	2825	107	ns	ns	ns
Day 49	3168	3025	3132	3096	82.6	ns	*	ns
Weight gain (g/per day) ($n = 60$ birds per group)								
Week 1	22.7	22.5	22.3	21.6	0.66	ns	ns	ns
Week 2	50.2^{A}	49.9^{A}	48.6^{AB}	45.7^{B}	1.79	**	ns	ns
Week 3	88.6^{A}	81.1^{B}	79.6^{B}	84.6^{AB}	3.51	ns	ns	***
Week 4	84.3^{A}	82.6^{A}	83.1^{A}	74.5^{B}	3.31	**	**	*
Week 5	87.7^{A}	85.9^{A}	92.7^{A}	104^{B}	3.71	***	*	***
Week 6	71.2^{A}	60.2^{Ba}	64.6^{B}	64.8^{Bb}	2.48	ns	***	***
Week 7	39.6^{BCD}	41.7^{BC}	48.4^{A}	38.6^{BD}	1.12	***	***	***
Week 1–7	63.5	60.6	62.7	61.9	2.36	ns	ns	ns
Feed intake (g/per day) ($n = 6$ pens with 10 birds/pen)								
Week 1	37.8	42.1	38.3	39.9	3.75	ns	ns	ns
Week 2	109.4	110.7	111.2	107.4	12.9	ns	ns	ns
Week 3	204.6	197.9	184.6	221.6	27.1	ns	ns	ns
Week 4	227	230	240	210	29.3	ns	ns	ns
Week 5	257^{a}	264^{ab}	274^{ab}	328^{b}	35.6	*	ns	ns
Week 6	252	246	230	262	29.8	ns	ns	ns
Week 7	135^{A}	167^{B}	191^{B}	137^{A}	13.2	ns	ns	***
Week 1–7	173	177	179	184	21.4	ns	ns	ns
Feed conversion ratio ($n = 6$ pens with 10 birds/pen)								
Week 1	1.65	1.87	1.72	1.85	0.17	ns	ns	ns
Week 2	2.18	2.22	2.29	2.35	0.27	ns	ns	ns
Week 3	2.31	2.44	2.32	2.62	0.33	ns	ns	ns
Week 4	2.7	2.79	2.89	2.82	0.36	ns	ns	ns
Week 5	2.93	3.07	2.96	3.15	0.38	ns	ns	ns
Week 6	3.54	4.10	3.57	4.04	0.46	ns	*	ns
Week 7	3.41	4.00	3.95	3.54	0.31	ns	ns	**
Weeks 1–7	2.73	2.93	2.86	2.97	0.34	ns	**	ns

S = duck strain factor; H = housing factor; S×H = interaction between duck strain and housing factors.
Within a row, means with a different superscript letter significantly differ ($^{a, b}$ - $P < 0.05$; $^{A, B, C, D}$ - $P < 0.01$); ns = no significance ($P > 0.05$); * ($P < 0.05$); ** ($P < 0.01$); *** ($P < 0.001$).
[1] Strain of Pekin duck.
[2] Housing system.

Table 3
Carcass characteristics of duck strains, STAR 53 medium (STAR 53) and SM3 heavy (SM3) hybrids of Pekin ducks, reared in two different housing systems (intensive vs semi-intensive), ($n = 60$).

		Experimental group				SEM	*P*-value		
		STAR 53[1]		SM3					
		Intensive system[2]	Semi-intensive system	Intensive system	Semi-intensive system		S	H	S×H
TL (%)		2.42^{A}	3.26^{B}	2.89^{ABa}	3.55^{Bb}	0.34	*	***	ns
HCW (g)		1975	1868	1946	1945	91.1	ns	ns	ns
DP (%)		63.9	63.6	64.1	65.1	0.82	*	ns	ns
Breast	(g)	651^{AB}	606^{A}	677^{AB}	697^{B}	41.2	**	ns	ns
	(%)	32.9^{A}	32.4^{A}	34.8^{B}	35.9^{B}	0.77	***	ns	*
Drumstick with thigh	(g)	443	427	429	419	16.3	ns	ns	ns
	(%)	22.4^{AB}	22.9^{A}	22.1^{AB}	21.6^{B}	0.48	***	ns	*
Wings	(g)	270	261	269	269	9.28	ns	ns	ns
	(%)	13.7	13.9	13.8	13.8	0.42	ns	ns	ns
Back with pelvis	(g)	611	574	569	559	31.9	ns	ns	ns
	(%)	30.9^{A}	30.7^{A}	29.3^{B}	28.8^{B}	0.52	***	ns	ns
Breast	Meat (%)	60.6^{A}	61.0^{A}	66.3^{B}	66.4^{B}	1.05	***	ns	ns
	Skin + SF (%)	22.9^{Aa}	20.8^{Ab}	17.9^{B}	18.2^{B}	1.12	***	ns	*
	Bone (%)	16.5^{A}	18.2^{B}	15.7^{A}	15.4^{A}	0.67	***	*	**
Drumstick with thigh	Meat (%)	60.5	61.9	61.7	61.7	0.93	ns	ns	ns
	Skin + SF (%)	21.8^{a}	19.8^{b}	20.3^{ab}	20.0^{ab}	1.02	ns	*	ns
	Bone (%)	17.6	18.3	18.0	18.2	0.52	ns	ns	ns

S = duck strain factor; H = housing factor; S×H = interaction between duck strain and housing factors; TL = transport weight loss; HCW = hot carcass weight; DP = dressing percentage of hot carcass weight; SF = subcutaneous fat.
Within a row, means with a different superscript letter significantly differ ($^{a, b}$ - $P < 0.05$; $^{A, B}$ - $P < 0.01$); ns = no significance ($P > 0.05$); * ($P < 0.05$); ** ($P < 0.01$); *** ($P < 0.001$).
[1] Strain of Pekin duck.
[2] Housing system.

Table 4
Physical meat traits of duck strains, STAR 53 medium (STAR 53) and SM3 heavy (SM3) hybrids of Pekin ducks, reared in two different housing systems (intensive vs semi-intensive), (n = 60).

Parameters	Experimental group				SEM	P-value		
	STAR 53[1]		SM3					
	Intensive system[2]	Semi-intensive system	Intensive system	Semi-intensive system		S	H	S×H
Breast (*Pectoralis superficialis* muscle)								
pH_{45min}	5.95^{ab}	5.98^{a}	5.92^{b}	5.97^{ab}	0.03	ns	*	ns
pH_{24h}	5.79	5.83	5.79	5.79	0.03	ns	ns	ns
EZ-drip loss (%)	2.64^{A}	4.28^{B}	2.74^{A}	3.56^{B}	0.41	ns	***	*
CL (%)	29.6^{A}	32.4^{B}	27.3^{C}	29.1^{A}	1.01	***	***	ns
WBSF (N)	73.51^{ABa}	63.9^{Ab}	77.2^{B}	81.2^{B}	5.25	***	ns	*
L*	43.2^{a}	44.6^{b}	43.3^{ab}	43.5^{ab}	0.72	ns	*	ns
a*	16.6^{AB}	17.0^{A}	16.3^{B}	16.6^{AB}	0.33	*	*	ns
b*	5.64^{AB}	6.08^{A}	5.36^{B}	5.59^{AB}	0.30	*	*	ns
Thigh (*Iliotibialis* muscle)								
L*	43.7	43.6	44.5	43.4	0.84	ns	ns	ns
a*	16.1^{ab}	16.8^{a}	15.3^{b}	15.6^{ab}	0.70	**	ns	ns
b*	4.95	5.24	4.77	4.86	0.38	ns	ns	ns

S = duck strain factor; H = housing factor; S×H = interaction between duck strain and housing factors; pH_{60min} and pH_{24h} = pH values measured 60 min and 24 h post mortem; EZ-drip loss = drip loss measured by method of Rassmussen and Andersson (1996); CL = cooking loss; WBSF = Warner-Bratzler shear force; L* = lightness (a higher L* value indicates a lighter color); a* = redness (a higher a* value indicates a redder color); b* = yellowness (a higher b* value indicates a more yellow color).
Within a row, means with a different superscript letter significantly differ ($^{a,\,b}$ - $P < 0.05$; $^{A,\,B,\,C}$-$P < 0.01$); ns = no significance ($P > 0.05$); * ($P < 0.05$); ** ($P < 0.01$); *** ($P < 0.001$).
[1] Strain of Pekin duck.
[2] Housing system.

Rearing conditions affected the percentage of weight loss during transport, with higher ($P < 0.001$) transport loss determined in the ducks from the semi-intensive system than in the ducks from the intensive housing system. Furthermore, the percentage of bone in breast was higher ($P < 0.05$), while the percentage of skin with subcutaneous fat in drumstick with thigh was lower ($P < 0.05$) in ducks reared with access to land outside than in ducks reared in the complete confinement system. Significant interactions between duck strains and housing systems were found for percentages in the carcasses of breasts and drumsticks with thighs, as well as for percentages of bone and skin with subcutaneous fat in breast. The highest percentage of bone in breasts ($P < 0.01$) was observed in STAR 53 hybrids raised in the semi-intensive housing system.

Physical meat quality traits

Physical meat quality parameters of STAR 53 medium hybrids and SM3 heavy hybrids of Pekin ducks reared in the two different housing systems (intensive vs semi-intensive) are presented in Table 4. Higher cooking losses and lower WBSF values ($P < 0.001$) were determined in STAR 53 than in SM3 ducks. Higher a* values in breasts and drumsticks with thighs, as well as higher b* value in breasts, were measured in STAR 53 than in SM3 ducks ($P < 0.05$). Housing conditions affected pH measured 45 min after slaughter, as lower pH_{45min} ($P < 0.05$) was determined in animals reared in the intensive than in the semi-intensive system. Higher EZ-drip loss and cooking loss ($P < 0.001$) were measured in ducks housed with access to land outside than in those housed in the complete confinement system. Housing system impacted on instrumental color of breasts, with higher L*, a*, and b* values ($P < 0.05$) determined in ducks reared in the semi-intensive system than in ducks reared in the intensive system. Significant interactions ($P < 0.05$) between duck strain and rearing system were found for two meat quality parameters (EZ-drip loss and WBSF value). A higher percentage of drip loss ($P < 0.01$) was determined in breasts of STAR 53 ducks raised in the semi-intensive housing system than in STAR 53 hybrids and SM3 hybrids from the intensive housing system. The lowest WBSF was determined in STAR 53 ducks raised in semi-intensive housing.

Discussion

In our study, final live weight ranged from 3 025 to 3 167 g for STAR 53 ducks and from 3 095 to 3 132 g for SM3 ducks. Similar results for final BW of Pekin ducks were determined by Kokoszynski et al. (2019c). However, studies by El-Edel et al. (2015) and Kokoszynski et al. (2019b) showed lower final live weight of commercial strains of Pekin ducks, while other authors found the opposite (Murawska, 2012; Kokoszynski et al., 2015; Baltić et al., 2017). The results from our study demonstrated that SM3 ducklings at the beginning of the study had higher live weight than STAR 53 ducklings, while on days 14 and 28 of the study, STAR 53 ducks had higher live weight than SM3 ducks. Following the same trend, in weeks 2 and 4 of the study, higher weight gain was determined in STAR 53 than in SM3 ducks, while in weeks 5 and 7, the opposite was found, causing no differences in final BW between the two duck strains. According to product specifications of Grimaud Frères and Cherry Valley companies, STAR 53 medium hybrids and SM3 heavy hybrids achieve at 49 days similar final live weights (3.65 kg and 3.76 kg, respectively). Similarly, Kokoszynski et al. (2015) did not find any difference in final live weight between SM3 and STAR 53 hybrids, as also we have observed. However, El-Edel et al. (2015) determined higher final BW in SM3 ducks than in STAR 53 ducks. Furthermore, in our study, as also found by other authors (El-Edel et al., 2015; Kokoszynski et al., 2015; Kokoszynski et al., 2019c), desired final live weights were not achieved for SM3 and STAR 53 hybrids of Pekin duck. Since, the composition of three diets was in accordance with recommendations of Grimaud Frères and Cherry Valley companies for STAR 53 and SM3 hybrids of Pekin ducks, in our study lower final live weights could be attributed to lower ambient temperature that was on average 14.7 °C after the fourth week of the experiment. Maintenance requirements of Pekin duck increase as ambient temperature decreases from 26 °C to 10 °C (Cherry and Morris, 2005). Although differences in weight gain could be attributed to the differences in feed intake, our results showed no differences in feed intake between the two duck strains, except for in week 5 of the study when higher feed intake was recorded for SM3 than STAR 53 ducks. Other authors (Murawska, 2012; Kokoszynski et al., 2015; Kokoszynski et al., 2019b) reported that BW of ducks was influenced by numerous factors such as duck strain, age, sex of the birds, feeding (including amount of feed intake), and chemical composition of feed. There was no difference between the two Pekin duck hybrids in the chemical composition of their diets, FCR, or feed intake almost throughout the entire study period. Therefore, in our study, differences in weight gain could indicate the greater genetic potential of STAR 53 ducks during the first 4 weeks, although from weeks 5 to 7, SM3 ducks exhibited better weight gains than STAR 53 ducks. In our study, the highest daily weight gains for both hybrids of Pekin duck were noted in animals between 14 and 35 days old, while Sari et al. (2013) and El-Edel et al. (2015) reported highest daily weight gains in ducks between 28 and 42 days old. Furthermore, in our study, overall FCR ranged from 2.73 to 2.97, which was in accordance with results of Kokoszynski et al. (2019b), but higher than was reported by other studies (Kokoszynski et al., 2015; Baltić et al., 2017). Feed conversion ratio determined in our study for STAR 53 hybrids and SM3 hybrids of Pekin duck were higher than those gave in product specifications of Grimaud Frères and Cherry Valley companies (2.18 and 2.29, respectively), possibly due to lower ambient temperature after the fourth week of the experiment when maintenance requirements of ducks increased.

Regarding the effect of housing system on the growth performance of ducks, in our study, final BW was higher in ducks reared in the complete confinement system than in ducks kept confined in a barn but with outdoor access. Weight gain results were in accordance with this, as higher weight gains were determined during weeks 4, 6, and 7 in ducks reared in the intensive system than in ducks reared in the semi-intensive system. However, during week 5, higher weight gain was observed in ducks that had access to land outside than in ducks that were housed indoors. Data on the effects of rearing system on growth performance of birds are inconsistent. El-Edel et al. (2015) found higher BWs and weight gains during week 4 of their study in indoor-housed ducks than in outdoor-housed ducks, while the opposite was observed during weeks 6 and 8 of their study. Furthermore, some authors found that birds reared indoors had lower growth performance results than birds reared outdoors (Erisir et al., 2009; Damaziak et al., 2014). Moreover, in our study, higher overall FCR was determined in ducks reared in the semi-intensive system than in ducks reared in our intensive system. These differences in growth performance of ducks from the two rearing systems could be attributed to different intensities of some animal activities. Ducks reared in the semi-intensive system had more space to walk, peck, and exhibit natural behaviors, and consequently, probably had increased energy requirements and needed more feed for growth. Moreover, ducks reared in the housing system with open access to land were exposed to greater oscillations of ambient temperature during the day, so the animals likely had higher needs for feed to maintain their body temperatures. The importance of stocking density for the growth performance of birds has been well documented (Onbasilar and Yalcin, 2018). Some authors determined that increasing stocking density negatively affected final BW and weight gain of ducks (Xie et al., 2014; Mallick et al., 2018; Bai et al., 2020), while in our study, better growth performance occurred in the system with higher stocking density (our intensive housing system).

In our study, dressing percentage ranged from 63 to 65%, while other authors found higher dressing percentages for commercial strains of Pekin ducks (Kwon et al., 2014; Kokoszynski et al., 2015; Baltić et al., 2017; Kokoszynski et al., 2019b; Kokoszynski et al., 2019c). Our results showed that duck strain influenced carcass characteristics of ducks. Higher dressing percentage, weight and percentage of breasts in carcasses, and lower percentages in carcasses of drumsticks with thighs and back with pelvis were determined in the SM3 hybrid than in the STAR 53 hybrid. On the contrary, Kokoszynski et al. (2015) did not determine any difference in dressing percentage and percentage of breast meat in carcass between these two duck strains. The higher dressing percentage of SM3 compared to STAR 53 ducks determined in our study could be attributed to the lower percentage weight of offals and giblets in SM3 than in STAR 53 ducks (Murawska, 2012). Moreover, our results showed that breasts of SM3 ducks had a more favorable composition with a higher percentage of meat and lower percentages of skin with subcutaneous fat and bones than breasts of STAR 53 ducks. Also, Kokoszynski et al. (2017) found that SM3 ducks had good muscling, and in particular, a large amount of meat in breasts, and low content of skin with subcutaneous fat. Our results indicate the SM3 hybrid used in our study perhaps had greater potential to achieve higher meat yield than did our STAR 53 ducks.

We found the two different housing systems did not significantly affect carcass quality of the ducks, except for the percentage of skin with subcutaneous fat in the carcasses and the percentage of animal weight loss during the transport from farm to slaughterhouse. Indoor-housed ducks had a higher percentage of skin with subcutaneous fat in drumsticks with thighs than those reared in the system with access to land outside, suggesting that ducks from our intensive system were less active and deposited more fat. Consequently, the higher content of skin and fat likely limited weight loss during the transport in ducks reared in the intensive system. However, Sari et al. (2013) found the production system affected carcass quality of ducks, as larger carcass cuts occurred in ducks reared on a floor system than in those reared in a cage system, while Bai et al. (2020) determined the opposite for thigh meat. Some authors (Xie et al., 2014; Mallick et al., 2018) found that stocking density did not influence carcass quality, which was consistent with our results, since our two rearing systems (intensive vs semi-intensive) differed in stocking density (0.15m^2/ head vs 0.38 m^2/head, respectively).

In our study, duck strain did not affect pH, drip loss, or L* value, as was similarly observed by Kokoszynski et al. (2015). pH_{24h} determined in our study ranged from 5.79 to 5.83, which was in line with Baltić et al. (2015) and Kokoszynski et al. (2019c). Higher pH_{24} was found by Kwon et al. (2014) and Kokoszynski et al. (2015). Those differences in pH could be attributed to different glycogen reserves at slaughter and different preslaughter treatments of animals (Rosenvold and Andersen, 2003). Moreover, drip loss determined in our study was higher than that reported by Kokoszynski et al. (2019b) and Kokoszynski et al. (2019c). Cooking loss in our study ranged from 27 to 32% and differed from results reported by Kwon et al. (2014), Kokoszynski et al. (2019b), and Kokoszynski et al. (2019c), probably due to the different procedures for measuring cooking loss in the cited studies. Furthermore, our results show that cooking loss was significantly higher in STAR 53 than in SM3 ducks, as was confirmed in other studies (Kwon et al., 2014; Kokoszynski et al., 2019b and 2019c). In our study, more tender breast meat was determined in STAR 53 than in SM3 ducks, which could be explained by the lower muscle fiber diameter of STAR 53 than SM3 ducks (Kokoszynski et al., 2019c). Moreover, in our study, higher a* values of breasts and drumsticks with thighs were found in STAR 53 than in SM3 ducks, although Kokoszynski et al. (2015) did not find any difference in a* value between those two genetic lines.

Our results showed that housing system affected the physical meat quality of the ducks. Ducks reared in the semi-intensive system had higher initial pH, higher percentages of EZ-drip loss and cooking loss, and higher L*, a*, and b* values measured in breasts compared to ducks reared in the intensive system. On the contrary, other authors did not find production system affected the meat quality of ducks (Chen et al., 2015). Michalczuk et al. (2016) found that production system did not affect chemical composition, cutting force or ultimate pH, but influenced meat color of ducks. Brighter meat was found in ducks from their free range system than in ducks from their intensive system, which was consistent with our results. As mentioned above, pH is influenced by numerous factors, but initial pH mostly depends on different preslaughter treatments of animals (Rosenvold and Andersen, 2003). The higher initial pH in semi-intensively-reared ducks determined in our study suggests those animals were exposed to less stress during preslaughter procedures than were the ducks housed in our intensive system.

In summary, SM3 heavy hybrid and STAR 53 hybrid of Pekin ducks achieved similar BWs at the end of the study. However, better carcass quality was observed in the SM3 hybrid than in the STAR 53 hybrid used in our study. Duck strain mainly did not affect physical meat quality traits. Although ducks with access to land outside were provided with better welfare conditions, ducks reared in our intensive system proved to have better growth performance results and better meat quality than did ducks from the semi-intensive system.

Ethics approval

Before the start of the study, the experimental protocol was approved by the Veterinary Directorate of the Serbian Ministry of Agriculture, Forestry and Water Management and the Ethics Committee of the Faculty of Veterinary Medicine, University of Belgrade (Resolution number: 323-07-00364/2017/05/2).

Data and model availability statement

The authors declare that the data of this research are not deposited in any official repository.

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Declaration of interest

The authors declare that there are no conflicts of interest.

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