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Age-related changes in the growth performance, meat quality, and oxidative processes in breast muscles of three chicken genotypes

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Abstract: The aim of this study was to determine growth performance, meat quality, and oxidative changes in breast muscles depending on the genotype and age of broiler chickens. The experiment was conducted on 1080 chickens: fast-growing Cobb 500, medium-growing Hubbard JA957, and a slow-growing experimental line. Chickens from all genetic groups were reared on litter for 8 weeks, but from the 5th week of age, 15 chickens from each group were slaughtered every week. After slaughter at weeks 5, 6, 7, and 8 of chickens' lives, their muscles were sampled for chemical composition, fatty acid profile, and cholesterol. Contents of reduced glutathione and ascorbic acid were determined as well. The fast-growing chickens achieved the highest daily gain and daily meat weight gain compared with the medium-growing chickens and the slow-growing experimental line. Meat of the fast-growing and medium-growing chickens was characterized by antioxidative potential decreasing with age, which was manifested by a decreased content of reduced glutathione. In turn, the slow-growing experimental line showed the lowest content of reduced glutathione (85.2 U/mL) in the sixth week and a systematic growth with age.

Key words: Chickens, age, growth performance, meat quality, oxidative processes

1. Introduction

Improvement has been observed in the growth rate, feed conversion ratio (FCR), and dressing percentage, but deterioration has been noted in meat quality (1,2). Contemporarily, the welfare of birds is a significant factor that determines the choice of a food product by consumers (3). Following the growing demand of consumers who are more sensitive to the ethical and cultural aspects of foods from animal origin, there is an increasing interest in animal-friendly farming systems, which can improve animal welfare as well as guarantee high qualitative standards concerning food safety and nutritional and sensory properties (4). Castellini et al. (5) emphasized that, owing to a higher content of polyunsaturated fatty acids (PUFAs), the meat of birds from alternative production systems is more exposed to unfavorable changes during storage, mainly including enhanced lipid oxidation. For this reason, such products have a shorter shelf life than the meat of commercial broilers. Hence, apart from applying a diet rich in antioxidants (6–8), the selection of genetic material adjusted to longer rearing periods is especially important (9,10). Broiler diets are often supplemented with oils to meet the high energy requirements of modern genotypes. Oils are rich in PUFAs. For this reason, PUFAs are also prevalent in the lipid fraction of poultry-derived foods. Their double bonds are highly prone to lipid oxidation; hence, special attention needs to be paid to avoid their deterioration in broiler meat (9).

The aim of this study was to determine growth performance, meat quality, and oxidative changes in breast muscle depending on the genotype and age of broiler chickens kept indoors on litter.

2. Materials and methods

All procedures were performed according to the guiding principles for the care and use of research animals and were approved by the local ethics commission.

2.1. Birds and experimental design

The experiment was conducted with fast-growing Cobb 500 chickens (group C), medium-growing Hubbard JA957 chickens (group H), and a slow-growing experimental line (group E). The experimental line was the second

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generation of crossing Polish native Greenleg Partridge and fast-growing commercial chickens (10). In the experiment, 1080 chickens were reared (only males), divided into 3 experimental groups (360 chickens each), each in 10 replications (36 chickens each), with an initial stock density of 12 chickens/m^2. From the 5th to the 8th week of the birds' lives, every week successive birds were taken for slaughter. As a result, the final stock density was 10 chickens/m^2. The birds had ad libitum access to feed and water. The composition of diets was determined by the standard AOAC method (11) (Table 1). Body weight (BW), feed intake, and mortality were checked at weekly intervals. Results collected each week allowed the computation of daily weight gain (DWG) and FCR.

On weeks 5, 6, 7, and 8 of birds' lives, 15 chickens from each group (15 chickens × 3 groups per week) were randomly selected by average body weight and fasted for 8 h. The chickens were electrically stunned in a water bath (120 mA, 50Hz) for 2 s. Next, they were slaughtered by the method of cutting the cervical blood vessels and bled out for about 7–10 min. After scalding in water with a temperature of 56–58 °C for about 60 s, the birds were manually plucked and eviscerated, and their carcasses were placed in cold storage at a temperature of 4 °C for 12 h (12). Breast muscle samples were collected for further analyses.

2.2. Meat quality

2.2.1. Chemical composition

The chemical composition of muscle samples was determined using a near-infrared spectrometer (NIRFlex N-500, Büchi, Switzerland). Measurements were conducted using an NIRFlex Solids module of spectral range at

Table 1. Formulation and nutritional composition of chicken diets.

Item	Days 0–14	Days 15–35	Days 36–49	Days 50–56
Ingredient (%)				
Yellow maize	10.00	11.40	10.00	10.00
Wheat	53.00	55.00	59.60	60.80
Soybean meal	30.60	27.40	23.20	21.60
Limestone Ca39	1.17	1.18	1.08	0.94
Sodium bicarbonate	0.20	0.14	0.14	0.16
Sodium chloride	0.24	0.28	0.28	0.26
Stimulant[1]	0.01	0.01	0.01	0.01
Phosphate 2-Ca	1.17	0.77	0.70	0.64
Soybean oil	2.10	2.40	3.60	4.40
Methionine	0.48	0.42	0.36	0.28
Lysine	0.36	0.34	0.36	0.28
Threonine	0.14	0.13	0.14	0.10
Vitamin-mineral premix[2]	0.53	0.53	0.53	0.53
Nutritional composition (% of weight)				
ME (MJ/kg)	12.52	12.76	13.20	13.47
Crude fat	3.67	4.00	5.14	5.92
Crude protein	21.99	20.78	19.26	18.51
Methionine	0.70	0.63	0.57	0.50
Methionine + cysteine	1.08	1.01	0.92	0.84
Lysine	1.38	1.28	1.19	1.08
Crude ash	5.83	5.35	4.96	4.67

[1]The combination of benzoic acid and essential oil compounds such as thymol, eugenol, and piperine.
[2]The vitamin-mineral premix supplied the following per kilogram of complete feed: Ca, 1005.165 mg; Mg, 11.55 mg; Na, 38.82375 mg; Se, 0.315 mg; Fe, 47.25 mg; Mn, 115.5 mg; Zn, 84.00, mg; Cu, 21.00 mg; J, 0.735 mg; vitamin A, 11,550 IU; vitamin D_3, 3150 IU; vitamin E, 44 mg; vitamin K, 2.1 mg; vitamin B_1, 2.1 mg; vitamin B_2, 7.35 mg; vitamin B_6, 4.2 mg; vitamin B_{12}, 0.02625 mg; niacin, 73.5 mg; D-pantothenic acid, 16.8 mg; folic acid, 1.575 mg; choline chloride, 420 mg; biotin, 0.2625 mg; 1.4-β-D-xylanase, 262.5 FX; 6-phytase, 2100 FT; ethoxyquin, 0.1575 mg; citric acid (E330), 0.0945 mg; gallate, 0.0315 mg.

12,500–400 cm^{-1} in reflectance mode. Measurements were made in reflectance mode between 1100 and 2498 nm every 2 nm. All samples were scanned in duplicate. The 2 subsamples were compared by root mean square and if the root mean square corrected for bias was too large, two new subsamples were scanned. The average spectrum was used for near-infrared analysis (13).

2.2.2. Fatty acid profile

Fatty acid profile was determined according PN-EN ISO 5509:2001 as modified by Poławska et al. (14). Total lipids were extracted according to Folch et al. (15). Fatty acids were separated using a gas chromatograph (Hewlett Packard 6890 Series GC System) with a flame-ionization detector and a BPX 70 capillary column (50 m × 0.25 mm × 0.25 µm film) by SGE Inc. (USA). Injection temperature was 220 °C; column temperature was programmed to 1 min at 140 °C, 1.5 min at 140/210 °C, and 8 min at 210 °C; and the samples were injected using a split ratio of 30:1. Helium was used as a carrier gas. Chromatograms were compared with Sigma standards, and fatty acid content was expressed as percentage in relation to the total amount of fatty acids determined.

2.2.3. Determination of muscle cholesterol content

The content of cholesterol was determined with the method of gas chromatography according to Polish Standard PN-EN ISO 12228:2002 (16) using an Agilent 6890 chromatograph equipped with a flame-ionization detector. Separation was performed on a BPX 5 capillary column (25 m × 0.25 mm × 0.25 mm) under the following conditions: injector, 300 °C; column, 250 °C (4 min) - 5° min^{-1} - 300 °C (5 min); detector, 310 °C; carrier gas, helium (130 kPa); split ratio, 25:1.

2.2.4. Reduced glutathione

Reduced glutathione (GSH) was determined using the Oxis Research TM kit (OXIS Health Products, Inc., USA). Immediately after collection, the muscle samples were deproteinized with a TCA and EDTA mixture (1:1:1). After mixing, the resultant mixture was centrifuged for 10 min at 3000 rpm and 4 °C. To 200 µL of prepared supernatant, 200-µL portions of the following reagents were added under continuous stirring in the respective order: potassium phosphate buffer, Tris, and 1-methyl-4-chloro-7 trifluoromethylquinolinium methylsulfate NaOH. After a 30-min incubation, absorbance was detected at a wavelength of 420 nm. The content of glutathione was expressed in micromoles using a calibration curve for GSH.

2.2.5. Ascorbic acid

Ascorbic acid (ASC) concentration was determined spectrophotometrically (LambdaBio-20 spectrophotometer, PE, USA) using the phosphotungstic acid method described by Omaye et al. (17) The concentration of vitamin C was expressed in mg/100 g of meat.

2.3. Statistical analysis

The statistical analysis included the characteristics of the analyzed traits: mean values and standard error of the mean (SEM), and the determination of the significance of differences in mean values between genetic groups, between ages, and their interaction (genotype × age). Data were subjected to ANOVA using the GLM procedure (18). The significance of differences between genetic groups of chickens regarding BW ($P \leq 0.05$), breast muscle weight (BMW; g/1000 g BW), DWG (daily BW gain), feed intake (kg), FCR (feed conversion ratio), and mortality ($P \leq 0.01$) was determined based on ANOVA and multiple comparisons with Tukey's procedure.

In the case of muscle parameters not showing normal distribution, the effect of genotype and age was determined with the Kruskal–Wallis test. In turn, to estimate the effect of genotype and age on variables showing normal distribution, the GLM procedure was used according to the following formula:

$$Y_{ijk} = \mu + G_i + T_j + (GT)_{ij} + e_{ijk},$$

where Y_{ijk} is a variable; μ is the general mean; G_i is the effect of the *i*th genetic group, i = 1, 2, 3; T_j is the effect of the *j*th week, j = 5, 6, 7, 8; GT_{ij} is the effect of genetic group × week interaction; and e_{ijk} is random error.

In addition, results were subjected to principal component analysis (PCA). The PCA method allows transforming the initial parameters into a set of new, mutually independent parameters (principal components, PCs). PCA analysis was used to explain the structure of the relationship between the observable parameters and to reduce their number, in this case from 13 to 3, and to find a set of common factors (PCs) and to define their relationship with observable parameters (19).

PCA analysis was conducted for parameters describing the quality of breast muscles: fatty acids (saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), PUFAs, and unsaturated fatty acids (UFAs)); n-6/n-3; contents of total cholesterol, moisture, fat, protein, and ASC; and BMW. The analysis of parameters was aimed at determining variable factorial coordinates interpreted as correlations of appropriate variables with each factor (PC). Projection of points representing particular breast muscles originating from chickens of the 3 genetic groups was performed in order to ascertain the similarities and differences between breast muscles of groups C, H, and E.

3. Results

The greatest ($P \leq 0.01$) daily BW gain and daily meat weight gain were determined in the group of fast-growing chickens (group C) compared to the medium-growing (group H) and slow-growing (group E) birds (Table 2).

Table 2. Growth performance characteristic at the end of the experiment (8th week).

Genotype	BW (g)	DWG (g/day)	BMW (g)	Feed intake (kg)	FCR (kg/kg)	Mortality (%)
C	3100^{A}	55.36^{A}	439^{A}	9.33^{A}	3.01^{B}	10.84^{C}
H	2279^{Ba}	40.77^{B}	355^{B}	7.29^{B}	3.20^{A}	5.28^{B}
E	2253^{Bb}	40.52^{B}	327^{C}	7.59^{B}	3.37^{A}	3.06^{A}
Pooled SEM	19.1	0.12	2.1	0.12	0.10	0.33

$^{A-C}$: Means within a column for the week are significantly different ($P \leq 0.01$).
^{a,b}: Means within a column for the week are significantly different ($P \leq 0.05$).
Chicken genotypes: C – Cobb 500; H – Hubbard JA957; E – experimental line.
BW = body weight – 8 weeks, DWG = daily BW gain, BMW = breast muscle weight – 8 weeks, FCR = feed conversion ratio; values in this table represent mean values (n = 10 per pen for each genetic group).

The chickens from group C were characterized by the best FCR value ($P \leq 0.01$) compared to the birds from groups H and E. However, the group of fast-growing birds was characterized by the poorest results of mortality compared to the remaining birds.

Significant differences were demonstrated in chemical composition and fatty acid profile depending on the age and genotype of birds (Tables 3 and 4). The results showed higher ($P \leq 0.01$) content of PUFAs and lower ($P \leq 0.01$) contents of SFAs and MUFAs in breast muscles of slow-growing birds of group E (Table 5). The main PUFA was $C18:2_{(n-6)}$, i.e. its content was lower in chickens from groups C and H than in chickens from group E (Table 4). In turn, the main acid of neutral fat is C18:1 c9, the content of which may increase along with an increase of body weight and adiposity, which may be observed in the group

Table 3. The effect of age and genotype on the chemical composition of chicken breast meat[1].

Factor		Chemical composition			
Age	Genotype	Total protein (%)	Fat (%)	Ash (%)	Moisture (%)
5 weeks	C	22.9^{B}	2.26^{C}	1.18^{A}	74.7^{A}
	H	22.7^{B}	3.02^{A}	1.20^{A}	73.8^{C}
	E	30.0^{A}	2.66^{B}	1.19^{A}	74.2^{B}
6 weeks	C	22.1^{C}	2.41^{B}	1.19^{A}	73.9^{B}
	H	22.7^{B}	2.73^{A}	1.20^{A}	74.1^{B}
	E	23.3^{A}	1.38^{C}	1.21^{A}	75.1^{A}
7 weeks	C	22.4^{B}	2.78^{A}	1.18^{A}	73.9^{A}
	H	22.7^{A}	2.02^{B}	1.18^{A}	74.1^{B}
	E	22.7^{A}	2.02^{B}	1.19^{A}	73.6^{A}
8 weeks	C	22.6^{A}	3.45^{A}	1.20^{A}	73.5^{A}
	H	22.7^{A}	2.66^{C}	1.19^{A}	73.8^{A}
	E	22.7^{A}	2.74^{B}	1.19^{A}	74.0^{A}
	Pooled SEM	0.07	0.09	0.14	0.17
P-values					
ANOVA					
Genotype		0.001	0.251	0.212	0.132
Age		0.232	0.001	0.174	0.022
Genotype × Age		0.001	0.001	0.118	0.001

$^{A-C}$: Means within a column for the week are significantly different ($P \leq 0.01$).
Chicken genotypes: C – Cobb 500; H – Hubbard JA957; E – experimental line.
[1]Values in this table represent mean values (n = 15).

Table 4. The effect of age and genotype on the selected fatty acid composition in chicken breast meat[1] (% of total fatty acids).

Age	Genotype	$C_{14:0}$	$C_{16:0}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	$C_{20:4}$	$C_{20:5}$	$C_{22:6}$
5 weeks	C	0.51^{A}	24.5^{B}	6.96^{B}	38.7^{A}	18.6^{C}	1.88^{A}	0.15^{C}	0.19^{A}	0.02^{A}
	H	0.51^{A}	25.0^{A}	7.50^{A}	37.1^{B}	19.2^{B}	1.83^{A}	0.26^{B}	0.03^{B}	0.02^{A}
	E	0.48^{B}	23.4^{C}	6.16^{C}	36.8^{B}	21.8^{A}	1.78^{B}	0.53^{A}	0.05^{B}	0.02^{A}
6 weeks	C	0.51^{A}	24.7^{A}	6.96^{B}	39.0^{A}	16.7^{C}	1.62^{C}	0.27^{A}	0.06^{A}	0.02^{A}
	H	0.50^{A}	23.1^{C}	7.50^{A}	38.8^{A}	19.1^{B}	1.76^{B}	0.17^{B}	0.03^{B}	0.01^{B}
	E	0.47^{B}	23.3^{B}	6.16^{C}	38.3^{B}	20.8^{A}	1.87^{A}	0.28^{A}	0.04^{AB}	0.02^{A}
7 weeks	C	0.46^{C}	23.9^{B}	7.01^{B}	38.0^{A}	20.0^{C}	1.73^{A}	0.39^{B}	0.05^{A}	0.02^{A}
	H	0.53^{A}	24.2^{A}	9.53^{A}	35.0^{C}	21.0^{B}	1.74^{A}	0.27^{C}	0.03^{A}	0.01^{B}
	E	0.49^{B}	23.0^{C}	6.06^{C}	37.3^{B}	22.4^{A}	1.77^{A}	0.44^{A}	0.04^{A}	0.02^{A}
8 weeks	C	0.18^{C}	24.4^{A}	7.31^{B}	37.3^{B}	19.2^{C}	1.59^{B}	0.31^{AB}	0.05^{B}	0.04^{A}
	H	0.56^{A}	24.2^{A}	7.00^{A}	38.4^{A}	20.0^{B}	1.57^{B}	0.29^{B}	0.03^{B}	0.01^{C}
	E	0.49^{B}	23.3^{B}	6.49^{C}	36.4^{C}	21.4^{A}	1.71^{A}	0.34^{A}	0.11^{A}	0.03^{B}
	Pooled SEM	0.01	0.11	0.31	0.00	0.20	0.15	0.12	0.08	0.03
P-values										
ANOVA										
Genotype		0.001	0.001	0.001	0.001	0.001	0.004	0.001	0.001	0.001
Age		0.001	0.001	0.003	0.001	0.001	0.001	0.002	0.001	0.001
Genotype × Age		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

$^{A–C}$: Means within a column for the week are significantly different ($P \leq 0.01$).
Chicken genotypes: C – Cobb 500; H – Hubbard JA957; E – experimental line.
Fatty acids: saturated ($C_{18:1}$), unsaturated ($C_{14:0}$, $C_{16:0}$, $C_{18:0}$) polyunsaturated ($C_{18:2}$, $C_{18:3}$, $C_{20:4}$, $C_{20:5}$), monounsaturated ($C_{22:6}$).
[1]Values in this table represent mean values (n = 15).

of fast-growing chickens (Tables 2 and 4). In the 6th and 8th weeks of life of the slow-growing birds, an increase ($P \leq 0.01$) was noted in the content of α-linolenic acid in their breast muscles (Table 4). It did not improve the n-6/n-3 ratio in the intramuscular fat of breast muscles of birds from this group (Table 5).

The lowest content of cholesterol (Table 5) was shown in all genetic groups at the 8th week of birds' lives. Meat of fast-growing and medium-growing chickens is characterized by antioxidative potential reducing with age, which is manifested in a decreasing content of GSH (Table 6). In contrast, the experimental line showed the lowest GSH level (85.2 U/mL) in the 6th week of life and it systematically increased with age. The highest GSH content noted in the 5th week of life of birds from all genetic lines points to the greatest potential of antioxidative protection of cells.

The highest concentration of ASC (Table 6) was reported for fast-growing chickens of all ages. The total results of the PCA for groups C, H, and E after 5, 6, 7, and 8 weeks of growth are presented in Table 7. Three components were applied to depict correlations between the analyzed parameters of breast muscle quality. The selected PC1, PC2, and PC3 components explained in total 70.7% of changes in the parameters of breast muscle quality (Figure; Table 7). The parameters of total protein, BW, breast weight, and PUFAs constituted the first component (PC1); whereas the second component (PC2) was formed by values of parameters of moisture, cholesterol, fat, and n-6/n-3 and the third component (PC3) was created by parameters of SFAs, MUFAs, ASC, GSH, and UFAs of the breast muscle quality (Figure; Table 7). PC1 was strongly positively correlated with protein content (r = 0.86), PUFAs (r = 0.75), and UFAs (r = 0.58) and negatively correlated with BW (r = –0.67) and BMW (r = –0.64). PC2 was negatively correlated with the n-3/n-6 ratio (r = –0.81) and fat content (–0.62) and positively correlated with cholesterol content (r = 0.73) and water content (r = 0.67). PC3 was negatively correlated with SFAs (r = –0.63) and positively correlated with MUFAs (r

Table 5. The effect of age and genotype on the total fatty acid (% of total fatty acids) composition and cholesterol (mg/100 g meat) in chicken breast meat[1].

Age	Genotype	SFA	UFA	PUFA	MUFA	n-6/n-3	Cholesterol
5 weeks	C	31.9^{B}	66.0^{B}	21.1^{B}	44.9^{A}	8.91^{C}	100^{A}
	H	33.0^{A}	64.8^{C}	21.6^{B}	43.2^{B}	10.3^{B}	93.6^{B}
	E	30.1^{C}	67.4^{A}	24.4^{A}	43.0^{B}	12.0^{A}	88.5^{C}
6 weeks	C	32.2^{A}	65.4^{C}	19.0^{C}	46.4^{A}	9.72^{B}	109^{A}
	H	32.2^{A}	66.4^{B}	21.3^{B}	45.1^{B}	10.7^{A}	100^{B}
	E	30.1^{B}	67.8^{A}	24.4^{A}	44.5^{C}	10.8^{A}	96.0^{C}
7 weeks	C	31.4^{B}	67.1^{B}	22.5^{C}	44.6^{A}	10.9^{C}	93.7^{C}
	H	34.2^{A}	64.2^{C}	23.3^{B}	40.9^{C}	11.8^{B}	105^{A}
	E	29.6^{C}	68.8^{A}	25.0^{A}	43.8^{B}	12.3^{A}	100^{B}
8 weeks	C	31.9^{A}	65.4^{B}	21.5^{C}	43.9^{B}	11.3^{C}	88.7^{A}
	H	31.8^{A}	67.0^{A}	22.1^{B}	44.8^{A}	12.5^{A}	82.9^{B}
	E	30.3^{B}	65.9^{B}	23.9^{A}	42.0^{C}	11.8^{B}	81.7^{B}
	Pooled SEM	0.15	0.17	0.16	0.17	0.14	0.14
P-values							
ANOVA							
Genotype		0.001	0.001	0.001	0.001	0.001	0.001
Age		0.001	0.002	0.001	0.002	0.064	0.020
Genotype × Age		0.001	0.001	0.001	0.001	0.001	0.001

$^{A–C}$: Means within a column for the week are significantly different ($P \leq 0.01$).
Chicken genotypes: C – Cobb 500; H – Hubbard JA957; E – experimental line.
SFA = Saturated fatty acids; UFA = unsaturated fatty acids; PUFA = polyunsaturated fatty acids; MUFA = monounsaturated fatty acids.
[1]Values in this table represent mean values (n = 15).

= 0.62), ASC (r = 0.60), and GSH (r = 0.59) (Table 7). The extent to which each of the variables was represented by PC1, PC2, and PC3 is depicted in the Figure. The further a variable is located from the center of the circle, the better it was represented by components PC1, PC2, and PC3. Considering the above correlations, the three groups of factors were characterized as PC1: growth, PC2: lipids, and PC3: oxidation.

Differences and similarities in the quality of breast muscle originating from chickens of three genotypes are also depicted in the Figure. The points of meat samples distributed across the figure form a group (E5, E7, E8, H8) with the highest weight and protein content.

Chickens with the medium growth rate were characterized by a lower fat content compared to the other genotypes. However, the lowest susceptibility to oxidative processes was demonstrated for meat of experimental chickens (group E), which was confirmed by a higher content of GSH noted in this group.

Meat of the slow-growing birds (group E), and likewise that of fast-growing birds (group C), exhibited high stability of redox processes. However, an additional factor, i.e. growth, points to better genetic adjustment of the slow-growing chickens (group E). Interestingly, meat of the medium-growing birds (group H) was characterized by the least stable redox environment. The growth rate of birds from particular genetic groups was found to depend on the factors of lipid fraction and antioxidative potential, with the poorest material from group C, which showed the best antioxidative defense until the 5th week of life.

4. Discussion

The ultimate antioxidant protection in Cobb 500 chickens is to the age of 5 weeks of life, probably because of long-term breeding works undertaken to achieve fast growth rate and breast muscle development. Therefore, the preferred term for slaughter for this group coincided with 5 week of rearing. In this period, statistically significant differences were also shown in the content of SFAs and UFAs between genetic groups. It was found that the experimental chicken line (group E) showed the lowest level of SFAs in comparison with the other two genetic lines.

Table 6. The effect of age and genotype on contents of ascorbic acid (ASC) and reduced glutathione (GSH) in chicken breast meat[1].

Factor		GSH (U/mL)	ASC (mg/100 g)
Age	Genotype		
5 weeks	C	137^{A}	2.73^{A}
	H	82.6^{C}	1.60^{C}
	E	130^{B}	1.96^{B}
6 weeks	C	91.8^{A}	1.78^{A}
	H	55.9^{C}	1.56^{B}
	E	85.2^{B}	1.40^{C}
7 weeks	C	61.7^{B}	1.81^{A}
	H	55.2^{C}	1.54^{C}
	E	117^{A}	1.71^{B}
8 weeks	C	84.0^{B}	2.45^{A}
	H	46.3^{C}	1.40^{B}
	E	123^{A}	1.35^{C}
	Pooled SEM	1.99	0.09
P-values			
ANOVA			
Genotype		0.001	0.001
Age		0.001	0.001
Genotype × Age		0.001	0.001

$^{A–C}$: Means within a column for the week are significantly different ($P \leq 0.01$).
Chicken genotypes: C – Cobb 500; H – Hubbard JA957; E – experimental line.
[1]Values in this table represent mean values (n = 15).

Oleic acid (18:1 cis 9), formed from stearic acid (18:0) by the enzyme stearoyl Co-A desaturase, is a major component of neutral lipid and in some animals the same enzyme forms conjugated linoleic acid, an important nutrient in human nutrition (20).

The increased concentration of n-3 fatty acids is desirable in food products of animal origin. The n-3 PUFAs have a beneficial effect on reducing the risk of development of 'civilization diseases' (21,22), but they are more susceptible to oxidative processes (23). Investigations conducted with lambs demonstrated, however, that the increased concentration of n-3 PUFAs in muscle tissue had no effect on acceleration of oxidative processes in meat (24,25).

The increasing concentration of cholesterol in the analyzed muscles may result from intensive growth of the birds until the 7th week of age. It is likely that the 6th and 7th weeks may be the weeks of peak development of muscle tissue in the analyzed heavy and medium-heavy genetic lines. In turn, the line with a low growth rate demonstrated the lowest cholesterol content and therefore should be reared for a longer period of time.

The free radical theory of aging suggests that antioxidants may be administered to diminish age-associated impairments in physiological performance (26). Cell compartmentation of antioxidants, and especially glutathione, is important because many of the free radical species generated in the cell are highly reactive and will attack preferentially those cell components that are close to the organelle in which the radicals are generated. Glutathione is the most abundant nonprotein thiol in the cell. Its roles in cell metabolism and physiological functions have been emphasized (27). Results achieved by Enkvetchakul and Bottje (28) provide an initial characterization of GSH metabolism in commercial male broilers and indicate that diethyl maleate produced dose- and time-dependent changes in GSH, similar to changes reported in mammals. Results of this study also indicate that increased tissue GSH may be beneficial for the growth of chickens.

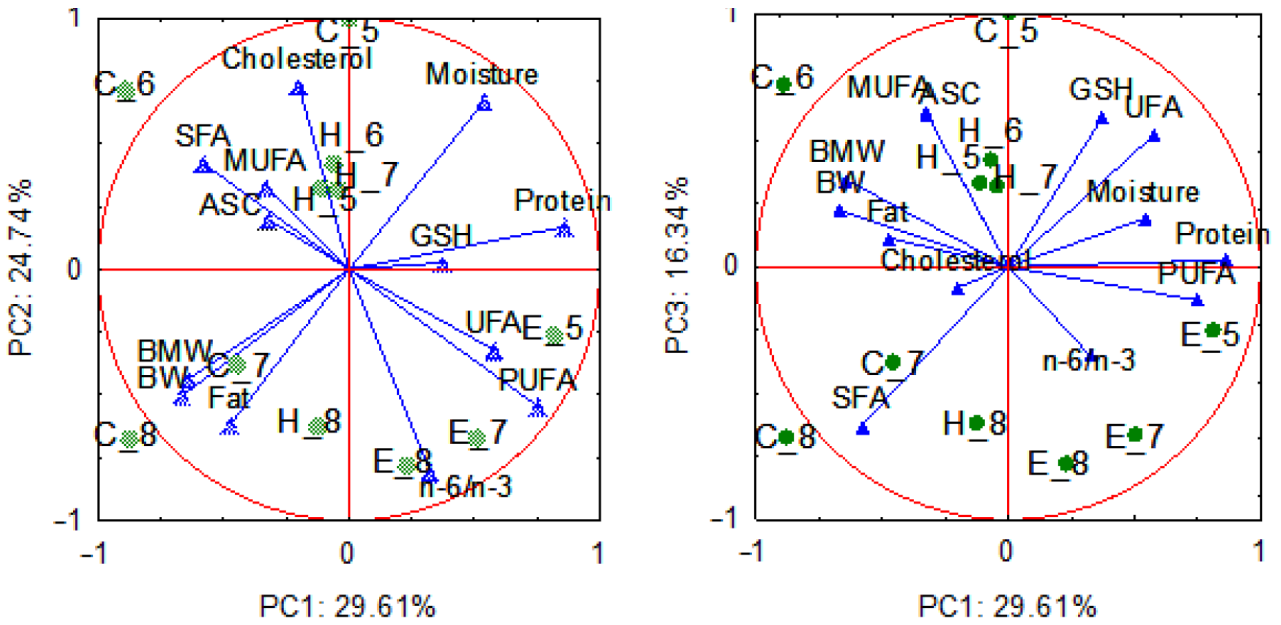

Figure. Principal component analysis projection of the parameters (SFA, MUFA, PUFA, UFA, n-6/n-3, cholesterol, fat, moisture, protein, ASC, GSH, BW, BMW) as well as structure differences and similarities of breast muscle quality. Cobb 500 (C), Hubbard JA 957 (H), experimental line (E) depending on birds age; PC1, PC2, PC3 – principal components.

Table 7. Contribution of parameters of breast muscle quality in the process of creation of three main components (PC1, PC2, and PC3).

Variable	PC1	PC2	PC3
SFA	–0.58	0.42	–0.63*
MUFA	–0.33	0.33	0.62*
PUFA	0.75*	–0.55	–0.13
UFA	0.58*	–0.32	0.52
n-6/n-3	0.32	–0.81*	–0.35
Cholesterol	–0.20	0.73*	–0.08
Fat	–0.47	–0.62*	0.11
Moisture	0.54	0.67*	0.19
Total protein	0.86*	0.17	0.03
ASC	–0.32	0.20	0.60*
GSH	0.37	0.03	0.59*
BW	–0.67*	–0.50	0.22
BMW	–0.64*	–0.44	0.34

*: Parameters that constitute PC1, PC2, and PC3.
SFA, MUFA, PUFA, UFA – fatty acids profile; n-6/n-3 ratio; ASC – ascorbic acid content; GSH – reduced glutathione content; BW - body weight; BMW - breast muscle weight.

The highest concentration of ASC was reported for the Cobb 500 chickens. The enhanced ASC synthesis in this group may indicate intensified oxidative processes. It is known that poultry does not require any dietary source of ASC as it is able to synthesize it. However, it was reported that the negative effects of environmental stress could be prevented by the use of some mineral and vitamin supplements such as ASC (29,30). An even more

interesting effect in this case seems to be the correlation between contents of GSH and ASC in particular age groups and genetic lines of birds, which may point to the synergistic effect of these antioxidants.

In conclusion, higher oxidative stability of meat from slow-growing birds, including the lowest level of SFAs and increased concentrations of $C_{18:2}$ and $C_{20:4}$ acids and GSH, may characterize the birds with a slow growth rate intended for alternative production. Hence, poorer performance results achieved by the chickens with a low growth rate may be compensated by better antioxidative parameters, a more beneficial fatty acid profile, and a lower cholesterol level. Results obtained in this study indicate the health-promoting character of meat from slow-growing chickens.

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References

1. Siegel PB, Dodgson JB, Anderson L. Progress from chicken genetics to chicken genome. Poult Sci 2006; 85: 2050–2060.
2. Thiruvenkadan AK, Prabakaran R, Panneerselvam S. Broiler breeding strategies over the decades: an overview. World Poultry Sci J 2011; 67: 309–336.
3. Napolitano F, Girolami A, Braghieri A. Consumer liking and willingness to pay for high welfare animal-based products. Tren Food Sci Tech 2010; 21: 537–543.
4. Latter-Dubois J. Poulets fermiers: leurs qualites nutritionnelle et organoleptiques et la perception du consommateur. MSc, Laval University, Quebec City, Canada, 2000 (in French).
5. Castellini C, Berri C, Le Bihan-Duval E, Martino G. Qualitative attributes and consumer perception of organic and free range poultry meat. World Poultry Sci J 2008; 64: 500–512.
6. Hugo A, Els SP, Bothma C, de Witt FH, van der Merwe HJ, Fair MD. Influence of dietary lipid sources on sensory characteristics of broiler meat. S Afr J Anim Sci 2009; 39: 11–14.
7. Ahadi F, Chekani-Azar S, Shahryar HA, Lotfi A, Mansoub NH, Bahrami Y. Effect of dietary supplementation with fish oil with selenium or vitamin E on oxidative stability and consumer acceptability of broilers meat. Global Veterinaria 2010; 4: 216–221.
8. Yesilbag D, Eren M, Agel H, Kovanlikaya A, Balci F. Effects of dietary rosemary, rosemary volatile oil and vitamin E on broiler performance, meat quality and serum SOD activity. Br Poultry Sci 2011; 52: 472–482.
9. Loetscher Y, Kreuzer M, Messikommer RE. Oxidative stability of the meat of broilers supplemented with rosemary leaves, rosehip fruits, chokeberry pomace, and entire nettle, and effects on performance and meat quality. Poultry Sci 2013; 92: 2938–2948.
10. Michalczuk M, Damaziak K, Łukasiewicz M, Tokarska G. Three genetic materials of broiler chickens growth evaluation. In: XXV International Poultry Symposium PB WPSA, 2–4 September 2013, Zegrze, Poland (in Polish with abstract in English).
11. AOAC. Official Methods of Analysis of AOAC International. 18th ed. Arlington, VA, USA: AOAC; 2005.
12. Michalczuk M, Łukasiewicz M, Zdanowska-Sąsiadek Ż, Niemiec J. Comparison of selected quality attributes of chicken meat as affected by rearing systems. Pol J Food Nutr Sci 2004; 64: 121–126.
13. Abeni F, Bergoglio G. Characterization of different strains of broiler chicken by carcass measurements, chemical and physical parameters and NIRS on breast muscle. Meat Sci 2001; 57: 133–137.
14. Poławska E, Horbańczuk JO, Pierzchała M, Srzałkowska N, Jóźwik A, Wójcik A, Pomianowski J, Gutkowska K, Wierzbicka A, Hoffman LC. Effect of dietary linseed and rapeseed supplementation on fatty acid profiles in the ostrich. Part 1. Muscles. Anim Sci Pap Rep 2013; 31: 239–248.
15. Folch J, Lees M, Sloane Stanley GH. A simple method for the isolation and purification of total lipids from animal tissues. J Biol Chem 1957; 266: 497–510.
16. Polish Standards Institute. PN-EN ISO 12228. Oleje i tłuszcze roślinne oraz zwierzęce. Metoda chromatografii gazowej. Oznaczenie poszczególnych steroli i ich całkowitej zawartości. Metoda chromatografii gazowej. Oznaczenie cholesterolu w mięsie. Warsaw, Poland: Polish Standards Institute; 2002 (in Polish)
17. Omaye ST, Turnbull JD, Sauberlich HE. Selected methods for the determination of ascorbic acid in animal cells, tissues, and fluids. Methods Enzymol 1979; 62: 3–11.
18. StatSoft Inc. STATISTICA (Data Analysis Software System), Version 10. Tulsa, OK, USA: StatSoft; 2011.
19. Stanisz A. Przystępny kurs statystyki z zastosowaniem STATYSTICA PL na przykładach z medycyny. Analizy wielowymiarowe. Krakow, Poland: StatSoft Polska Sp. Z o.o.; 2007 (in Polish).
20. Wood JD, Enser M, Fisher AV, Nute GR, Sheard PR, Richardson RI, Hughes SI, Whittington FM. Fat deposition, fatty acid composition and meat quality. Meat Sci 2008; 78: 343–358.
21. Simopoulos AP. Omega-3 fatty acids in inflammation and autoimmune diseases. J Am Coll Nutr 2002; 21: 495–505.

22. Borys B, Oprządek J, Borys A, Przegalińska-Goraczkowska M. Lipid profile of intramuscular fat in lamb meat. Anim Sci Pap Rep 2012; 30: 45–56.

23. Urso ML, Clarkson PM. Oxidative stress, exercise, and antioxidant supplementation. Toxicology 2003; 189: 41–54.

24. Cifuni GF, Napolitano F, Pacelli C, Riviezzi AM, Girolami A. Effect of age at slaughter on carcass traits, fatty acid composition and lipid oxidation of Apulian lambs. Small Rumin Res 2000; 35: 65–70.

25. Radzik-Rant A, Rant W, Kuźnicka E. The fatty acid composition of *longissimus lumborum* muscle of suckling and early-weaned dual-purpose wool/meat lambs. Arch Tierz Dummerstorf 2012; 55 : 285–293.

26. Sastre J, Pallardó FV, Viña J. Glutathione, oxidative stress and aging. Age 1996; 19: 129–139.

27. Śliwa-Jóźwik A, Jóźwik A, Kołątaj A. Influence of exogenous glutathione (GSH), as stress factor, on the activity of lysosome enzymes in some organs of mice. Arch Tierz Dummerstorf 2002; 45 : 307–314.

28. Enkvetchakul B, Bottje WG. Influence of diethyl maleate and cysteine on tissue glutathione and growth in broiler chickens. Poultry Sci 1995; 74: 864–73.

29. Pardue SL, Thaxton JP, Brake J. Role of ascorbic acid in chicks exposed to high environmental temperature. J Appl Physiol 1985; 58: 1511–151.

30. Talebi E, Khademi M. Combination effects of ascorbic acid glucose in drinking water on the broiler performance under acute heat stress. International Journal of Applied Biology and Pharmaceutical Technology 2011; 2: 92–96.