THE EFFECT OF STORAGE DURATION ON SOME QUALITY TRAITS AND COMPOSITION OF EGGS FROM DIFFERENT HOUSING SYSTEMS*

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Abstract

The effect of storage time at a temperature of 8°C on the direction and dynamics of changes in quality traits of eggs was investigated in shelled table eggs obtained from different egg production systems (cage system – CS, barn system – BS, free-range system – FRS). After 7, 14 and 28 d of storage, eggs from each housing system were tested for physical characteristics and for cholesterol content and fatty acid profile in the yolk. The weight of eggs from all studied housing systems declined with storage duration. The rate of weight loss was smallest in eggs from CS ($P<0.05$). Storage duration influenced eggshell traits but the rate and direction of these changes did not differ among the studied housing systems. Albumen height and Haugh unit score for eggs from rearing systems under study declined during storage ($P<0.05$). The greatest reduction of albumen height (18.85%) after the storage period was observed for CS eggs and the lowest (13.24%) for FRS eggs ($P<0.05$). No effect of storage duration on yolk colour intensity was observed for eggs from all the studied housing systems ($P>0.05$). Albumen pH increased with storage duration in eggs from all the egg production systems ($P<0.05$). The increase in the yolk pH during storage was the highest in FRS eggs and the lowest in the CS eggs. The storage duration of eggs from the different housing systems did not significantly influence albumen foaming capacity but adversely affected foam stability. There was no impact of storage duration of eggs from different housing systems on cholesterol content in the yolk. Eggs obtained from the different housing systems showed diverse fatty acid profiles in the yolk but this parameter did not significantly change during storage ($P>0.05$).

Key words: egg storage duration, production system, egg quality

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In accordance with the Regulation (European Union) 2017/625, table eggs can be produced in furnished cage, deep-litter, free-range and organic systems. In general, laying hen rearing systems differ in stocking density, free access and performing natural behavioural patterns, grooming, scratching, exploration, etc., which impacts on the level of laying hen welfare. Housing systems that have free access are considered as the best welfare-friendly systems (Pettersson *et al.*, 2016). Under pressure from consumers and welfare movements, layer hen welfare became an important issue in stimulating market innovations which led to the classification of commercially available table eggs into different categories. It has provided consumers with a tool to make informed choices of the eggs produced in their preferred housing system (Buller and Roe, 2014; Scrinis *et al.*, 2017). Consumers are aware of the housing system in which an egg has been produced from the alphanumeric code printed on each egg in which the first digit signifies the housing system (Commission Regulation EC No. 589/2008). Many consumers may prefer eggs from alternative housing systems in spite of their higher prices (Timoshanko, 2015; Clark *et al.*, 2017). Housing systems that allow free access to outdoors are gaining popularity among the other alternative housing systems (Rault *et al.*, 2013). In recent years, a constant downward trend has been observed in the numbers of hens housed in the cage systems (Riddle *et al.*, 2018). Although the dynamics of those changes vary between the countries, the proportion of hens kept in cage systems in Europe fell by nearly 10% between 2010 and 2015 – from 65.5% to 56.1% (Windhorst, 2017). In 2017, the number of hens kept in cage systems in the European Union dropped to 53.2%, and in 2019 – to 48%. In spite of the increasing interest of consumers in eggs from alternative systems and the declining trend in the numbers of laying hens maintained in the cage system in favour of alternative systems (Riddle *et al.*, 2018), cage eggs are still the backbone of egg supply to consumers and the processing industry in many EU countries.

Since a variety of housing systems are in use, it is necessary to determine how the housing system influences egg quality traits. In recent years, there have been many scientific studies concerning the effect of rearing system on egg quality. An extensive review of the scientific literature concerning the effect of different rearing systems of laying hens on egg quality characteristics has been published by Rossi and De Reu (2011) and Jones (2017).

Due to a special structure and content of biologically active compounds, eggs belong to the most durable food products of animal origin. Shell and shell membranes are relatively effective in protecting egg contents from microbiological contamination but do not prevent aging processes accompanied by physicochemical changes in egg contents (Berardinelli *et al.*, 2008). Storage time is one of the fundamental factors affecting the eggs' quality deterioration (Brodacki *et al.*, 2019). One of the major changes during the storage of table eggs is a decrease in the height of dense albumen and the associated number of Haugh units (Vlčková *et al.*, 2019; Drabik *et al.*, 2021). The movement of carbon dioxide and moisture through the egg shell increases the pH of the albumen and the yolk, decreases moisture percentage of egg albumen and decreases the albumen weight (Eke *et al.*, 2013; Vlčková *et al.*, 2019). During egg storage, the weight of yolk increases due to the diffusion of water from albumen to yolk (Menezes *et al.*, 2012). Sekeroglu *et al.* (2008) reported the increase in yolk

colour intensity during storage. Chen et al. (2019) demonstrated that the foaming ability decreased significantly while the foaming stability decreased slightly during cold storage. The changes of yolk fatty acid profile value during storage were found by Wang et al. (2017). Naviglio et al. (2012) documented that cholesterol content after storage was similar as before storage.

The aim of the present study was to evaluate the effect of housing system (cage, deep-litter, free-range) on rate and direction of changes in physical egg characteristics during storage, functional properties of the albumen (pH, foaming capacity, foam stability) after storage, and level of cholesterol and fatty acid profile in the yolk.

Material and methods

The study was conducted on eggs from 3960 Hy-line Brown hens housed in different housing systems: 1320 in cage system (11 hens per cage, 750 cm² per hen), 1320 in barn system, on deep litter (7 birds per m²), 1320 in free-range system (indoor stocking density was 9 hens/m², while outdoor stocking density was 1 hen/4 m²). The daily photoperiod was set at 16 h light: 8 h darkness. The temperature was kept at 17–22°C with air humidity of 60–70%. All the hens were fed standard layer diet (15.32% protein; 2.88% fibre; 11.31% ash; 3.3% fat, 3.80% Ca) *ad libitum* and had free access to water. Fatty acid profile of the layer diet is presented in Table 1.

Table 1. Fatty acid profile of layer diet

Fatty acids ¹	Content (g/100 g)
Σ SFA ²	16.74
Σ UFA ³	83.26
Σ MUFA ⁴	30.84
Σ PUFA ⁵	52.42
PUFA n-6	49.37
PUFA n-3	3.05
PUFA n-6/n-3	16.18

¹This diet was given in CS, BS, FRS housing systems.

²SFA – saturated fatty acids (C8, C10, C12, C14, C16, C18, C20, C22).

³UFA – unsaturated fatty acids (C16:1, C18:1, C22:1, C18:2, C20:4, gamma 18:3, C18:3, CLA, EPA, DHA).

⁴MUFA – monounsaturated fatty acids (C16:1, C18:1, C22:1).

⁵PUFA – polyunsaturated fatty acids (C18:2, C20:4, gamma 18:3, C18:3, EPA, DHA).

At 56 weeks of hen age, eggs were collected from each housing system. Physical characteristics of the eggs from each rearing system (CS, BS, FRS) were tested on the first day after laying and after 14-d and 28-d storage. All the eggs were stored at a constant temperature of 8°C and 45–50% humidity. The following physical characteristics were determined: egg weight and yolk weight (g); shell characteristics: colour (%), weight (g), thickness (µm), density (mg/cm³), shell breaking strength (N); egg contents characteristics: thick albumen height (mm), Haugh units (HU), yolk colour (according to a 15-point La Roche scale), pH of the albumen and the

yolk. Foaming properties of the albumen, i.e. foaming capacity (%) and foam stability (%) were also evaluated.

Egg weight was determined by weighing individually with a digital laboratory balance (Ohaus Navigator NOB 110, Sweden) exact to 0.1 g. Weight loss (%) of whole eggs was calculated according to the equation (Carter, 1975):

$$\text{Weight loss} = \frac{\text{initial egg weight} - \text{egg weight after storage}}{\text{initial egg weight}} \times 100$$

The percentage of egg morphological components (albumen, yolk and shell) was calculated based on their weights measured individually for each egg.

Shell colour, eggshell weight, density and thickness, albumen height, Haugh units and yolk colour according to DSM scale were measured using electronic equipment for egg quality measurements (EQM – Egg Quality Measurements, Technical Services and Supplies, UK).

Eggshell strength (N) was measured using a multipurpose testing system, model BT1-FR1.OTH.D14 with measuring head 100N and the test Xpertsoftware (Zwick/Roell GmbH & Co. KG, Ulm Germany).

Cholesterol (mg/g and mg/egg) and fatty acid profile (g/100 g) in the yolk were determined on the first day after laying and after 28-d storage.

A gas chromatographic validated method was used for the determination of cholesterol in egg yolks (Gašior and Pietras, 2013). The method involves KOH (60 g/100 ml) saponification and hexane extraction of the cholesterol. Analysis was performed in isothermal conditions (265°C) on a Shimadzu GC 2010 Plus gas chromatograph, on a column (30 m, I.D.=0.25 mm, df=0.25 mm) with 5% phenyl, 95% dimethylpolysiloxane phase, at helium flow 1.9 ml/min, and FID detector temperature 300°C. Cholesterol standard 5-Cholesten-3 α -ol, C₂₇H₄₆O, for chromatography (Sigma-Aldrich, USA) and internal standard 5 α -cholestane, C₂₇H₄₈, >97% (Sigma-Aldrich, USA) for quantification was used.

Higher fatty acids in egg yolks were quantified as methyl esters by gas chromatography. The samples were prepared according to Folch et al. (1957) whereby the sample was homogenised in chloroform: methanol in a 2:1 ratio, the solvent was evaporated, and the evaporation residue was saponified (0.5 N NaOH in methanol) and esterified (BF₃ in methanol). The fatty acid methyl esters were extracted in hexane and analysed with a Varian 3400 gas chromatograph using a column filled with acid-modified polyethylene glycol (e.g. Zebron ZB-WAX 30m), an 8200 CX autosampler and data processing software.

Foaming properties were evaluated by foaming capacity (FC) and foam stability (FS) based on the method described by Ferreira et al. (1995) with some modification. The foam was processed by whipping 100 ml of albumen for 3 min at 20°C using a mixer operating at 1220 rpm. The volumes of the foam and the drained liquid were assessed just after whipping and during holding up for 30 min at 20°C. For the determination of FC and FS, the following formula was used (Ferreira et al., 1995):

$$\text{FC (\%)} = \frac{FV}{ILV} \times 100\%$$

$$FS (\%) = \frac{ILV - DV}{ILV} \times 100\%$$

where: *FV* – volume of foam, *ILV* – volume of the initial liquid phase, *DV* – volume of drainage.

The measurement of albumen and yolk pH was performed with a pH-meter (Hanna Instruments).

The results were statistically analysed by Statistica 13.1. The results for the effect of storage time (T) and housing system (S) were subjected to a two-way analysis of variance. The main effects (S – effect of housing system, T – effect of storage time) and the effect of S×T interaction were determined. Significant differences between the means in the groups were estimated by Duncan's test. Differences were considered as significant at $P < 0.05$, and highly significant at $P < 0.01$ (StatSoft, Software Inc., PL).

The alterations (reduction or increase) in every quality trait of eggs were calculated as a difference between the value of a trait determined on the first day after laying and the value of this trait after 14 and 28 d of storage, and were expressed as a percentage.

Results

The eggs of the Hy-line Brown laying hens reared in various housing systems differed in weight ($P < 0.05$). The weight of the eggs from all the housing systems (CS, BS, FRS) declined with storage time (Table 2). The lowest egg weight reduction during 28-d storage was observed for cage eggs (3.31%), while the weight reduction of eggs from different alternative systems was larger and ranged from 4.13% in the deep-litter (BS) eggs to 5.81% in the free-range (FRS) eggs.

The present study indicated that storage duration influenced the weight of all the morphological components of the eggs from all the housing systems (CS, BS, FRS) ($P < 0.05$). After 28-d storage, the smallest shell weight reduction (4.47%) was noted in cage (CS) eggs, while in eggs from alternative systems it ranged from 7.15% in BS eggs to 9.86% in FRS eggs. In contrast, yolk weight increased with storage time ($P < 0.05$) (Table 2). After 28-d storage, the yolk weight increase was the highest in the CS eggs (7.16%) and the lowest (5.50%) in the FRS eggs. In addition, water content increased in the yolk and decreased in the albumen. The albumen weight in the tested eggs declined during storage. The greatest albumen weight reduction was seen in the free-range eggs (9.76%) and the lowest in the cage eggs (7.87%).

Our study did not show the effect of storage duration on the shell colour intensity in the eggs from all the rearing systems (Table 3). We also showed no influence of storage duration on shell characteristics (thickness, density, strength) in the eggs from the different housing systems (Table 3).

Storage duration affected albumen height and Haugh unit score in the eggs from the studied housing systems ($P < 0.05$) (Table 4). Thick albumen height and Haugh unit score declined with storage time (Table 4). The largest differences in albumen height after storage were seen in the cage eggs (18.85%) and the smallest in the FRS eggs (13.25%). The cage eggs showed the largest decrease in Haugh unit score in the course of 28-d storage (10.27%), while the decrease was the smallest in the free-range (6.20%).

Table 2. The effect of storage duration on the weight and morphological traits of the eggs from the different housing systems

Egg label ¹	Time	Trait/Change (increase or reduction in trait value) ²							
		egg weight (g)	reduction (%)	shell weight (g)	reduction (%)	yolk weight (g)	increase (%)	albumen weight (g)	reduction (%)
CS	1	xxX63.20	–	7.77	–	xxX17.83	–	xxX37.60	–
	14	xxX62.38	xxX1.26	7.59	xxX2.24	yY18.67	4.83	xxX36.12	xxX3.85
	28	yY61.08	yY3.31	7.42	yY4.47	yY19.07	7.16	yY34.60	yY7.87
	SEM	0.19	0.33	0.07	0.35	0.12	0.66	0.27	0.47
BS	1	x62.17	–	x7.72	–	xxX18.93	–	xxX35.52	–
	14	61.02	x1.81	7.44	3.11	xxX19.33	x2.27	xxX34.26	x3.34
	28	y59.57	y4.13	y7.12	7.15	yY20.26	y7.06	yY32.20	y9.20
	SEM	0.33	0.70	0.09	1.62	0.14	1.38	0.34	1.27
FRS	1	xxX61.16	–	xx7.07	–	x18.00	–	xxX36.08	–
	14	yY57.68	4.08	xxX6.72	x3.25	18.26	2.82	yY32.70	7.03
	28	yY56.69	5.81	yY6.25	y9.86	y18.73	5.50	yY31.71	9.76
	SEM	0.49	0.92	0.08	1.88	0.14	1.94	0.47	1.67
P-value for main effects ³									
T		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
S		<0.05	<0.05	<0.05	0.26	<0.05	0.58	<0.05	0.29
T×S		0.07	0.95	0.50	0.54	0.51	0.69	0.33	0.65

¹eggs from laying hens raised in: furnished cages – CS, barns – BS, free-range – FRS.
²n = 30 eggs at every assessment time.
³values differing at P<0.05 are statistically significant; T – effect of storage duration, S – effect of housing system.
(x, y, z) values in columns with various letters differ statistically significantly within the trait at P<0.05.
(X, Y, Z) values in columns with various letters differ statistically significantly within the trait at P<0.01.

Table 3. The effect of storage duration on shell traits in the eggs from the different housing systems

Egg label ¹	Time	Trait/Change (increase or reduction in trait value ²)							
		shell colour (%)	reduction (%)	shell thickness (μm)	reduction (%)	shell density (mg/cm ²)	change (%)	shell strength (n)	change (%)
CS	1	32.08	–	xX351.56	–	95.32	–	x36.75	–
	14	32.04	0.08	xX337.04	4.03	98.65	4.67	35.00	3.09
	28	32.00	0.03	yY330.12	6.55	102.62	6.76	y33.96	5.09
	SEM	0.20	1.01	2.30	0.75	1.08	1.16	0.51	2.36
BS	1	32.96	–	351.88	–	100.14	–	35.91	–
	14	32.60	0.50	347.96	0.35	100.64	1.16	35.59	1.54
	28	32.08	1.71	341.04	2.24	102.14	3.11	33.91	3.21
	SEM	0.31	1.67	4.52	1.20	1.17	1.93	0.51	2.77
FRS	1	32.30	–	320.70	–	102.53	–	31.37	–
	14	32.15	0.33	319.85	0.51	102.58	1.46	31.22	2.90
	28	32.00	0.92	316.35	1.13	104.47	2.99	31.01	3.37
	SEM	0.35	0.70	3.49	0.92	1.41	1.92	0.50	2.54
P-value for main effects ³									
T		0.59	0.74	0.05	0.28	0.17	0.38	0.06	0.52
S		0.44	0.58	<0.05	<0.05	<0.05	0.35	<0.05	0.20
T×S		0.95	0.97	0.67	0.96	0.82	0.95	0.66	0.83

¹eggs from laying hens raised in: furnished cages – CS, barns – BS, free-range – FRS.²n = 30 eggs at each assessment time.³values differing at P<0.05 are statistically significant; T – effect of storage duration, S – effect of housing system.

(x, y, z) values in columns with various letters differ statistically significantly within the trait at P<0.05.

(X, Y, Z) values in columns with various letters differ statistically significantly within the trait at P<0.01.

Table 4. The effect of storage duration on characteristics of the egg contents in the eggs from the different housing systems

Egg label ¹	Time	Trait/Change (increase or reduction in trait value) ²					
		albumen height (mm)	change (%)	Haugh units (hu)	change (%)	yolk colour (dsm)	change (%)
CS	1	xX7.90	–	xx87.79	–	8.43	–
	14	xX7.45	xX5.31	xX85.31	xX2.72	8.40	0.55
	28	yY6.31	Y18.85	yY78.45	yY10.27	8.05	3.67
	SEM	0.13	1.66	0.73	0.95	0.11	1.84
BS	1	xx8.00	–	xx88.57	–	7.68	–
	14	xX7.47	xX5.20	xx85.94	xX2.55	7.52	0.06
	28	yY6.40	yY18.48	yY79.39	yY9.90	7.44	0.90
	SEM	0.14	2.51	0.82	1.39	0.11	2.80
FRS	1	xx8.07	–	xx89.25	–	9.58	–
	14	xX7.80	x1.09	87.62	1.57	9.04	5.63
	28	yY6.75	y13.24	y82.91	6.20	9.96	3.97
	SEM	0.19	2.91	1.02	1.47	0.13	2.31
P-value for main effects ³							
T		<0.05	<0.05	<0.05	<0.05	0.23	0.61
S		0.20	0.15	<0.05	0.25	<0.05	0.92
T×S		0.96	0.99	0.79	0.64	<0.05	0.13

¹eggs from laying hens raised in: furnished cages – CS, barns – BS, free-range – FRS.
²n = 30 eggs at each assessment time.
³values differing at P<0.05 are statistically significant; T – effect of storage duration, S – effect of housing system.
(x, y, z) values in columns with various letters differ statistically significantly within the trait at P<0.05.
(X, Y, Z) values in columns with various letters differ statistically significantly within the trait at P<0.01.

Table 5. The effect of storage duration on albumen and yolk pH and quality of foam in albumen of the eggs produced in the different housing systems

Egg label ¹	Time	Trait/Change (increase or reduction of trait value) ²							
		albumen pH	increase (%)	yolk pH	increase (%)	foaming capacity ⁴ (%)	increase (%)	foam stability ⁴ (%)	reduction (%)
CS	1	xX8.31	–	xX6.09	–	536.60	–	xX91.19	–
	14	yY8.77	x5.82	yY6.28	3.52	549.00	2.83	xX89.60	x1.64
	28	zZ9.11	y9.87	yY6.36	4.88	541.00	1.31	yY86.48	y5.07
	SEM	0.05	1.02	0.03	0.69	4.96	1.56	0.53	0.94
BS	1	xX8.22	–	xX5.99	–	538.00	–	xX92.20	–
	14	yY8.59	xX4.63	yY6.25	4.35	543.60	1.19	x88.40	3.98
	28	zY8.92	yY8.73	yY6.30	5.31	553.50	3.16	yY86.86	5.68
	SEM	0.05	0.79	0.03	0.63	5.11	1.54	0.79	1.29
FRS	1	xX8.30	–	xX6.07	–	570.00	–	x88.69	–
	14	yY8.68	4.98	yY6.41	5.49	578.57	1.96	y87.14	2.65
	28	yY8.75	6.00	yY6.47	6.49	594.29	4.71	y84.13	5.94
	SEM	0.05	0.64	0.02	0.33	10.14	4.04	0.89	1.68
P-value for main effects ³									
T		<0.05	<0.05	<0.05	0.12	0.28	0.69	<0.05	<0.05
S		<0.05	0.11	<0.05	0.14	<0.05	0.92	<0.05	0.68
T×S		0.12	0.27	0.63	0.97	0.86	0.79	0.83	0.86

¹⁾eggs from laying hens raised in: furnished cages – CS, barns – BS, free-range – FRS.²⁾n = 30 eggs at each assessment time.³⁾values differing at P<0.05 are statistically significant; T – effect of storage duration, S – effect of housing system.⁴⁾n = 10 samples at each assessment time; 1 sample = 100 ml of albumen.

(x, y, z) values in columns with various letters differ statistically significantly within the trait at P<0.05.

(X, Y, Z) values in columns with various letters differ statistically significantly within the trait at P<0.01.

Table 6. The effect of storage duration on the level of cholesterol in the yolk of the eggs from the different housing systems

Cholesterol ²	Time	Egg label ¹			P-value for main effects ³		
		CB	BS	FRS	T	S	T×S
mg/g	1	14.43	14.34	14.51	0.58	0.05	0.37
	28	13.62	14.29	13.75			
	SEM	0.28	0.10	0.33			
mg/egg	1	255.92	269.81	261.34	0.77	0.23	0.99
	28	258.34	271.45	262.94			
	SEM	431	5.32	8.98			

Explanations:

¹eggs from laying hens raised in: furnished cages – CS, barns – BS, free-range – FRS.

²n = 5 samples at any sampling time; 1 sample = 3 yolks.

³values differing at P<0.05 are statistically significant; T – effect of storage duration, S – effect of housing system.

Table 7. The effect of storage duration on fatty acid profile in the yolk of the eggs from the different housing systems (g/100 g)

Fatty acids ²	Time	Egg label ¹			P-value for main effects ³		
		CS	BS	FRS	T	S	T×S
SFA ⁴	1	36.74	35.78	34.21	0.81	0.19	0.95
	28	36.33	35.33	34.37			
	SEM	0.42	0.62	1.19			
UFA ⁵	1	63.26	64.22	65.79	0.81	0.20	0.96
	28	63.67	64.69	65.63			
	SEM	0.39	0.60	1.19			
MUFA ⁶	1	42.58	45.08	47.87	0.06	< 0.05	0.61
	28	39.67 a	42.05	46.95 b			
	SEM	0.94	0.85	1.06			
PUFA ⁷	1	20.68	19.13	17.93	0.19	0.24	0.81
	28	23.99 a	22.63 a	18.68 b			
	SEM	1.72	0.94	2.03			
PUFA n-6	1	18.60	17.68	15.77	0.22	0.19	0.79
	28	21.97	20.84	16.27			
	SEM	1.74	0.92	2.06			
PUFA n-3	1	1.40 a	1.09 b	1.91 c	0.42	< 0.05	0.68
	28	1.37 a	1.16 a	1.73 b			
	SEM	0.14	0.03	0.05			
PUFA n-6/n-3	1	14.87 a	16.58 a	8.43 b	0.26	< 0.05	0.95
	28	17.22	18.14 a	9.78 b			
	SEM	2.17	1.03	1.32			

Explanations:

¹eggs from laying hens raised in: furnished cages – CS, barns – BS, free-range – FRS.

²n = 5 yolks at each assessment time.

³values differing at P<0.05 are statistically significant; T – effect of storage duration, S – effect of housing system.

⁴SFA – saturated fatty acids (C8, C10, C12, C14, C16, C18, C20, C22).

⁵UFA – unsaturated fatty acids (C16:1, C18:1, C22:1, C18:2, C20:4, gamma 18:3, C18:3, CLA, EPA, DHA).

⁶MUFA – monounsaturated fatty acids (C16:1, C18:1, C22:1).

⁷PUFA – polyunsaturated fatty acids (C18:2, C20:4, gamma 18:3, C18:3, EPA, DHA).

Eggs produced in the studied rearing systems differed in yolk colour intensity ($P<0.05$). However, storage duration had no effect on the yolk colour intensity in eggs from the housing systems ($P>0.05$) (Table 4).

The albumen pH measured on the first post-laying day was the lowest in the deep-litter eggs and the highest in the cage eggs ($P<0.05$). Albumen pH was shown to increase with storage duration in the eggs from all the studied housing systems ($P<0.05$) (Table 5). However, storage time influenced the dynamics of changes in this trait in the rearing systems ($P<0.05$).

The yolk pH value determined on the first day after laying was the lowest in the deep-litter (BS) eggs and the highest in the cage eggs ($P<0.05$) (Table 5). Yolk pH increased with storage time in the eggs from all the rearing systems ($P<0.05$). The greatest increase in this trait value was observed in the free-range eggs (6.49%) and the lowest in the cage eggs (4.88%).

The highest foaming capacity on the first post-laying day was observed in the free-range (FRS) eggs and the lowest in the cage (CS) eggs. Storage time had no effect on the foaming capacity of albumen of the eggs from all the studied housing systems ($P>0.05$).

In the present study, foam stability deteriorated with storage duration (Table 5). The smallest foam stability changes were observed in the BS eggs (5.07%) and the highest in the FRS (5.94%).

Our study demonstrated that 28-d storage of eggs did not influence the cholesterol level in the yolk of the eggs from the studied housing systems (Table 6).

The eggs obtained from the various rearing systems differed in the fatty acid profile in the yolk (Table 7). The highest level of MUFA and the lowest level of PUFA were characteristic of the egg yolks from the free range system ($P<0.05$). The fatty acid profile in the yolk of eggs from the studied housing systems (CS, BS, FRS) did not significantly change during storage ($P<0.05$). The PUFA n-6/n-3 ratio was smaller in the egg yolk from FRS system compared to CS and BS systems ($P<0.05$). The fatty acid profile in the yolk of eggs from the studied housing systems (CS, BS, FRS) did not significantly change during storage ($P>0.05$).

The interactions between housing systems and storage time were significant for yolk colour ($P<0.05$).

Discussion

In our study, the egg weight of Hy-line Brown laying hens from all the housing systems (furnished cages, barn system, free-range system) declined with storage time. Egg weight reduction during storage was also noted by Jin et al. (2011), Tayeb (2012), Eke et al. (2013), Chung and Lee (2014), Vlčková et al. (2019), Tomczyk et al. (2019). According to Eke et al. (2013), egg weight reduction during storage is caused by a loss of water and carbon dioxide, and the rate of egg weight reduction depends on storage temperature and the number of pores in the eggshell and also on the rate of changes in the mucin layer coating the shell. According to Zhang et al.

(2016), egg volume and area are important in egg quality assessment. These traits can also be significant for egg weight reduction during storage. The largest weight losses of eggs from the alternative systems (BS, FRS) can be related to their smaller weight and more disadvantageous area-to-weight ratio (Zhang *et al.*, 2016).

The present study indicated that storage duration influenced the weight of all the morphological components of the eggs from all the housing systems. The yolk weight in the tested eggs increased with storage time. A similar direction of storage-related changes (i.e. weight increase) in the yolk weight in the eggs from all the housing systems can be explained by the diffusion of water through the vitelline membrane to the yolk which results in the increase in its volume and weight (Hidalgo *et al.*, 2008). Reduction of the egg white weight in storage can be associated with the migration of water through the vitelline membrane to the yolk and the evaporation of water from the protein through the egg shell (Brodacki *et al.*, 2019). The study showed the effect of the storage time on the shell weight. Shell weight losses during egg storage were also found by Samli *et al.* (2005) and Jin *et al.* (2011).

Our study did not show the effect of storage duration on shell characteristics in the eggs from the different housing systems. Alsobayel and Albadry (2011) observed a decrease in shell thickness and an increase in shell density after 20-d storage, which was seen also in our study as a tendency, although it was statistically insignificant.

Storage duration affected albumen height and Haugh unit score in the eggs from the studied housing systems. Albumen height reduction during storage was also reported by Ramos *et al.* (2008), Buba *et al.* (2013), Chung and Lee (2014), and Krawczyk and Obrzut (2016). Raji *et al.* (2009) confirmed the influence of storage time on thick albumen quality which in their opinion became aqueous due to structural losses. The Haugh unit score reduction during storage was also indicated by Alsobayel and Albadry (2011) and Tomczyk *et al.* (2019).

In our study, the cage eggs showed the largest decrease in Haugh unit score in the course of 28-d storage. Jones *et al.* (2014) did not demonstrate significant differences in the rate of reduction of different egg quality parameters after 4-wk storage between various housing systems but Tomczyk *et al.* (2019) after 4 wk of storage at 8°C demonstrated significant differences in the rate of reduction of different egg quality parameters. Eggs produced in the studied housing systems differed in yolk colour intensity. However, storage duration had no effect on the yolk colour intensity. Alsobayel and Albadry (2011) also did not note the impact of storage time on yolk colour intensity, but Jin *et al.* (2011) documented that storage duration significantly affected the yolk colour intensity which declined with time. However, Sekeroglu *et al.* (2008) reported the opposite results, i.e. an increase in yolk colour intensity during storage. The discrepancy of the results on the direction of the changes in yolk colour intensity obtained by the different authors can be explained by yolk marbling, which develops during storage. According to King'ori (2012), longer storage of eggs causes vitelline membrane deterioration, leading to permeation of water and albumen to the yolk and to the appearance of spots of different shades.

Albumen pH was shown to increase with storage duration in the eggs from all the studied housing systems. The increase in albumen pH value during storage that was observed in our studies can be explained by carbon dioxide release. An increase

in albumen pH during storage was also reported by Silversides and Budgell (2004), Samli et al. (2005) and Akyurek and Okur (2009). In addition, an interaction between storage time and albumen pH was observed by Jin et al. (2011), who found that pH rapidly increased in the first days of storage and then the rate of pH increase declined. This relationship was also confirmed by our study.

Yolk pH increased with storage time in the eggs from all the rearing systems. The elevation of yolk pH value observed by us corresponds with the results of other authors (Chung and Lee, 2014; Wang et al., 2015; Drabik et al., 2021). During storage of eggs, yolk pH increases because of absorption of water from the albumen or lipid peroxidation of polyunsaturated fatty acids (Wang et al., 2015).

Storage time had no effect on the foaming capacity of albumen of the eggs from all the studied housing systems. Hammershøj and Qvist (2001) also did not reveal any impact of storage time on foaming capacity of albumen. It was shown that many factors influenced foaming capacity of albumen, including pH (Sadahira et al., 2015), protein concentration (Lau and Dickinson, 2010), ionic strength (Kato et al., 1983), intermolecular interactions (Żmudziński et al., 2014), protein composition (Johnson and Zabik, 2010) and temperature (Samli et al., 2005). Kuropatwa et al. (2009) also found a better foaming capacity of albumen at pH 5 than at pH 7 and 9.

Foam stability is an important characteristic of albumen because egg foam is a component of numerous food products, e.g. bread, cakes, ice cream, and confectionery (Curschellas et al., 2012; Li et al., 2019). Therefore, the present study demonstrated that storage time did not significantly impair foaming capacity but adversely affected foam stability, which can be connected with the changes in albumen pH value during storage. Deterioration of foam stability after storage can also be related with structural changes in the albumen proteins (Alleoni and Antunes, 2004). According to Alleoni and Antunes (2004), pH rise during storage induces a transformation of a part of the N-ovalbumin molecules in the albumen into S-ovalbumin, which is less hydrophobic. It hinders the formation of a compact interface layer and the foam becomes less stable.

In our study, we found no effect of rearing system on the yolk cholesterol content of eggs. Similarly, Anderson (2011), Küçükyılmaz et al. (2012) and Dong et al. (2017) reported no effect of the housing system on egg yolk cholesterol content. Our study demonstrated that storage of eggs did not influence the cholesterol level in the yolk of the eggs. Naviglio et al. (2012) likewise documented that cholesterol content after 4-wk storage was similar as before storage.

The eggs are considered as one of the most complete foods in the human diet, especially due to their composition. Nutritionally they are one of the main sources of dietary lipids, impacting human health. The current study has confirmed the influence of housing systems on the content of fatty acids PUFA n-6 and PUFA n-3 in egg yolks. Lordelo et al. (2017) also demonstrated that the content of PUFA n-6 fatty acids in eggs from free-range systems was lower than in eggs from a litter floor system. The UFA content of free-range eggs can be associated with the outdoor access, because the factors increasing the proportion of PUFA n-3 in egg yolk include forage, fresh vegetables and invertebrates (Campos et al., 2016). The optimum PUFA n-6/n-3 fatty acids ratio ranges from 4 to 10 (Simopoulos, 2000). In our study, this

PUFA n-6/n-3 ratio was found in free-range eggs, which points to the beneficial effect of outdoor access on this trait. During storage, the PUFA n-6/n-3 fatty acids ratio in the yolks of CS, BS and FRS eggs do not change significantly. During storage, the lipids can be hydrolysed by the endogenous enzymes in the egg yolk, ultimately changes in the fatty acid profile (Wang *et al.*, 2017). In our study, the fatty acid profile in the yolk of eggs from the studied housing systems did not significantly change during storage at 8°C for 28 days. It can therefore be assumed that in our own studies the rate of hydrolysis was low and had no effect on the fatty acids profile after storage.

Conclusions

The present studies indicated that:

- Time has a significant influence on the loss of egg weight and the share of morphological components in eggs from all tested systems,
- A slower rate of changes in pH, protein level and HU in eggs from FRS farming may indicate that they are better for the food industry than for CS and BS,
- During storage, the fatty acid profile and cholesterol content in the yolks of CS, BS and FRS eggs do not change significantly.

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