

EFFECT OF GENOTYPE AND ORGANIC FEEDING OF HENS ON EGG QUALITY

Józefa Krawczyk

National Research Institute of Animal Production, Department of Poultry Breeding, 32-083
Balice near Kraków, Poland
E-mail: jozefa.krawczyk@iz.edu.pl

Abstract

The aim of the study was to assess the egg quality of two selected conservation breeds of hens fed an organic feed mixture. The study included a total of 960 hens (480 Z-11 and 480 S-66) included in the Polish conservation programme, at 41-52 weeks of age. Birds of both breeds were divided into a control group (Z-11K and S-66K) and an experimental group fed a certified organic mixture (Z-11E and S-66E). The study showed that it is possible to produce eggs with eco-friendly quality characteristics without the hens having to use costly free-range areas. The use of an organic mixture in the feeding of the hens improved the colour of the yolk, increased the content of crude protein in the albumen and mono- and polyunsaturated fatty acids in the yolk. The eggs obtained from these hens were also distinguished by good sensory evaluation results. The daily intake of the mixture in all groups remained at a similar level, but there was a slight decrease in laying performance in the groups fed the organic mixture. The effect of the origin of the hens on egg quality traits was also found. Eggs from Z-11 hens differed in lower levels of albumen height and Haugh units, higher crude protein content in albumen, shells with higher weight, density, thickness and crushing strength compared to eggs from S-66 layers.

Keywords: laying hens, ecology, feeding, egg quality, fatty acids, vitamins

Introduction

Commercial egg production is based on highly productive commercial laying-hen hybrids developed through many years of breeding work aimed at improving performance traits. In recent years, consumer interest in eggs from, among other systems, organic production has increased; in this system the use of native hen breeds is recommended. These birds have lower laying performance but are better adapted to difficult environmental conditions. Numerous studies indicate that free-range housing may slightly reduce laying-hen productivity while positively affecting egg quality traits (Krawczyk et al., 2013; Hammershøj and Steenfeldt, 2015; Hammershøj and Johansen, 2016; Sokołowicz et al., 2019).

The organic hen production system is the most costly because it requires compliance with a technological regime concerning both stocking density in poultry houses and on outdoor ranges, as well as feeding. This results in high organic egg prices, which constitute an important barrier limiting demand (Sokołowicz et al., 2008). The efficiency of egg production depends primarily on laying performance, feed consumption per bird, and market conditions (Sokołowicz et al., 2023). Studies show that free-range systems involve higher feed consumption than housing in closed poultry houses, thereby increasing production costs (Michel and Huonnic, 2003; Tauson, 2005; Sokołowicz et al., 2018b). Crnčan et al. (2018) calculated that the highest profit from egg production is achieved in a litter system in a closed poultry house

(12.8%), whereas the lowest is obtained in organic production (1.29%). Consumers perceive free-range housing as providing hens with a higher level of welfare and improving egg quality. At the same time, Mesias et al. (2011) found that price is the most important attribute determining consumer egg preferences, followed by feeding and housing conditions. In intensive egg production, litter housing is perceived as more beneficial to birds than cage housing (Sokołowicz et al., 2023).

Egg quality is influenced by many factors, the most important of which are feeding and hen origin. From the consumer perspective, egg quality consists of traits that can generally be divided into external traits (egg weight and shell characteristics - colour and breaking strength) and internal traits concerning egg contents, i.e. yolk colour, albumen quality, taste and aroma, and nutritional value. Egg yolks are a valuable source of fatty acids, including unsaturated fatty acids, and fat-soluble vitamins (A, D and E), which determine the nutritional value of eggs and are essential in the human diet (Marciniak-Łukasiak, 2011). Hansstein (2011) and Lordelo et al. (2017) note that many consumers perceive organic eggs as food of higher nutritional value and better taste, for which they are willing to pay a higher price. Consumer studies by Sokołowicz et al. (2008) indicate that the price increase for such eggs should not exceed 20-30%. Demand decreases markedly at higher prices despite the eggs originating from a housing system supported by respondents.

The site conditions of many farms do not allow laying hens access to green outdoor ranges of the size required by standards, while the high cost of establishing ranges discourages organic production. It is therefore of interest to analyse the quality of eggs obtained from two selected native breeds when hens are fed an organic mixture while kept on litter in a closed poultry house without outdoor access.

The aim of the study was to assess the effects of hen genotype and feeding a certified organic feed mixture on egg quality. The initial hypothesis assumed that applying only one of the basic conditions of organic farming - feeding hens a certified organic mixture - would produce higher-quality eggs meeting consumer expectations for taste and nutritional value, while reducing production costs by eliminating the costs of establishing and maintaining outdoor ranges.

Material and methods

The experimental material comprised a total of 960 hens, including 480 Green-legged Partridge hens (Z-11) and 480 Sussex hens (S-66), both covered by the conservation programme in Poland. The experiment was conducted between 41 and 52 weeks of age. Hens of both breeds were divided into control groups (Z-11K and S-66K) and experimental groups fed an organic mixture (Z-11E and S-66E). Each group was divided into four replicates of 60 hens. All layers were kept on litter in a closed poultry house at a stocking density of 6 birds/m², with a lighting programme of 16 h light and 8 h darkness (16L:8D). Birds were fed *ad libitum*: the control groups received a complete feed mixture for laying hens (15.59% protein), whereas the experimental groups received an organic mixture (16.0% protein) purchased from a certified German producer (Mischfutter und Landhandel GmbH; distributor: Agro-Handel Mirsk). The composition of the feed mixtures is shown in Tables 1-2. The mixtures contained no synthetic yolk pigments.

Effect of genotype and feeding of hens with an organic feed mixture on egg quality

Table 1. Composition of feed mixtures

Item	Content (%)
DJ mixture – control group	
Ground maize	26,0
Extracted soybean meal	14,0
Ground wheat	30,0
Ground barley	8,0
Wheat bran	4,00
Ground limestone	8,00
Dicalcium phosphate	0,3
NaCl	0,3
QQRQ concentrate	9,4
Organic mixture – experimental group (as declared by the manufacturer on the packaging)	
Crude protein	16,00
Oils and crude fats	4,00
Crude fibre	5,50
Crude ash	5,80
Methionine	0,32
Lysine	0,70
Calcium	1,00
Phosphorus	0,65
Sodium	0,16

Note: Detailed composition of organic mixture is a trade secret. The organic components are indicated on the packaging of the mixture, i.e. maize, wheat, wheat bran, peas, sunflower, maize, sunflower and soybean cake, calcium carbonate and monocalcium phosphate. The proportion of these components in the mixture is not stated, indicating only that its production complies with EU regulations on organic production requirements.

Table 2. Results of chemical analysis of feed mixtures performed at the Central Laboratory of the National Research Institute of Animal Production (%)

Feed mixture	Dry matter	Crude ash	Crude fat	Crude protein	Crude fibre
Control	90,02	9,01	2,34	15,59	2,22
Experimental	90,29	9,07	2,60	16,00	4,58

After 12 weeks of the experiment, i.e. at 52 weeks of age, seven eggs from each replicate (28 eggs per group) were collected to assess physical egg-quality traits, and four eggs from each replicate (16 eggs per group) were collected for laboratory chemical analyses and sensory evaluation. Shell colour, weight, density and thickness, albumen height, Haugh units, and yolk colour on the La Roche scale were measured using electronic EQM (Egg Quality

Measurements) equipment manufactured by Technical Services and Supplies, UK. Shell breaking strength (N) was measured using an EGG Crusher. A sensory evaluation of boiled eggs identified only by coded group numbers was also performed by 10 adults. Egg taste and aroma and yolk colour were evaluated on a 0-5 point scale, with 5 as the highest score.

The nutritional value of eggs was determined from chemical analyses of cholesterol and vitamins A and E and from the yolk fatty-acid profile. Vitamin A and E contents were determined using an accredited procedure based on Polish standards PN-EN ISO 14565 (all-trans-retinol, vitamin A) and PN-EN ISO 6867 (tocopherol, vitamin E). Determinations were performed by HPLC (Merck-Hitachi) using a LiChroCART TM 250-4 Superspher TM 100 RP-18 column and UV-VIS (324 nm, vitamin A) and FL (Ex 295 nm, Em 350 nm, vitamin E) detectors. Cholesterol in egg yolks was determined chromatographically according to Gąsior and Pietras (2013). Higher fatty acids in egg yolks were determined as methyl esters by gas chromatography. Samples were prepared according to Folch et al. (1957): samples were homogenised in chloroform:methanol (2:1), the solvent was evaporated, and the residue was redissolved (0.5 N NaOH in methanol) and esterified (BF₃ in methanol). Fatty-acid methyl esters were extracted in hexane and analysed using a VARIAN 3400 gas chromatograph with an acid-modified polyethylene glycol column (e.g. Zebron ZB-Wax 30 m) and 8200 CX automatic data-processing software.

The results were subjected to multifactor analysis of variance (feeding × breed). The main effects of feeding and hen breed and their interaction were determined. The significance of differences between group means was estimated using Duncan's multiple range test. Differences were considered significant at $P < 0.05$ and highly significant at $P < 0.01$. Statistical calculations were performed using Statistica 13.1.

Results

In all groups, daily feed intake remained at a similar level of about 107 g/bird (Fig. 1). Greater differences were observed in laying performance, which was lower in the groups fed the organic mixture by 4.9% in Z-11 layers and by 4% in S-66 layers, although these differences were not statistically significant. As shown in Table 3, regardless of hen genotype, groups fed the organic mixture had increased albumen height and crude protein content in albumen, as well as improved yolk colour. At the same time, these groups showed lower yolk weight and numerically lower egg weight and vitamin contents, which would be unfavourable from a health-promoting perspective, but these differences were not statistically confirmed. Hen origin also affected some egg-quality traits. Eggs from Z-11 hens had lower albumen height and Haugh units and higher crude protein content in albumen. Yolks from Z-11 hens contained more vitamins A and E and less cholesterol, although these differences were not statistically significant.

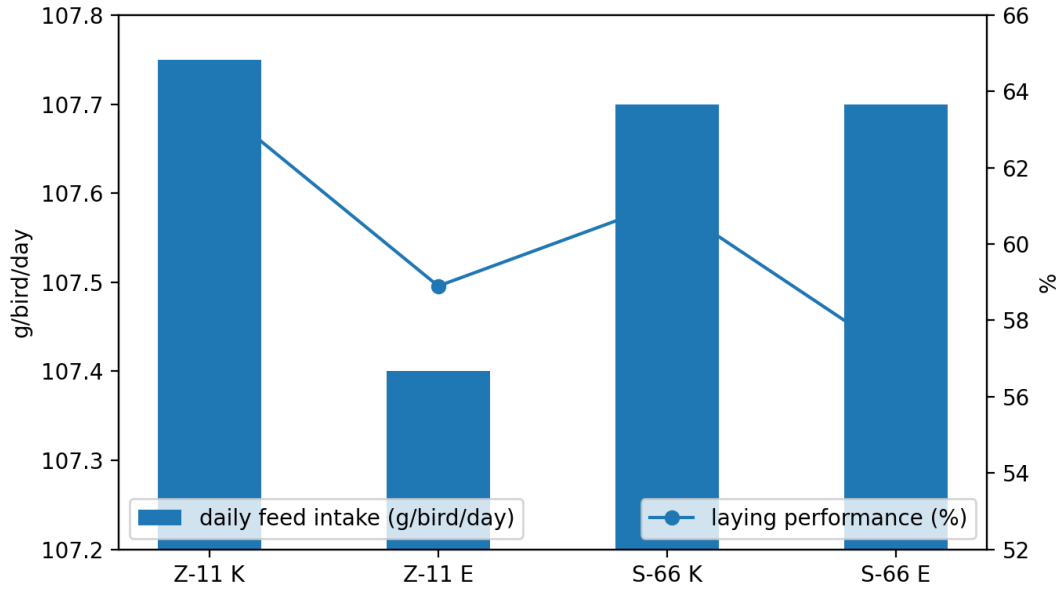


Fig. 1. Feed consumption (g/bird/day) and laying performance (%)
Notes: see Table 3.

Different feeding treatments did not significantly affect eggshell quality traits, except shell colour, which was lighter in eggs from hens fed the organic mixture (Table 4). Significant differences were found between breeds. Z-11 hens laid eggs with lighter and heavier shells of greater density, thickness and breaking strength than eggs from S-66 hens (Table 4). Changes in the fatty-acid profile were observed in yolks of eggs from hens fed the organic mixture (Table 5). The proportions of mono- and polyunsaturated fatty acids, including oleic (C18:1), linoleic (C18:2), α -linolenic (C18:3) and its derivative docosahexaenoic acid (DHA), increased, while saturated fatty acids (SFA) decreased. These yolks had significantly higher ($P < 0.01$) MUFA content and lower PUFA content, together with a marked reduction in the PUFA n-6:n-3 ratio. Hen origin also affected yolk fatty-acid composition. Compared with S-66, yolks from Z-11 hens contained less C16, C18, C18:3 gamma and SFA and more C18:1, C18:3 and UFA. In sensory evaluation, eggs from hens fed the organic mixture had better taste, aroma and yolk colour, although statistical significance was confirmed only for yolk colour (Table 6).

Table 3. Mean values of selected internal egg quality traits

Groups	Egg weight (g)	Albumen height (mm)	Haugh units	Yolk colour	Yolk weight (g)	Vit. A (mcg/g)	Vit. E (mcg/g)	Cholesterol	Crude protein in albumen (%)
Z-11 K	61,9	5,0	67,1	4,2	19,9	3,65	104,0	14,70	10,20
Z-11 E	58,0	6,0	75,0	4,8	18,2	3,99	87,5	14,37	10,54
S-66 K	60,5	6,4	79,0	4,1	19,2	4,05	97,3	14,86	9,83
S-66 E	61,9	6,6	78,8	4,8	18,9	3,30	87,6	16,04	10,41
Breed									
Z-11	60,0	5,5	71,1	4,5	19,0	3,82	95,7	14,53	10,37
S-66	61,2	6,5	78,9	4,4	19,1	3,68	92,4	15,45	10,12
Diet									
K	61,2	5,7	73,0	4,1	19,6	3,85	100,6	14,78	10,02
E	59,9	6,3	76,9	4,8	18,5	3,64	87,5	15,20	10,48
Breed	NS	**	**	NS	NS	NS	NS	NS	*
Diet	NS	*	NS	**	**	NS	NS	NS	**
Breed × Diet	**	NS	NS	NS	*	NS	NS	NS	NS
SEM	3,9	1,4	10,0	0,8	1,5	0,37	18,0	1,63	0,43

Notes: Z-11– Green-legged Partridge hens, S-66 Sussex hens; K – control groups fed standard feed mixtures, E – experimental groups fed organic certified feed mixtures; * significant differences at $P<0.05$; ** – highly significant differences at $P<0.01$; NS – non-significant differences at $P>0.05$.

Table 4. Mean values of selected egg shell quality traits

Groups	Shape index (%)	Shell colour	Shell weight (g)	Shell density (mg/cm ²)	Shell thickness (µm)	Strength (N)
Z-11 K	73.6	56.4	5.67	76.3	338	31.6
Z-11 E	73.9	60.7	5.65	78.1	344	31.9
S-66 K	74.3	39.7	5.40	73.9	325	24.1
S-66 E	74.9	40.3	5.35	73.1	330	23.8
Breed						
Z-11	73.7	58.5	5.66	77.2	341	31.7
S-66	74.6	40.0	5.37	73.5	327	23.9
Diet						
K	74.0	48.0	5.53	75.1	332	27.8
E	74.4	50.5	5.50	75.6	337	27.9
Breed	NS	**	**	**	*	**
Diet	NS	*	NS	NS	NS	NS
Breed × Diet	NS	NS	NS	NS	NS	NS
SEM	0.26	0.98	0.04	0.68	2.48	0.87

For notes see Table 3

Table 5. Fatty acid content of egg yolks of 56-week-old hens

Strain/group																
	C14	C16	C16-1	C18	C18-1	C18-2	C18-3 gamma	C18-3	C20-4	DHA	SFA	UFA	MUFA	PUFA n-6	PUFA n-3	PUFA n-6/n-3
Z-11K		32.0	4.48	7.92	39.9	11.27	0.06	0.41	2.01	0.60	40.6	58.8	41.4	13.3	1.01	13.2
Z-11E		28.9	3.92	8.14	46.0	7.62	0.04	0.56	1.79	0.89	38.5	61.9	49.9	9.46	1.47	6.81
S-66K		33.3	4.58	8.43	38.6	10.83	0.86	0.36	2.02	0.64	42.4	57.1	43.2	12.9	1.00	12.9
S-66E		31.4	3.63	9.59	42.7	7.68	0.05	0.44	2.07	0.94	41.8	57.6	46.4	9.80	1.41	7.12
Breed																
Z-11	0.58	30.9	4.20	8.03	43.0	9.45	0.05	0.48	1.90	0.75	39.6	60.3	45.7	11.4	1.24	10.0
S-66	0.67	32.4	4.10	9.01	40.6	9.26	0.07	0.40	2.04	0.79	42.1	57.3	44.8	11.4	1.21	10.0
Diet																
K	0.62	32.7	4.53	8.17	39.2	7.65	0.07	0.38	2.01	0.62	41.5	57.9	42.3	13.1	1.01	13.1
E	0.64	30.7	3.78	8.87	44.3	11.05	0.04	0.50	1.93	0.92	40.2	59.7	48.2	9.63	1.44	6.96
Breed	NS	**	NS	*	**	NS	**	NS	NS	NS	**	**	NS	NS	NS	NS
Diet	NS	**	NS	NS	**	**	**	NS	NS	*	*	*	**	**	*	**
B × D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

For notes see Table 3

Table 6. Sensory evaluation of eggs

Groups	Taste	Aroma	Yolk colour
Z-11 K	3.75	3.94	3.37
Z-11 E	4.44	4.50	4.25
S-66 K	4.19	4.31	3.19
S-66 E	4.56	4.62	4.50
Breed			
Z-11	4.09	4.22	3.81
S-66	4.37	4.47	3.84
Diet			
K	3.97	4.12	3.28
E	4.50	4.56	4.37
Breed	NS	NS	NS
Diet	NS	NS	**
Breed × Diet	NS	NS	NS

For notes see Table 3

Discussion

The native breeds studied here are characterised by low laying performance, which in the control groups was similar to that reported by Krawczyk et al. (2023). The slight decrease in laying performance in the experimental groups may suggest lower digestibility of organic feed, as observed by Świątkiewicz and Koreleski (2008). Those authors stated that laying-hen productivity under organic conditions could be effectively improved by supplementing feed with synthetic methionine because organic mixtures are difficult to balance adequately for amino acids. Current organic feed-production requirements, however, do not permit synthetic amino-acid supplementation. Krzykawski et al. (2023) point to the possibility of improving productivity and gastrointestinal function through natural phytotherapeutic additives. Crnčan et al. (2018), in turn, indicated that 172 eggs/hen/year is the threshold performance required for profitable organic production. These findings illustrate the difficulty of maintaining an optimal level of laying performance in organic systems, which is also supported by the present results.

In the present study, the organic mixture favourably affected egg-quality traits important to consumer health, namely increased crude protein and unsaturated fatty acids; these findings agree with those of Skiba et al. (2009) in organically kept hens. Lordelo et al. (2017) obtained different results, reporting lower crude protein in the albumen of eggs from organically kept commercial hybrids. In the experimental groups, as in Sokołowicz et al. (2018a), yolk pigmentation was better even though the layers had no outdoor access, which many authors consider an important influence on this trait, although not always a positive one (Martínez-Alesón and Hamelin, 2014). Terčič et al. (2012) reported contrasting results: organically kept hens laid eggs with paler yolks than hens kept indoors. The better yolk pigmentation in the organically fed groups in the present study may be partly explained by the fact that none of the diets contained synthetic pigments, while organic feed generally contains more plant ingredients rich in carotenoids (see note under Table 1). Van Ruth et al. (2011) found a different carotenoid profile in organic eggs than in free-range and litter-system eggs and suggested that this probably resulted from the prohibition on synthetic carotenoids in organic production.

No significant differences in egg or shell weight were found between groups in the present study, whereas Banaszewska et al. (2020) reported significantly lower values for these traits in organic eggs. The literature is inconsistent regarding the effect of breed on yolk cho-

lesterol. Pintea et al. (2012) found lower cholesterol in eggs from primitive Araucana hens than in commercial hybrids, whereas Millet et al. (2006) reported the opposite relationship. In the present study, a slight negative trend in yolk cholesterol was observed in Z-11 compared with S-66 hens and in control groups compared with organically fed groups, but the differences were not statistically significant. Z-11 hens showed a more favourable fatty-acid profile than S-66 layers. Sokołowicz et al. (2018a) obtained somewhat different results, with S-66 eggs from a free-range system showing a markedly better fatty-acid profile than eggs from two other breeds. Lordelo et al. (2017) emphasised that yolk fatty-acid composition depends on housing system, feeding and genotype. They analysed yolk fatty acids in eggs enriched, among other components, with polyunsaturated fatty acids and originating from four housing systems and a native Portuguese breed. PUFA content was low in yolks from native breeds, but n-3 PUFA was higher in all organically kept hens, in agreement with the present findings. The authors also demonstrated that appropriate feeding can substantially increase n-3 PUFA in enriched eggs.

In yolks from both breeds, feeding the organic mixture reduced the PUFA n-6/n-3 ratio by half, markedly improving the health-related value of the eggs. A similar pattern is reported in free-range and organic systems (Lordelo et al., 2017). Many authors attribute this to birds consuming green forage and invertebrates (Lopez-Bote et al., 1998; Sokołowicz et al., 2018a). The present results suggest that similar changes in yolk fatty-acid composition can be achieved by feeding a certified organic mixture without costly outdoor-range housing. Świątkiewicz et al. (2020) showed that yolk fatty-acid composition can be effectively modified by enriching laying-hen diets with vegetable, fish and algal oils. Long-chain n-3 PUFA increased, but egg taste and aroma deteriorated in the group receiving algal oil. In the present study, eggs from hens fed the organic mixture received better scores for taste, aroma and yolk colour, although only the difference in yolk colour was statistically significant. Lordelo et al. (2017) noted that it is difficult to assess the extent to which outdoor access, which is obligatory in organic production, affects egg quality. Outdoor ranges involve factors that influence egg quality but are difficult to control because they depend on pasture type, season and the amount of time an individual hen spends outside. Consumers do not have this information and therefore make less informed choices among eggs from different systems. When choosing organic eggs, consumers mainly expect greater health-promoting value, which, as shown by the present and other studies (Lordelo et al., 2017; Świątkiewicz et al., 2020), can be achieved without providing costly outdoor ranges, particularly given the increasing threat of avian influenza.

Conclusions

The study showed that it is possible to produce eggs with eco-friendly quality characteristics without providing hens with costly outdoor ranges. Feeding an organic mixture made it possible to obtain eggs with good freshness parameters (Haugh units), better yolk pigmentation, increased crude protein content in albumen, and higher mono- and polyunsaturated fatty-acid content. Eggs from these hens also achieved good sensory evaluation results, although only the improvement in yolk colour was statistically confirmed. Daily feed intake remained similar in all groups, but a slight decrease in laying performance was observed in the groups fed the organic mixture. Hen origin also affected egg-quality traits. Eggs from Z-11 hens had lower albumen height and Haugh units, higher crude protein content in albumen, and shells of greater weight, density, thickness and breaking strength than eggs from S-66 layers.

References

- Banaszewska D., Biesiada-Drzazga B., Marciniuk M., Hrnčár C., Arpášová H., Kaim-Mirowski S. (2020). Comparison of the quality of cage and organic eggs available in retail and their content of selected macro-elements. *Acta Sci. Pol. Technol. Aliment.*, 19 (2): 159–167.
- Crnčan A., Hadelan L., Kralik I., Kranjac D., Jelič S., Kristič J. (2018). Break-even analysis of poultry egg production in Croatia. *Europ. Poultry Sci.*, 82; doi: 10.1399/eps.2018.230.
- Folch J., Lees M., Stanley G.H.S. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.*, 226: 497–509
- Gąsior R., Pietras M. (2013). Validation of a method for determining cholesterol in egg yolks. *Ann. Anim. Sci.*, 13, 1: 143–153.
- Hammershøj M., Steenfeldt S. (2015). Organic egg production. II: The quality of organic eggs is influenced by hen genotype, diet and forage material analyzed by physical parameters, functional properties and sensory evaluation. *Anim. Feed Sci. Tech.*, 208: 182–197.
- Hammershøj M., Johansen N.F. (2016). Review: The effect of grass and herbs in organic egg production on egg fatty acid composition, egg yolk color and sensory properties. *Livest. Sci.*, 194: 37–43.
- Hansstein F. (2011). Profiling the egg consumer: Attitudes, perceptions and behaviors. In: Van Immerseel F., Nys Y., Bain M. (Eds), *Improving the safety and quality of egg and egg products: Egg safety and nutritional quality*, pp. 39–61. Cambridge UK: Woodhead Publishing.
- Krawczyk J., Sokołowicz Z., Świątkiewicz S., Sosin-Bzducha E. (2013). Effect of outdoor access and increased amounts of local feed materials in the diets of hens covered by the gene-pool protection programme for farm animals in Poland on quality of eggs during peak egg production. *Ann. Anim. Sci.*, 13, 2: 327–339.
- Krawczyk J., Lewko L., Świątkiewicz S. (2023). Effect of feeding selected strains of conserved breed hens with diets containing legumes on egg quality and content and activity of lysozyme. *Ann. Anim. Sci.*, 24 (1): 201–209.
- Krzykawski A., Gugolek M., Gugolek A. (2023). Makleja sercowata w żywieniu drobiu. *Rocz. Nauk. Zoot.*, 50 (1): 13–21. J. Krawczyk
- Lopez-Bote C.J., Sanz Aris R., Rey A.I., Castano A., Isabel B., Thos J. (1998). Effect of free-range feeding on n-3 fatty acid and alpha-tocopherol content and oxidative stability of eggs. *Anim. Feed Sci. Technol.*, 72: 33–40.
- Lordelo M., Fernandes E., Bessa R.J.B., Alves P. (2017). Quality of eggs from different laying hen production systems, from indigenous breeds and specialty eggs. *Poultry Sci.*, 96: 1485–1491.
- Marciniak-Łukasiak K. (2011). Rola i znaczenie kwasów tłuszczowych omega-3. *Żywność. Nauka. Technologia. Jakość*, 6 (79): 24–35.
- Martínez-Alesón R., Hamelin C. (2014). Estudio de huevos de gallina adquiridos en supermercados de distintas regiones en la península Ibérica: Etiquetado, precio y color de la yema. *Proc. LI Scientific Symposium WPSA's Spanish Branch, Valencia*, <http://www.wpsaaeca.com>
- Mesias F.J., Martínez-Carrasco F., Martínez J.M., Gaspar P. (2011). Functional and organic eggs as an alternative to conventional production: a conjoint analysis of consumers' preferences. *J. Sci. Food Agric.*, 91 (3): 532–538.

- Michel V., Huonnic D. (2003). A comparison of welfare, health and production performance of laying hens reared in cages or in aviaries. *Br. Poult. Sci.*, 44 (5): 775–776.
- Millet S., De Ceulaer K., Van Paemel M., Raes K., De Smet S., Janssens G.P.J. (2006). Lipid profile in egg of Araucana hens compared with Lohmann Selected Leghorn and Isa Brown hens given diets with different fat sources. *Br. Poult. Sci.*, 47 (3): 294–300.
- Pintea A., Dulf F.V., Bunea A., Matea C., Andrei S. (2012). Comparative analysis of lipophilic compounds in egg of organically raised Isa Brown and Araucana hens. *Chemical Papers*, 66: 955–963.
- Skiba M., Oziembłowski M., Kaźmierska M. (2009). Fatty acids and cholesterol profile in egg yolk from laying hens housed in ecological conditions. W: *Food Technology Operations New Vistas*. Wrocław, ss. 310–314.
- Sokołowicz Z., Krawczyk J., Dykiel M. (2008). Hen housing system and egg quality as viewed by consumer. *Ann. Anim. Sci.*, 8, 1: 71–80.
- Sokołowicz Z., Krawczyk J., Dykiel M. (2018a). Effect of alternative housing system and hen genotype on egg quality characteristics. *Emir. J. Food Agric.*, 30, 8: 695–703.
- Sokołowicz Z., Krawczyk J., Dykiel M. (2018b). Productivity of laying hens in different production systems. *Acta Scient. Pol. Zoot.*, 17, 2: 23–30.
- Sokołowicz Z., Dykiel M., Krawczyk J., Augustyńska-Prejsnar A. (2019). Effect of layer genotype on physical characteristics and nutritive value of organic eggs. *CyTA – Journal of Food*, v. 17 (1): 11–19.
- Sokołowicz Z., Dykiel M., Topczewska J., Krawczyk J., Augustyńska-Prejsnar A. (2023). A comparison of the plumage condition of three egg-laying poultry genotypes housed in non-cage systems. *Animals*, 13 (2) 185: 1–13.
- Świątkiewicz S., Koreleski J. (2008). The effect of zinc and manganese source in the diet for laying hens on eggshell and bones quality. *Wet. Med.*, 53 (10): 555–563.
- Świątkiewicz S., Arczewska-Włosek A., Szczurek W., Calik J., Bederska-Łojewska D., Orzechowska-Dudek S., Muszyński S., Tomaszewska E. (2020). Algal oil as source of polyunsaturated fatty acids in laying hens nutrition: effect on egg performance, egg quality indices and fatty acid composition of egg yolk lipids. *Ann. Anim. Sci.*, 20 (3): 961–973.
- Tauson R. (2005). Management and housing systems for layer – effects on welfare and production. *World's Poultry Sci. J.*, 61 (3): 491–487.
- Terčič D., Žlender B., Holcman A. (2012). External, internal and sensory qualities of table eggs as influenced by two different production system. *Agro-knowledge J. University of Banjaluka, Faculty of Agriculture*, 13: 555–562. Wpływ genotypu i żywienia kur mieszańką ekologiczną na jakość jaj
- Van Ruth S., Alewijn M., Rogers K., Newton-Smith E., Tena N., Bollen M., Koot, A. (2011). Authentication of organic and conventional eggs by carotenoid profiling. *Food Chem.*, 126: 1299–1305.