

Article

Comparison of lipid components, iron and zinc levels in chicken and quail eggs available on the market

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Abstract: All over the world birds' eggs are an important and valuable component of the human diet. The study aimed to compare the content of lipid components and their nutritional value as well as iron and zinc levels in chicken and quail eggs commonly available on the market. In egg lipids, unsaturated acids were dominated, especially oleic acid, the content of which was about 40% of total fatty acids (TFA). Linoleic acid was the major polyunsaturated fatty acid. Compared to other products of animal origin, eggs were characterized by favourable values of lipid quality indices, especially index of atherogenicity, thrombogenicity and hypocholesterolemic to hypercholesterolemic ratio. In the present study, no differences in the content of tested nutrients between eggs from different production methods (organic, free-range, barn, cages), as well as inter-breed differences were noticed. Cluster analysis showed that eggs enriched in n3 PUFA (according to producers' declaration) differ from other groups of chicken eggs. However, only in eggs from one producer, the amount of EPA and DHA exceed 80 mg per 100 g, entitling to use the nutrition claim on the package. Quail eggs differed from chicken eggs in FA profile; they also had much higher iron and cholesterol levels.

Keywords: chicken eggs, quail eggs, fatty acids, iron, zinc, cholesterol

Abbreviations:

AA - arachidonic acid; AI - index of atherogenicity; ALA - α -linolenic acid; B - Barn chicken eggs; C - eggs from caged hens; DFA - hypocholesterolaemic fatty acids; DHA - docosahexaenoic acid; E - chicken eggs from ecological production; EPA - eicosapentaenoic acid; F - free range chicken eggs; FA - fatty acids; FLQ - flesh-lipid quality index; GL - Green-legged partridge eggs; GLA - γ -linolenic acid; H/H - hypocholesterolemic to hypercholesterolemic ratio; LA - linoleic acid; MUFA - monounsaturated fatty acids, N3 - chicken eggs with an increased content of n3 fatty acids; OFA - hypercholesterolaemic fatty acids; OL - oleic acid; PUFA - polyunsaturated fatty acids; Q - Partridge quail eggs; SFA - saturated fatty acids; TFA - total fatty acids; TI - Index of thrombogenicity.

1. Introduction

Bird eggs have always been an important and valuable component of the human diet. The consumption of eggs depends on various factors such as economic, cultural, religious and habits of feed. However, all over the world, they are perceived as nutritious, easily digestible, and delicious meals ingredient [1,2].

In the 1960s, it was recommended to limit the consumption of eggs due to the high content of cholesterol, which was supposed to promote hypercholesterolemia in the body [3]. This view became deeply ingrained in consumers thoughts. Today it is known that die-

tary cholesterol does not affect the levels of low-density lipoproteins in the body. The most hypercholesterolemic/atherogenic effect is related to saturated fatty acids [4]. The unsaturated fatty acids that dominate egg fat have the opposite effect. Furthermore, recent studies on egg consumption demonstrate that eating those products daily does not alter LDL levels and can improve postmeal metabolic responses [5]. The profile of fatty acids in the diet has a significant impact on the body's lipid balance. In addition to fatty acids and cholesterol, the lipids of eggs include choline, fat-soluble vitamins, carotenoids [6]. A whole egg contains many valuable nutrients and bioactive ingredients: wholesome protein, most vitamins, and minerals, including iron and zinc [7]. Eggs are a great alternative to meat in the diet.

There are several product groups on the egg market. The most popular is the division into eggs obtained from various species of birds. All over the world, chicken eggs (*Gallus domesticus*) are the most popular, but also eggs of quail, duck, turkey, and other species are presented on the market [8]. In the European Union, hen eggs are classified in terms of weight and the production method. Organic eggs marked on the shell are number 0, free-range eggs have number 1, barn eggs 2, and cage eggs 3 [9]. There are also premium products on the market; eggs from less common breeds (e.g., Green-legged partridge) or enriched with selected vitamins, minerals or other bioactive ingredients [10]. Studies showed that the nutritional value of birds' eggs depends on many factors, such as the species and breed of animals from which the eggs were obtained, the production method and the type of feed [6]. Most of the research, however, was conducted under controlled conditions. There are much fewer studies that evaluated market products.

The study aimed to compare the content of lipid components and their nutritional value as well as iron and zinc levels in chicken and quail eggs commonly available on the market. Because, the amount of lipids in egg white usually does not exceed 0.2% [8], this study was limited to the nutritional composition of eggs yolk.

2. Materials and Methods

2.1. Research material

The research material comprised six groups of chicken eggs and quail eggs available on the Polish market. The groups were as follows:

- chicken eggs from organic production (E)
- free range chicken eggs (F)
- barn chicken eggs (B)
- chicken eggs from caged hens (C)
- chicken eggs with an increased content of n3 fatty acids (N3) (according to producers' declaration / nutrition claim on the package)
- chicken eggs from Green-legged partridge (GL)
- partridge quail eggs (Q)

The packaging of eggs from the first five groups lacked the indication of the breed of hens from which the eggs were obtained. Laying hens breeds predominating in the region are Rhode Island Red and Leghorn. Characteristic of examined egg samples; the weight parameters of all groups of eggs are presented in Table 1. In each group there were 8 brands (producers) evaluated. Three eggs were randomly collected from each package (brand) and separate analyses were performed for each egg ($n = 3 \times 8 = 24$ per group). Six eggs were collected from each quail egg pack. Due to the small size, three yolks were combined into one sample ($n = 6 / 3 \times 8 = 16$).

2.2. Analytical methods

2.2.1. Fat content determination

Fat content in egg yolk samples was determined gravimetrically after three-times extraction with a mixture of chloroform/methanol (v/v 2:1) and solvents evaporation under a stream of nitrogen, according to the procedure described by Folch et al. [11].

2.2.2. Fatty acids analysis

Fatty acid concentration and profile was determined by gas chromatography with flame ionization detector after methylation procedure was based on method described by Białek et al. [12]. To extracted egg yolk fat (about 20 mg) 1 mL of 0.5M NaOH in methanol was added and heated in 80°C for 15 minutes. Then 1 mL of BF₃ solution in methanol (14% w/v) was added and again heated in 80°C for 15 minutes. Then extraction of FAME was performed by adding 1 mL of saturated solution of NaCl in water and 1 mL of hexane and shaking. After phase separation the hexane layer was transferred to 2 mL vial and injected on the column.

Analyses were performed on a gas chromatograph with flame ionization detector (Shimadzu GC-17A, Kyoto, Japan). Chromatographic separations were conducted on a capillary column SGE BPX70 (60 m / 0,25 mm ID / film thickness 0,20 µm; Ringwood, Australia). Helium was used as the carrier gas (flow: linear velocity at 0.9 mL min⁻¹), the injection was 1 µL, the split has been set to 10. The injector was heated to 250°C, the detector to 270°C. The temperature program was as follows: initial temperature - 140°C for 1 min, increase by 20°C per min to 200°C, hold for 20 min, increase by 5°C per min to 220°C, hold for 25 min. FAME standards (Supelco 37Component FAME Mix, Sigma, St. Louis, MO, USA) were used to identify the FA present in the samples.

Based on the percentage of fatty acids, the following indices of lipid quality were calculated [13,14]:

a. Flesh-lipid quality (FLQ)

$$\text{FLQ} = \text{EPA} + \text{DHA}$$

b. Index of atherogenicity (AI):

$$\text{AI} = [(4 \times \text{C14:0}) + \text{C16:0}] / (\text{MUFA} + \text{n3 PUFA} + \text{n6 PUFA})$$

c. Index of thrombogenicity (TI):

$$\text{TI} = [\text{C14:0} + \text{C16:0} + \text{C18:0}] / [(0.5 \times \text{MUFA}) + (0.5 \times \text{n6 PUFA}) + (3 \times \text{n3 PUFA}) + (\text{n3 PUFA} / \text{n6 PUFA})]$$

d. Hypercholesterolaemic fatty acids (OFA):

$$\text{OFA} = \text{C14:0} + \text{C16:0}$$

e. Hypocholesterolaemic fatty acids (DFA):

$$\text{DFA} = \text{C18:0} + \text{MUFA} + \text{PUFA}$$

f. Hypocholesterolemic/hypercholesterolemic ratio (H/H)

$$\text{H/H} = (\text{c9 C18:1 OL} + \text{C18:2 LA} + \text{C18:3 ALA}) / (\text{C14:0} + \text{C16:0})$$

2.2.3. Cholesterol content determination

Cholesterol was determined using the RP-HPLC method with UV detection at 210 nm. To about 50 mg of egg yolk 2 mL 0.5 M KOH in ethanol and 20 µL of butylated hydroxytoluene solution (5 mg mL⁻¹ in ethanol) were added. The sample was put into an ultrasonic bath for 20 minutes and heated at 80°C for 30 minutes. Then 4 mL of the citric acid solution (4.5% w/v in water) and 4 mL of hexane were added and shaken for 5 minutes. After phase separation, the upper layer was transferred into a 10 mL volumetric flask. Extraction was repeated twice with 2 mL hexane. Volumetric flask was filled to the mark by hexane and mixed thoroughly. 500 µL of the solution was transferred to a 2 mL vial and evaporated under a stream of nitrogen. Dry residue was dissolved in 500 µL of isopropanol.

Chromatographic analysis was performed on a Merck Hitachi HPLC system (Darmstadt, Germany; pump: L-7100; UV-VIS detector: L-7420). Separation was carried

out on Luna 5uC18(2) (Phenomenex, Torrance, CA, USA; pore size: 100 Å, L × I.D.: 150 × 2 mm) operated at 35 °C. Isocratic elution was executed with mixture of acetonitrile and isopropanol (9:1, v/v). Flow rate was 0.4 mL min⁻¹ and injection volume 10 µL were used. The cholesterol concentration was calculated against the calibration curve.

2.2.4. Iron and Zinc content determination

Iron and Zinc determination was carried out by atomic absorption spectrometry. Before the analysis, the egg yolk samples were mineralised by microwave mineralizer (Plazmatronika, Ertec, Wrocław, Poland) in a nitric acid medium. 0.3-0.4 g of sample was weighed directly into a closed PTFE vessel and 6 mL of nitric acid (ultrapure) was added. The heating program was performed in three steps: [a] 4 min, power: 80%, pressure: 19-22 atm; [b] 4 min, power: 90%, pressure: 23 – 26 atm; [c] 8 min, power: 100%, pressure 33-36 atm. Mineralizate was diluted with ultra-pure water to 10 mL.

The determination was carried out by an air-acetylene flame atomic absorption spectrometer (Philips Analytical PU-9100, Cambridge, GB) with a single element hollow cathode lamp. The analytical wavelength was 248.3 nm for Fe and 213.9 nm for Zn, respectively. Minerals concentration was calculated against the calibration curve.

2.3. Statistical analysis

All chemical analyses were performed in triplicate. Results are presented as mean values (\bar{x}) ± standard deviation (SD). Distributions of the data (normality) was assessed by Shapiro-Wilk test. Differences among examined groups of eggs were analysed with one-way ANOVA ($\alpha = 0.05$), with post-hoc RIR Tukey test ($\alpha = 0.05$). Cluster analysis of lipids components content (fatty acids, cholesterol) in eggs yolk was performed; Ward agglomeration procedure and Euclidean function of the distance was applied. Cut-off point was established at 33% of the maximum distance, according to the Sneath's criterion.

All results were evaluated using Statistica 13.3 software (StatSoft, Kraków, Poland).

3. Results

In the present study, the content of lipid components (fatty acids, cholesterol), iron and zinc in selected groups of eggs available on the market was assessed. Hen egg weight, shell weight, yolk weight, and the share of edible parts between products from hens did not differ significantly. Quail eggs were clearly smaller, therefore the other factors mentioned above were also much lower. Fat content in eggs yolk differed between egg groups, the largest was in products from ecological production (32.0%), the lowest in egg yolks from caged hens (25.7%). Characteristic of examined eggs samples is presented in Table 1.

The examined groups of eggs differed in the content and profile of fatty acids. The results of fatty acids and cholesterol content in egg yolks (in mg g⁻¹ of yolk) are presented in Table 2, while the share of the main groups of fatty acids in the total FA content and FA quality indices are in Table 3.

Table 1. Characteristic of examined egg samples (x ± SD).

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Group	E	F	B	C	N3	GL	Q	P value
Egg [g]	60.0 ± 4.7 ^b	62.9 ± 2.0 ^{a,b}	62.0 ± 4.8 ^{a,b}	61.3 ± 3.6 ^{a,b}	64.2 ± 3.9 ^a	56.4 ± 4.5	11.9 ± 1.0	< 0.001
Yolk [g]	17.0 ± 1.8 ^a	17.1 ± 1.1 ^a	17.0 ± 1.7 ^a	17.1 ± 1.3 ^a	17.4 ± 1.7 ^a	16.9 ± 2.0 ^a	4.60 ± 0.69	< 0.001
Eggshell [g]	7.46 ± 0.56 ^{b,c}	7.95 ± 0.50 ^{a,b}	8.24 ± 1.14 ^{a,b}	8.02 ± 0.93 ^{a,b}	8.37 ± 0.87 ^a	7.12 ± 0.63 ^c	1.66 ± 0.18	< 0.001
Edible part [g]	52.5 ± 4.3 ^a	55.0 ± 1.9 ^a	53.7 ± 4.4 ^a	53.3 ± 3.2 ^a	55.8 ± 3.4 ^a	49.3 ± 4.1	10.2 ± 0.9	< 0.001
Yolk fat [%]	32.0 ± 7.1 ^a	29.5 ± 2.5 ^{a,b}	29.6 ± 4.8 ^{a,b}	25.7 ± 5.0 ^b	28.7 ± 7.2 ^{a,b}	26.9 ± 4.2 ^b	30.0 ± 5.1 ^{a,b}	0.002

E - chicken eggs from organic production, F - free range chicken eggs, B - barn chicken eggs, C - chicken eggs from caged hens, N3 - chicken eggs with an increased content of n3 fatty acids, GL - chicken eggs from Green-legged Partridge, Q - partridge quail eggs

P value, result of one-way ANOVA ($\alpha = 0.05$)

^{a-c} homogeneous groups in rows; comparison between product groups (Tukey's test, $\alpha = 0.05$)

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Table 2. Fatty acids and cholesterol content in examined eggs yolk (x ± SD).

Group	E	F	B	C	N3	GL	Q	P value
Fatty acids	[mg g ⁻¹]							
C14:0	0.96 ± 0.26 ^a	0.86 ± 0.15 ^{a,b}	0.92 ± 0.19 ^{a,b}	0.74 ± 0.20 ^b	0.81 ± 0.22 ^{a,b}	0.82 ± 0.23 ^{a,b}	1.25 ± 0.26	< 0.001
C15:0	0.26 ± 0.14 ^{a,b}	0.22 ± 0.05 ^{a,b}	0.28 ± 0.14 ^{a,b}	0.19 ± 0.07 ^b	0.39 ± 0.44 ^a	0.24 ± 0.13 ^{a,b}	0.18 ± 0.05 ^b	0.011
C16:0	65.3 ± 15.7 ^a	61.2 ± 5.8 ^{a,b}	64.2 ± 10.5 ^a	52.7 ± 11.4 ^b	58.2 ± 15.8 ^{a,b}	56.0 ± 10.0 ^{a,b}	64.6 ± 12.1 ^a	0.002
C17:0	0.59 ± 0.17 ^a	0.53 ± 0.08 ^{a,b}	0.51 ± 0.18 ^{a,b}	0.47 ± 0.16 ^b	0.52 ± 0.18 ^{a,b}	0.49 ± 0.11 ^{a,b}	0.44 ± 0.05 ^b	0.031
C18:0	20.9 ± 4.8 ^{a,b}	19.2 ± 2.4 ^{b,c}	18.7 ± 3.4 ^{b,c}	15.5 ± 2.6 ^d	17.0 ± 4.4 ^{c,d}	17.7 ± 3.0 ^{c,d}	22.8 ± 3.8 ^a	< 0.001
C20:0	0.13 ± 0.04 ^a	0.12 ± 0.03 ^{a,b}	0.14 ± 0.03 ^a	0.10 ± 0.04 ^b	0.13 ± 0.05 ^{a,b}	0.12 ± 0.03 ^{a,b}	0.14 ± 0.04 ^a	0.002
C21:0	0.36 ± 0.13 ^a	0.36 ± 0.10 ^a	0.31 ± 0.11 ^a	0.32 ± 0.12 ^a	0.32 ± 0.18 ^a	0.34 ± 0.14 ^a	0.17 ± 0.05	< 0.001
C24:0	0.56 ± 0.22 ^{b,c}	0.90 ± 0.44 ^a	0.79 ± 0.37 ^{a,b}	0.72 ± 0.38 ^{a,b}	0.67 ± 0.58 ^{a,b}	0.52 ± 0.24 ^{b,c}	0.43 ± 0.20 ^c	< 0.001
SFA	89.1 ± 20.6 ^a	83.4 ± 8.0 ^{a,b}	85.9 ± 14.2 ^a	70.9 ± 14.0 ^b	78.1 ± 21.5 ^{a,b}	76.2 ± 13.2 ^{a,b}	90.1 ± 15.9 ^a	< 0.001
C14:1	0.20 ± 0.11 ^{a,b}	0.17 ± 0.06 ^{a,b}	0.23 ± 0.08 ^a	0.14 ± 0.05 ^b	0.17 ± 0.09 ^{a,b}	0.19 ± 0.13 ^{a,b}	0.22 ± 0.05 ^{a,b}	0.008
C16:1	8.65 ± 3.71 ^{a-c}	7.64 ± 1.93 ^c	10.04 ± 2.23 ^{a,b}	6.62 ± 2.09 ^c	8.28 ± 2.89 ^{a-c}	7.90 ± 2.77 ^{b,c}	10.59 ± 2.96 ^a	< 0.001
C17:1	0.42 ± 0.11 ^a	0.33 ± 0.06 ^{b,c}	0.39 ± 0.12 ^{a,b}	0.31 ± 0.09 ^c	0.40 ± 0.13 ^{a,b}	0.35 ± 0.05 ^{a-c}	0.28 ± 0.06 ^c	< 0.001
c9 C18:1 OL	106.3 ± 24.0 ^a	96.3 ± 10.6 ^{a,b}	95.4 ± 15.7 ^{a,b}	85.0 ± 16.3 ^b	96.3 ± 22.2 ^{a,b}	89.5 ± 11.5 ^b	96.1 ± 20.6 ^{a,b}	0.004
c11 C18:1	8.95 ± 3.30 ^a	7.32 ± 1.30 ^{a-c}	8.25 ± 1.94 ^{a,b}	6.57 ± 1.26 ^{b,c}	7.55 ± 2.03 ^{a,b}	7.45 ± 1.77 ^{a,b}	5.35 ± 1.09 ^c	< 0.001
C20:1	0.48 ± 0.15 ^a	0.41 ± 0.06 ^a	0.41 ± 0.11 ^a	0.39 ± 0.10 ^a	0.50 ± 0.20 ^a	0.46 ± 0.12 ^a	0.25 ± 0.09	< 0.001
MUFA	124.2 ± 30.0 ^a	110.1 ± 13.4 ^{a,b}	113.7 ± 18.1 ^{a,b}	97.4 ± 19.2 ^b	112.8 ± 25.8 ^{a,b}	104.7 ± 15.1 ^b	112.5 ± 24.5 ^{a,b}	0.002
C18:2 LA	42.5 ± 12.5	42.8 ± 9.2	36.7 ± 10.4	37.6 ± 10.4	38.5 ± 14.2	34.6 ± 9.0	35.9 ± 4.6	0.050
C18:3 GLA	0.28 ± 0.09 ^a	0.27 ± 0.07 ^a	0.29 ± 0.10 ^a	0.22 ± 0.08 ^a	0.26 ± 0.10 ^a	0.25 ± 0.08 ^a	0.53 ± 0.16	< 0.001
C18:3 ALA	2.12 ± 0.61 ^a	1.38 ± 0.81 ^b	2.00 ± 1.71 ^{a,b}	1.34 ± 0.86 ^b	1.85 ± 0.93 ^{a,b}	1.55 ± 0.49 ^{a,b}	1.78 ± 1.08 ^{a,b}	0.047
C20:2	0.09 ± 0.05 ^a	0.07 ± 0.02 ^a	0.09 ± 0.03 ^a	0.06 ± 0.03 ^a	0.08 ± 0.05 ^a	0.09 ± 0.04 ^a	0.15 ± 0.07	< 0.001
C20:3	0.32 ± 0.08	0.27 ± 0.05	0.29 ± 0.07	0.26 ± 0.09	0.27 ± 0.1	0.30 ± 0.07	0.29 ± 0.09	0.180
C20:4 AA	4.54 ± 1.16 ^{a,b}	4.54 ± 0.81 ^{a,b}	4.12 ± 0.96 ^{a-c}	3.68 ± 0.91 ^c	3.78 ± 1.12 ^{b,c}	3.93 ± 0.67 ^{b,c}	5.01 ± 1.16 ^a	< 0.001
C20:5 EPA	0.06 ± 0.06 ^{a,b}	0.03 ± 0.01 ^b	0.09 ± 0.07 ^{a,b}	0.03 ± 0.01 ^b	0.06 ± 0.05 ^{a,b}	0.03 ± 0.02 ^b	0.11 ± 0.07 ^a	0.001
C22:2	0.13 ± 0.09	0.14 ± 0.08	0.14 ± 0.13	0.17 ± 0.13	0.12 ± 0.08	0.18 ± 0.26	0.11 ± 0.05	0.622
C22:5	0.29 ± 0.10 ^{a,b}	0.18 ± 0.08 ^c	0.24 ± 0.13 ^{b,c}	0.17 ± 0.10 ^c	0.21 ± 0.11 ^{b,c}	0.19 ± 0.10 ^c	0.36 ± 0.06 ^a	< 0.001
C22:6 DHA	2.12 ± 0.46 ^a	1.37 ± 0.61 ^b	1.81 ± 0.74 ^{a,b}	1.45 ± 0.81 ^b	1.96 ± 1.10 ^{a,b}	1.49 ± 0.27 ^b	1.97 ± 0.29 ^{a,b}	< 0.001
PUFA	52.4 ± 14.0	51.1 ± 9.2	45.8 ± 12.5	44.9 ± 12.2	47.0 ± 15.7	42.6 ± 10.3	46.2 ± 5.2	0.062

n3	4.28 ± 1.01 ^a	2.76 ± 1.38 ^{a,b}	3.84 ± 2.41 ^{a,b}	2.80 ± 1.64 ^b	3.84 ± 2.01 ^{a,b}	3.06 ± 0.67 ^{a,b}	3.85 ± 1.33 ^{a,b}	0.004
n6	48.1 ± 13.6	48.3 ± 9.5	41.9 ± 11.3	42.1 ± 11.4	43.2 ± 15.4	39.5 ± 9.8	42.3 ± 5.6	0.063
Cholesterol	[mg g ⁻¹]							
	13.9 ± 0.6 ^{a-c}	14.1 ± 0.8 ^{a-c}	14.4 ± 0.6 ^a	13.1 ± 0.6 ^d	13.3 ± 0.9 ^{c,d}	13.6 ± 0.9 ^{b-d}	14.2 ± 1.3 ^{a,b}	< 0.001

E - chicken eggs from organic production, F - free range chicken eggs, B - barn chicken eggs, C - chicken eggs from caged hens, N3 - chicken eggs with an increased content of n3 fatty acids, GL - chicken eggs from Green-legged Partridge, Q - partridge quail eggs 7
P value, result of one-way ANOVA ($\alpha = 0.05$) 8
^{a-d} homogeneous groups in rows; comparison between product groups (Tukey's test, $\alpha = 0.05$) 9
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Table 3. The share of the main groups of fatty acids in the total FA content and fat quality indices ($\bar{x} \pm SD$) in eggs yolk.

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Group	E	F	B	C	N3	GL	Q	P value
SFA [%]	33.5 ± 1.18 ^c	34.1 ± 1.0 ^{b,c}	35.0 ± 0.89 ^{a,b}	33.3 ± 1.2 ^c	32.8 ± 2.2 ^c	34.1 ± 1.5 ^{b,c}	36.2 ± 1.5 ^a	< 0.001
MUFA [%]	46.7 ± 3.8	45.0 ± 3.8	46.4 ± 3.3	45.7 ± 3.8	47.6 ± 3.2	47.0 ± 2.4	44.9 ± 3.2	0.100 *
PUFA [%]	19.8 ± 3.9	20.9 ± 3.7	18.6 ± 3.48	21.0 ± 3.40	19.6 ± 3.13	19.9 ± 2.8	18.9 ± 2.7	0.086 *
n3 PUFA [%]	1.64 ± 0.37 ^a	1.13 ± 0.56 ^b	1.57 ± 1.02 ^a	1.26 ± 0.56 ^b	1.65 ± 0.84 ^a	1.37 ± 0.23 ^{a,b}	1.66 ± 0.90 ^a	0.042
n6 PUFA [%]	18.2 ± 3.8 ^{a,b}	19.8 ± 3.9 ^a	17.0 ± 2.9 ^b	19.7 ± 3.6 ^a	17.9 ± 2.9 ^{a,b}	17.6 ± 2.7 ^{a,b}	17.2 ± 2.1 ^{a,b}	0.015
n6/n3 PUFA	10.7 ± 3.0 ^c	24.2 ± 18.5 ^a	12.5 ± 4.7 ^{b,c}	20.3 ± 14.6 ^{a,b}	13.4 ± 8.1 ^{b,c}	12.1 ± 1.8 ^{b,c}	10.6 ± 2.8 ^c	< 0.001
FLQ	0.83 ± 0.17 ^a	0.57 ± 0.25 ^b	0.75 ± 0.30 ^{a,b}	0.66 ± 0.29 ^{a,b}	0.86 ± 0.47 ^a	0.69 ± 0.14 ^{a,b}	0.86 ± 0.26 ^a	0.003
AI	0.39 ± 0.02 ^b	0.40 ± 0.02 ^b	0.43 ± 0.02 ^a	0.39 ± 0.03 ^b	0.39 ± 0.04 ^b	0.40 ± 0.03 ^b	0.44 ± 0.03 ^a	< 0.001
TI	0.88 ± 0.06 ^{c,d}	0.93 ± 0.05 ^{a-c}	0.94 ± 0.07 ^{a,b}	0.89 ± 0.07 ^{b-d}	0.85 ± 0.12 ^d	0.91 ± 0.07 ^{b-d}	0.99 ± 0.09 ^a	< 0.001
OFA	24.9 ± 1.1 ^c	25.4 ± 1.0 ^{b,c}	26.6 ± 1.0 ^a	25.0 ± 1.2 ^c	24.8 ± 1.7 ^c	25.7 ± 1.5 ^{b,c}	26.4 ± 0.9 ^{a,b}	< 0.001
DFA	74.6 ± 1.1 ^a	73.7 ± 0.9 ^{a,b}	72.6 ± 1.0 ^c	74.1 ± 1.3 ^{a,b}	74.4 ± 1.8 ^a	73.9 ± 1.5 ^{a,b}	73.0 ± 1.5 ^{b,c}	< 0.001
H/H	2.29 ± 0.19 ^a	2.27 ± 0.17 ^a	2.06 ± 0.14 ^c	2.33 ± 0.17 ^a	2.33 ± 0.27 ^a	2.23 ± 0.19 ^{a,b}	2.04 ± 0.14 ^{b,c}	< 0.001

FLQ - flesh-lipid quality; AI – index of atherogenicity; TI- index of thrombogenicity; OFA – hypercholesterolaemic fatty acids; DFA- hypocholesterolaemic fatty acids; H/H – hypo-cholesterolemic to hypercholesterolemic ratio

E - chicken eggs from organic production, F - free range chicken eggs, B - barn chicken eggs, C - chicken eggs from caged hens, N3 - chicken eggs with an increased content of n3 fatty acids, GL - chicken eggs from Green-legged Partridge, Q - partridge quail eggs

P value, result of one-way ANOVA ($\alpha = 0.05$); * lack of differences between product groups

^{a-d} homogeneous groups in rows; comparison between product groups (Tukey's test, $\alpha = 0.05$)

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The content of saturated fatty acids (SFA) ranged from 32.8% (N3) to 36.2% (Q) of total fatty acids (TFA). The dominant saturated fatty acid was palmitic acid; its average content was 25.1% TFA. The lowest C16:0 levels were found in egg yolks from caged hens (24.2% TFA), and the highest in barn (25.8% TFA) and quail eggs (25.5% TFA). The second SFA in egg yolks was stearic acid (C18:0). The highest levels were determined in quail eggs (9.1% TFA). The mean content of this acid in chicken eggs was 7.6% TFA. The content of remaining SFA (C13:0, C14:0, C15:0, C17:0, C20:0, C21:0, C24:0) determined in eggs did not exceed 0.5% of TFA.

Monounsaturated fatty acids (MUFA) dominated in egg yolks, which constituted on average 45.7% of the TFA. Oleic acid (c9 C18:1, OL) was the main one. Although its content significantly differed between the examined eggs, the share in the total pool of fatty acids (average 39.7% TFA) was similar ($p = 0.189$). The content of palmitoleic acid (C16:1) ranged from 3.04 (C) to 4.13 (Q)% TFA, while the c11 C18:1 acid ranged from 2.08 (Q) to 3.27 (GL)% TFA. The content of the remaining MUFA (C14:1, C15:1, C17:1, C20:1) did not exceed 0.2% TFA.

The content of polyunsaturated fatty acids (PUFA) was average 19.7% TFA and did not differ significantly between the examined groups. Linoleic acid (c9c12 C18:2, LA) was the dominant PUFA. Its share [%] in TFA ranged from 14.4 (Q) to 17.4 (C). The second largest n6 PUFA fatty acid was arachidonic acid (c5c8c11c14C20:4, AA); its amount was between 1.58 (N3) and 1.96 (Q)% TFA. The content of α -linolenic acid (c9c12c15 C18:3, ALA), belonging to the n3 family, did not differ significantly between the groups; the average level was 0.72%. The content of long-chain PUFA from the n3 fatty acid family was low. The share of eicosapentaenoic acid (c5c8c11c14c17 C20:5, EPA) in any group did not exceed 0.05% TFA. The docosahexaenoic acid (c4c7c10c13c16c19 C22:6, DHA) level was higher, ranging between 0.56 (F) and 0.8 (E, Q)% of TFA. The FLQ index, being the sum of the share of EPA and DHA in TFA, differed significantly between the studied groups of products. The highest value was recorded for N3 and quail eggs (0.86) and the lowest for free range chicken eggs (0.57). The content of the remaining determined PUFAs (C18:3 n6, C20:2, C20:3, C22:2) was low, not exceeding 0.2% of TFA. The n6 to n3 polyunsaturated fatty acids ratio fluctuated within a wide range between the studied groups. Egg yolks from free-range chicken had the highest value (24.2), while egg yolks from ecological production and quail eggs had the lowest (10.6).

Index of atherogenicity (AI) was calculated between 0.39 (E, C, N3) and 0.44 for quail egg fat. Index of thrombogenicity (TI) was the lowest for N3 eggs fat (0.85) and the highest for quail egg fat (0.99). The richest in hypercholesterolaemic fatty acids (OFA) was barn chicken eggs. OFA was lowest in N3 eggs fat. Hypocholesterolaemic fatty acids (DFA) levels are inversely proportional to OFA ($r = 0.989$). DFA was highest for fat from N3 eggs (74.36) and the lowest for fat from barn chicken eggs (72.6). Hypocholesterolemic to hypercholesterolemic ratio was ranged in 2.04 (Q) and 2.33 (C, N3).

Cholesterol levels ranged from 13.09 mg g⁻¹ to 14.35 mg g⁻¹. The highest content of this compound was found in barn chicken eggs yolks and the lowest in eggs yolks from caged hens. The cholesterol amount in one hen egg was on average 234.4 and 65.2 mg in quail eggs, but in 100 g of eggs levels were 385.4 and 545.7 mg, respectively. In 100 g of edible parts of a chicken eggs 442.3 mg and 634.2 mg in quail eggs.

In cluster analysis of lipids components, three clusters were distinguished. The first cluster includes most of the examined chicken eggs (E, GL, B, F, C), except for N3. In the second cluster are N3 eggs, in the third one quail eggs. Content of lipid compounds in quail eggs significantly differed from their content in chickens eggs. Results are presented in Figure 1.

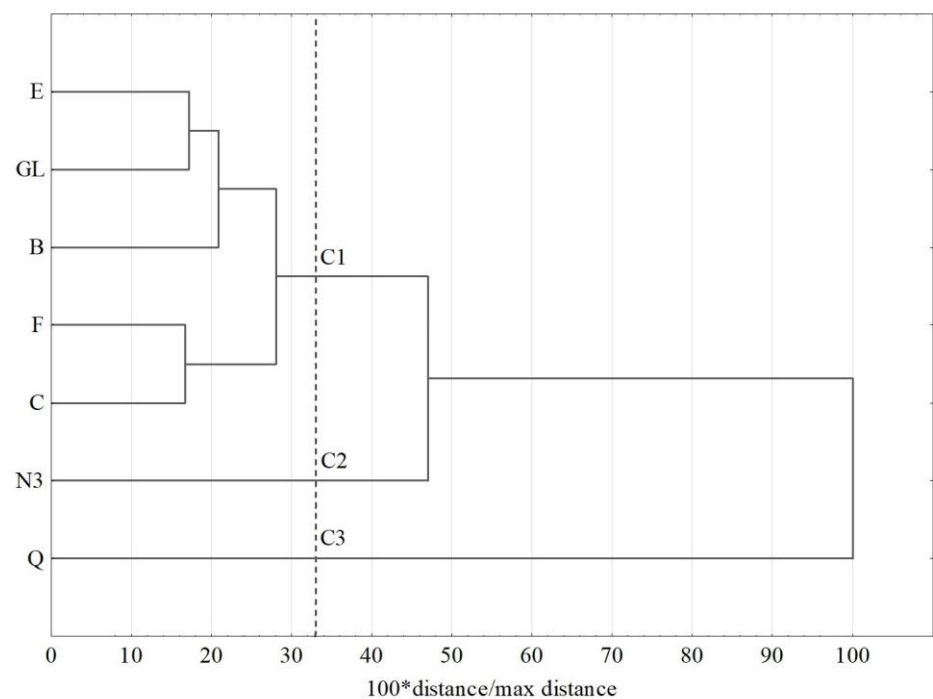


Figure 1. Dendrogram of similarity in fatty acid and cholesterol content in yolk fat of investigated groups of eggs; C1-C3 – clusters.
E - chicken eggs from organic production, F - free range chicken eggs, B - barn chicken eggs, C - chicken eggs from caged hens, N3 - chicken eggs with an increased content of n3 fatty acids, GL - chicken eggs from Green-legged Partridge, Q - partridge quail eggs

The iron content in egg yolks differed between the studied groups. The lowest amount was found in GL eggs ($40.7\text{ }\mu\text{g g}^{-1}$), and the highest in the yolk of quail eggs ($57.2\text{ }\mu\text{g g}^{-1}$). The amount of Fe in 100 g of chicken eggs was on average 1.26 mg and 2.20 mg in 100 g of quail eggs. For 100 g of edible parts, the results were 1.45 and 2.56, respectively. Zinc levels in egg yolks did not differ significantly between groups, the mean content of this mineral was $29.1\text{ }\mu\text{g g}^{-1}$. The results of the iron and zinc content in the examined product groups are presented in Table 4.

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Table 4. Iron and zinc content in eggs yolk (x ± SD).

Group	E	F	B	C	N3	GL	Q	P value
Iron [µg g ⁻¹]	43.5 ± 7.0 ^{a,b}	49.1 ± 8.8 ^a	49.3 ± 6.6 ^a	44.1 ± 6.8 ^{a,b}	47.7 ± 5.9 ^{a,b}	40.7 ± 8.0 ^b	57.2 ± 6.8	< 0.001
Zinc [µg g ⁻¹]	28.6 ± 3.3	29.3 ± 3.1	28.2 ± 2.0	28.5 ± 3.2	29.8 ± 2.4	29.4 ± 3.1	30.5 ± 4.0	0.216

E - chicken eggs from organic production, F - free range chicken eggs, B - barn chicken eggs, C - chicken eggs from caged hens, N3 - chicken eggs with an increased content of n3 fatty acids, GL - chicken eggs from Green-legged Partridge, Q - partridge quail eggs

P value, result of one-way ANOVA (α = 0.05)

^{a-b} homogeneous groups in row; comparison between product groups (Tukey's test, α = 0.05)

4. Discussion

Dietary fatty acids affect the level of low- and high- density lipoproteins and thus the dynamic of atherosclerotic plaque formation. They may be pro- or anti- atherogenic and thrombogenic [15]. However, dietary fatty acids affect not only the proper function of the circulatory system in the body but also the immune, neurological and many others [16,17]. Eggs are an important part of the diet of a large part of the population therefore their fatty acid composition can affect the daily lipid profile of the diet. In 100 g of the edible part of chicken eggs, there is an average of 9.2 g (13.4 g in quail eggs) of fat. The average content of fatty acids in eggs fat is 83% [18], which gives 7.7 g of fatty acids (11.1 g for quail) in 100 g of edible parts of these products.

There are twice as many unsaturated fatty acids as the saturated ones in eggs. The dominant FA is oleic acid, which has a beneficial effect on the prevention of CVD [19]. Linoleic acid is also of considerable value as one of the essential unsaturated fatty acids [20]. Unfortunately, the ratio of n6/n3 PUFAs is not the best, so the efforts of producers to increase the content of n3 PUFA seem to be reasonable. The recommended daily intake (RDI) of EPA and DHA with the diet by various organizations (including WHO and EFSA) is between 200 and over 600 mg per day, most often around 250 mg [21]. Considering the content of these acids in eggs, consumption of 100 g of edible parts (about two chicken eggs) covers over 20% of RDI, while quail eggs - about 37%.

The beneficial composition of fatty acids is best illustrated by the lipid quality indices. These indices were created to approximate the effect of fat on the body [13]. The index of atherogenicity was first described by Ulbricht and Southgate in 1991 [22]. It characterizes the atherogenic potential of FA. The higher values are associated with a greater atherogenic effect on the body. In eggs, this AI was about 0.4. In other animal products, it is usually higher. For example, for fish, it ranges from 0.2 - 1.2 [23–26], red meat 0.3 - 1.3 [27–30], milk and its products 1.0 - 5.0 [31–35]. Naturally, vegetable oils have an incomparably lower AI [36].

The same authors who developed AI also proposed an index of thrombogenicity [22], referring to the ability to form clots. Like AI, the higher the TI value is, the stronger the thrombogenic effect on the body is exerted. The lowest TI among animal products, due to the high share of N3 PUFA, were found in fishes (0.1-0.8) [14,23,26,37]. In the examined eggs, the TI was 0.8-1.0, whereas in red meat it ranges from 0.8-1.6 [28,38,39], and in milk and its products from 0.4 (yoghurt) to 5.0 [33–35].

The indices of hypercholesterolemic fatty acids (OFA) and hypocholesterolemic fatty acids (DFA) indicate the potential influence on the increase or reduction of the total and LDL cholesterol levels in the blood serum. In 2002 Santos-Silva et al. [40] proposed a hypocholesterolemic to hypercholesterolemic ratio. The higher the H/H index, the more beneficial the effect of fat on the body. The H/H ratio for eggs was determined at the level of 2.0 - 2.3. For fish it was 0.9 - 2.9 [24], for red meat 1.2-2.6 [40–42], and for dairy products 0.3 - 1.3 [33,34,43]. H/H index for vegetable oils is usually 5.0-15.0 [44,45]. The values of the indices, just like the fatty acid profile (based on which they are calculated), depend on many factors. Nevertheless, egg lipids compared to other products of animal origin (except for fish oil) are characterized by favourable values of these indicators.

Eggs are a source of high amounts of cholesterol [46]. While there is currently no evidence that dietary cholesterol adversely affects the level of LDL in the body, it is a compound that can be oxidized. Oxidized cholesterol derivatives (COPs) are much better absorbed from the gastrointestinal tract than cholesterol itself [47]. The high levels of these compounds in the body are very unfavourable. COPs act in many directions and may contribute to the development of non-communicable diseases [48]. Therefore, there are recommendations to pay attention to the cholesterol level in the diet. Nevertheless, the latest research shows that eating even two eggs a day has no adverse health effects [49,50].

During the evaluation of the nutritional value of eggs, not only lipids components levels but also amounts of other nutritional elements should be considered. In this study, the content of iron and zinc was also assessed. The daily reference intakes in the Euro-

pean Union for these minerals are 14 and 10 mg, respectively [51]. 100 g of the edible part of a hen's egg covers the RDA for iron in 10.4% (18.3% of quail eggs) and for zinc in 9.3% (13.7% of quail eggs). Our results of iron and zinc are consistent with the studies published by other authors [52–54].

Consumers perceive organic products as richer in nutrients and healthier. Eggs with a lower number on a shell (denoting the production method) are better received [55]. According to the presented results, there are a little (but statistically significant) deviations in the content of tested components between groups. However, based on these results it is not possible to point eggs from the exact production system based on lipid components content or profile (as cluster analysis confirmed). For each tested ingredient in one product group, there was quite a high variation in the results, which could be due to the individual variability, hens age and different feeds used by different producers. Some other authors have drawn similar conclusions [56,57]. Another issue is the welfare of the animals from which eggs are obtained. Nowadays, animal welfare is a significant concern in the consumer's decision about animal products, even if it relates to a higher price and knowledge about no significant differences in nutritional value [58,59]. Due to their very high nutritional value, eggs can be considered a functional food [60]. However, producers wanting to meet consumers demands and competition modify their products. Eggs enriched with vitamins, minerals, and other bioactive ingredients are created [10]. On the polish market, quite common are eggs declared in high content of omega-3 FA. Modification of the egg lipid components profile is usually done by modifying the hens' diet. A series of studies have shown that the addition of ALA-rich linseed to the feed can increase the n3 PUFA content in egg yolk. Alternatively, hens are fed fish oil or microalgae products as a source of long chain n3 PUFA. Modifications of the fatty acid profile of eggs were also obtained by feeding hens with vegetable oils or various seeds (chia, hemp) [61–63].

In the present study to the N3 group was chosen only product with a clear nutrition claim (high in omega-3 FA) on the package. This group of products was distinguished by the content of fatty components compared to others; had the most favourable values of fat quality indices. However, according to the European Commission Regulation No. 1924/2006 (as amended): "A claim that a food is high in omega-3 fatty acids, and any claim likely to have the same meaning for the consumer, may only be made where the product contains at least 0.6 g α -linolenic acid per 100 g and per 100 kcal or at least 80 mg of the sum of eicosapentaenoic acid and docosahexaenoic acid per 100 g and per 100 kcal" [64]. Unfortunately, none of the eggs in group N3 achieved the level of 0.6 g ALA per 100 g of product or 100 g of the edible part. Only one producer (out of eight) met the second condition; the sum of EPA and DHA was 95.87 mg 100g⁻¹ of the product (average in chicken eggs was 48.00 mg 100 g⁻¹) and 126,02 mg per 100 g of edible parts (average 55.10 mg in chicken eggs). The seven producers whose eggs were evaluated in this study should not include a nutrition claim on their packages with an increased n3 PUFA content. Many experiments are confirming the possibility of increasing the n3 PUFA content in eggs [65]. There are also studies of marketed products where the nutrition claim corresponds to an increased amount of these valuable fatty acids [57]. Our research proves that controls on the compatibility of nutrition claims with the real level of the declared nutrients in eggs are necessary.

Another tested premium product are eggs from Green-legged partridge hens. These eggs have gained popularity on the Polish market due to their better sensory quality than traditional products [66]. Consumers may also believe that they have higher nutritional value. Moreover, their price is higher than other products. The parameters of the egg (the whole egg, edible parts, and yolk weight) were slightly lower than in other groups of chicken eggs, which is characteristic feature of this breed [67]. However, the content of fat, fatty acids, cholesterol, iron, and zinc in the yolk did not differ from other groups of chicken eggs. Previous studies have shown that the breed of laying hens affects the nutritional value of eggs [65,68]. However, these studies were usually conducted under controlled conditions. However, in the case of market eggs, many factors are affecting the

final quality of the product, so the differences between breeds can be equalized by other determinants. Only selected parameters of the nutritional quality of eggs were evaluated in this study. Perhaps the differences in the content of other nutrients or bioactive components between eggs from Green-legged partridge hens and traditional products would be significant.

Quail eggs are quite popular in some regions of the world. Their appearance, size, sensory features, and nutritional value are different from chicken eggs, as they are laid by completely different species of birds [69]. In this study, attention should be paid to higher iron and cholesterol content in quail eggs than in chicken eggs. The differences are even more pronounced when converted into 100 g of whole egg or 100 g of edible parts. The share of yolk in a quail egg is about 10% higher than in a hen's egg (38.5 vs 28.1%). Although the percentage share of the main groups of FA (SFA, MUFA, PUFA) in the total FA content is similar, the content of individual acids distinguishes quail eggs from the other studied groups. The data for quail eggs presented in this study are consistent with the results of studies obtained by other authors [69–71]. Quail eggs seem to be an interesting alternative to chicken eggs in the kitchen.

5. Conclusions

Bird eggs are an almost perfect product, intended to provide the bird embryo with all the nutrients necessary for development. Therefore, they also play a significant role in people diet. Compared to other products of animal origin, the fatty acid profile is favourable, and modification of the laying hens' diet may contribute to the increase of the level of n3 fatty acids, especially valuable EPA and DHA. In this study, no differences in the content of tested nutrients between eggs from different production methods (E, F, B, C), as well as inter-breed differences (GL) were noticed. Quail eggs differed in terms of FA profile, as well as iron and cholesterol levels from chicken eggs. Meals prepared from them can be an interesting alternative to a traditional omelette.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Figure S1: title, Table S1: title, Video S1: title.

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