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Fat Content, Fatty Acid Composition, and Fatty Acid-based Nutritional Indices/Ratios of Egg Yolks from Different Poultry Species and Breeds

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The nutritional value of egg yolk in terms of fat content and fatty acid (FA) composition is needed to evaluate their possible effect on human cardiovascular health and disease. This study determined the FA-based nutritional indices/ratios of egg yolks from 29 breeds belonging to seven poultry species (chicken, mallard, quail, Muscovy, guinea fowl, turkey, and ostrich) in a government poultry research station at Tiaong, Quezon, Philippines. At least four pooled samples (each consisting of four egg yolks) per breed were randomly collected and immediately frozen at –20 °C until analyzed for fat content and FA composition by gas chromatography. The major FAs in egg yolk with the highest proportions by weight of total FAs were oleic acid C18:1 n-9 (30.6–43.9%), palmitic acid C16:0 (22.2–54.4%), linoleic acid (LA) C18:2 n-6 (0.4–16.6%), and stearic acid C18:0 (4.0–12.1%). Compared to chicken and quail eggs, the mallard egg yolk seems to have more health benefits because of a lower LA to α-linolenic acid C18:3 n-3 (ALA) ratio (15.70: 1), atherogenicity (0.45), and thrombogenicity (0.91) – as well as higher yolk weight (22.7 g), fat content (31.8%), monounsaturated fatty acids (MUFA) to saturated fatty acids (SFA) ratio (1.73: 1), health-promoting index (2.20), and hypocholesterolemic/hypercholesterolemic ratio (2.26). Among mallard breeds, the egg yolks from Tsaiya and Pekin were superior to that from Itik-Pinas breeds. Egg yolk from other poultry species generally had lower FA-based nutritional values. Significant breed differences in fat content, FA composition, and nutritional indices/ratio were also reported for egg yolks from chicken, quail, and turkey.

Keywords: fatty acids, nutritional indices/ratios, poultry eggs

INTRODUCTION

Eggs from different poultry species are important components of the human diet all over the world. In the Philippines, the commonly used eggs as food come from chickens, mallard ducks, and quails. In 2021, the local production of chicken and duck eggs from commercial layer farms was 661.39 thousand metric tons valued at PHP 77.27 billion and 50.45 thousand metric tons worth PHP 5.44 billion, respectively (PSA 2022a, b). Unfortunately, no data is available on eggs produced by quails and native/improved native chickens and ducks raised in backyard or poor smallholder farms. Eggs from Muscovy, guinea fowl, turkey, and ostrich obtained from the local niche market may also be eaten, although information on their commercial production is limited since they are mainly used to produce hatching eggs.

Other than a traditional source of dietary protein, the egg yolk contains fats that may have different nutritional qualities and effects on human health. Dietary fat quality had been reported to be more important than total dietary

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fat intake to prevent cardiovascular disease (Guasch-Ferre *et al.* 2015). Hence, the fatty acid (FA) composition of yolk fats and their classification into saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA) such as omega-3 and omega-6 FAs are now used to evaluate the yolk's nutritional and/or medicinal values (Chen and Liu 2020). Research studies on the chicken egg, for example, showed that the FA composition may be influenced by the genetic strain (Scheideler *et al.* 1998; Grobas *et al.* 2001; Rey *et al.* 2021), egg size and the relative proportion of yolk (Cantor *et al.* 2007), and the source of supplemental fat and lipid composition of the hen's diet (Grobas *et al.* 2001; Bean and Leeson 2003; Zhao *et al.* 2013; Wu *et al.* 2019). Among these factors, diet is considered the main single determinant of the FA composition of yolk (Goldberg *et al.* 2013). While the amount of SFA or MUFA in eggs is hardly influenced by the lipids in the feed, the PUFA content in the egg can be modified through dietary supplementation using flaxseed, fish oil, and microalgae (Fraeye *et al.* 2012). Variations in the FA composition of eggs have also been reported between species (Polat *et al.* 2013). However, there is little information on the measurement of the nutritional quality of egg yolk from adapted poultry species and breeds that would signify the possible effect of FAs on human cardiovascular health and disease (Chen and Liu 2020). Such information may be added to the local "Food Composition Tables" and "Food Exchange Lists" used by consumers and health professionals who have become increasingly interested in functional foods that can prevent or ameliorate disease. The distinctive FA composition of egg yolk from local poultry genetic resources may also be used to provide the justification to conserve them.

In this regard, this study aimed to compare the fat content, FA composition, and FA-based nutritional indices/ratios of egg yolk produced by 29 breeds belonging to seven poultry species (chicken, mallard, quail, Muscovy, guinea fowl, turkey, and ostrich) in a government poultry research station at Tiaong, Quezon in the Philippines.

MATERIALS AND METHODS

This study was conducted in compliance with the requirements of the Institutional Animal Care and Use Committee (IACUC Protocol Number 2019-0034) of the University of the Philippines Los Baños, Laguna, Philippines.

Data

A total of 637 eggs were randomly collected from 29 breeds of seven poultry species raised in similar semi-intensive farm conditions at the National Swine and Poultry Research and Development Center (NSPRDC), Bureau of Animal Industry–Department of Agriculture (BAI-DA) in Tiaong, Quezon (see Table 1). The same layer mash used for chickens was fed to quails, guinea fowls, turkeys, and ostriches, whereas duck layer mash was given to mallards and Muscovy ducks. All birds of the same breed were of the same laying age.

Chicken eggs were gathered from four native breeds (Banaba or Banabang Kalabaw, Joloano, Paraoakan, and Palawan Lasak), seven exotic breeds [meat-type (White Rock), egg-type (White Leghorn), dual-purpose (Black Australorp, Barred Plymouth Rock, Nagoya, New Hampshire, Rhode Island Red, and Taiwan Yellow), and two fancy-type breeds (Black Silkies and White Silkies)]. Mallard eggs were collected from three Itik-Pinas (IP) breeds (IP-Itim, IP-Khaki, and Kayumanggi-IP) and four other mallard breeds (Khaki Campbell, Pekin, Tsaiya, and White Mallard). Quail eggs were obtained from three breeds (Japanese Seattle, Silver White, and Taiwan). Eggs from turkey were gathered from two breeds (Broad Breasted Bronze and Nicholas White). Other poultry species represented by one breed each included the Muscovy duck (White Muscovy), guinea fowl (Bengala), and ostrich (Blue Neck).

All eggs were individually recorded for egg weight, yolk weight, and yolk color (measured using a 16-scale color index DSM yolk color fan, formerly Roche Yolk Color Fan, USA) within 24 h after their collection. Four yolk samples collected on the same day and belonging to the same breed of chicken, mallard, Muscovy, guinea fowl, and turkey were pooled and placed in 200-mL plastic bottles and immediately frozen at –20°C until further analysis. In the case of quail and ostrich, a pooled sample was obtained from ten quail eggs and one ostrich egg, respectively. Four pooled samples per breed (except for IP-Itim, IP-Khaki, and Kayumanggi-IP mallard breeds with 16, 16, and 8 pooled samples, respectively) or a total of 145 pooled samples were analyzed for fat, protein, and moisture content and FA composition.

The FAs were analyzed as a percentage of the total identified FAs (g/ 100 g). These included 8 saturated fatty acids (SFA) [C12:0 (lauric acid), C14:0 (myristic acid), C15:0 (pentadecylic acid), C16:0 (palmitic acid), C17:0 (margaric acid), C18:0 (stearic acid), C20:0 (arachidic acid), and C22:0 (behenic acid)], 6 monounsaturated fatty acids (MUFA) [C14:1 n-5 (myristoleic acid), C16:1 n-7 (palmitoleic acid), C18:1 n-9 (oleic acid), C18:1 n-7 (trans-vaccenic acid), C20:1 n-11 (eicosenoic acid), and C22:1 n-9 (erucic acid)], and 5 polyunsaturated fatty acids (PUFA) [C18:2 c9tll (conjugated linoleic acid, CLA), C18:2 n-6 (linoleic acid, LA), C18:3 n-3 (alpha α-linolenic acid, ALA), C20:4 n-6 (arachidonic acid, AA), and C22:6 n-3 (docosahexaenoic acid, DHA)].

Table 1. Number and distribution of egg samples (by species and breed) and corresponding least-square mean for egg weight and hen's age at lay.

Common and scientific name **Breed name**	**No. of breeds**	**No. of eggs**	**Egg weight, g**	**Age at lay, yr**
Chickens, *Gallus gallus domesticus*	14	223	56.86 ± 0.77^{d}	1.50 ± 0.01^{d}
Banaba		16	53.34 ± 2.89^{x}	1.68 ± 0.03^{w}
Joloano		16	51.28 ± 2.89^{x}	1.54 ± 0.03^{x}
Paraoakan		16	52.91 ± 2.89^{x}	1.64 ± 0.03^{x}
Palawan lasak		16	50.48 ± 2.89^{x}	1.64 ± 0.03^{x}
White Leghorn		16	66.98 ± 2.89^{v}	1.05 ± 0.03^{y}
Black Silkies		15	46.73 ± 2.99^{y}	1.04 ± 0.03^{y}
White Silkies		16	45.35 ± 2.89^{y}	1.02 ± 0.03^{y}
White Rock		16	55.86 ± 2.89^{wx}	2.14 ± 0.03^{v}
Black Australorp		16	60.87 ± 2.89^{w}	2.12 ± 0.03^{v}
Barred Plymouth Rock		16	62.01 ± 2.89^{vw}	0.93 ± 0.03^{z}
Nagoya		16	66.46 ± 2.89^{vw}	2.12 ± 0.03^{v}
New Hampshire		16	62.68 ± 2.89^{vw}	2.18 ± 0.03^{v}
Rhode Island Red		16	60.08 ± 2.89^{w}	0.92 ± 0.03^{e}
Taiwan Yellow		16	61.02 ± 2.89^{w}	1.00 ± 0.03^{d}
Mallard ducks, *Anas platyrynchos*	7	219	73.37 ± 0.92^{c}	0.87 ± 0.01^{f}
Itik-Pinas (IP) – Itim		63	72.72 ± 1.46^{w}	0.74 ± 0.01^{x}
Itik-Pinas (IP) – Khaki		60	73.37 ± 1.49^{w}	0.69 ± 0.00^{y}
Kayumanggi – IP		32	73.55 ± 2.04^{w}	1.31 ± 0.02^{w}
Khaki Campbell		16	70.96 ± 2.89^{wz}	1.47 ± 0.03^{v}
Pekin		16	85.89 ± 2.89^{w}	0.66 ± 0.03^{y}
Tsaiya		16	69.97 ± 2.89^{wx}	0.63 ± 0.03^{y}
White Mallard		16	68.09 ± 2.89^{x}	0.61 ± 0.03^{y}
Quails, *Coturnix coturnix*	3	120	9.66 ± 1.06^{f}	1.79 ± 0.01^{c}
Japanese Seattle		40	9.55 ± 1.83^{v}	1.79 ± 0.02^{v}
Silver White		40	9.82 ± 1.83^{v}	1.79 ± 0.02^{v}
Taiwan		40	9.62 ± 1.83^{v}	1.81 ± 0.02^{v}
Muscovy ducks, *Cairina moschata* White Muscovy	1	16	71.74 ± 2.89^{c}	1.55 ± 0.03^{d}
Guinea fowl, *Numida meleagris* Bengala	1	16	47.66 ± 2.89^{e}	1.21 ± 0.03^{e}
Turkey, *Meleagris gallopavo*	2	32	83.71 ± 2.04^{b}	2.09 ± 0.02^{b}
Broad Breasted Bronze		16	84.14 ± 2.89^{v}	2.09 ± 0.03^{v}
Nicholas White		16	83.27 ± 2.89^{v}	2.09 ± 0.03^{v}
Ostrich, *Struthio camelus* Blue Neck	1	11	1398.4 ± 3.5^{a}	9.45 ± 0.03^{a}
Total	**29**	**637**		

Least-square means with different superscript letters (a, b, c, d, e, f) within a column are significantly different between species ($P < 0.05$).
Least-square means with different superscript letters (v, w, x, y, z) within a column are significantly different between breeds of the same species ($P < 0.05$).

The FA acid composition of feeds was also analyzed. The major FAs found in chicken layer mash were oleic acid (15.31%), palmitic acid (12.51%), linoleic acid (11.00%), and stearic acid (3.90%), whereas those for duck layer mash were linoleic acid (38.95%), oleic acid (26.86%), palmitic acid (16.65%), and stearic acid (2.13%).

Six FA groups (*i.e.* SFA, MUFA, PUFA, UFA = MUFA + PUFA, omega-3 FA = C18:3 n-3 and C22:6 n-3, and omega-6 FA = C18:2 n-6 + C20:4 n-6) were initially determined. In addition, eight FA-based nutritional indices/ratios with health implications (Chen and Liu 2020) were calculated, including: [1] PUFA to SFA ratio, [2] MUFA to SFA ratio, [3] omega-6 FA to omega-3 FA ratio, [4] linoleic acid to α-linolenic acid ratio, [5] atherogenicity index (IA), [6] thrombogenicity index (IT), [7] health-promoting index (HPI), and [8] hypocholesterolemic/hypercholesterolemic (HH) ratio.

The IA and IT were calculated using the equations of Ulbricht and Southgate (1991), *i.e.* IA = [C12:0 + (4 × C14:0) + C16:0] / ΣUFA; and IT = (C14:0 + C16:0 + C18:0) / [(0.5 × MUFA) + (0.5 × n-6 PUFA) + (3 × n-3) + (n-3 / n-6)]. The HPI was HPI = UFA / [C12:0 + (4 × C14:0) + C16:0] as used by Chen *et al.* (2004). The HH ratio was calculated as per Mierlita (2018), *i.e.* HH = (C18:1 n-9 + PUFA) / (C12:0 + C14:0 + C16:0).

Analysis of Fat and Protein Content

The fat content of egg yolk samples was analyzed using the Mojonnier method (AOAC Official Method 925.32 2016a), whereas the crude fat percentages of the chicken and duck layer mash were analyzed using the Soxhlet extraction method (AOAC Official Method 2003.6 2006) to contain 3.36 and 3.84%, respectively. In addition, the percent protein in the yolk was determined using the Kjeldahl method (AOAC Official Method 932.31 2016b).

Fatty Acid (FA) Analysis

Fat was extracted from yolk samples following the method presented by Folch *et al.* (1957) and transferred in a screw-capped glass test tube (16.5 × 105 mm). The fatty acid methyl esters (FAMEs) were prepared following the rapid methanolysis/methylation procedure that uses concentrated HCl of Ichihara and Fukubayashi (2010). The FAMEs were stored in the refrigerator (–20 °C) prior to FA analysis by gas chromatography.

The FAMEs were quantified using a Shimadzu GC 2010 Plus – Capillary Gas Chromatograph System (Shimadzu Corporation, Kyoto, Japan) that is equipped with a flame ionization detector and AOC-20i autosampler. It used a FAMEWax (USP G16) capillary column (30 m, 0.32 mm ID, and 0.25 μm film thickness, Restek Corporation, USA). The FAME peaks were identified by comparing their retention times with known FAME standards. The data were in duplicates and analyzed using the LabSolutions software. The FAME standard mix was purchased from Sigma Aldrich.

Statistical Analysis

Species and breed differences in hen's age at lay, yolk weight, yolk color, and percent fat, protein, and moisture were determined using ANOVA (SAS Institute Inc., Cary, NC).

The general least squares procedures for unbalanced data were used to analyze each FA using the following statistical model: $y_{ijklmno} = \mu + Species_i + Breed_j\ (Species_i) + Age_k + YW_l + YC_m + PFat_n + e_{ijklmno}$ where y_{ijk} is the proportion of FA, μ is the overall mean, $Species_i$ is the fixed effect of the i^{th} poultry species, $Breed_j\ (Species_i)$ is the fixed effect of the j^{th} breed of the i^{th} poultry species, Age_k is the covariate effect of the k^{th} hen's age at lay (years), YW_l is the covariate effect of l^{th} yolk weight (g), YC_m is the covariate effect of the m^{th} color of the yolk, $PFat_n$ is the covariate effect of the n^{th} fat percentage, and $e_{ijklmno}$ is the error term. In this model, the effect of feeds was confounded in the observed differences between species. Statistical significance was set at $P < 0.05$. The least-square means for each FA were used to calculate the FA-based nutritional indices/ratios, which were compared between species and between breeds. Regression coefficients (no intercept model) were also determined for FAs and found to be significantly associated with the hen's age at lay, yolk weight, yolk color, and fat percentage.

RESULTS AND DISCUSSION

Yolk Characteristics

The weight of the egg yolk was significantly higher in mallard (22.7 g) compared to chicken (16.4 g) and quail (3.1 g). The proportion of yolk weight to egg weight, however, was slightly higher in quail (32.0%) than in mallard (31.0%) and chicken (29.0%). In other poultry species, the egg yolk was highest in ostrich (379.8 g), followed by turkey (25.3 g), Muscovy (23.5 g), and guinea fowl (14.0 g). However, the percent yolk was highest in Muscovy (32.6%), followed by turkey (30.5%), guinea fowl (29.4%), and lowest in ostrich (27.2%) (see Table 4). Yolk weight was widely different between chicken breeds (13.9–20.5 g) and between mallard breeds (21.2–27.1 g), whereas small differences were found between quail breeds (3.06–3.12 g) and between turkey breeds (25.0–26.1 g) (see Tables 5–8).

On a scale of 1–16, yolk color was highest (*i.e.* deep yellow) for ostrich (10.2), followed by Muscovy (7.9), chicken (7.4), turkey (7.4), guinea fowl (7.2), quail (6.4), and lowest (*i.e.* pale yellow) in mallard (6.2). Yolk color was widely different between chicken breeds (6.4–9.2) and between mallard breeds (4.5–9.0), whereas small differences were found between quail breeds (6.3–6.4) and between turkey breeds (7.0–7.8). Unlike other poultry species, ostriches were allowed to free range where there may be an abundance of carotenoids, which are responsible for the deep yellow color of their egg yolks.

The fat content of egg yolk was slightly higher in mallard (31.8%) than in quail (31.1%) and chicken (29.8%). In other poultry species, Muscovy (34.0%) had the highest percent fat, followed by turkey (28.8%), guinea fowl (28.2%), and ostrich (27.0%). Slight differences in fat content of egg yolk were found between chicken breeds (28.5–31.8%), between mallard breeds (31.2–33.4%), between quail breeds (30.0–33.0%), and between turkey breeds (27.0–30.6%).

The protein content of egg yolk was highest in guinea fowl (16.3%), followed by mallard (16.1%), chicken (16.1%), Muscovy (16.0%), quail (15.9%), turkey (15.3%), and lowest in ostrich (14.1%). Small differences in the protein content of egg yolk were found between chicken breeds (14.5–16.7%), between mallard breeds (15.7–16.6%), between quail breeds (15.8–16.0%), and between turkey breeds (15.2–15.4%). In addition, the moisture content of egg yolk was highest in ostrich (54.5%), followed by guinea fowl (49.6%), chicken (49.6%), quail (49.4%), turkey (49.1%), mallard (48.0%), turkey (49.1%), and lowest in Muscovy (46.1%). Considerable differences in moisture content of egg yolk were found between chicken breeds (47.6–52.6%), between mallard breeds (46.5–49.8%), and between turkey breeds (48.2–52.0%), whereas small differences in percent moisture were found between quail breeds (48.8–49.7%).

Major Fatty Acids (FAs) in Poultry Eggs

The major FAs with the highest proportions by weight of total FAs in egg yolk were oleic acid C18:1 n-9 (30.6–43.9%), palmitic acid C16:0 (22.2–54.4%), linoleic acid C18:2 n-6 (0.4–16.6%), and stearic acid C18:0 (4.0–12.1%) (see Table 2). The major FAs in egg yolk were the same major FAs present in chicken and duck feeds, although the yolk had a higher concentration of palmitic acid and oleic acid. On the other hand, linoleic acid in the yolk was lower compared to that in the feed. This is because linoleic acid is synthesized in the egg yolk, whereas feed linoleic acid is metabolized (Khang *et al.* 2007).

Table 2. Mean square F tests for the effects of species and breed within species, and covariate effects of age at lay, yolk weight, yolk color, and percent fat on fatty acids (g/ 100 g of total identified fatty acids) in poultry eggs.

	Species	Breed within species	Age at lay	Yolk weight	Yolk color	% fat	CV (%)
Saturated FAs							
C12:0	**	**	**–0.04 ± 0.01	ns	**-0.003 ± 0.000	ns	22.90
C14:0	**	**	**–0.25 ± 0.06	ns	**0.015 ± 0.003	**0.011 ± 0.004	16.29
C15:0	**	**	*–0.01 ± 0.00	ns	ns	**0.001 ± 0.000	13.53
C16:0	**	**	**–2.77 ± 0.46	ns	ns	**0.168 ± 0.033	4.99
C17:0	**	**	ns	ns	**0.004 ± 0.002	ns	59.06
C18:0	**	**	**–0.78 ± 0.24	ns	ns	*-0.035 ± 0.017	9.37
C20:0	**	ns	ns	**0.004 ± 0.000	ns	*-0.004 ± 0.002	30.33
C22:0	**	**	**–0.10 ± 0.02	ns	ns	ns	> 100
Monounsaturated FAs							
C14:1 n-5	**	**	**–0.05 ± 0.01	ns	ns	ns	26.00
C16:1 n-7	**	**	**–0.51 ± 0.17	**-0.015± 0.002	ns	**0.054 ± 0.012	15.21
C18:1 n-9	**	**	ns	ns	ns	*0.082 ± 0.039	3.64
C18:1 n-7	**	**	ns	ns	*–0.013 ± 0.006	ns	23.46
C20:1 n-11	**	**	*0.04 ± 0.01	ns	ns	**0.004 ± 0.001	33.04
C22:1 n-9	**	**	*0.05 ± 0.02	ns	ns	**0.005 ± 0.002	> 100
Polyunsaturated FAs					ns		
C18:2 c9 t11	**	**	*0.06 ± 0.03	**-0.015 ± 0.000	**–0.005 ± 0.002	*–0.005 ± 0.002	33.44
C18:2 n-6	**	**	ns	**0.023 ± 0.005	ns	*0.055 ± 0.025	9.05
C18:3 n-3	**	**	ns	ns	ns	ns	10.87
C20:4 n-6	**	**	*0.21 ± 0.10	ns	ns	ns	96.91
C22:6 n-3	**	**	**0.17 ± 0.06	ns	**–0.016 ± 0.003	ns	94.53

Note: [ns] no significant differences ($P > 0.05$); [*] significant differences ($P < 0.05$); [**] highly significant differences ($P < 0.01$).
Numbers in covariate columns are the regression coefficients and corresponding standard errors.

Other FAs which comprised less than 0.5 percent of total FAs in the egg yolk included the SFAs (C12:0, C15:0, C17:0, C20:0, and C22:0), MUFAs (C14:1 n-5, C20:1 n-11, and C22:1 n-9), and PUFAs (C18:2 c9t11 or CLA, C18:2 c9 t11 or ALA, C20:4 n-6 or AA, and C22:6 n-3 or DHA). In addition, the C22:1 n-9 (erucic acid) was not detected in the egg yolk of Muscovy, guinea fowl, and ostrich, whereas CLA was not detected in the egg yolk of quail and turkey.

Oleic acid, a MUFA, was 1.07–1.16 times higher in the egg yolk of mallard (43.9%) compared to that in quail (41.2%) and chicken (37.7%). Lower oleic acid was found in turkey (37.5%), Muscovy (35.6%), ostrich (32.9%), and guinea fowl (30.6%).

Palmitic acid, an SFA, was 1.14 times higher in the egg yolk of both chicken and quail (25.2%) than that in mallard (22.2%). In other poultry species, palmitic acid was highest in ostrich (54.4%), followed by guinea fowl (27.5%), turkey (26.0%), and lowest in Muscovy (24.6%).

Linoleic acid, an omega-6 PUFA, was 1.48–1.93 times higher in the egg yolk of chicken (13.5%) than that in quail (9.1%) and mallard (7.0%). In other poultry species, linoleic acid was highest in guinea fowl (16.6%), followed by turkey (12.3%), Muscovy (11.8%), and ostrich (0.4%).

Stearic acid, also an SFA, was 1.29–2.42 times higher in the egg yolk of quail (9.7%) compared to that in chicken (7.5%) and mallard (4.0%). In other poultry species, stearic acid was highest in ostrich (12.1%), followed by guinea fowl (9.1%), turkey (7.7%), and Muscovy (6.0%).

The same major FAs of egg yolk from chicken, goose, duck, turkey, peacock, guinea fowl, pheasant, quail, and partridge living in the natural environment in Turkey were reported by Polat *et al.* (2013), including oleic acid (33.9–48.3%), palmitic acid (21.1–26.3%), linoleic acid (10.7–28.5%) and stearic acid (4.3–8.1%). They also showed that chicken egg yolk had lower oleic and palmitic acid but higher linoleic and stearic acid than that in the duck egg yolk. The major FAs (except stearic acid) in quail egg yolk were always in between that of chicken and mallard. In another study in India, Sarma *et al.* (2017) reported lower oleic and palmitic acid but higher linoleic and stearic acid in yolk fat from Desi, Vanarajah, and Kamrupa chickens than that from Pati, Nageswari, and Chara-Chemballi ducks.

Factors Affecting FA Composition in Poultry Eggs

Among the major FAs, stearic acid C18:0 was the most variable with a coefficient of variation (CV) of 9.37% – followed by linoleic acid C18:2 n-6 (CV = 9.05%), palmitic acid C16:0 (CV = 4.99%), and oleic acid C18:1 n-9 (CV = 3.64%) (see Table 3). The major FAs in egg yolk were significantly different ($P < 0.01$) between species and between breeds.

Oleic acid was higher in large egg yolks (*i.e.* higher by 0.02% per additional gram of yolk weight) and in egg yolks having higher percent fat (*i.e.* higher by 0.08% for every increase in percent fat). Palmitic acid was lower from older hens (*i.e.* lower by 2.77% for every additional year of age at lay) but higher in egg yolks having higher percent fat (*i.e.* higher by 0.17% for every unit increase in percent fat). Linoleic acid was also higher in egg yolks having higher percent fat (*i.e.* higher by 0.06% for every unit increase in percent fat). Stearic acid was lower in older hens (*i.e.* lower by 0.78% for every additional year of age at lay) and in egg yolks having higher percent fat (*i.e.* lower by 0.04% for every unit decrease in percent fat). Yolk color was not related to the proportion of major FAs in egg yolk ($P > 0.05$).

FA-based Nutritional Indices/Ratios

The comparison of nutritional indices/ratios related to human cardiovascular health for egg yolk among poultry species is shown in Table 4, whereas breed differences are shown in Tables 5 and 6 (chicken), Table 7 (mallard), and Table 8 (quail and turkey), respectively.

PUFA/SFA ratio. The PUFA/SFA ratio is the commonly used index to assess the impact of dietary fat on cardiovascular health (Chen and Liu 2020). Yolk fats with a higher PUFA/SFA ratio may imply greater health benefits. This is because PUFAs in the diet have been shown to reduce low-density lipoprotein cholesterol and serum cholesterol, whereas SFAs contribute to high levels of serum cholesterol concentration (Dietschy 1998; Mensink *et al.* 2003). While a decrease in the consumption of SFAs and an increase in unsaturated FAs may decrease the risk factors for cardiovascular disease (CVD) (including heart disease and stroke), a significant reduction in CVD risk can be achieved if SFAs are replaced by unsaturated fats, especially PUFAs. (Guasch-Ferre *et al.* 2015; Wang and Hu 2017; Froyen and Burns-Whitmore 2020).

In chicken eggs, the amount of SFA or MUFA is hardly influenced by the lipids in the feed. In contrast, the PUFA content in the egg can be modified through dietary supplementation (Fraeye *et al.* 2012). The PUFA content in the quail egg can also be modified through dietary supplementation (Gladkowski *et al.* 2014). In this study, the PUFA/SFA ratio was higher (more health benefits) in chicken egg yolk (0.42: 1) than that from mallard (0.30: 1) and quail (0.26: 1). In other poultry species, the PUFA/SFA ratio was highest in guinea fowl (0.44: 1), followed by Muscovy (0.38: 1), turkey (0.35: 1), and lowest for ostrich (0.01: 1).

Table 3. Least-square means for the proportion of fatty acids in egg yolk from different poultry species.

	Chicken	Mallard	Quail	Muscovy*	Guinea fowl*	Turkey	Ostrich**
Saturated FAs							
C12:0	0.08 ± 0.00^{d}	0.10 ± 0.01^{c}	0.05 ± 0.00^{e}	0.06 ± 0.01^{de}	0.15 ± 0.01^{b}	0.10 ± 0.01^{c}	0.42 ± 0.07^{a}
C14:0	1.02 ± 0.01^{c}	0.80 ± 0.04^{d}	0.62 ± 0.03^{e}	0.63 ± 0.04^{e}	2.04 ± 0.04^{b}	1.06 ± 0.04^{d}	3.35 ± 0.49^{a}
C15:0	0.05 ± 0.00^{b}	0.03 ± 0.00^{b}	0.03 ± 0.00^{b}	0.04 ± 0.00^{b}	0.10 ± 0.00^{a}	0.05 ± 0.00^{b}	0.04 ± 0.02^{ab}
C16:0	25.21 ± 0.10^{d}	22.24 ±0.31^{e}	25.17 ±0.40^{de}	24.60 ±0.33^{e}	27.53 ±0.35^{b}	26.03 ± 0.35^{c}	54.37 ± 4.06^{a}
C17:0	0.14 ± 0.01^{c}	0.09 ± 0.02^{d}	0.11 ± 0.01^{cd}	0.13 ± 0.02^{cd}	0.20 ± 0.02^{b}	0.12 ± 0.02^{c}	0.40 ± 0.24^{a}
C18:0	7.49 ± 0.05^{c}	4.03 ± 0.16^{e}	9.66 ± 0.12^{b}	6.02 ± 0.17^{d}	9.08 ± 0.18^{b}	7.72 ± 0.18^{c}	12.14 ± 2.10^{b}
C20:0	0.23 ± 0.01^{bc}	0.43 ± 0.06^{c}	0.22 ± 0.01^{d}	0.94 ± 0.01^{bc}	0.34 ± 0.02^{a}	0.23 ± 0.02^{b}	0.00 ± 0.22^{b}
C22:0	0.04 ± 0.01^{c}	0.11 ± 0.02^{b}	0.00 ± 0.02^{c}	0.02 ± 0.02^{c}	0.04 ± 0.02^{c}	0.18 ± 0.02^{a}	0.00 ± 0.22^{c}
Monounsaturated FAs							
C14:1 n-5	0.19 ± 0.00^{c}	0.07 ± 0.01^{e}	0.11 ± 0.01^{d}	0.05 ± 0.01^{e}	0.25 ± 0.01^{b}	0.23 ± 0.01^{b}	0.52 ± 0.12^{a}
C16:1 n-7	2.49 ± 0.04^{d}	2.60 ± 0.11^{d}	3.58 ± 0.09^{c}	1.89 ± 0.12^{e}	2.64 ± 0.13^{d}	4.26 ± 0.13^{b}	14.14 ± 1.49^{a}
C18:1 n-9	37.66 ±0.12^{c}	43.87 ± 0.36^{a}	41.19 ±0.28^{b}	35.89 ±0.39^{d}	30.59 ± 0.42^{d}	37.53 ± 0.41^{c}	32.91 ± 4.75^{a}
C18:1 n-7	1.20 ± 0.02^{b}	0.99 ± 0.07^{b}	1.43 ± 0.05^{a}	1.46 ± 0.07^{a}	0.94 ± 0.07^{c}	1.11 ± 0.07^{a}	2.07 ± 0.86^{abc}
C20:1 n-11	0.13 ± 0.00^{a}	0.14 ± 0.01^{a}	0.12 ± 0.01^{a}	0.15 ± 0.01^{a}	0.05 ± 0.01^{b}	0.12 ± 0.01^{a}	0.00 ± 0.13^{ab}
C22:1 n-9	0.01 ± 0.01^{c}	0.05 ± 0.01^{b}	0.01 ± 0.02^{c}	n/d	n/d	0.17 ± 0.02^{a}	n/d
Polyunsaturated FAs							
C18:2 c9 t11, CLA	0.14 ± 0.01^{b}	0.26 ± 0.01^{a}	n/d	0.20 ± 0.02^{ab}	0.03 ± 0.02^{c}	n/d	0.16 ± 0.25^{abc}
C18:2 n-6, LA	13.51 ± 0.08^{b}	6.97 ± 0.23^{a}	9.12 ± 0.18^{d}	11.81± 0.25^{c}	16.62 ± 0.26^{a}	12.27 ± 0.26^{c}	0.35 ± 3.05^{e}
C18:3 n-3, ALA	0.31 ± 0.00^{b}	0.44 ± 0.01^{a}	0.14 ± 0.01^{d}	0.16 ± 0.01^{d}	0.19 ± 0.01^{c}	0.22 ± 0.01^{c}	0.00 ± 0.11^{e}
C20:4 n-6, AA	0.24 ± 0.02^{b}	0.43 ± 0.06^{a}	0.03 ± 0.05^{c}	0.21 ± 0.07^{b}	0.12 ± 0.08^{b}	0.06 ± 0.07^{c}	0.00 ± 0.83^{c}
C22:6 n-3, DHA	0.21 ± 0.01^{b}	0.27 ± 0.04^{ab}	0.00 ± 0.03^{c}	0.10 ± 0.04^{c}	0.33 ± 0.05^{a}	0.00 ± 0.05^{c}	0.00 ± 0.53^{c}

Note: [*] White Muscovy breed; [**] Bengala breed; [***] Blue Neck breed; [n/d] not detected.
Least-square means within a row without common letter superscripts are significantly different ($P < 0.05$).

Table 4. Least-square means for yolk characteristics, FA groups, and nutritional indices/ratios of egg yolk from different poultry species.

	Chicken	Mallard	Quail	Muscovy*	Guinea fowl	Turkey	Ostrich
Yolk weight, g	16.43^{d}	22.74^{c}	3.09^{e}	23.54^{bc}	13.98^{d}	25.53^{b}	379.8^{a}
Yolk color	7.42^{b}	6.15^{c}	6.38^{c}	7.88^{b}	7.19^{b}	7.38^{b}	10.18^{a}
% moisture	49.59^{b}	47.95^{c}	49.37^{b}	46.12^{c}	49.62^{b}	49.12^{b}	54.53^{a}
% protein	16.06^{b}	16.08^{b}	15.88^{c}	16.05^{b}	16.32^{a}	15.32^{d}	14.07^{e}
% fat	29.80^{d}	31.77^{b}	31.08^{c}	33.95^{a}	28.25^{e}	28.81^{e}	26.96^{f}
Fatty acid groups							
SFA	34.25	27.57	35.86	32.43	39.47	35.48	70.72
UFA	56.10	56.10	55.75	51.93	51.77	55.96	50.14
MUFA	41.69	47.72	46.45	39.45	34.47	43.42	49.63
PUFA	14.42	8.38	9.30	12.48	17.30	12.54	0.51
n-3 (ALA + DHA)	0.53	0.72	0.14	0.26	0.53	0.22	0.00
n-6 (LA + AA)	13.75	7.40	9.15	12.02	16.74	12.33	0.35

Table 4. Cont.

Nutritional indices/ratios							
PUFA/SFA ratio	0.42	0.30	0.26	0.38	0.44	0.35	0.01
MUFA/SFA ratio	1.22	1.73	1.30	1.22	0.87	1.22	0.70
LA/ALA ratio	43.15	15.70	64.25	73.38	85.68	56.79	–
n-6/n-3 ratio	26.14	10.33	64.46	45.53	31.71	57.06	–
Atherogenicity index	0.52	0.45	0.50	0.52	0.69	0.54	1.36
Thrombogenicity index	1.15	0.91	1.26	1.18	1.42	1.22	2.80
Health-promoting index	1.91	2.20	2.01	1.91	1.44	1.84	0.74
Hypo/hypercholesterolemic ratio	1.98	2.26	1.95	1.91	1.61	1.84	0.57

Least-square means within a row without common letter superscripts are significantly different ($P < 0.05$).
Abbreviations: [SFA] saturated fatty acids; [UFA] unsaturated fatty acids; [MUFA] monounsaturated fatty acids; [PUFA] polyunsaturated fatty acids; [LA] linoleic acid (C18:2 n-6); [ALA] α-linolenic acid (C18:3 n-3); [AA] arachidonic acid (C20:4 n-6); [DHA] docosahexaenoic acid (C22:6 n-3); [n-3] omega-3 fatty acids; [n-6] omega-6 fatty acids

Table 5. Least-square means for yolk characteristics, FA groups, and nutritional indices/ ratios of egg yolk from Philippine native, egg-type (White Leghorn), and fancy-type chicken breeds.

	Banaba	Joloano	Paraoakan	Palawan lasak	White Leghorn	Black Silkies	White Silkies
Yolk weight, g	16.23^{b}	14.53^{b}	14.88^{b}	15.78^{b}	17.40^{ab}	14.67^{b}	13.94^{b}
Yolk color	7.12^{c}	6.44^{cd}	7.12^{c}	6.38^{cd}	6.06^{d}	9.20^{a}	6.94^{cd}
% moisture	50.24^{bc}	50.48^{bc}	49.22^{c}	47.60^{e}	47.78^{e}	49.87^{bc}	49.80^{c}
% protein	15.98^{c}	16.00^{c}	16.40^{b}	16.25^{bc}	16.50^{ab}	14.85^{d}	16.70^{a}
% fat	29.21^{cd}	29.05^{cd}	29.48^{c}	30.42^{b}	30.10^{b}	30.44^{b}	31.78^{a}
Fatty acid groups							
SFA	35.96	33.77	33.58	34.86	34.65	33.16	33.57
UFA	57.75	58.64	56.56	57.53	55.59	54.80	55.93
MUFA	43.72	41.31	41.63	43.62	41.14	42.37	44.10
PUFA	14.03	17.33	14.93	13.91	14.45	12.43	11.82
n-3 (ALA + DHA)	0.58	0.79	0.40	0.39	0.58	0.42	0.99
n-6 (LA + AA)	13.46	16.54	14.29	13.46	13.80	11.87	10.71
Nutritional indices/ratios							
PUFA/SFA ratio	0.39	0.51	0.44	0.40	0.42	0.37	0.35
MUFA/SFA ratio	1.22	1.22	1.24	1.25	1.19	1.28	1.31
LA/ALA ratio	71.54	81.46	45.01	37.84	31.63	45.71	32.20
n-6/n-3 ratio	23.36	20.83	35.36	34.42	23.87	28.47	10.79
Atherogenicity index	0.53	0.50	0.50	0.52	0.54	0.50	0.50
Thrombogenicity index	1.17	1.06	1.13	1.16	1.17	1.15	1.09
Health-promoting index	1.87	2.01	1.99	1.91	1.85	1.98	2.02
Hypo/hypercholesterolemic ratio	1.94	2.12	2.05	2.01	1.93	2.03	2.04

Least-square means within a row without common letter superscripts are significantly different ($P < 0.05$).
Abbreviations: [SFA] saturated fatty acids; [UFA] unsaturated fatty acids; [MUFA] monounsaturated fatty acids; [PUFA] polyunsaturated fatty acids; [LA] linoleic acid (C18:2 n-6); [ALA] α-linolenic acid (C18:3 n-3); [AA] arachidonic acid (C20:4 n-6); [DHA] docosahexaenoic acid (C22:6 n-3); [n-3] omega-3 fatty acids; [n-6] omega-6 fatty acids

Table 6. Least-square means for yolk characteristics, FA groups, and nutritional indices/ ratios of egg yolk from meat-type (White Rock) and dual-purpose chicken breeds.

	White Rock	Barred Plymouth Rock	Black Australorp	Nagoya	New Hampshire	Rhode Island Red	Taiwan Yellow
Yolk weight, g	16.23^{b}	17.04^{ab}	17.48^{b}	20.52^{a}	18.51^{ab}	16.09^{b}	16.70^{b}
Yolk color	7.06^{cd}	7.88^{bc}	8.12^{b}	9.81^{a}	8.06^{bc}	6.94^{cd}	6.81^{cd}
% moisture	50.78^{b}	49.65^{c}	49.75^{c}	52.60^{a}	48.30^{d}	48.78^{d}	49.50^{c}
% protein	16.52^{ab}	15.88^{c}	15.88^{c}	14.52^{e}	16.38^{b}	16.60^{ab}	16.35^{b}
% fat	31.40^{ab}	29.25^{cd}	28.50^{d}	27.95^{a}	30.65^{b}	28.85^{cd}	30.15^{b}
<u>Fatty acid groups</u>							
SFA	35.39	34.75	35.87	35.45	34.55	31.20	31.26
UFA	55.65	53.33	55.95	54.88	57.29	56.72	54.26
MUFA	42.17	39.13	41.74	40.32	42.05	41.46	38.90
PUFA	13.47	14.20	14.21	14.56	15.23	15.26	15.36
n-3 (ALA + DHA)	0.28	0.63	0.33	0.39	0.32	0.53	0.75
n-6 (LA + AA)	13.07	13.49	13.71	14.02	14.75	14.46	14.49
<u>Nutritional indices/ratios</u>							
PUFA/SFA ratio	0.38	0.41	0.40	0.41	0.44	0.49	0.49
MUFA/SFA ratio	1.19	1.13	1.16	1.14	1.22	1.33	1.24
LA/ALA ratio	50.85	30.35	47.45	38.95	51.87	47.59	33.52
n-6/n-3 ratio	47.52	21.54	41.54	36.04	45.54	27.44	19.35
Atherogenicity index	0.55	0.56	0.55	0.54	0.54	0.48	0.48
Thrombogenicity index	1.22	1.21	1.23	1.23	1.16	1.04	1.06
Health-promoting index	1.83	1.77	1.81	1.84	1.87	2.10	2.07
Hypo/hypercholesterolemic ratio	1.89	1.80	1.86	1.93	1.95	2.19	2.11

Least-square means within a row without common letter superscripts are significantly different ($P < 0.05$).
Abbreviations: [SFA] saturated fatty acids; [UFA] unsaturated fatty acids; [MUFA] monounsaturated fatty acids; [PUFA] polyunsaturated fatty acids; [LA] linoleic acid (C18:2 n-6); [ALA] α-linolenic acid (C18:3 n-3); [AA] arachidonic acid (C20:4 n-6); [DHA] docosahexaenoic acid (C22:6 n-3); [n-3] omega-3 fatty acids; [n-6] omega-6 fatty acids

Table 7. Least-square means for yolk characteristics, FA groups, and nutritional indices/ ratios of egg yolk from different mallard breeds.

	Itik-Pinas (IP) – Itim	Itik-Pinas (IP) – Khaki	Kayumanggi (IP)	Khaki Campbell	Pekin	Tsaiya	White Mallard
Yolk weight, g	23.22^{b}	21.87^{b}	21.76^{b}	21.67^{b}	27.09^{a}	22.44^{b}	21.16^{b}
Yolk color	8.98^{a}	6.92^{b}	6.53^{b}	4.50^{c}	4.81^{c}	4.81^{c}	6.50^{b}
% moisture	49.84^{a}	49.31^{b}	48.96^{c}	47.52^{d}	45.62^{f}	46.50^{e}	47.85^{d}
% protein	15.73^{c}	15.76^{c}	16.09^{b}	16.52^{a}	16.55^{a}	16.08^{bc}	15.80^{c}
% fat	30.77^{d}	32.10^{b}	31.76^{bc}	31.22^{c}	33.35^{a}	31.80^{b}	31.40^{c}
<u>Fatty acid groups</u>							
SFA	26.89	27.31	29.21	29.44	26.50	26.06	27.03
UFA	55.26	52.96	53.61	57.40	57.95	57.59	58.30
MUFA	45.87	43.90	45.46	49.35	50.18	49.62	49.70
PUFA	9.33	9.06	8.15	8.05	7.77	7.97	8.60
n-3 (ALA + DHA)	0.66	1.01	0.70	0.85	0.63	0.72	0.74
n-6 (LA + AA)	8.49	7.76	7.21	7.00	6.95	6.84	7.54

Table 7. Cont.

Nutritional indices/ratios							
PUFA/SFA ratio	0.35	0.33	0.28	0.27	0.29	0.31	0.32
MUFA/SFA ratio	1.71	1.61	1.56	1.68	1.89	1.90	1.84
LA/ALA ratio	19.54	18.28	18.73	13.18	14.34	13.75	14.20
n-6/n-3 ratio	12.81	7.70	10.30	8.23	11.04	9.57	10.22
Atherogenicity index	0.45	0.49	0.52	0.47	0.42	0.41	0.43
Thrombogenicity index	0.90	0.92	1.00	0.94	0.85	0.84	0.86
Health-promoting index	2.24	2.02	1.91	2.11	2.36	2.42	2.31
Hypo/hypercholesterolemic ratio	2.33	2.18	2.03	2.18	2.41	2.44	2.33

Least-square means within a row without common letter superscripts are significantly different ($P < 0.05$).
Abbreviations: [SFA] saturated fatty acids; [UFA] unsaturated fatty acids; [MUFA] monounsaturated fatty acids; [PUFA] polyunsaturated fatty acids; [LA] linoleic acid (C18:2 n-6); [ALA] α-linolenic acid (C18:3 n-3); [AA] arachidonic acid (C20:4 n-6); [DHA] docosahexaenoic acid (C22:6 n-3); [n-3] omega-3 fatty acids; [n-6] omega-6 fatty acids

Table 8. Least-square means for yolk characteristics, FA groups, and nutritional indices/ ratios of egg yolk from different quail and turkey breeds.

	Quail breeds			**Turkey breeds**	
	Japanese Seattle	Silver White	Taiwan	Broad Breasted Bronze	Nicholas White
Yolk weight, g	3.12[a]	3.09[a]	3.06[a]	24.97[a]	26.10[a]
Yolk color	6.32[a]	6.42[a]	6.38[a]	7.00[a]	7.75[a]
% moisture	49.65[a]	48.78[b]	49.68[a]	48.22[b]	50.02[a]
% protein	15.80[a]	15.98[a]	15.88[a]	15.25[a]	15.40[a]
% fat	30.15[b]	33.02[a]	30.05[b]	30.65[a]	27.00[a]
Fatty acid groups					
SFA	36.60	35.76	35.25	35.84	35.12
UFA	55.45	56.98	54.53	55.41	56.51
MUFA	46.80	47.51	45.08	42.40	44.44
PUFA	8.64	9.47	9.45	13.01	12.08
n-3 (ALA + DHA)	0.15	0.13	0.15	0.20	0.23
n-6 (LA + AA)	8.49	9.35	9.31	12.81	11.84
Nutritional indices/ratios					
PUFA/SFA ratio	0.24	0.26	0.27	0.36	0.34
MUFA/SFA ratio	1.28	1.33	1.28	1.18	1.27
LA/ALA ratio	54.66	74.39	64.13	64.13	50.52
n-6/n-3 ratio	54.91	74.76	64.19	64.36	50.83
Atherogenicity index	0.52	0.48	0.49	0.55	0.53
Thrombogenicity index	1.29	1.23	1.26	1.24	1.20
Health-promoting index	1.94	2.07	2.02	1.80	1.88
Hypo/hypercholesterolemic ratio	1.86	2.02	1.98	1.83	1.86

Least-square means within a row of the same species without common letter superscripts are significantly different ($P < 0.05$).
Abbreviations: [SFA] saturated fatty acids; [UFA] unsaturated fatty acids; [MUFA] monounsaturated fatty acids; [PUFA] polyunsaturated fatty acids; [LA] linoleic acid (C18:2 n-6); [ALA] α-linolenic acid (C18:3 n-3); [AA] arachidonic acid (C20:4 n-6); [DHA] docosahexaenoic acid (C22:6 n-3); [n-3] omega-3 fatty acids; [n-6] omega-6 fatty acids

The PUFA/SFA ratio in chicken egg yolk ranged from 0.38–0.51: 1. The highest PUFA/SFA ratio was found in Joloano (0.51: 1). The PUFA/SFA ratio for other native chickens – Banaba (0.39: 1), Paraoakan (0.44: 1), and Palawan Lasak (0.40: 1) – were comparable with the egg-type White Leghorn (0.42: 1), meat-type White Rock (0.38: 1) and dual-purpose breeds (0.40–0.49: 1) but slightly higher than the fancy-type breeds (0.35–0.37: 1). The PUFA/SFA ratio in egg yolk of mallard ranged from 0.27–0.35: 1. The PUFA/SFA ratio for the IP breeds was 0.35: 1, 0.33: 1, and 0.28: 1 for IP-Itim, IP-Khaki, and Kayumanggi-IP, respectively. The PUFA/SFA ratios were similar with Khaki Campbell (0.27: 1) and White Mallard (0.32: 1) and slightly higher than in Pekin and Tsaiya (0.25: 1). The PUFA/SFA ratio in yolk fats was similar for the three quail breeds (0.24–0.27: 1) and for the two turkey breeds (0.34–0.36: 1).

MUFA/SFA ratio. Yolk fat with a higher MUFA/SFA ratio can have beneficial effects on human health. This is because the MUFA which is dominated by oleic acid that is found abundantly in dietary food increases the activity of low-density lipoprotein receptors and decreases the cholesterol concentration in serum (Dietschy 1998). Intakes of MUFAs were associated with a lower risk of CVD and death, whereas SFA intakes were associated with a higher risk of CVD (Guasch-Ferre *et al.* 2015). There is, however, no need for supplementation as oleic acid is considered a non-essential FA since it is synthesized in the human body.

In this study, the MUFA/SFA ratio in the mallard egg yolk (1.73: 1) was considerably higher than that from quail (1.30: 1) and chicken (1.22: 1). The high MUFA/SFA ratio for mallard yolk fats was mainly due to its higher proportion of oleic acid and lower proportion of palmitic acid. In other poultry species, the MUFA/SFA ratio was highest in Muscovy (1.22), followed by turkey (1.22), guinea fowl (0.87), and ostrich (0.70). The MUFA/SFA ratio in egg yolk was widely different between mallard breeds (1.56–1.90: 1) and between chicken breeds (1.13–1.33: 1). In contrast, a narrower range of MUFA/SFA ratio was found between quail breeds (1.27–1.33: 1) and between turkey breeds (1.18–1.27: 1).

Linoleic acid to α-linolenic acid (LA/ALA) ratio. The LA/ALA ratio is an important index for baby food and infant formula. According to Chen and Liu (2020), the LA/ALA ratio describes the balance between linoleic acid (C18:2 n-6) and α-linolenic acid (C18:3 n-3), wherein both PUFAs compete for the same desaturase and elongase enzymes, which are used to synthesize long-chain unsaturated FAs. Since essential FAs are not synthesized by humans, these PUFAs should be supplemented in infant formulas. The minimum and maximum proportions of LA and ALA in an LA/ALA ratio within 5:1–15:1 are commonly set when judging the nutritional value of baby food and infant formula (Chen and Liu 2020). In contrast, the LA/ALA ratio in the diet does not have too much of an effect on adults since the tissues of adults have a lower rate of synthesis of α-linolenic acid than those of infants.

In this study, the LA/ALA ratio in egg yolk was substantially lower in mallard (15.70: 1) compared to that in chicken (43.15: 1) and quail (64.25: 1). In other poultry species, the LA/AL ratio was highest in guinea fowl (85.68: 1), followed by Muscovy (73.38: 1) and turkey (56.79: 1). The LA/ALA ratio for different breeds of chicken, quail, and turkey ranged from 30.35–81.46: 1, 54.66–74.39: 1, and 50.52–64.31: 1, respectively.

The LA/ALA ratio in egg yolk from different poultry species (except mallard) was above the prescribed LA/ALA ratio and, thus, should not be given to infants. The LA/ALA ratio in mallard egg yolk ranged from 13.18–19.54: 1, implying that some mallard breeds may be considered a supplement to infant food. For example, the LA/ALA ratio lower than 15: 1 was found in yolk fat from Khaki Campbell (13.18: 1), Tsaiya (13.75: 1), White Mallard (14.20: 1), and Pekin (14.34: 1). On the other hand, the egg yolk from the IP breeds with LA/ALA ratio greater than 15: 1, *i.e.* IP-Khaki (18.28: 1), Kayumanggi-IP (18.73: 1), and IP-Itim (19.54: 1) should not be given to infants.

Omega-6 FA to omega-3 FA (n-6/n-3) ratio. The omega-6/omega-3 ratio is an important determinant of PUFAs and their effects on inflammatory diseases. According to Patterson *et al.* (2012), the n-6 PUFAs (*i.e.* LA and AA) and n-3 PUFAs (*i.e.* ALA and DHA) are precursors to eicosanoids, which have important roles in the regulation of inflammation. The eicosanoids derived from omega-6 FAs are proinflammatory while eicosanoids derived from omega-3 FAs are anti-inflammatory. Hence, an increase in the n-6/n-3 ratio (as high as ~ 15:1 in the Western diet) could aid the inflammatory processes and consequently favor or aggravate many inflammatory diseases such as nonalcoholic fatty liver disease, cardiovascular disease, obesity, inflammatory bowel disease, rheumatoid arthritis, and Alzheimer's disease. Patterson *et al.* (2012) recommended optimal dietary intakes of the n-6/n-3 ratio to be around 1–4: 1. This is higher than the n-6/n-3 ratio (1–2: 1) suggested by Simopoulos (2002), although the optimal ratio may vary depending on the degree of severity of the disease.

In this study, the n-6/n-3 ratio in yolk fat from various poultry species was more than the optimal ratio (1–4: 1), mainly due to the high proportion of omega-6 FA – especially linoleic acid and the low proportion of ALA and DHA, each less than 0.5%. Nonetheless, the n-6/n-3 ratio in egg yolk was lower (*i.e.* more balanced) for mallard

(10.33: 1) than for chicken (26.14: 1) and quail (64.46: 1). In other poultry species, the n-6/n-3 ratio was highest for turkey (57.06: 1), followed by Muscovy (45.53: 1) and guinea fowl (31.71: 1). The n-6/n-3 ratio in egg yolk was widely different between chicken breeds (10.79–47.52: 1). In contrast, a narrower range of n-6/n-3 ratio was found for mallard breeds (7.70–12.81: 1), quail breeds (54.91–74.76: 1), and turkey (50.83–64.36: 1).

Atherogenicity index (IA). The IA proposed by Ulbricht and Southgate (1991) is a measure of the dietary contribution of some SFAs (C12:0, C14:0, and C16:0 except C18:0) that are pro-atherogenic (*i.e.* they favor the adhesion of lipids to cells of the circulatory and immunological systems) in relation to all MUFAs and PUFAs that are anti-atherogenic (*i.e.* they inhibit the accumulation of fatty plaque and reduce the levels of phospholipids, cholesterol, and esterified FAs). Dietary fat with lower IA values may, thus, offer greater health benefits as its consumption may reduce the risk of coronary heart disease through reduced levels of total cholesterol and LDL cholesterol in human blood plasma (Poppitt *et al.* 2002).

In this study, the atherogenicity in egg yolk was lower (*i.e.* greater health benefits) for mallard (0.45) than that for quail (0.50) and chicken (0.52). The low IA value for mallard yolk fats was mainly due to its lower proportion of palmitic acid relative to a higher proportion of oleic acid. In other poultry species, the IA was highest in ostrich (1.36), followed by guinea fowl (0.69), turkey (0.54), and Muscovy (0.52).

The IA in egg yolk from different mallard breeds ranged from 0.41–0.52. The IA was lowest for Tsaiya (0.41), followed by Pekin (0.42) and White Mallard (0.43). Higher atherogenicity was reported for Khaki Campbell (0.47) and the IP breeds, *i.e.* IP-Itim (0.45), IP-Khaki (0.49), and Kayumanggi-IP (0.52).

The IA in egg yolk from different chicken breeds ranged from 0.48–0.56. The lowest IA was found in Rhode Island Red (0.48). The IA for native chickens [Banaba (0.53), Joloano (0.50), Paraoakan (0.50), and Palawan Lasak (0.52)] were similar to the fancy-type breeds [Black Silkies (0.50) and White Silkies (0.50)] and dual-purpose breeds [Rhode Island Red (0.48) and Taiwan Yellow (0.48)]. The IAs for native chickens, however, were lower than that for the egg-type White Leghorn (0.54), meat-type White Rock (0.55), and dual-purpose breeds [New Hampshire (0.54), Nagoya (0.54), Black Australorp (0.55), and Barred Plymouth Rock (0.56)].

Small differences in atherogenicity in yolk fats were found between quail breeds (0.48–0.52) and between turkey breeds (0.53–0.55).

Thrombogenicity index (IT). Developed by Ulbricht and Southgate (1991), the IT is used to determine the dietary contribution of pro-thrombogenic SFAs (*i.e.* C12:0, C14:0, and C16:0) in relation to the anti-thrombogenic MUFAs and PUFAs. Consumption of foods or products with lower IT values (*i.e.* lower tendency to form clots in blood vessels) is beneficial for cardiovascular health (Chen and Liu 2020).

In this study, the thrombogenicity in egg yolk was lower (*i.e.* more beneficial for cardiovascular health) for mallard (0.91) than in chicken (1.15) and quail (1.26). The low IT value for mallard yolk fats was mainly due to its lower proportion of palmitic acid relative to a higher proportion of oleic acid despite a slightly lower linoleic acid percentage. In other poultry species, the IT was highest in ostrich (2.80), followed by guinea fowl (1.42), turkey (1.22), and Muscovy (1.18).

The IT in egg yolk from different mallard breeds ranged from 0.84–1.00. The IT was lowest for Tsaiya (0.84), closely followed by Pekin (0.85) and White Mallard (0.86). Higher thrombogenicity was reported for Khaki Campbell (0.94) and the IP breeds, *i.e.* IP-Itim (0.90), IP-Khaki (0.92), and Kayumanggi-IP (1.00).

The IT in egg yolk from different chicken breeds ranged from 1.04–1.23. The lowest IT was found in Rhode Island Red (1.04). Similarly low IT was reported for Taiwan Yellow (1.06) and Joloano (1.06). Slightly higher thrombogenicity was reported for other native chickens, *i.e.* Paraoakan (1.13), Palawan Lasak (1.16), and Banaba (1.17), fancy-type breeds [White Silkies (1.09) and Black Silkies (1.15)], New Hampshire (1.16), and the egg-type White Leghorn (1.17). Higher thrombogenicity in egg yolk was found in the meat-type White Rock (1.22) and other dual-purpose breeds, *i.e.* Barred Plymouth Rock (1.21), Black Australorp (1.23), and Nagoya (1.23).

Small differences in thrombogenicity in yolk fats were found between quail breeds (1.23–1.29) and between turkey breeds (1.20–1.24).

Health-promoting index (HPI). The HPI, as proposed by Chen *et al.* (2004), is the inverse of the IA. A high HPI value is considered more beneficial to human health. In this study, the HPI in egg yolk was considerably higher for mallard (2.20) compared to that in quail (2.01) and chicken (1.91). The high HPI ratio in mallard yolk fats was largely due to its high proportion of oleic acid and the low proportion of palmitic acid. In other poultry species, the HPI was highest in Muscovy (1.91), followed by turkey (1.84), guinea fowl (1.44), and ostrich (0.74).

The HPI in egg yolk from different mallard breeds ranged from 1.91–2.42. The IA was highest for Tsaiya (2.42), followed by White Mallard (2.31) and Pekin (2.36). Lower HPI was reported for Khaki Campbell (2.11) and the IP breeds [IP-Itim (2.24), IP-Khaki (2.02), and Kayumanggi-IP (1.91)].

The HPI in egg yolk from different chicken breeds ranged from 1.77–2.10. The highest HPI was found in Rhode Island Red (2.10). Slightly lower HPI was reported for Taiwan Yellow (2.07), Joloano (2.01), and fancy-type breeds [Black Silkies (1.98) and White Silkies (2.02)]. The HPI in egg yolk from the New Hampshire (1.87) and other native chicken breeds [Banaba (1.87), Palawan Lasak (1.91), and Paraoakan (1.99)] were higher than that from the meat-type White Rock (1.22), egg-type White Leghorn (1.85), and other dual-purpose breeds [Barred Plymouth Rock (1.77), Black Australorp (1.81), and Nagoya (1.84)].

The HPI in egg yolk of quail was highest for Silver White (2.07), followed by Taiwan (2.02), and lowest for Japanese Seattle (1.94). The HPI in the egg yolk of turkey was higher for Nicholas White (1.88) than in the Broad Breasted Bronze breed (1.83).

Hypocholesterolemic FA to hypercholesterolemic FA (HH) ratio. The HH ratio is used to assess the effect of dietary FA composition on cholesterol (Chen and Liu 2020). The HH ratio characterizes the relationship between hypocholesterolemic FAs (*i.e.* oleic acid and PUFA) and hypercholesterolemic FAs (*i.e.* C12:0, C14:0, and C16:0). Dietary fat with higher HH ratio has greater health benefits (Santos-Silva *et al.* 2002; Mierlita 2018).

In this study, the HH ratio in egg yolk was notably higher for mallard (2.26) than in chicken (1.98) and quail (1.95). The high HH ratio in mallard yolk fats was mainly due to a combination of its higher proportion of oleic acid and lower proportion of palmitic acid. A lower HH ratio was found in other poultry species, *i.e.* Muscovy (1.91), followed by turkey (1.84), guinea fowl (1.61), and ostrich (0.57).

The HH ratio in egg yolk from different mallard breeds ranged from 2.03–2.44. The HH ratio was highest for Tsaiya (2.44) and Pekin (2.41). The HH ratio in the egg yolk of IP breeds [IP-Itim (2.33), IP-Khaki (2.18), and Kayumanggi-IP (2.03)] was comparable to those from White Mallard (2.33) and Khaki Campbell (2.18).

The HH ratio in egg yolk from different chicken breeds ranged from 1.80–2.19. The highest HH ratio was found in Rhode Island Red (2.19). A slightly lower HH ratio was reported for fancy-type breeds [Black Silkies (2.03) and White Silkies (2.04)]. The HH ratio in egg yolk from the native chicken breeds [Banaba (1.94), Palawan Lasak (2.01), and Paraoakan (2.05)] and Joloano (2.12) was comparable with that from the egg-type White Leghorn (1.93) and dual-purpose breeds [Nagoya (1.93), New Hampshire (1.95), and Taiwan Yellow (2.11)] but higher than that from the meat-type White Rock (1.89), Barred Plymouth Rock (1.80), and Black Australorp (1.86).

The HH ratio in egg yolk of quail was highest for Silver White (2.02), followed by Taiwan (1.98) and Japanese Seattle (1.86). The HH ratio in the egg yolk of turkey was slightly higher for Nicholas White (1.86) than in the Broad Breasted Bronze breed (1.83).

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There is no conflict of interest between the authors and other people and organizations.

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