Fats extracted from oil press cakes, fish meat, and chicken hearts as potential CoQ10 supplements

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Abstract

Coenzyme Q10 (CoQ10) is a liposoluble compound naturally occurring in plant and animal cells, with some benefits for health, mainly due to its antioxidant properties. The food industry gives large quantities of by-products and waste; these could be used to recover the natural form of CoQ10, which has a higher bioavailability than synthetic. The Folch method was used in this study to extract and characterise the fats from some food by-products (oil press cakes of rapeseed, sunflower, pumpkin, linseed, walnut, and hempseed) and waste (fish meat and chicken hearts), previously identified as sources of CoQ10, for potential uses as dietary supplements. The highest CoQ10 content was found in fats extracted from chicken hearts-CH (2041.74 µg/g) and pumpkin press cakes-PPC (661.40 µg/g). Both fats are triglycerides but have a low CVD risk (AI values below the recommended limit). CH fat is dominated by oleic acid (n-9) and PPC fat by linoleic acid (n-6). PUFAs/MUFAs ratio is above the recommended minimum in both fats; however, the n-6/n-3 PUFAs ratio in CH fat exceeds the maximum value. They also contain tocopherols (PPC-138.09 µg/g and CH-54.22 µg/g) that, along with CoQ10, give them antioxidant properties; therefore, they meet the criteria of a food supplement.

Highlights

- The highest CoQ10 content is in chicken hearts and pumpkin press cake fats
- Both fats are triglycerides but have AI values below the recommended limit
- PUFAs/MUFAs ratio is above the recommended minimum in both fats
- The *n-6/n-3* PUFAs ratio in fat from chicken hearts exceeds the maximum value
- Their antioxidant properties are also due to the presence of tocopherols

Introduction

Coenzyme Q10 (CoQ10), an integral part of the mitochondrial respiratory chain, is an endogenous enzyme cofactor synthesised in all living cells and distributed in cellular membranes [1]. The chemical nomenclature of CoQ10, also known as ubiquinone-10, is 2,3-dimethoxy-5-methyl-6-decaprenyl-1,4-benzoquinone [2,3]. In addition to being crucial for energy conversion, CoQ10 is a powerful antioxidant [4]. This property may have numerous beneficial and therapeutic effects, particularly in preventing conditions linked to ageing, such as cancer, diabetes, or cardiovascular diseases [5]. Despite its dietary intake and endogenous synthesis, some investigations highlighted the age-related variation of CoQ10, i.e., that it decreases in the human body with it [6-8]. Even though CoQ10 is available in foods, its absorbability is less efficient as we grow older [9]. In cases of deficiency, it is recommended supplementation with CoQ10, at least to restore the antioxidant capacity and prevent LDL (low-density lipoprotein) cholesterol oxidation [10].

In a recent literature review, Podar et al. [11] have identified vegetable and fish oils, organs, and meat as the primary sources of CoQ10. Press cakes, by-products from the cold pressing of seeds or nuts, still contain significant amounts of oils. As the edible oil industry generates them in large quantities, they can be regarded as prospective sources of CoQ10 [12]. The meat and fish sectors also produce much solid waste; their primary products, listed among the potential CoQ10 sources, have a short shelf-life when kept refrigerated [13,14]. Hence, in a previous study [15], we investigated the level of this compound in some food by-products (oil press cakes) and waste (fish meat and chicken hearts) to determine if they indeed are a considerable source of CoQ10. The CoQ10 content ranged from 36.56 to 84.80 µg/g in oil press cakes; it was between 114.39 and 383.25 µg/g in chicken hearts (raw and lyophilised, respectively) and not detected in fish meat and hempseed press cakes. According to Directive 2008/98/EC [16], the by-product is considered "a substance or object resulting from a production process the primary aim of which is not the production of that substance or object", while waste is "any substance or object which the holder discards or intends or is required to discard".

Natural CoQ10 has a higher bioavailability than the synthetic one [17]; it is an all-trans isomer, while synthetic CoQ10 is a mixture of trans- and cis isomers [18]. Being a liposoluble compound [3], CoQ10 could be recovered in larger quantities if the fat is extracted from these matrices before further use. There are several methods of extracting lipids from food matrices, such as the Folch method, the Bligh and Dyer method, Soxhlet extraction, or supercritical CO_2 extraction [19]. The Folch method using a 2:1 (v/v) mixture of chloroform and methanol was chosen for this characterisation study because of its analytical performance; even though chloroform is not a food-grade solvent, an anhydrous fat is obtained [20], while the extraction yield is good [19], moreover, being a cold extraction procedure, it not destroy the CoQ10, which is thermolabile [15]. To allow nonpolar solvents (like methanol) to enter the cell cytoplasm, where lipid disintegration occurs, polar solvents (such as chloroform) must first make the cell membrane permeable; therefore, the cosolvent—a combination of polar and nonpolar solvents—is preferable for lipid extraction [21].

As far as we know, this is the first evaluation of the fats extracted from oil press cakes, fish meat, and chicken hearts for their potential to be used as dietary supplements based on CoQ10. Considering that along with CoQ10, other liposoluble compounds are extracted from the food matrix, which could have beneficial or adverse health effects, an in-depth assessment of the fat composition is needed. Thus, this study aimed to characterise the fats extracted from rapeseed press cakes (RPC), sunflower press cakes (SPC), pumpkin press cakes (PPC), linseed press cakes (LPC), walnut press cakes (WPC), hempseed press cakes (HPC), whole fish (WF), and chicken hearts (CH) in terms of their content in CoQ10, tocopherols and tocotrienols, or cannabinoids (only for HPC fat); the main lipid classes and fatty acids composition were also determined. The TEAC (Trolox equivalent antioxidant capacity) of each type of fat was assessed by the DPPH (2,2-diphenyl-1-picrylhydrazyl) method, while the oxidative status was evaluated using the PV (peroxide value; for primary oxidation products) and TBARS (thiobarbituric acid reactive substances; for secondary oxidation products) tests. Several lipid quality indices were calculated to estimate the benefit-harm balance of each potential dietary supplement.

Materials And Methods

2.1. Sampling and Experimental Design

Oil press cakes. The oil press cakes (RPC, SPC, PPC, LPC, WPC, and HPC) were supplied by the Taf Presoil S.R.L. (Luncani, Romania) as pellets, 1 kg of each type. They were kept in a refrigerator (at 4 °C) until analysis, when they were milled into fine powders using an electric grinder (Titan Mil 300 DuoClean; Grupo Cecotec Innovaciones S.L., Valencia, Spain).

Fish meat. The fish, 1.573 kg of chilled whole trout (*Oncorhynchus mykiss*), was purchased from Bistromar La Timona S.R.L. (Bucharest, Romania) and kept in the refrigerator (at 4 °C) until the expiration date listed on the packaging, at which point was considered waste (see Appendix A). The following day, the fish specimens were cut into pieces with a stainless-steel knife before being minced with a meat grinder (N12; Lancom Distribution S.R.L., Bucharest, Romania). The minced meat was then homogenised using a silicone spatula, divided into 50- and 100-g portions (WF), sealed in polyethylene bags, and stored at -18 °C up to analysis.

Chicken hearts. A quantity of 2.1 kg of chicken hearts was acquired from S.C. Puiul Regal S.R.L. (Gilău, Romania) and maintained in the refrigerator (at 4 °C) until the expiration date when it became waste (see Appendix A). The next day, chicken hearts were minced using a meat grinder (N12; Lancom Distribution S.R.L., Bucharest, Romania), homogenised with a silicone spatula, divided into portions of 50 and 100 g (CH) in polyethylene bags and sealed, then kept at -18 °C until further analysis.

The samples prepared as described above were used for fat extraction according to the Folch method modified by Boselli et al. [22] described in subsection 2.2. In addition, the fat fractions of RPC, SPC, PPC, LPC, WPC, HPC, WF, and CH were subjected to the gas chromatographic semiquantitative determination of main lipid classes (2.2.1), total FAMEs (fatty acid methyl esters) (2.2.2), tocopherols and tocotrienols (2.2.4), CoQ10 (2.2.6), TEAC (2.2.7), and PV (2.2.8) as well as the calculation of lipid quality indices (2.2.3). The determination of cannabinoids (2.2.5) was performed only for HPC fat. The TBARS were determined in all samples using their aqueous extracts, as detailed in subsection 3.3. Three 50 g portions of WF and CH, previously thawed in the refrigerator, were used to extract fat (Folch extraction) and prepare aqueous extract (TBARS procedure).

Subsections 2.2, 2.2.1–2.2.8, and 2.3, analysis methods, are reported as a Supplementary online resource (see Appendix B).

2.4. Statistical analysis

Using the Minitab statistical software (version 19.1.1; LEAD Technologies, Inc., Charlotte, NC, USA), one-way ANOVA with a post-hoc Tukey's test at a 95% confidence level ($p < 0.05$) was used to ascertain the statistically significant differences between mean values of all tested parameters in oil press cakes, fish meat, and chicken hearts. The strength of the relationship between CoQ10 content and TEAC was determined by computing Pearson's correlation coefficient (r).

Results And Discussion

3.1. Lipid composition

The fat extraction yield by the Folch method was 16.65±0.485^{a} g/100 g for RPC, 15.50±0.079^{b} g/100 g for SPC, 11.8±0.234^{d} g/100 g for PPC, 13.8±0.171^{c} g/100 g for LPC, 6.16±0.057^{g} g/100 g for WPC, 8.2±0.167^{f} g/100 g for HPC, 10.25±0.226^{e} g/100 g for WF, and 7.49±0.498^{f} g/100 g for CH. Oil contents between 9.6–31.3 g/100 g sample were formerly reported by other authors in rapeseed press cakes resulting from oil extraction by cold pressing, 11.7–31.4 g/100 g in sunflower press cakes, 9.0–36.2 g/100 g in pumpkin press cakes, 8.9–16.4 g/100 g in HPC, 11.5–21.4 g/100 g in linseed press cakes, and 7.34–18.4 g/100 g in walnut press cakes [23-25]. As for the fat content in CH, a lower amount (4.27 g/100 g sample) was found by Pikul et al. [26] in an earlier study. Fat contents between 5.5 and 8.7 g/100 g were reported by Van Doan et al. [27] in rainbow trout, depending on age and tested muscle.

Results of the chromatographic analysis to determine the main lipid classes in fats extracted from oil press cakes, fish meat, and chicken hearts are shown in Table 1. TAGs represent the dominant class of fat fraction, regardless of the matrix, with the highest value in WF (94.44 mg/100 mg), followed by LPC (92.20 mg/100 mg) and PPC (92.15 mg/100 mg), then by SPC (89.89 mg/100 mg), RPC (87.09 mg/100 mg) and WPC (86.71 mg/100 mg), HPC (83.00 mg/100 mg), and finally by CH (81.76 mg/100 mg). A TAGs amount of 88.9–91.6% was previously quantified in fish [28], 96.5% in linseed oil [29], 78.7% in pumpkin oil [30], 87.4% in sunflower oil [29], 98% in walnut oil [31], 94.4–99.1% in rapeseed oil [32], 97.8% in hempseed oil [33], and 46.9% in chicken heart fat [26].

Next to TAGs, DAGs was the second most abundant lipids class in CH (10.34 mg/100 mg), WPC (9.23 mg/100 mg), RPC (7.62 mg/100 mg), SPC (5.93 mg/100 mg), LPC (5.49 mg/100 mg), and PPC (4.54 mg/100 mg), while FFAs in HPC (8.97 mg/100 mg). In WF, similar levels of DAGs (2.24 mg/100 mg) and FFAs (1.88 mg/100 mg) followed that of TAGs. DAGs and FFAs in high amounts indicate a degradation state of lipids due to oxidation. Vegetable fats that contained the most DAGs and FFAs also had the highest PVs; changes in their oxidative status can be either due to heat stress induced by seeds/nuts pressing or poor conditions at storage. HPC fat was the most oxidatively degraded, given that it has had the highest DAGs plus FFAs content (15.21 mg/100 mg) and PV (21.92 meq O_2/kg; see Table 4); this is probably due to its peculiar composition of unsaturated fatty acids (UFAs). Even though the content of UFAs in RPC fat (79.99 mg/100 mg) was close to that in HPC fat (78.91 mg/100 mg), the content of DAGs plus FFAs (11.17 mg/100 mg) and PV (19.03 meq O_2/kg; see Table 4) were lower, while the total tocopherols content (997.44 µg/g) was higher; it can thus be deduced that also tocopherols provide oxidative protection to fat.

As for MAGs content, the highest level was found in CH (1.35 mg/100 mg) followed by HPC (0.69 mg/100 mg) and RPC (0.67 mg/100 mg), then by WPC (0.52 mg/100 mg), SPC (0.42 mg/100 mg) and WF (0.48 mg/100 mg), and finally by LPC (0.27 mg/100 mg) and PPC (0.23 mg/100 mg).

3.2. Fatty acid composition and lipid quality indices

The composition and fatty acid content in oil press cakes, fish meat and chicken hearts are presented in Table 2. Determination of total fatty acids returned qualitative-quantitative profiles characteristic to the provenance matrices. Vegetable fats showed higher contents in UFAs (6.54–15.21 mg/100 mg) than animal fats (4.12–14.13 mg/100 mg). Oleic acid (C18:1 *n-9*; 53.78 mg/100 mg) and linoleic acid (C18:2 *n-6*; 17.98 mg/100 mg) were majoritarian in RPC fat, followed by *α*-linolenic acid (C18:3 *n-3*; 6.79 mg/100 mg) and palmitic acid (C16:0; 4.46 mg/100 mg). In LPC fat however, *α*-linolenic acid (C18:3 *n-3*; 50.25 mg/100 mg) was in the highest amount, followed by oleic acid (C18:1 *n-9*; 21.28 mg/100 mg), linoleic acid (C18:2 *n-6*; 11.19 mg/100 mg), palmitic acid (C16:0; 6.49 mg/100 mg), and stearic acid (C18:0; 3.65 mg/100 mg).

SPC and PPC fats had similar fatty acid profiles (18 fatty acids detected in SPC and 16 in PPC), in which linoleic acid (C18:2 *n-6*) was dominant (59.22 mg/100 mg in SPC and 43.52 mg/100 mg in PPC), followed by oleic acid (C18:1 *n-9*; 21.43 mg/100 mg in SPC and 27.59 mg/100 mg in PPC), palmitic acid (C16:0; 7.49 mg/100 mg in SPC and 11.04 mg/100 mg in PPC), and stearic acid (C18:0; 3.31 mg/100 mg in SPC and 5.08 mg/100 mg in PPC). In addition to these four fatty acids, the fats extracted from WPC and HPC also contained *α*-linolenic acid (C18:3 *n-3*; 12.30 mg/100 mg in WPC and 16.33 mg/100 mg in HPC), the third as a share in WPC fat and the second in HPC fat. The linoleic acid (C18:2 *n-6*) content was 53.89 mg/100 mg in WPC and 48.22 mg/100 mg in HPC, the oleic acid one (C18:1 *n-9*) of 13.78 mg/100 mg in WPC and 11.50 mg/100 mg in HPC, the palmitic acid (C16:0) of 7.67 mg/100 mg in WPC and 6.58 mg/100 mg in HPC, and the stearic acid (C18:0) content of 2.59 mg/100 mg in WPC and 2.51 mg/100 mg in HPC. Stearidonic acid (C18:4 *n-3*; 0.52 mg/100 mg) found in HPC fat is peculiar and characteristic; it was also detected in WF fat (0.55 mg/100 mg), as this fatty acid is typical for fish derivatives. In agreement with our findings, Symoniuk et al. [34] reported similar fatty acid profiles for cold-pressed rapeseed, sunflower, pumpkin, linseed, and hempseed oils. Instead, Vingering et al. [35] have found C18:1 *n-9* (72.7%) as the primary fatty acid in walnut oil, followed by C18:2 *n-6* (12.9%), C16:0 (5.6%), C18:0 (2.5%) and C18:1 *n-7* (2.4%).

WF fat was the most complex in terms of fatty acid composition, with oleic acid (C18:1 *n-9*; 31.84 mg/100 mg) > palmitic acid (C16:0; 12.75 mg/100 mg) > linoleic acid (C18:2 *n-6*; 11.64 mg/100 mg) > docosahexaenoic acid (C22:6 *n-3*; 8.52 mg/100 mg) > palmitoleic acid (C16:1; 4.35 mg/100 mg) > stearic acid (C18:0; 3.52 mg/100 mg) > *α*-linolenic acid (C18:3 *n-3*; 2.95 mg/100 mg) > eicosenoic acid (C20:1; 2.45 mg/100 mg) > myristic acid (C14:0; 2.39 mg/100 mg) > eicosapentaenoic acid (C20:5 *n-3*; 2.31 mg/100 mg). In the study of Kowalska-Góralska et al. [36], C18:1 (29.10%) was found to be the most abundant fatty acid in rainbow trout fat, followed by C22:6 *n-3* (18.85%), C16:0 (15.86%), C18:2 (7.49%), C18:3 (5.30%), C20:3 *n-3* (5.33%), C20:5 *n-3* (4.58%), and C18:0 (1.72%).

In CH fat, oleic acid (C18:1 *n-9*; 29.58 mg/100 mg) was predominant, followed by linoleic acid (C18:2 *n-6*; 20.62 mg/100 mg), palmitic acid (C16:0; 16.97 mg/100 mg), stearic acid (C18:0; 6.75 mg/100 mg), palmitoleic acid (C16:1; 4.32 mg/100 mg), and arachidonic acid (C20:4 *n-6*; 2.60 mg/100 mg). The fatty acid profile reported by Pikul et al. [26] for fat extracted from chicken hearts was slightly different, with 21.07% C20:4, 19.35% C18:2, 18.96% C16:0, 18.57% C18:0, 15.24% C18:1, 1.70% C20: 4.

Fatty acids classification based on their chain length. Long-chain fatty acids [LCFAs; 13–21 carbons [37]] predominated in all fat samples (78.56–93.61 mg/100 mg), followed by very long-chain fatty acids [VLCFAs (≥ 22 carbons); 0.21–10.78 mg/100 mg] and medium-chain fatty acids [MCFAs (6–12 carbons); 0.01–0.08 mg/100 mg]. No MCFAs were found in SPC and WPC fats, and no short-chain fatty acids[SCFAs (< 6 carbons)], regardless of fat.

Fatty acids classification based on their saturation degree. Saturated fatty acids (SFAs) were minoritarian in all fats. RPC, WF, and CH fats have abounded in monounsaturated fatty acids (MUFAs), while SPC, PPC, LPC, WPC, and HPC fats in polyunsaturated fatty acids (PUFAs). The American Heart Association's Step 1 diet guideline recommends a fat intake with a balanced (1:1:1) composition of SFAs/MUFAs/PUFAs [38]. A high intake of dietary PUFAs reduces LDL-C (low-density lipoprotein cholesterol) and triglyceride plasma levels [39]. A careful review of numerous reports in the literature highlighted the importance of SFAs/MUFAs/PUFAs balance for generating the best LDL-C/HDL-C (high-density lipoprotein cholesterol) ratio in human serum [40]. The present study revealed SFAs/MUFAs/PUFAs ratios of 1:8.2:3.7 in RPC fat, 1:1.8:4.9 in SPC fat, 1:1.6:2.6 in PPC fat, 1: 2:5.8 in LPC fat, 1:1.3:6.1 in WPC fat, 1:1.1:6.4 in HPC fat, 1:2:1.6 in WF fat, and 1:1.3:0.9 in CH fat, showing an imbalance in the fatty acid composition of CH fat.

According to current nutritional recommendations [41], the PUFAs/SFAs ratio in the human diet should be above 0.45 and the omega-6 (*n-6*)/omega-3 (*n-3*) PUFAs ratio, less than 4.0; a higher dietary PUFAs/SFAs ratio than recommended contributes to the prevention of cardiovascular and some chronic diseases, such as cancer [42] while a higher *n-6*/*n-3* PUFAs ratio is linked with an increased risk of carcinogenesis [43]. As for *n-3* PUFAs, previous studies have demonstrated that they exert anti-inflammatory effects in the human body, whereas *n-6* PUFAs, particularly arachidonic acid, are pro-inflammatory [43]. Although all fats showed PUFAs/MUFAs ratios higher than the minimum recommended value, the *n-6*/*n-3* PUFAs ratio was slightly over the maximum value in the fat extracted from WPC (4.4) and well above it in fats from CH (14.5), PPC (124.5), and SPC (592.5). The arachidonic acid (C20:4 *n-6*) content was 2.60 mg/100 mg in CH fat, 0.55 mg/100 mg in WF fat, 0.04 mg/100 mg in PPC fat, and 0.02 mg/100 mg in SPC fat but was absent in the other fats.

Lipid quality indices. LA/ALA [linoleic acid (C18:2 *n-6*) to *α*-linolenic acid ratio (C18:3 *n-3*)], EPA+DHA (sum of eicosapentaenoic and docosahexaenoic acids), FLQ (flesh lipid quality), AI (atherogenicity index), TI (thrombogenicity index), DFAs (desirable fatty acids), OFAs (undesirable fatty acids), h/H (hypocholesterolemic/hypercholesterolemic ratio), NVI (nutritive value index), HPI (health-promoting index), UI (unsaturation index), and COX (calculated oxidizability) value were calculated based on fatty acids content (mg/100 mg fat for the first three indices and percentages for the rest).

Oleic acid, linoleic acid, and *α*-linolenic acid are competitive toward 6-desaturase, with conversion rates increasing with the number of double bonds [44]. Linoleic acid (LA) is an *n-6* fatty acid, while *α*-linolenic acid (ALA) is *n-3*. Since they compete for the same enzyme and have different biological functions, their proportion in the diet is essential; the FAO/WHO experts recommend an LA/ALA ratio in the diet between 5:1 and 10:1; individuals with a dietary intake of LA more than ten times higher than ALA are encouraged to consume more *n-3*-rich foods [44]. LA/ALA ratios below 5 came out in RPC (2.7), LPC (0.2), WPC (4.4), HPC (3.0), and WF (4.0) fats and above 10 in SPC (592.2), PPC (124.3), and CH (14.9) fats (see Table 2). Other researchers reported ratios of 2.4 for rapeseed oil, 0.28–0.31 for linseed oil, 4.8 for walnut oil, 3.5 for hempseed oil, 2.6–3.1 for rainbow trout fat, 576.4 for sunflower oil, 252.0 for pumpkin oil, and 17.6 for

the chicken heart fat [26,32,35,45,46], comparable to our results except for rainbow trout fat (lower than in our WF fat) and pumpkin oil (twice higher than in our PPC fat).

The content of eicosapentaenoic acid (EPA)+docosahexaenoic acid (DHA) is an index of *n-3* PUFAs in fats, as they belong to the same class of compounds. Because of their low levels in terrestrial plants and animals, this index is mainly used to assess the nutritional value of fish and seafood. The FAO/WHO experts recommend an acceptable macronutrient distribution range (AMDR) EPA+DHA intake to adults of 0.25 to 2 g/day [47]. Since both fatty acids were present in the fat extracted from chicken hearts, their sum was also calculated for this sample (see Table 2); a concentration of 10.8 mg/100 mg fat was found in WF and 0.12 mg/100 mg fat in CH. Levels between 10.5 and 13.7 mg/100 g fillet were reported by Van Doan et al. [27] in fillets (dorsal and ventral) of rainbow trout (age 10–24 months). FLQ index instead estimates the EPA plus DHA amount as a percentage of total fatty acids [48]. Since the absolute amount of EPA and DHA is more significant than the FLQ, the latter may be considered a supplement to EPA+DHA. The FLQ value of 11.7 found in WF fat and 0.14 in CH fat (see Table 2) corroborates with the findings for EPA+DHA.

The AI reveals the relationship between the sum of primary SFAs and that of UFA main classes (*n-3* PUFAs, *n-6* PUFAs, and MUFAs), the first being considered pro-atherogenic (favouring the adhesion of lipids to the immunological and circulatory system cells) and the latter anti-atherogenic (inhibiting the plaque aggregation and diminishing levels of cholesterol, esterified fatty acids, and phospholipids, thus preventing thus the appearance of micro-and macro-coronary diseases) [49]. AI values between 0.06–0.34 were found in fats extracted from press cakes, fish meat, and chicken hearts (see Figure 1a). The highest AI value was found in WF and CH fats (0.34 and 0.30, respectively) and, among vegetable matrices, in PPC fat (0.16), as they had the lowest UFA and highest SFA concentrations. The least atherogenic is RPC fat (0.06), having the fewest SFAs and the most UFAs, followed by LPC (0.08), HPC (0.09), SPC and WPC (0.10) fats. Our values are slightly higher than those in the literature reported for cold-pressed oils of rapeseed (0.02), sunflower (0.04), pumpkin (0.08), and walnut (0.07), consistent with those for oils of linseed (0.06) and hempseed (0.07), but much lower than that for rainbow trout fat (0.58–0.68, depending on season) [46,50,51,52]. There is no published value regarding the AI value in chicken heart fat. Kasprzyk et al. [53] suggested that the AI value in fat should be lower than 0.5; given that AI values in our fats were below this limit, they present a low risk for cardiovascular disease (CVD).

The TI characterises a fat's thrombogenic potential and shows its tendency to form clots in blood vessels [48]; it represents the relationship between pro-thrombogenic (SFAs) and anti-thrombogenic fatty acids (MUFAs, *n-3* PUFAs, and *n-6* PUFAs) [49]. Consuming fats with low TI can benefit the cardiovascular health score (CHS) [48], which is the average of 8 health measurement scores, having a value between 0 and 100. According to the American Health Association, a CHS below 50 shows "poor" cardiovascular health, between 50 and 79 means "moderate" cardiovascular health, and a score ≥ 80 indicates "high" cardiovascular health [54]. The highest TI values were found in CH (0.51) and WH (0.28) fats, explained by the fact that they also have the highest SFA values and some of the lowest sums of MUFAs, *n-3* PUFAs, and *n-6* PUFAs (see Figure 1b). Bušová et al. [51] reported much higher values for rainbow trout fat, between 0.44 and 0.53, depending on the season; no TI value is available in the literature for chicken heart fat. Regarding samples of vegetable origin, WPC fat (0.14) had the highest TI value, followed by HPC (0.11), RPC and PPC (0.10), LPC (0.06), and SPC (0.02) fats. Comparable TI values were found by Razmaitė et al. [46] in hempseed (0.10) and linseed (0.05) oils. Rabiej-Kozioł et al. [32] reported a similar TI value for linseed (0.06) oil, comparable for rapeseed oil (0.09), and much higher for pumpkin (0.45) and sunflower (0.23) oils. Sandulachi et al. [50] found a much lower TI value in walnut oil (0.02).

DFA is an index that gives information about the hypocholesterolemic capacity of fat, while OFA is about the hypercholesterolemic one. RPC and LPC fats had the highest DFA values (93.8% and 92.4%, respectively) since they had the highest amounts of UFAs, followed by WPC and HPC fats (91.1%), then by SPC (90.7%), PPC (86.8%), WF (79.7%), and CH (76.3%) fats (see Figure 1c). An in-the-mirror image was noticed for OFA values (5.2–20.2%) in these fats (see Figure 1d), the sum of hypercholesterolemic fatty acids being higher in WPC fat (8.4%) than in the HPC one (7.4%) because of its palmitic acid content (C16:0). Comparable DFA and OFA values (81.73% and 16.20%, respectively) were reported by Kowalska-Góralska et al. [36] in fat extracted from rainbow trout.

The h/H index describes the relationship between hypocholesterolemic and hypercholesterolemic fatty acids [48]. As shown in Figure 1e, the h/H values in vegetable fats (17.6 in RPC>12.3 in LPC>11.5 in HPC>10.8 in SPC>10.4 in WPC>6.5 in PPC) were higher than in animal ones (3.1 in WF>3.0 in CH). Higher h/H values were found in rapeseed (19.6), linseed (14.8–17.1), and sunflower (13.2) oils, comparable in hempseed oil (11.8–12.9), and similar in pumpkin oil (6.5) [32,46,55].

The NVI evaluates the nutritional value of dietary fat, representing the sum of stearic (C18:0) and oleic (C18:1) acids relative to the palmitic acid (C16:0) amount [56]. The highest NVI value was found in RPC fat (12.5), followed by LPC (3.9), SPC (3.4), PPC (3.0), and WF (2.8) fats, then by WPC, HPC, and CH fats (2.2).

The HPI evaluates the effect of the fatty acid composition in dietary fat on CVD; the higher its value, the more beneficial fat is to human health [48]. Values between 3.0 and 17.3 were found in fats extracted from press cakes, fish meat, and chicken hearts. They are very close to those of the h/H index with which it seems to correlate, except for WF and CH fats; the HPI value in CH fat (3.2) was higher than in WF one (3.0).

The UI shows the unsaturation degree of fat [48]; the greater the level of fatty acid unsaturation, the more susceptible it is to oxidation [57]. It is calculated as the sum of each UFA type, in percentages, multiplied by the double-bond number within that FA. Unlike the Σ UFA or Σ PUFA, the UI also considers the weight of UFAs, which is proportional to their length. This index expresses the impact of highly unsaturated fatty acids and does not ignore the effect of fatty acids with a low degree of unsaturation. The UI more precisely depicts the proportion of fatty acids with different unsaturation degrees in the total fatty acid composition [48]. All our fats contain MUFAs, with the highest content found in RPC fat (64.1%), followed by WF (44.4%), CH (40.8%), and PPC (31.6%) fats, then by LPC (23.7%) and SPC (23.4%) fats, and finally, by WPC (15.7%) and HPC (13.7%) fats. As for PUFAs, in RPC, LPC, and WPC fats are found only dienoic and trienoic fatty acids; SPC, PPC, and HPC fats include tetraenoics too, while WPC and CH fats contain all PUFA types (of 2 to 6 double bonds). LPC fat had the highest UI value (205.5), followed by HPC (183.2), WPC (173.7), WF (153.9), SPC (151.0), PPC (131.1), RPC (128.1), and CH (99.7) fats (see Figure 1h). Although it features the highest amount of UFAs (92.4%), RPC fat showed the lowest UI value among vegetable-origin fats; this is because monoenoics have the largest

share in it (64.1%), dienoics (20.83%) and trienoics (7.43%) being less represented. Szabo et al. [58] reported comparable UI values in rapeseed (129.5) and sunflower (149.1) oils, Montesano et al. [59] in pumpkin oil (116.3), and Zuk et al. [60] in linseed oil (161.8–204.2). There is no data regarding the UI value in walnut and hempseed oils, rainbow trout and chicken heart fats.

The COX value was calculated based on its composition in unsaturated C18 fatty acids (C18:1, C18:2, and C18:3). In fats extracted from oil press cakes, the calculated oxidizability showed values between 4.4 (RPC fat) and 12.8 (LPC fat), revealing the same susceptibility to oxidation as the unsaturation index (see Figure 1i). Similar COX values were found by Rabiej-Kozioł et al. [32] in rapeseed (4.4) and pumpkin (5.5) oils, while in linseed (13.1) and sunflower (6.3) oils, comparable. The COX value for rainbow trout fat (2.2) reported by Kowalska-Góralska et al. [36] was close to ours; instead, Symoniuk et al. [34] have calculated a lower COX value in hempseed oil (5.0–6.1). COX values for walnut oil and chicken heart fat have yet to be reported. The high oxidative stability of RPC fat is due to the high percentages of C18:1 (62.6%), C18:2 (20.8%), and C18:3 (7.4%), which it contains. In exchange, the considerable COX value of LPC fat is the result of a lower C18:1 (23.56%) and C18:2 (12.28%) but higher C18:3 (52.09%) content in it than in RPC fat. Fats of animal origin had lower COX values than those of vegetable origin, of 2.5 in WF fat and 3.3 in CH fat. Both UI and the COX value show the oxidative stability of fat. When calculated with the COX equation, WF fat shows less susceptibility to oxidation as this formula does not include the fatty acids with 4, 5, and 6 double bonds detected in it; an underestimation of the oxidative stability could also be in the case of SPC, PPC, and HPC fats, which also contain tetraenoics.

3.3. Content of tocopherols, tocotrienols, cannabinoids, and CoQ10. Antioxidant capacity and oxidative status

Tocopherols and tocotrienols. The content of tocopherols and tocotrienols determined in fats extracted from press cakes, fish meat, and chicken hearts can be seen in Table 3. Tocopherols and tocotrienols are phenolic compounds, both forms of vitamin E, known together as tocols [61,62]. They share an amphiphilic 6-chromanol ring, the basic structural unit, and a terpenoid side chain at the ring second position; a saturated phytyl side chain or an unsaturated geranyl side chain can be joined to the chromanol head group to form tocopherols or tocotrienols, respectively [63]. Tocopherols and tocotrienols are among the endogenous antioxidant molecules that protect the lipid matrix by preventing the oxidation of its PUFAs [64,65].

The highest *α*-tocopherol content was found in SPC fat (472.81 µg/g), followed by RPC fat (399.35 µg/g), and HPC fat (81.65 µg/g); it was found in traces in WF fat but not detected in PPC, LPC, WPC, and CH fats. *β*-Tocopherol was found only in HPC fat, in amounts below the limit of quantification. *γ*-Tocopherol was not detected in SPC fat and was found in traces in WF fat; HPC fat instead showed the highest amount of *γ*-tocopherol (695.34 µg/g), followed by RPC fat (533.93 µg/g), then by WPC (295.38 µg/g) and LPC (278.24 µg/g) fats, and finally by PPC fat (138.09 µg/g). *δ*-Tocopherol was found in WPC fat (77.61 µg/g), RPC fat (64.16 µg/g), and HPC fat (in traces) and was not detected in the other fats. *γ*-Tocotrienol was detected only in HPC fat but in trace amounts.

A similar tocopherols profile as that of RPC fat was reported by Rabiej-Kozioł et al. [52] for cold-pressed rapeseed oil but lower concentrations (270.0 µg/g for *α*-tocopherol; 421.1 µg/g for *γ*-tocopherol; 11.0 µg/g for *δ*-tocopherol). In cold-pressed sunflower oil, they found a higher level of *α*-tocopherol (734.0 µg/g) as well as *β*-tocopherol (25.6 µg/g), which was not detected in SPC fat. Their cold-pressed pumpkin and linseed oils showed a higher *γ*-tocopherol content (569.6 µg/g and 422.6 µg/g, respectively) than PPC and LPC fats; in addition to us, they also detected *α*-tocopherol (74.9 µg/g and 17.8 µg/g, respectively).

The tocopherols content in cold-pressed oils extracted from five walnut cultivars by Rabrenovic et al. [66] ranged from 18.0 to 26.0 µg/g for *α*-tocopherol (not detected in WPC fat), from 254.0 to 332.0 µg/g for *β*+*γ*-tocopherol (comparable levels to that of *γ*-tocopherol in WPC fat), and from 10.0 to 26.0 µg/g for *δ*-tocopherol (lower levels than in WPC fat). In the thirteen commercially available cold-pressed hempseed oils investigated by Tura et al. [64], *γ*-tocopherol was the main quantified compound, as in HPC fat, falling between 594.0 and 967.0 µg/g; they found *α*-tocopherol in lower concentrations (14.6–53.0 µg/g), but in addition to us, have detected *δ*-tocopherol (19.6–50.3 µg/g). Unlike us in WF fat, López et al. [67] have found *α*-tocopherol in fats extracted from rainbow trout samples (in concentrations between 190.0 and 359 µg/g, depending on weight and sex). As for fat extracted from chicken hearts, there is no report regarding the content of tocopherols.

Cannabinoids. The hemp plant (*Cannabis sativa* L.) contains more than a hundred different cannabinoids, the most common ones being cannabidiol (CBD) and its precursor acidic form cannabidiolic acid (CBDA), cannabigerol (CBG), cannabinol (CBN), cannabichromene (CBC), delta-9-tetrahydrocannabinol (Δ9-THC) and its precursor acid form, delta-9-tetrahydrocannabinolic acid (Δ9-THCA) [68]; Δ9-THCA and CBDA decarboxylate during storage or heating, resulting Δ9-THC and CBD, respectively [69]. Cannabinoids are regarded as residues in hempseed oils, occurring due to contamination (contact of hempseeds with other parts of the plant, such as inflorescence or bracts) during harvesting or processing [64]. The European Commission has set a maximum level of 3.0 mg/kg (that is 0.3 µg/100 mg) for Δ9-THC equivalents in hempseeds and of 7.5 mg/kg (that is 0.75 µg/100 mg) in hempseed oil [70]. By cold pressing of hemp seeds, part of the cannabinoids end up in the oil, and the rest remain in the press cakes.

CBDA and CBD were found in the highest amount in HPC fat, of 19.15±0.579 µg/100 mg and 21.96±0.552 µg/100 mg, respectively; delta-8-tetrahydrocannabinol (Δ8-THC), a mildly euphoric isomer of psychoactive Δ9-THC [71], was not detected. CBD is a cannabinoid with some therapeutic properties; it treats epilepsy and schizophrenia, reduces pain and inflammation, alleviates anxiety, and improves sleep quality [72]. CBDA has many similar properties to CBD, given that it is its precursor. The other six cannabinoids detected were found in small amounts as 1.03±0.042 µg/100 mg fat for CBG, 0.99±0.028 µg/100 mg for cannabigerolic acid (CBGA, the precursor of CBG), 0.93±0.014 µg/100 mg for delta-9-tetrahydrocannabivarin (Δ9-THCV), 0.38±0.014 µg/100 mg for CBN, 1.68±0.042 µg/100 mg for Δ9-THC, and 1.83±0.049 µg/100 mg for Δ9-THCA-A. The sum of Δ9-THC and Δ9-THCA expressed as Δ9-THC has been exceeded in HPC fat (3.28 µg/100 mg, that is 32.8 mg/kg). Cannabinoids were also present in commercially available hempseed oils assessed by Tura et al. [64], with CBDA between 0.43 and 9.16 µg/100 mg, Δ9-THC up to 0.53 µg/100 mg, and Δ9-THCA up to 0.50 µg/100 mg.

CoQ10 and antioxidant capacity. Results regarding the CoQ10 content in fats extracted from press cakes, fish meat and chicken hearts are visible in Table 4. The highest CoQ10 content was found in CH (2041.74 µg/g; 3-7.5 times higher than in oil press cakes), followed by PPC fat (661.40 µg/g), WPC fat (416.54

μg/g), SPC fat (322.21 μg/g), and RPC fat (271.50 μg/g); it was not detected in HPC and WF fats. Much lower concentrations were reported by Mattila and Kumpulainen [73] in rapeseed oil (63.5 μg/g), respectively, by Rodríguez-Acuña et al. [74] in sunflower oil (8.7 μg/g) but a comparable level, by Villanueva-Bermejo and Temelli [75], in fat extracted from chicken hearts (2310 μg/g). Unlike us, Laplante et al. [76] have found CoQ10 in fish oil (133.2 μg/g in Mackerel oil and 286.1 μg/g in Herring oil). No published data exists about the CoQ10 content in pumpkin, linseed, walnut, and hempseed oils. As for the antioxidant capacity of fats extracted from press cakes, fish meat, and chicken hearts, the highest TEAC level was found in RPC fat (12.89 μmol TE/g), followed by fats from WPC (8.30 μmol TE/g), HPC (4.61 μmol TE/g), LPC (2.26 μmol TE/g), WF (0.96 μmol TE/g), and CH (0.48 μmol TE/g), without significant differences between the last two levels (see Table 4). There is no significant correlation between the CoQ10 content and the TEAC level in these fats; it is likely that in fats with low CoQ10 content and high antioxidant capacity, this be due to the presence of other antioxidant compounds (such as tocopherols or tocotrienols) in the sample [77]. CoQ10 dosages of up to 1200 mg/day can treat chronic diseases, while levels between 100 and 200 mg/day are recommended to achieve a beneficial effect [6]; 152 g of PPC fat or 48.98 g of CH fat contains the minimum recommended amount (100 mg).

Oxidative status. It was evaluated by determining the PV in fats, which shows the occurrence of primary oxidation products (hydroperoxide) and TBARS, which indicate the presence of secondary oxidation products (like aldehydes and ketones) [20,78]. The highest PV was found in HPC (21.92 meq O_2/kg) and WPC (19.38 meq O_2/kg) fats, followed by fats from RPC (19.03 meq O_2/kg), SPC (18.22 meq O_2/kg), PPC (16.96 meq O_2/kg), and LPC (16.90 meq O_2/kg). The maximum level of 15 meq O_2/kg oil, stipulated in the CXS 19-1981 [79] and CXS 210-1999 [80] Codex standards, was exceeded in all vegetable fats; this is due to the age of oil press cakes used to extract the vegetable fats (8 months for RPC, SPC, LPC, and WPC, respectively, 9 months for PPC and HPC). The PV in WF fat was 1.79 meq O_2/kg, and in CH fat, 1.19 meq O_2/kg, below the limit level of 5 meq O_2/kg fish oil [81] and 10 meq O_2/kg animal fat [82], respectively.

This study is the first attempt to measure the secondary oxidation products in oil press cakes and chicken hearts. WPC had the highest TBARS concentration (59.39 mg MDA/kg), followed by LPC (45.19 mg MDA/kg), PPC (23.73 mg MDA/kg), RPC (20.38 mg MDA/kg), and SPC (16.55 mg MDA/kg). Given that the differences between their fats in terms of PV were not that large, we can assume that in the case of linseed and walnut press cakes, there is an overestimation of secondary oxidation products with this test due to the formation of adducts with thiobarbituric acid [78]. Therefore, a chromatographic method would be more suitable for determining malondialdehyde in these matrices. The lack of a significant correlation between the levels of PV in fats and TBARS in these oil press cakes corroborates these findings. As for TBARS in animal tissues, a concentration of 2.19 mg MDA/kg was found in WF and 0.86 mg MDA/kg in CH. Socaciu et al. [83] have reported the following limits for the TBARS level in fish: less than 3 mg MDA/kg means perfect quality material, between 3 and less than 5 MDA/kg means good quality material, whereas between 5 and less than 8 MDA/kg means material suitable for human consumption. Considering these recommendations, the WF sample is a perfect quality material regarding TBARS level, which is explained by the fact that it was collected on the day next to the expiration date. TBARS concentrations between 0.28 and 0.83 mg MDA/kg were reported by Socaciu et al. [14] in brook trout fish patties during 15 days of refrigerated storage.

Conclusion

The matrices tested in this study represent a source of CoQ10, except for hempseed press cakes and fish meat. Chicken hearts and pumpkin press cakes are the richest in CoQ10; extracting their fats using a green solvent could represent a sustainable and safer method of recovering and valorising CoQ10. Vegetable fats have better antioxidant properties than animal fats, more thanks to their content in total tocopherols than in CoQ10.

The delayed extraction of fats from press cakes caused an accumulation of primary oxidation products above the limit level in all samples; animal fats were not the case since they were extracted from their matrices immediately after expiration. This means that the initial oxidative status of a food by-product/waste is essential for the storage stability of its fat. Hence, the fat extraction must be done immediately after processing (in the case of oil press cakes)/expiration date (for animal tissues).

In short, chicken hearts are the most suitable for preparing a dietary supplement based on CoQ10, as they have the highest fat content; pumpkin press cakes are recommended when a vegan supplement is needed.

Declarations

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Appendix A. Supplementary material

The following is Supplementary material to this article:

Appendix B. Supplementary material

The following is Supplementary material to this article:

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Author Contributions Cristina Anamaria Semeniuc, Sonia Ancuţa Socaci: Conceptualization, Methodology, Software. **Andersina Podar, Mara Mandrioli, Cristina Anamaria Semeniuc**: Data curation, Writing - original draft. **Cristina Anamaria Semeniuc, Andersina Simina Podar, Mara Mandrioli, Floricuţa Ranga, Maria-Ioana Socaciu, Simona Raluca Ionescu, Melinda Fogarasi, Anca Corina Fărcaş, Tullia Gallina Toschi, Dan Cristian Vodnar, Sonia Ancuţa Socaci:** Visualization, Investigation. **Sonia Ancuţa Socaci**: Supervision. **Andersina Simina Podar, Mara Mandrioli, Floricuţa Ranga, Maria-Ioana Socaciu, Simona Raluca Ionescu, Melinda Fogarasi, Anca Corina Fărcaş**: Formal analysis. **Sonia Ancuţa Socaci, Tullia Gallina Toschi**: Writing - review & editing. **Cristina Anamaria Semeniuc, Sonia Ancuţa Socaci, Tullia Gallina Toschi:** Funding acquisition. **Cristina Anamaria Semeniuc, Sonia Ancuţa Socaci, Dan Cristian Vodnar, Tullia Gallina Toschi:** Resources. **Cristina Anamaria Semeniuc:** Project administration.

Data Availability All data generated during this study are shown and discussed in the paper.

Compliance with Ethical Standards

Consent for Participation Not applicable.

Consent for Publication Not applicable.

Ethical Approval Not applicable.

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Tables

Table 1

Lipid composition of oil press cakes, fish meat, and chicken hearts.

Crt. No.	Lipid class	RPC	SPC	PPC	LPC	WPC	HPC	WF	CH
		mg/100 mg fat							
1	FFAs	3.55±0.339^{b}	3.06±0.156^{bc}	2.10±0.113^{d}	1.49±0.163^{d}	2.40±0.064^{cd}	8.97±0.389^{a}	1.88±0.297^{d}	3.79±0.134^{b}
2	MAGs	0.67±0.014^{b}	0.42±0.035^{c}	0.23±0.021^{d}	0.27±0.028^{d}	0.52±0.007^{c}	0.69±0.014^{b}	0.48±0.085^{c}	1.35±0.014^{a}
3	DAGs	7.62±0.099^{c}	5.93±0.113^{d}	4.54±0.099^{e}	5.49±0.255^{d}	9.23±0.339^{b}	6.24±0.007^{d}	2.24±0.332^{f}	10.34±0.184^{a}
4	TAGs	87.09±0.255^{d}	89.89±0.078^{c}	92.15±0.035^{b}	92.20±0.071^{b}	86.71±0.509^{d}	83.00±0.368^{e}	94.44±0.672^{a}	81.76±0.127^{e}
5	Σ Others*	1.07	0.72	0.99	0.56	1.15	1.11	0.98	2.76

FFAs, free fatty acids; MAGs, monoacylglycerols; DAGs, diacylglycerols; TAGs, triacylglycerols; *, the sum of free sterols and esterified sterols; RPC, rapeseed press cakes; SPC, sunflower press cakes; PPC, pumpkin press cakes; LPC, linseed press cakes; WPC, walnut press cakes; HPC, hempseed press cakes; WF, whole fish; CH, chicken hearts. Results are expressed as mean ± standard deviation of triplicate data (n=3). Different letters in the row indicate a statistically significant difference at $p < 0.05$ (Tukey's test).

Table 2

Fatty acid composition of oil press cakes, fish meat, and chicken hearts.

Crt. No.	FAME of	RPC	SPC	PPC	LPC	WPC	HPC	WF	CH
		mg/100 mg fat							
1	Lauric acid, C12:0	0.01±0.0^{b}	n.d.	0.01±0.0^{b}	0.01±0.0^{b}	0.08±0.035^{a}	n.d.	0.05±0.0^{ab}	0.02±0.
2	Myristic acid, C14:0	0.05±0.0^{d}	0.08±0.0^{c}	0.08±0.0^{c}	0.05±0.0^{d}	0.04±0.0^{e}	0.04±0.0^{e}	2.39±0.007^{a}	0.27±0.
3	Myristoleic acid, C14:1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.04±0.007^{b}	0.10±0.
4	Pentadecanoic acid, C15:0	0.04±0.0^{c}	0.02±0.0^{e}	0.02±0.0^{e}	0.03±0.0^{d}	0.03±0.0^{d}	0.03±0.007^{de}	0.23±0.0^{a}	0.05±0.
5	Palmitic acid, C16:0	4.46±0.021^{f}	7.49±0.057^{d}	11.04±0.028^{c}	6.49±0.134^{e}	7.67±0.113^{d}	6.58±0.042^{e}	12.75±0.057^{b}	16.97±(
6	Σ Palmitoleic acid, C16:1	0.36±0.014^{b}	0.07±0.099^{c}	0.13±0.007^{c}	0.14±0.0^{c}	0.14±0.0^{c}	0.15±0.0^{c}	4.35±0.057^{a}	4.32±0.
7	Margaric acid, C17:0	0.10±0.0^{b}	0.04±0.0^{f}	0.07±0.0^{c}	0.05±0.0^{e}	0.07±0.0^{c}	0.06±0.0^{d}	0.23±0.0^{a}	0.08±0.
8	Stearic acid, C18:0	1.21±0.014^{f}	3.31±0.014^{d}	5.08±0.007^{b}	3.65±0.085^{c}	2.59±0.035^{e}	2.51±0.014^{e}	3.52±0.035^{c}	6.75±0.
9	Σ Oleic acid, C18:1 (*n-9*)	53.78±0.318^{a}	21.43±0.106^{e}	27.59±0.530^{d}	21.28±0.481^{e}	13.78±0.311^{f}	11.50±0.007^{g}	31.84±0.262^{b}	29.58±(
10	Σ Linoleic acid, C18:2 tt, ct, tc	0.02±0.0^{d}	0.05±0.0^{cd}	0.04±0.0^{d}	0.05±0.0^{cd}	0.05±0.0^{cd}	0.08±0.0^{c}	0.31±0.0^{a}	0.24±0.
11	Linoleic acid, C18:2 (*n-6*)	17.98±0.099^{f}	59.22±0.304^{a}	43.52±0.841^{d}	11.19±0.240^{g}	53.89±1.322^{b}	48.22±0.021^{c}	11.64±0.078^{g}	20.62±(
12	Arachidic acid, C20:0	0.43±0.007^{b}	0.24±0.0^{d}	0.36±0.0^{c}	0.16±0.0^{f}	0.13±0.0^{g}	0.74±0.0^{a}	0.20±0.0^{e}	0.07±0.
13	*γ*-Linolenic acid, C18:3 (*n-6*)	0.03±0.0^{d}	n.d.	n.d.	0.21±0.007^{b}	0.06±0.007^{d}	1.68±0.007^{a}	0.19±0.007^{b}	0.13±0.
14	Σ Eicosenoic acid, C20:1	0.85±0.007^{b}	0.12±0.0^{f}	0.10±0.007^{f}	n.d.	0.18±0.007^{e}	0.35±0.0^{d}	2.45±0.014^{a}	0.42±0.
15	*α*-Linolenic acid, C18:3 (*n*-3)	6.79±0.021^{d}	0.10±0.007^{f}	0.35±0.007^{f}	50.25±1.146^{a}	12.30±0.354^{c}	16.33±0.120^{b}	2.95±0.028^{e}	1.38±0.
16	Stearidonic acid, C18:4 (*n*-3)	n.d.	n.d.	n.d.	n.d.	n.d.	0.52±0.0^{b}	0.55±0.007^{a}	n.d.
17	Eicosadienoic acid, C20:2 (*n-9*)	0.05±0.0^{c}	0.01±0.0^{e}	n.d.	0.02±0.0^{de}	0.03±0.0^{d}	0.06±0.0^{c}	1.24±0.007^{a}	0.27±0.
18	Behenic acid, C22:0	0.26±0.0^{c}	0.71±0.0^{a}	0.14±0.0^{d}	0.11±0.0^{f}	0.13±0.007^{e}	0.34±0.0^{b}	0.10±0.007^{g}	0.11±0.
19	Dihomo-*γ*-linolenic acid, C20:3 (*n-6*)	n.d.	n.d.	n.d.	0.04±0.0^{c}	n.d.	n.d.	0.46±0.007^{a}	0.35±0.
20	Eicosatrienoic acid, C20:3 (*n*-3)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.36±0.0^{a}	0.02±0.
21	Arachidonic acid, C20:4 (*n-6*)	n.d.	0.02±0.0^{c}	0.04±0.021^{c}	n.d.	n.d.	n.d.	0.55±0.007^{b}	2.60±0.
22	Eicosapentaenoic acid, C20:5 (*n*-3)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.31±0.049^{a}	0.07±0.
23	Erucic acid, C22:1 (*n-9*)	0.01±0.0^{c}	n.d.	n.d.	0.02±0.0^{b}	0.01±0.0^{c}	0.02±0.0^{b}	0.76±0.0^{a}	0.02±0.
24	Docosadienoic acid, C22:2 (*n-6*)	n.d.	0.01±0.0^{b}	n.d.	n.d.	n.d.	n.d.	0.15±0.007^{a}	n.d.
25	Docosatetraenoic acid, C22:4 (*n-6*)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.08±0.0^{b}	0.31±0.
26	Docosapentaenoic acid, C22:5 (*n*-3)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.17±0.021^{a}	0.14±0.
27	Docosahexaenoic acid, C22:6 (*n*-3)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	8.52±0.127^{a}	0.05±0.
28	Lignoceric acid, C24:0	0.13±0.0^{c}	0.26±0.0^{a}	0.13±0.0^{c}	0.13±0.0^{c}	0.07±0.0^{d}	0.18±0.0^{b}	n.d.	n.d.

Crt. No.	FAME of	RPC	SPC	PPC	LPC	WPC	HPC	WF	CH
		mg/100 mg fat							
29	Nervonic acid, C24:1 (*n-9*)	0.12±0.0[a]	0.01±0.0[b]	n.d.	0.01±0.0[b]	n.d.	n.d.	n.d.	n.d.
	Σ Others*	-	-	-	-	-	-	2.55	0.30
	TOTAL, of which	**86.68**	**93.19**	**88.70**	**93.89**	**91.25**	**89.39**	**91.94**	**85.24**
	MCFAs	0.01	-	0.01	0.01	0.08	-	0.05	0.02
	LCFAs	86.15	92.20	88.42	93.61	90.96	88.85	78.56	84.29
	VLCFAs	0.52	0.99	0.27	0.27	0.21	0.54	10.78	0.63
	SFAs	6.69	12.15	16.93	10.68	10.81	10.48	19.47	26.92
	MUFAs	55.12	21.63	27.82	21.45	14.11	12.02	39.44	34.44
	PUFAs	24.87	59.41	43.95	61.76	66.33	66.89	30.48	23.58
	Ratio of								
	UFAs/SFAs	12.0	6.7	4.2	7.8	7.4	7.5	3.6	2.2
	MUFAs/SFAs	8.2	1.8	1.6	2.0	1.3	1.1	2.0	1.3
	PUFAs/SFAs	3.7	4.9	2.6	5.8	6.1	6.4	1.6	0.9
	PUFAs/MUFAs	0.5	2.7	1.6	2.9	4.7	5.6	0.8	0.7
	n-6/*n*-3 PUFAs	2.7	592.5	124.5	0.2	4.4	3.0	0.8	14.5
	Lipid quality indices								
	LA/ALA	2.7	592.2	124.3	0.2	4.4	3.0	4.0	14.9
	EPA+DHA	-	-	-	-	-	-	10.8	0.12
	FLQ	-	-	-	-	-	-	11.7	0.14

*, the sum of unidentified fatty acids; MCFAs, medium-chain fatty acids; LCFAs, long-chain fatty acids; VLCFAs, very-long-chain fatty acids; SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids; UFAs/SFAs, unsaturated to saturated fatty acids ratio; MUFAs/SFAs, monounsaturated to saturated fatty acids ratio; PUFAs/SFAs, polyunsaturated to saturated fatty acids ratio; PUFAs/MUFAs, polyunsaturated to monounsaturated fatty acids ratio; *n-6*/*n*-3 PUFAs, omega-6 to omega-3 polyunsaturated fatty acids ratio; LA/ALA, linoleic acid (C18:2 *n-6*) to *α*-linolenic acid (C18:3 *n-3*) ratio; EPA, eicosapentaenoic acid (C20:5 *n-3*); DHA, docosahexaenoic acid (C22:6 *n-3*); FLQ, flesh lipid quality; RPC, rapeseed press cakes; SPC, sunflower press cakes; PPC, pumpkin press cakes; LPC, linseed press cakes; WPC, walnut press cakes; HPC, hempseed press cakes; WF, whole fish; CH, chicken hearts; n.d., not detected. Results are expressed as mean ± standard deviation of triplicate data (n=3). Different letters in the row indicate a statistically significant difference at $p < 0.05$ (Tukey's test).

Table 3

Content of tocopherols and tocotrienols in fats extracted from oil press cakes, fish meat, and chicken hearts, respectively, of cannabinoids in hempseed press cakes fat.

Crt. No.	Tocopherols and tocotrienols	RPC	SPC	PPC	LPC	WPC	HPC	WF	CH
		µg/g fat							
1	*α*-tocopherol	399.35±2.510^{b}	472.81±7.460^{a}	n.d.	n.d.	n.d.	81.65±9.178^{c}	tr.	n.d.
2	*β*-tocopherol	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	tr.	n.d.
3	*γ*-tocopherol	533.93±15.832^{b}	n.d.	138.09±7.156^{d}	278.24±12.056^{c}	295.38±14.531^{c}	695.34±51.852^{a}	tr.	54.22±4.73
4	*δ*-tocopherol	64.16±0.198^{b}	n.d.	n.d.	n.d.	77.61±1.188^{a}	tr.	n.d.	n.d.
5	*γ*-tocotrienol	n.d.	n.d.	n.d.	n.d.	n.d.	tr.	n.d.	n.d.
	TOTAL, of which	**997.44**	**472.81**	**138.09**	**278.24**	**372.99**	**777.99**	**tr.**	**54.22**
	Tocopherols	997.44	472.81	138.09	278.24	372.99	777.99	-	54.22
	Tocotrienols	-	-	-	-	-	tr.	-	-

RPC, rapeseed press cakes; SPC, sunflower press cakes; PPC, pumpkin press cakes; LPC, linseed press cakes; WPC, walnut press cakes; HPC, hempseed press cakes; WF, whole fish; CH, chicken hearts; n.d., not detected; tr., traces (< 44 µg/g, the limit of quantification). Results are expressed as mean ± standard deviation of triplicate data (n=3). Different letters in the row indicate a statistically significant difference at $p < 0.05$ (Tukey's test).

Table 4

The CoQ10 content, PV, and TEAC of fats extracted from oil press cakes, fish meat, and chicken hearts. Content of TBARS in the samples as such.

Crt. No.	Parameter	RPC	SPC	PPC	LPC	WPC	HPC	WF	CH
1	CoQ10 (µg/g fat)	271.50±4.957^{e}	322.21±1.902^{d}	661.40±1.471^{b}	250.56±8.344^{f}	416.54±7.799^{c}	n.d.	n.d.	2041.74±4.
2	TEAC (µmol TE/g fat)	12.89±0.665^{a}	2.26±0.424^{d}	2.61±0.219^{d}	2.26±0.021^{d}	8.30±0.099^{b}	4.61±0.184^{c}	0.96±0.099^{e}	0.48±0.007
3	PV (meq O_2/kg fat)	19.03±0.665^{b}	18.22±0.707^{b}	16.96±0.396^{b}	16.90±1.103^{b}	19.38±1.004^{ab}	21.92±0.269^{a}	1.79±0.007^{c}	1.19±0.007
4	TBARS (mg MDA/kg sample)	20.38±0.325^{d}	16.56±0.021^{e}	23.73±1.301^{c}	45.20±0.233^{b}	59.39±0.467^{a}	9.25±0.488^{f}	2.19±0.035^{g}	0.86±0.042

CoQ10, coenzyme Q10; TEAC, Trolox equivalent antioxidant capacity; PV, peroxide value; TBARS, thiobarbituric acid reactive substances; RPC, rapeseed press cakes; SPC, sunflower press cakes; PPC, pumpkin press cakes; LPC, linseed press cakes; WPC, walnut press cakes; HPC, hempseed press cakes; WF, whole fish; CH, chicken hearts; n.d., not detected. Results are expressed as mean ± standard deviation of triplicate data (n=3). Different letters in the row indicate a statistically significant difference at $p < 0.05$ (Tukey's test).

Figures

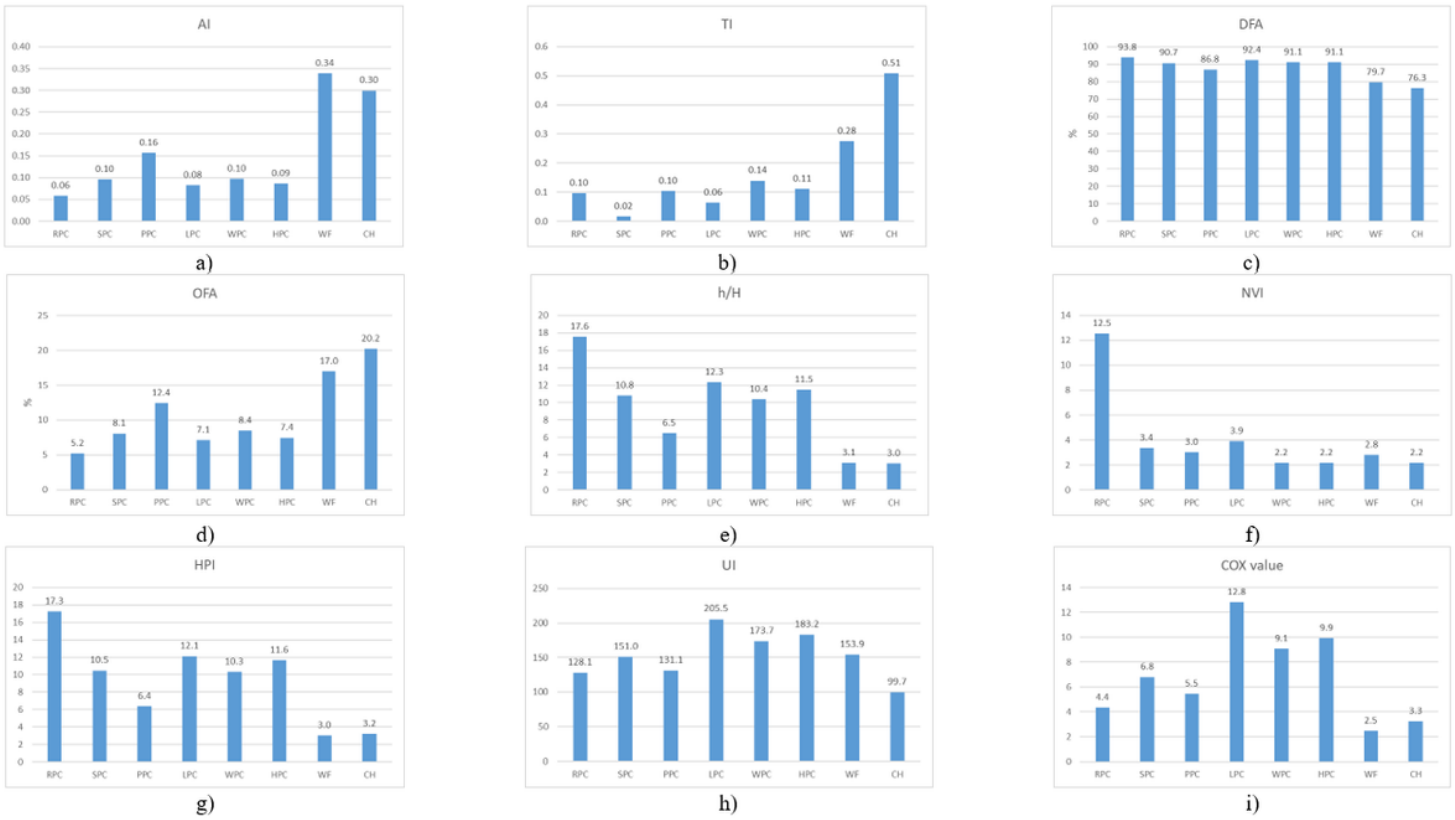

Figure 1

Lipid quality indices of oil press cakes, fish meat, and chicken hearts. a) AI, atherogenicity index. b) TI, thrombogenicity index. c) DFAs, desirable fatty acids. d) OFAs, undesirable fatty acids. e) h/H, hypocholesterolemic/hypercholesterolemic ratio. f) NVI, nutritive value index. g) HPI, health-promoting index. h) UI, unsaturation index; i) COX value, calculated oxidizability value. RPC, rapeseed press cakes; SPC, sunflower press cakes; PPC, pumpkin press cakes; LPC, linseed press cakes; WPC, walnut press cakes; HPC, hempseed press cakes; WF, whole fish; CH, chicken hearts.

Supplementary Files

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