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Dietary Orange Pulp and Organic Selenium Effects on Growth Performance, Meat Quality, Fatty Acid Profile, and Oxidative Stability Parameters of Broiler Chickens

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Abstract: In this study, orange pulp (OP) and/or organic Se were fed to broilers in order to investigate their effects on the performance, behavior, breast meat quality, and oxidative stability. A total of 240 chicks were allocated to four groups: a control group; an OP group, fed with OP at 50 g/kg of diet; a Se group, fed with organic Se at 0.15 ppm; and an OP + Se group, fed with OP and organic Se at 50 g/kg and 0.15 ppm, respectively. The selenium and OP + Se groups showed improved meat oxidative stability during frozen storage from 90 to 210 days (p < 0.05), whereas the performance and meat quality were unaffected by the dietary treatments (p > 0.05), apart from a reduction in the meat pH and the dressing percentage in the OP-supplemented groups (p < 0.05). A synergistic action between OP and Se was observed for the meat oxidative stability. The polyunsaturated fatty acid (FA) and α-linolenic acid (ALA) contents in the breast meat lipid fractions were increased in the OP groups (p < 0.05). Dietary intervention did not affect the feeding or drinking behaviors of the broilers (p > 0.05). The dietary supplementation of broiler chickens with the citrus industry byproduct orange pulp at 50 g/kg, along with organic Se at 0.15 ppm, beneficially improves the meat oxidative stability and the meat nutritional value, with no negative side effects on the performance or the meat quality.

Keywords: broilers; orange pulp; organic selenium; antioxidant activity; meat quality; behavior; fatty acid profile

1. Introduction

In recent years, a continuous increase in livestock production costs has been observed, due to the increased prices of feedstuffs, such as soybean products and cereal grains. As a result, low-input feeding strategies are a prerequisite for minimizing the animal nutrition expenses that are based on alternative feeding resources, such as shrubs, bushes, novel pastures, and agroindustrial byproducts [1]. At the same time, animal products are, nowadays, intended not only to satisfy nutritional needs, but also to protect human organisms against degenerative diseases that are linked to oxidative stress. The consumption of foods rich in functional compounds (nutraceuticals) can, therefore, reinforce the activity of the endogenous systems against these diseases and lead to an improvement in mental and physical wellbeing [2,3]. Agroindustrial byproducts are considered to be a cheap source of these compounds, and their application in animal nutrition minimizes the environmental impact induced by their disposal (due to their high organic load) and enables the sustainability of high-added value ingredients inside the food chain [4].
Dried citrus pulp is produced after the extraction of the juice from citrus fruits and the drying of the residues. It is a mixture of the peel, the inside portions, and the culled fruits of the citrus family that contain biologically active compounds (i.e., flavonoids), with positive and beneficial effects for the human organism [5]. Flavonoids (hesperidin, naringin, etc.) are found in the pulp, albedo, membranes, and the pith of citrus, and they are a class of secondary plant phenolics with significant antioxidant and chelating properties [6]. Citrus pulp and its flavonoids have already been used in diets intended for broilers, with varying results regarding the growth performance parameters, but positive effects on the meat antioxidant properties. No effect on the final weight, the hot carcass weight, nor the carcass yield was observed after the dietary inclusion of dried Citrus sinensis peel at the levels of 1.5 or 3.0% [7]. Simitzis et al. [8] and Goliomytis et al. [9] reached the same conclusions following hesperidin (1.5–3.0 g/kg) and naringin (0.75–1.5 g/kg) dietary supplementation, respectively. On the other hand, the use of dried orange residues at 2% [10], or dried tangerine peel extract at 80–480 mg/kg [11], improved the feed intake and body weight gain. When higher doses of citrus pulp (5 or 10%) were examined, reductions in the daily weight gain and the carcass yields were reported [12]. In general, the inclusion of hesperidin [8,13] or naringin [9] into the diet of broilers improves the meat antioxidant capacity. Improved antioxidant capacity in breast and thigh meat was also observed when broiler chickens were fed with Citrus junos byproducts fermented with multistrain probiotics, at 5, 10, and 20 g/kg of the diet [14]. However, no data exist regarding the effects of orange pulp dietary supplementation on the meat oxidative stability of broilers.

Selenium (Se) is an essential trace element with several important biological roles in poultry, such as the regulation of the antioxidant defense system, and improvements in the immunity, normal growth, and body maintenance [15]. Selenium protects the organism from oxidative stress through the amendment of the antioxidant defense system, since it regulates the expressions of various enzymes, such as glutathione peroxidases, deiodinases, thioredoxin reductases, and other selenoproteins [16,17]. Sodium selenite (SS) is an inorganic form of Se, and it is the most common Se source used in animal diets. However, dietary supplementation with Se organic forms in poultry diets, such as Se-enriched yeast (SY) and selenomethionine (SM), has been legally allowed since 2000 [18]. Se organic forms have improved the bioavailability and antioxidant properties [19], and they are less toxic and more environmentally friendly [20] than inorganic forms [21,22]. The majority of studies regarding selenium supplementation in broilers do not report any effects of selenium on the growth performance and feed conversion [23,24], but there are also researchers who found an increase in the live weight due to the inclusion of Se in broilers diets [25,26]. In general, the broiler meat quality and the antioxidant properties are improved after Se dietary supplementation [17,23,27].

However, the combined action of dietary Se, which triggers the biological endogenous antioxidant defense system, along with orange pulp, which is rich in natural antioxidants, has not yet been evaluated in broiler diets, and their synergistic effects have not been examined. Therefore, the aim of the present study is to highlight the effects of orange pulp and/or organic selenium dietary supplementation on the broiler performance, behavioral traits, meat quality, fatty acid (FA) profile, and oxidative stability.

2. Materials and Methods

2.1. Birds and Diets

A total of 240 one-day-old Cobb 500 broiler chickens, obtained from a commercial hatchery, as hatched, were housed in a controlled environment. The birds were reared for 42 days in 16 pens, with 15 birds per pen, with a surface area of 1.5 m² each. The environmental conditions and management practices were in accordance with the standard Cobb guidelines. Feed, in mash form, and water were provided ad libitum. The lighting program consisted of 23L:1D upon arrival, and it was decreased to 18L:6D at Day 7, remained constant until Day 38, and thereafter gradually increased to 23L:1D at slaughter. The birds were vaccinated for Marek’s disease at the hatchery, and for infectious bursal,
infectious bronchitis, and Newcastle disease on the farm via drinking water. The 240 chicks were randomly allocated to 4 treatment groups, with 4 replicate pens each. The treatment groups were offered a starter (at 1 day to 11 days of age), a grower (at 12 to 22 days of age), and a finisher diet (at 23 to 42 days of age), in crumbled form (Table 1). One of the treatment groups was offered the diet with no additive and it served as a control (C), whereas the other three treatment groups were offered finisher diets further supplemented with dried orange pulp, Citrus sinensis, at 50 g/kg (OP group), or organic Se (SelSaf®, Lesaffre, Cimetiere Bourg, France) at 0.15 ppm (Se group), or OP and organic Se (OP + Se group), at 50 g/kg and 0.15 ppm, respectively, in a factorial design. The main compounds of the organic Se used were L-selenomethionine and L-selenocysteine. The treatment diets were isocaloric and isonitrogenous.

Table 1. Ingredients and calculated chemical compositions of the diets used.

| Ingredients g/kg                          | Starter, Days 1 to 10 | Grower, Days 11 to 22 | Control, Finisher, Days 23 to 42 | Orange Pulp Diet, Finisher with 50 g/kg Orange Pulp, Days 23 to 42 | Orange Pulp |
|------------------------------------------|-----------------------|-----------------------|----------------------------------|---------------------------------------------------------------|------------|
| Orange pulp                              | 0                     | 0                     | 0                                | 50                                                            |            |
| Maize                                    | 200                   | 120                   | 0                                | 200                                                           |            |
| Wheat                                    | 409.3                 | 521.6                 | 673.2                            | 370                                                           |            |
| Soybean meal, 46% CP                     | 283                   | 260                   | 220                              | 244                                                           |            |
| Sesame meal                              | 30                    | 30                    | 30                               | 50                                                            |            |
| Fish meal 72% CP                        | 12.5                  | 0                     | 0                                | 0                                                             |            |
| Soybean oil                              | 18                    | 29                    | 40                               | 50                                                            |            |
| Limestone                                | 15                    | 13                    | 13                               | 12                                                            |            |
| Monocalcium phosphate                     | 13                    | 10                    | 9                                | 10                                                            |            |
| Sodium chloride                          | 2                     | 2                     | 2                                | 2                                                             |            |
| Sodium bicarbonate                       | 2                     | 2                     | 2                                | 2                                                             |            |
| Lysine                                   | 6.4                   | 5                     | 4                                | 3.2                                                           |            |
| Methionine                               | 3.5                   | 2.8                   | 2.2                              | 2.2                                                           |            |
| Threonine                                | 1.7                   | 1                     | 1                                | 1                                                             |            |
| Choline                                  | 0.6                   | 0.6                   | 0.6                              | 0.6                                                           |            |
| Natugrain® wheat                         | 0.1                   | 0.1                   | 0.1                              | 0.1                                                           |            |
| Phytase, Natuphos®                       | 0.1                   | 0.1                   | 0.1                              | 0.1                                                           |            |
| Antioxidant (BHA; E320)                  | 0.1                   | 0.1                   | 0.1                              | 0.1                                                           |            |
| Coccidiostat, Clinacox®, 0.5%            | 0.2                   | 0.2                   | 0.2                              | 0.2                                                           |            |
| Vitamin and mineral premix †             | 2.5                   | 2.5                   | 2.5                              | 2.5                                                           |            |

| Chemical composition g/kg                | 12.89                 | 13.23                 | 13.57                            | 13.57                                                         | 58.3       |
| Metabolizable energy (MJ/kg)             | 217.8                 | 202                   | 190.1                            | 189.9                                                         | 12         |
| Crude protein                            | 55.8                  | 64                    | 71.5                             | 92.5                                                          | 101        |
| Fat                                      | 30.6                  | 30.3                  | 29.5                             | 33                                                            | 8.5        |
| Fiber                                    | 13.8                  | 12                    | 10.7                             | 10.8                                                          |            |
| Lysine                                   | 10.2                  | 9.2                   | 8.3                              | 8.5                                                           |            |
| Methionine + cystine                     | 10                    | 8.5                   | 8.5                              | 8.5                                                           |            |
| Calcium                                  | 8                     | 6.9                   | 6.7                              | 6.9                                                           |            |
| Phosphorus                               | 56.4                  | 49.7                  | 48.1                             | 48.7                                                          |            |

† The vitamin and mineral premix provided per kg of diet: 13,000 IU of vitamin A (retinyl acetate); 5000 IU of cholecalciferol; 80 mg of vitamin E (DL-α-tocopheryl acetate); 4 mg of menadione; 4.2 mg of thiamine; 8 mg of riboflavin; 6 mg of pyridoxin; 20 μg of cobalamin; 75 mg of nicotinic acid; 18 mg of pantothenic acid; 2 mg of folic acid; 240 μg of biotin; 10 mg of vitamin C (ascorbic acid); 500 mg of choline chloride; 0.23 mg of Co; 1.2 mg of I; 0.35 mg of Se; 50 mg of Fe; 140 mg of Mn; 25 mg of Cu; and 115 mg of Zn.

The OP included both the peels and seeds that remained after the processing of the orange fruits. An inclusion rate of 50 g/kg for the OP was the maximum one for a balanced broiler finisher diet. An inclusion rate of 0.15 ppm for the Se was selected by taking into
consideration that the maximum inclusion rate in broiler diets is legally limited to 0.50 ppm in the European Union, and the mineral and vitamin premix already provided 0.35 ppm of Se. The dried OP contents in the hesperidin and naringin were determined at 8.52 and 0.0223 g/kg OP, respectively [28]. Subsequently, the hesperidin and naringin contents of the experimental finisher diets were estimated at 0.426 and 0.001 g/kg, respectively.

The behavior of the broilers was videotaped daily, from 23 days of age till 42 days of age, using video cameras with infrared lighting (TX-1430OA, Turbo-X, Plaisio Computers, Athens, Greece). The numbers of birds standing over a feeder or a drinker with their heads towards the trough were recorded through a camera that was placed in a fixed position in each pen, by using time-lapse photography, every ten minutes of an hour. The data were then stored in a digital video recorder equipped with a hard disk (TX168, Telexper Inc., Union City, CA, USA).

The feed intake and the body weights of the broilers were recorded weekly, and the feed conversion ratio (g of feed:g of body gain, FCR) was calculated on a pen basis (4 pens per treatment). At Day 42 of the experiment, 8 chickens per treatment group, randomly chosen, were individually weighed, electrically stunned, and slaughtered. The carcass, liver, heart, gizzard, and fat pad weights were recorded. The chicken carcasses were then chilled, at 4 °C for 24 h, for the subsequent breast meat quality assessment, the fatty acid profile determination, and the oxidative stability measurement in the pectoralis major muscles.

The study was conducted in accordance with Directive 2010/63/EU of the European Parliament and of the Council on the protection of animals used for scientific purposes. The protocol was approved by the Research Ethics Committee of the Agricultural University of Athens, with the code number: 32/20052015.

2.2. Meat Quality

At 8 chicken carcasses per treatment group, the meat color was measured (thrice per sample) on the surfaces of the right pectoralis major muscles, after exposure to the air at room temperature for 30 min, with a Miniscan XE (HunterLab, Reston, VA, USA) chromameter, set on the L* (lightness), a* (redness), and b* (yellowness) systems. The chroma value, C* = (a*² + b*²)₁/², and the hue angle value, H* = tan⁻¹(b*/a*), were also calculated. The instrument was calibrated with a white tile and a black tile, using illuminant D65, with 0° viewing.

The pH was measured in the right pectoralis major muscle, 24 h after slaughter (pH24), by the insertion of a pH meter electrode (HI 99,163 Meat pH Temperature Meter, Hanna Instruments, Nusfalau, Romania). The calibration was performed with buffers of pH 4.0 and pH 7.0.

The cooking loss and the shear force values were also determined in the right pectoralis major muscle, which was dissected, weighed, placed into a thin-walled plastic bag, and cooked in a water bath at 80 °C for 30 min. Each sample was then cooled under tap water and equilibrated at room temperature. The muscle was weighed again for the determination of the cooking loss (%). The shear force was evaluated by cutting two 1.9-mm-wide × 10 mm × 10 mm strips from the center of the muscles parallel to the muscle fibers. The samples were then cut perpendicular to the fiber direction using a Zwick Testing Machine Model Z2.5/TN1S (Zwick GmbH and Co., Ulm, Germany), equipped with a Warner–Bratzler shear [29]. The peak force values were obtained in N/cm².

2.3. Oxidative Stability

The oxidative stability was assessed on the basis of the malondialdehyde (MDA) content. MDA is a secondary product originating from the hydrolysis of lipid hydroperoxides during lipid oxidation. In the present study, the MDA concentrations were determined in the muscle samples from 8 chickens per treatment. The measurements were implemented after storage in plastic sealed bags at 4 °C, for 1, 3, 6, and 9 days, and at −20 °C, for 90, 120, and 210 days after slaughter, by using the selective third-order derivative spectrophotometric method. One breast fillet sample from the left pectoralis major muscle per storage time
was used for the MDA determination. In brief, 2 g of each sample (two samples per chicken) were homogenized (Unidrive × 1000, CAT, M. Zipperer GmbH, Ballrechten-Dottingen, Germany) in the presence of 8 mL of aqueous trichloroacetic acid (TCA) (50 g/L), and 5 mL of butylated hydroxytoluene in hexane (8 g/L), and the mixture was centrifuged for 5 min at 3000× g. The top hexane layer was discarded, and a 2.5-mL aliquot from the bottom layer was mixed with 1.5 mL of aqueous 2-thiobarbituric acid (8 g/L), to be further incubated at 70 °C for 30 min. Following incubation, the mixture was cooled under tap water and submitted to third-order derivative (3D) spectrophotometry (Hitachi U3010 Spectrophotometer, Hitachi High-Technologies Corporation, Tokyo, Japan), in the range of 500–550 nm. The concentration of MDA (ng/g wet tissue) in the samples was determined as the height of the third-order derivative peak at 521.5 nm, by referring to the standard calibration curve, prepared using 1,1,3,3-tetraethoxypropane, the malondialdehyde precursor [30].

2.4. Fatty acid Profile

The fatty acid profile was determined in the feed samples of the experimental diets and orange pulp, and on the breast-muscle samples, from 8 chickens per treatment group, that were dissected at slaughter. Any external fat and connective tissue were dissected out of the left pectoralis major muscle samples, which were then blended in a domestic food processor (Multi Izzy C-5160, 600 W, Benroubi & Fils SA, Marousi, Greece) until smooth. The blending was performed in short bursts to ensure the homogeneous distribution of intramuscular fat in the sample. The FAs of the diets and the intramuscular fat were extracted and methylated directly, according to O’Fallon et al. [31]. Duplicate samples of 1 (±0.05) g were hydrolyzed for 1.5 h at 55 °C, in 1 N of potassium hydroxide in methanol, containing a known amount (approximately 0.5 mg) of tridecanoic acid (C13:0) as the internal standard. The potassium hydroxide was then neutralized, and the free FAs were methylated by sulphuric acid catalysis (24 N H2SO4) for 1.5 h at 55 °C. Hexane (3 mL) was added to the reaction tube, which was vortex-mixed and centrifuged at 1100× g. The supernatant hexane layer, containing the FA methyl esters, was kept at −20 °C, until analyzed by gas chromatography. A temperature-programmed run was followed on a Perkin Elmer Autosystem XL gas chromatograph, equipped with a 30 m × 0.25 mm × 0.25-µm internal diameter HP-Innowax capillary column (Agilent Technologies, J&W GC columns, Santa Clara, CA, USA), and a flame ionization detector (FID). The column temperature was programmed for 1 min at 140 °C, was raised by 2.5 °C/min to 200 °C, then to 230 °C by 1 °C/min, and was held for 1 min, and finally increased to 240 °C by 4 °C/min, and held for 10 min. Helium was the carrier gas, at a constant pressure of 18 psi, and the temperatures of both the injector and FID were set at 250 °C. The fatty acids were identified through comparison with the standards purchased from the Sigma-Aldrich Co. (FAME 37 Component; Sigma-Aldrich Co. Supelco, St. Louis, MO, USA), and quantification was achieved using the internal standard (13:0), added prior to hydrolysis. The total weights of the FAs (mg/100 g) were calculated as the sums of the areas for all the FA peaks, compared to the area for the 0.5-mg internal standard. The individual FAs were expressed as the % by weight of the total FAs [31].

2.5. Statistical Analysis

The data were subjected to an analysis of variance with the MIXED procedure of the SAS software [32], with the dietary treatment with OP and Se, and their interaction as the fixed effects in the factorial design. The mean comparisons were tested at a 0.05 significance level with a Bonferroni adjustment. The synergistic effect of the combined supplementation of OP and Se was tested with pairwise comparisons between the OP + Se group means and each of the OP group and Se group means. When the OP + Se group mean was different from both the OP and Se group means, a synergistic effect was considered significant, in accordance with the highest single-agent reference model, which assumes that a synergistic compound combination should produce additional benefits, on top of what the compounds can achieve alone [33]. The results are presented as least square means ± SEM.
3. Results

Table 2 presents the FA profiles of the experimental diets and orange pulp used in the present experiment. No significant differences were determined among the experimental diets, apart from an increase in n-3 fatty acids, and a slight increase in the monounsaturated fatty acid (MUFA) content, whereas the saturated fatty acids (SFA) were slightly decreased in the OP-supplemented diets.

Table 2. Fatty acid (FA) profiles of orange pulp and experimental diets (% of total FA).

| FA     | C     | OP   | Se    | OP + Se | Orange Pulp |
|--------|-------|------|-------|---------|-------------|
| 12:0   | 0.01  | 0.01 | 0.01  | 0.01    | 0.02        |
| 14:0   | 0.00  | 0.09 | 0.12  | 0.09    | 0.37        |
| 15:0   | 0.03  | 0.03 | 0.04  | 0.03    | 0.08        |
| 16:0   | 14.28 | 12.75| 12.71 | 12.47   | 17.73       |
| 7c16:1 | 0.04  | 0.04 | 0.05  | 0.04    | 0.27        |
| 9c16:1 | 0.15  | 0.14 | 0.16  | 0.13    | 1.70        |
| 17:0   | 0.11  | 0.11 | 0.10  | 0.10    | 0.12        |
| 17:1   | 0.05  | 0.06 | 0.06  | 0.06    | 0.13        |
| 18:0   | 4.91  | 4.49 | 4.23  | 4.37    | 7.81        |
| 9c18:1 | 24.52 | 26.78| 26.55 | 26.40   | 26.70       |
| 11c18:1| 0.00  | 0.00 | 0.00  | 0.00    | 1.71        |
| 18:2n-6| 48.02 | 47.00| 48.01 | 48.08   | 29.80       |
| 18:3n-6| 0.02  | 0.02 | 0.02  | 0.01    | 0.19        |
| 18:3n-3| 4.49  | 5.86 | 4.97  | 5.66    | 2.56        |
| 20:0   | 0.52  | 0.45 | 0.44  | 0.44    | 0.09        |
| 20:1n-9| 0.31  | 0.27 | 0.33  | 0.27    | 0.33        |
| 20:2   | 0.06  | 0.06 | 0.06  | 0.06    | 0.50        |
| 20:3n-6| 0.03  | 0.03 | 0.03  | 0.03    | 0.49        |
| 20:4n-6| 0.01  | 0.01 | 0.01  | 0.01    | 2.36        |
| 20:3n-3| 0.01  | 0.01 | 0.01  | 0.01    | 0.08        |
| 20:5n-3| 0.05  | 0.05 | 0.05  | 0.01    | 0.19        |
| 22:0   | 0.38  | 0.35 | 0.31  | 0.34    | 0.03        |
| 22:1   | 0.08  | 0.05 | 0.09  | 0.07    | 0.03        |
| 22:2   | 0.60  | 0.53 | 0.56  | 0.53    | 1.30        |
| 22:4n-6| 0.00  | 0.01 | 0.01  | 0.01    | 0.66        |
| 22:5n-3| 0.01  | 0.05 | 0.01  | 0.00    | 0.55        |
| 22:6n-3| 0.08  | 0.03 | 0.10  | 0.03    | 0.46        |
| SFA ‡  | 20.2  | 18.27| 17.96 | 17.85   | 26.25       |
| MUFA ‡ | 25.2  | 27.33| 27.23 | 26.96   | 30.86       |
| PUFA ‡ | 53.4  | 53.65| 53.81 | 54.43   | 39.16       |
| n-3    | 4.64  | 6.01 | 5.13  | 5.71    | 3.85        |
| n-6    | 48.08 | 47.05| 48.06 | 48.14   | 33.51       |
| n-6/n-3| 10.37 | 7.89 | 9.42  | 8.44    | 8.70        |

† C: diet with no additive; OP: diet supplemented with 50 g orange pulp per kg feed; Se: diet supplemented with 0.15 ppm Se; OP + Se: diet supplemented with 0.15 ppm Se and 50 g orange pulp per kg feed. ‡ SFA: saturated FA; MUFA: monounsaturated FA; PUFA: polyunsaturated FA.

Table 3 presents the results on the OP and/or Se dietary supplementation on the broiler performances and carcass traits. The performances and the internal organ weights of the broilers were not affected by dietary supplementation with OP and/or Se ($p > 0.05$). However, the dressing percentage was lower in the group of birds fed the OP diet, in comparison with groups fed the C and Se diets ($p < 0.05$). At the same time, no differences were found in the percentages of chickens standing at the feeder (Pf) or the drinker (Pw) among the experimental groups ($p > 0.05$) (Table 3).
Table 3. Effects of dietary supplementation with orange pulp (*Citrus sinensis*) and/or Se on broiler performance, feeding and drinking behaviors, and carcass and internal organ weights, at 42 days of age (*n* = 8).

| Parameter | OP | Se | OP × Se | Source of Variation |
|-----------|----|----|---------|---------------------|
| BW, g | 2730 | 2671 | 2636 | 2765 | 71 | 2741 | 2532 | 2720 | 2809 | 101 | 0.556 | 0.213 | 0.150 |
| Cumulative FI, g | 4552 | 4463 | 4507 | 4488 | 92 | 4607 | 4407 | 4457 | 4519 | 130 | 0.603 | 0.889 | 0.333 |
| FCR, g/g | 1.72 | 1.73 | 1.77 | 0.02 | 1.73 | 1.71 | 1.72 | 1.74 | 0.03 | 0.965 | 0.669 | 0.444 |
| Carcass weight, g | 2112 | 2057 | 2013 | 2133 | 57 | 2117 | 1911 | 2108 | 2159 | 81 | 0.348 | 0.150 | 0.122 |
| DP, % | 77.3 | 76.1 | 76.4 | 77.1 | 0.30 | 77.3 | 75.5 | 77.4 | 76.8 | 0.4 | 0.009 | 0.093 | 0.196 |
| Liver, % | 1.71 | 1.70 | 1.71 | 0.05 | 1.64 | 1.76 | 1.77 | 1.65 | 0.07 | 0.812 | 0.945 | 0.072 |
| Heart, % | 0.40 | 0.43 | 0.40 | 0.02 | 0.40 | 0.46 | 0.41 | 0.39 | 0.02 | 0.431 | 0.149 | 0.089 |
| Gizzard, % | 1.28 | 1.22 | 1.25 | 1.26 | 0.07 | 1.27 | 1.23 | 1.30 | 1.37 | 0.14 | 0.252 | 0.455 | 0.517 |
| Fat pad, % | 7.22 | 7.30 | 7.58 | 6.94 | 0.35 | 7.39 | 7.89 | 7.26 | 6.83 | 0.47 | 0.887 | 0.217 | 0.362 |

a, b means in the OP × Se row sharing no common superscript are statistically different (*p* < 0.05). † C: diet with no additive; OP: diet supplemented with 50 g orange pulp per kg feed; Se: diet supplemented with 0.15 ppm Se; OP + Se: diet supplemented with 0.15 ppm Se and 50 g orange pulp per kg of feed. ‡ BW: body weight; FI: feed intake; FCR: feed conversion ratio; DP: dressing percentage. % of BW; PF: percentage of chickens standing at the feeder; Pw: percentage of chickens standing at the drinker. n for FI, and FCR = 4 replicate pens.

Among the meat quality trait measurements (color, cooking loss, tenderness, and pH24), it was only pH24 that was altered, and this change was due to OP supplementation (Table 4). The meat from the birds fed with OP (alone or in combination with Se) exhibited lower pH24 values (*p* < 0.05), in comparison with the meat from the controls.

Table 4. Effect of dietary supplementation with orange pulp (*Citrus sinensis*) and/or Se on broiler meat quality at 42 days of age (*n* = 8).

| Parameter | OP | Se | OP × Se | Source of Variation |
|-----------|----|----|---------|---------------------|
| pH24 | 5.96 | 5.83 | 5.92 | 5.87 | 0.02 | 5.98 | 5.85 | 5.93 | 5.90 | 0.03 | <0.001 | 0.128 | 0.896 |
| L* | 56.7 | 58.6 | 57.5 | 57.8 | 0.77 | 56.5 | 58.5 | 56.9 | 58.6 | 1.1 | 0.095 | 0.881 | 0.891 |
| a* | 3.50 | 3.65 | 3.65 | 3.50 | 0.26 | 3.47 | 3.82 | 3.53 | 3.47 | 0.36 | 0.686 | 0.686 | 0.579 |
| b* | 12.4 | 13.0 | 12.6 | 12.9 | 0.33 | 11.1 | 12.6 | 12.7 | 12.4 | 0.80 | 0.220 | 0.531 | 0.230 |
| H* | 74.4 | 74.4 | 73.9 | 74.8 | 0.91 | 73.9 | 73.9 | 74.8 | 74.9 | 1.29 | 0.973 | 0.491 | 0.987 |
| Cooking loss (%) | 14.8 | 15.7 | 15.5 | 15.0 | 0.6 | 15.1 | 15.9 | 14.4 | 15.6 | 0.89 | 0.283 | 0.598 | 0.786 |
| Shear force, N/cm² | 23.6 | 23.9 | 23.2 | 24.3 | 1.5 | 24.1 | 22.4 | 23.1 | 25.4 | 2.1 | 0.893 | 0.618 | 0.350 |

a, b means in the OP × Se row sharing no common superscript are statistically different (*p* < 0.05). † C: diet with no additive; OP: diet supplemented with 50 g orange pulp per kg feed; Se: diet supplemented with 0.15 ppm Se; OP + Se: diet supplemented with 0.15 ppm Se and 50 g orange pulp per kg of feed. ‡ L*: lightness; a*: redness; b*: yellowness; H*: hue angle; C*: chroma.

The meat oxidative stability results are presented in Table 5. Lower MDA values in the treatment groups compared to the controls were detected throughout the entire storage period, which is indicative of a reduced rate of lipid peroxidation in the meat from birds fed with OP and/or Se. However, a significant effect (*p* < 0.05) was determined as the storage period increased. Significantly lower MDA values were detected in the breast meat samples of the OP + Se group, from Day 9 of storage and onwards, of the Se group during long-term frozen storage (90 to 210 days), and of the OP group at 150 days of storage, in comparison with the control group (*p* < 0.05). Nevertheless, the factorial analysis results show that the diets supplemented with OP or Se resulted in reduced MDA percentages in the breast meat stored for more than 90 or 9 days, respectively (*p* < 0.05). A synergistic effect of the combined supplementation of OP and Se was determined during the long-term frozen storage period from 150 to 210 days (*p* < 0.05). In the aforementioned period, the OP + Se group exhibited significantly lower MDA values in comparison with either the OP group or the Se group alone (*p* < 0.05).
Table 5. Effects of dietary supplementation with orange pulp (Citrus sinensis) and/or Se on the broiler meat (pectoralis major) oxidative stability during storage (ng MDA/g meat) (n = 8).

| Storage Time †, Days | Treatment † | Source of Variation |
|----------------------|-------------|---------------------|
|                      | OP          | Se                  | OP × Se               |
| −                    | +           | +                   | SEM                   |
| 1                    | 9.43        | 8.08                | 9.99                  | 7.93                |
| 3                    | 12.3        | 10.8                | 12.0                 | 11.1               |
| 6                    | 17.8        | 16.5                | 17.9                 | 16.4               |
| 9                    | 43.2        | 39.2                | 46.9                 | 35.5               |
| 90                   | 16.9        | 14.0                | 17.8                 | 13.1               |
| 150                  | 32.4        | 26.3                | 32.8                 | 25.9               |
| 210                  | 44.0        | 37.9                | 43.5                 | 38.4               |

‡, †, ‡ means in the OP × Se row sharing no common superscript are statistically different (p < 0.05). A denotes that the OP + Se group mean is different from both the OP and Se group means in pairwise comparisons (p < 0.05), which is indicative of a synergistic effect. B: diet with no additive; OP: diet supplemented with 50 g orange pulp per kg feed; Se: diet supplemented with 0.15 ppm Se; OP + Se: diet supplemented with 0.15 ppm Se and 50 g orange pulp per kg feed. † stored for 1, 3, 6, and 9 days at 4 °C, and for 90, 150, and 210 days at −20 °C.

The FA profiles of the lipid fractions of the breast meat are presented in Table 6. The dietary modification due to OP supplementation decreased the percentage of palmitoleic acid (9C16:1) by 38.4%, when OP alone was fed, and by 31%, when fed in combination with Se, compared to the C group. The results of the factorial analysis show that the OP groups exhibited increased percentages of both n-3 and n-6 FAs (3.57 and 32.14% of total FAs, respectively), in comparison with the C and Se groups (3.11 and 27.71% of total FAs, for n-3 and n-6 FAs, respectively, p < 0.05). The alpha-linolenic acid (ALA, 18:3n-3) concentration exhibited increased percentages for the OP + Se group, compared to the Se group, by 21.3% (p < 0.05). However, the most notable PUFA increase observed was for the OP + Se group, compared to the Se group, by 21.3% (p < 0.05).

Table 6. Effects of dietary supplementation with orange pulp (Citrus sinensis) and/or Se on broiler breast meat fatty acid (FA) profiles at 42 days of age (% of total FA, n = 8).

| Parameter | Treatment † | Source of Variation |
|-----------|-------------|---------------------|
| OP        | Se          | OP × Se             |
| −         | +           | +                   | SEM                   |
| Total FA weight (mg 100 g −1 meat) | 1352.4 | 1317.2 | 1215.2 | 1454.5 | 163.8 | 1226.5 | 1308.0 | 1478.4 | 1430.6 | 231.6 | 0.880 | 0.310 | 0.957 |

FA

12:0 | 0.022 | 0.016 | 0.021 | 0.018 | 0.003 | 0.028 | 0.014 | 0.018 | 0.018 | 0.005 | 0.180 | 0.552 | 0.152 |
14:0 | 0.50 | 0.43 | 0.47 | 0.45 | 0.020 | 0.020 | 0.51 | 0.44 | 0.49 | 0.42 | 0.027 | 0.014 | 0.467 | 0.982 |
15:0 | 0.092 | 0.086 | 0.090 | 0.088 | 0.003 | 0.091 | 0.090 | 0.093 | 0.083 | 0.004 | 0.152 | 0.532 | 0.305 |
16:0 | 22.70 | 20.34 | 21.44 | 21.60 | 1.270 | 21.42 | 21.45 | 21.45 | 23.97 | 19.23 | 1.800 | 0.870 | 0.541 | 0.602 |
16:1| 9c16:1 | 0.34 | 0.27 | 0.30 | 0.32 | 0.020 | 0.020 | 0.32 | 0.27 | 0.35 | 0.28 | 0.029 | 0.035 | 0.497 | 0.728 |
9c16:1 | 2.17 | 1.52 | 1.87 | 1.81 | 0.120 | 2.32 | 1.43 | 2.02 | 1.60 | 0.170 | <0.001 | 0.727 | 0.176 |
17:0 | 0.14 | 0.15 | 0.14 | 0.14 | 0.009 | 0.12 | 0.15 | 0.14 | 0.14 | 0.013 | 0.402 | 0.823 | 0.167 |
17:1 | 0.19 | 0.20 | 0.20 | 0.19 | 0.017 | 0.18 | 0.22 | 0.20 | 0.18 | 0.024 | 0.700 | 0.642 | 0.192 |
18:0 | 10.41 | 10.36 | 10.56 | 10.20 | 1.028 | 9.54 | 11.59 | 11.28 | 9.12 | 1.454 | 0.972 | 0.805 | 0.159 |
9c18:1 | 23.08 | 21.67 | 22.45 | 22.36 | 0.965 | 24.02 | 20.88 | 22.15 | 22.46 | 1.365 | 0.308 | 0.918 | 0.218 |
11c18:1 | 1.87 | 1.69 | 1.80 | 1.76 | 0.060 | 1.97 | 1.63 | 1.77 | 1.75 | 0.085 | 0.043 | 0.677 | 0.072 |
18:2n-6 | 22.92 | 27.85 | 24.50 | 25.47 | 1.140 | 23.34 | 25.66 | 22.50 | 28.45 | 1.612 | 0.016 | 0.551 | 0.269 |
18:3n-6 | 0.19 | 0.16 | 0.19 | 0.20 | 0.013 | 0.014 | 0.14 | 0.21 | 0.19 | 0.018 | 0.110 | 0.039 | 0.443 |
18:3n-3 | 1.56 | 2.09 | 1.77 | 1.88 | 0.108 | 1.58b | 1.96b | 1.54b | 2.22b | 1.053 | 0.001 | 0.465 | 0.344 |
20:0 | 0.09 | 0.10 | 0.09 | 0.10 | 0.008 | 0.008 | 0.08 | 0.10 | 0.010 | 0.011b | 0.773 | 0.828 | 0.146 |
20:1n-9 | 0.23 | 0.23 | 0.25 | 0.21 | 0.014 | 0.27 | 0.23 | 0.20 | 0.22 | 0.020 | 0.737 | 0.042 | 0.106 |
20:2 | 0.55 | 0.60 | 0.57 | 0.58 | 0.040 | 0.58 | 0.56 | 0.52 | 0.65 | 0.056 | 0.331 | 0.785 | 0.223 |
20:3n-6 | 0.60 | 0.56 | 0.61 | 0.56 | 0.041 | 0.67 | 0.55 | 0.54 | 0.58 | 0.059 | 0.503 | 0.412 | 0.207 |
20:4n-6 | 3.25 | 3.55 | 3.47 | 3.32 | 0.251 | 3.41 | 3.53 | 3.08 | 3.56 | 0.355 | 0.410 | 0.677 | 0.619 |
Table 6. Cont.

| Parameter          | OP     | Se     | OP x Se | Source of Variation |
|--------------------|--------|--------|---------|---------------------|
| OP Se OP × Se      |        |        |         |                     |
| 20:3n-3            | 0.08   | 0.09   | 0.08    | 0.09                |
| 20:5n-3            | 0.19   | 0.17   | 0.19    | 0.17                |
| 22:0               | 0.03   | 0.03   | 0.03    | 0.03                |
| 22:1               | 0.02   | 0.01   | 0.02    | 0.01                |
| 22:2               | 1.91   | 1.86   | 1.96    | 1.79                |
| 22:4n-6            | 0.74   | 0.81   | 0.79    | 0.76                |
| 22:5n-3            | 0.65   | 0.70   | 0.68    | 0.67                |
| 22:6n-3            | 0.63   | 0.52   | 0.60    | 0.55                |
| SFA               | 33.97  | 31.50  | 32.84   | 32.63               |
| MUFA              | 27.90  | 25.58  | 26.88   | 26.60               |
| PUFA              | 33.28  | 38.17  | 35.40   | 36.04               |
| n-3               | 32.84  | 32.63  | 32.52   | 32.43               |
| n-6               | 27.71  | 32.14  | 29.53   | 30.32               |
| n-6/n-3           | 9.07   | 9.00   | 8.88    | 9.17                |

a,b means in the OP × Se row sharing no common superscript are statistically different (p < 0.05). C: diet with no additive; OP: diet supplemented with 50 g orange pulp per kg feed; Se: diet supplemented with 0.15 ppm Se; OP + Se: diet supplemented with 0.15 ppm Se and 50 g orange pulp per kg feed. SFA: saturated FA; MUFA: monounsaturated FA; PUFA: polyunsaturated FA.

4. Discussion

The performance and carcass traits were not affected by OP and/or organic Se dietary supplementation, apart from a reduced carcass dressing percentage (DP) in the group of birds fed with OP. This reduction may be attributed to the increased fiber content, by 10%, of the OP diet, in comparison with the control diet, 33 vs. 29.5 g/kg, respectively. The increased fiber levels in the broiler rations are associated with the increased digestive tract weight [34] and, consequently, with the reduced carcass yield. Our results are in partial agreement with Murao et al. [12], who detected a reduced DP in broilers fed with citrus pulp at the level of 10%, but not at 5%, of the diet. On the other hand, in the aforementioned study, the broiler performance was deteriorated because of the high-fiber content of the citrus pulp used (insoluble and soluble fiber contents more than 30%), whereas, in the present study, the fiber content of the orange pulp was much lower, at 10.1% [28], and the performance traits were unaffected by the OP supplementation. The broiler performance in the present study was also not influenced by the dietary supplementation with organic Se, which is in agreement with a number of studies related to organic selenium supplementation in broiler chickens, at dosages ranging from 0.1 to 0.5 ppm [35–39]. The data concerning the growth performance parameters are also supported by the behavioral recordings, since no significant differences in the percentages of chickens standing at the feeder (Pf) or the drinker (Pw) were observed among the OP and/or organic Se groups.

The cooking loss, shear force, and the color attributes of the broiler meat remained unaffected by OP and/or Se dietary supplementation. However, the pH24 values were lower in the breast muscles from the birds fed with OP, in comparison with the controls. In close agreement with our study, Mourao et al. [12] report that the meat from broilers fed with citrus pulp at 10% exhibited reduced pH24 values, in comparison with the meat from broilers fed with 5% or 0% citrus pulp. On the other hand, it has been reported that ostriches fed with a diet supplemented with citrus pulp at 20% showed increased meat pH values and, consequently, decreased cooking losses, in comparison with the controls [40]. However, in our study, not only was the pH lower in the meat from broilers fed with OP compared to the controls, but this reduction was also not accompanied by an increased cooking loss, which was unaffected by the dietary intervention.

The meat oxidative stability of the broilers fed with OP + Se was improved during storage of more than nine days. Dietary supplementation with OP and/or Se alone also enhanced the meat oxidative stability, though to a lesser extent, in comparison with the supplementation of a combination of OP and Se. The favorable combined effects of OP and Se are attributed to their synergistic effects, which were determined in the present study. The antioxidant properties of added Se and hesperidin, which were present in the added citrus pulp at a rate of 0.426 g/kg, are most likely responsible for the beneficial
effects of the experimental diets in the broiler meat. The dietary supplementation of broiler chickens with hesperidin at 0.75 and 1.5 g/kg feed [9], or at 5 mg/kg feed [13], or at 1.5 and 3 g/kg feed [8], improved the meat oxidative stability, without any negative side effects on the performance or the meat quality. However, undetermined substances found in citrus pulp, such as carotenoids or other phenolic compounds, may have also contributed to the improved meat oxidative stability in the OP-supplemented diets. An extra group of birds, offered a diet supplemented with pure hesperidin at 0.426 g/kg, would assist us in answering the question of whether the improved meat oxidative stability determined in the OP group was attributed solely to hesperidin or not. Unfortunately, our resources did not allow for an expansion of the experimental design with the addition of an extra treatment.

Dietary supplementation with organic Se beneficially improves the meat oxidative stability, and, subsequently, the meat shelf life, of broiler chickens, at doses of 0.3–0.6 ppm [41], 0.1–0.4 ppm [16], 0.5 ppm [42], 0.3 ppm [43], or 0.15–3 ppm [44], and of turkeys at the level of 0.3 ppm [45], in agreement with the present study.

The antioxidant activity of the flavonoid, hesperidin, is presumed to be analogous to that of vitamin E, and this is attributed to its scavenging property of lipid peroxyl radicals, which, in turn, terminates the chain reactions of the lipid peroxidation in the cell membrane [46]. On the other hand, Se is strongly associated with the biological endogenous antioxidant defense system because it is an essential constituent for the formation of the antioxidant enzyme, glutathione peroxidase (GSH-Px), which, along with the non-Se-containing enzymes, such as catalase and superoxide dismutase, comprise the primary antioxidant defense system [43].

In the present study, we found the presence of a synergism between the citrus pulp and the Se. The substances under investigation exhibited synergistic action and, therefore, their antioxidant activity was enhanced when they were fed together. The interaction among natural antioxidants, which may result in an enhanced or decreased oxidative stability of the meat, has been reported in a number of studies. A combination of rosemary and green tea extracts, and a combination of green tea and natural tocopherols, exhibited synergistic antioxidant action in chicken patties when fed to broiler chickens at 200 mg/kg [47]. Synergistic antioxidant effects in meat have also been observed between oregano and rosemary essential oils, when fed in broilers at a dose of 300 mg/kg [48], and between oregano oil and α-tocopheryl acetate, when fed to turkeys at 200 mg/kg [49]. On the other hand, a considerable decrease in the antiradical activity values of an ethanol solution containing resveratrol, catechin, and quercetin was observed, in comparison with each of the aforementioned phenol compounds alone, because of an unfavorable interaction among the phenols [50]. However, this decreased antiradical activity of the combination of the antioxidants was measured by the α, α-diphenyl-β-picrylhydrazyl (DPPH) free radical scavenging method, and it has not been tested in vivo.

The synergistic action between Se and natural antioxidants has already been reported. The combined supplementation of Se and vitamin E improved the antioxidant status of the skeletal muscles of heat-stressed broiler chickens, more than Se and vitamin E alone [51]. The dietary supplementation of vitamin E in combination with organic Se has a synergistic effect in minimizing lipid peroxidation, and it improves the antioxidative status in the seminal plasma of cockerels, which may result in an increased spermatozoa count and enhanced motility, and a reduced percentage of dead spermatozoa under heat-stress conditions [52]. It has been proposed that the synergistic effects involve two antioxidants, of which one reacts with the peroxy radical, and is consumed, and the second regenerates the first, effectively sparing [53]. A sparing effect of dietary grape pomace, rich in natural antioxidants, on liver vitamin E has also been observed in broiler chickens [54].

Dietary modification by OP supplementation significantly improved the breast meat FA profiles because of the increases in the health-promoting ALA and PUFA contents. A mean increase in the ALA content by 25.4% was determined between the OP-supplemented groups and the non-OP-supplemented groups. Therefore, the supplementation of broiler diets with OP not only improved the antioxidant properties of the breast meat stored in
the refrigerator, but also enhanced its nutritional value through fortification with health-promoting n-3 fatty acids and PUFAs. The observed increase in the n-3 fatty acid content may be attributed to the increased n-3 fatty acid content of the OP-supplemented diets, in comparison with the non-OP-supplemented diets. On the other hand, the increased PUFA content in the breast muscles of broilers fed with OP may possibly be attributed to the protective action of the OP antioxidants on PUFAs from the oxidation breakdown, since no PUFA differences were observed among the experimental diets. In agreement with our study, the PUFAs and the ALA content in broiler meat were increased as a result of the dietary supplementation with citrus pulp at 10% of the feed [12]. A significant increase in the PUFA content has also been reported for the meat of ostriches fed with dried citrus pulp at 20% of the feed [40]. However, in the aforementioned studies, the increase in the PUFA content was accompanied by decreases in both the MUFA and SFA intramuscular fat contents, and no effect of dried citrus pulp on the n-3 fatty acid content in ostrich meat was observed. Species and diet differences may explain the discrepancies found among the published studies.

5. Conclusions
The dietary supplementation of broiler chicks with OP and organic Se, at 50 g/kg and 0.15 ppm, respectively, improved the oxidative stability of breast meat during storage, with the improvement being more noticeable for long-term frozen storage. The observed synergistic action of the OP and organic Se suggests that the combined supplementation of the byproduct of the citrus industry, which is rich in natural antioxidants and Se, supports both the first-line enzymatic and second-line nonenzymatic antioxidant defense systems, with beneficial effects on the product shelf life. Dietary modification by OP supplementation improved the breast meat nutritional value through the fortification with PUFAs and, more importantly, the health-promoting ALA n-3 fatty acid. Nevertheless, the beneficial effects observed in the present study were not accompanied by negative side effects on the performance or meat quality, suggesting that the inclusion of OP into broiler diets, at 50 g/kg of feed, along with organic Se, may improve the meat nutritional value and the shelf life, with benefits for both the farmer and the consumer. More research is required in order to elucidate the underlying mechanisms that explain the synergistic action between OP and organic Se.

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References
1. Vasta, V.; Luciano, G. The effects of dietary consumption of plants secondary compounds on small ruminants’ products quality. Small Rumin. Res. 2011, 101, 150–159. [CrossRef]
2. Pisoschi, A.M.; Pop, A. The role of antioxidants in the chemistry of oxidative stress: A review. *Eur. J. Med. Chem.* 2015, 97, 55–74. [CrossRef] [PubMed]

3. Embusco, M.E. Spices and herbs: Natural sources of antioxidants—A mini review. *J. Funct. Foods* 2015, 18, 811–819. [CrossRef]

4. Simitzis, P.E.; Deligeorgis, S.G. Agroindustrial By-Products and Animal Products: A Great Alternative for Improving Food-Quality Characteristics and Preserving Human Health. In *Food Quality: Balancing Health and Disease. Handbook of Food Bioengineering*, 1st ed.; Holian, A.M., Grumescu, A.M., Eds.; Academic Press Elsevier: London, UK, 2018; Volume 13, pp. 253–290.

5. Bampidis, V.A.; Robinson, P.H. Citrus by-products as ruminant feeds: A review. *Anim. Feed Sci. Technol.* 2006, 128, 175–217. [CrossRef]

6. Kamboh, A.A.; Arain, M.A.; Mughal, M.J.; Zaman, A.; Arain, Z.M.; Soomro, A.H. Flavonoids: Health promoting phytochemicals for animal production—A review. *J. Anim. Health Prod.* 2015, 3, 6–13. [CrossRef]

7. Ebrahimi, A.; Qolbi, A.A.A.; Seidavi, A. The effects of different levels of dried *Citrus sinensis* peel on broiler carcass quality. *Acta Sci. Vet.* 2013, 41, 1169.

8. Simitzis, P.E.; Symeon, G.K.; Charismiadou, M.A.; Ayoutanti, A.G.; Deligeorgis, S.G. The effects of dietary hesperidin supplementation on broilers performance and chicken characteristics. *Cm. J. Anim. Sci.* 2011, 91, 275–282. [CrossRef]

9. Goliomytis, M.; Karstonas, N.; Charismiadou, M.A.; Symeon, G.; Simitzis, P.E.; Deligeorgis, S.G. The influence of naringin or hesperidin dietary supplementation on broiler meat quality and oxidative stability. *PLoS ONE* 2015, 10, e0141652. [CrossRef] [PubMed]

10. Abbasi, H.; Seidavi, A.; Liu, W.; Asadpour, L. Investigation on the effect of different levels of dried sweet orange (*Citrus sinensis*) pulp on performance, carcass characteristics and physiological and biochemical parameters in broiler chicken. *Saudi J. Biol. Sci.* 2015, 22, 139–146. [CrossRef]

11. Jiang, X.R.; Zhang, H.J.; Wang, J.; Wu, S.G.; Yue, H.Y.; Lü, H.Y.; Cui, H.; Bontempo, V.; Qi, G.H. Effect of dried tangerine peel extract supplementation on the growth performance and antioxidant status of broiler chicks. *Ital. J. Anim. Sci.* 2016, 15, 642–648. [CrossRef]

12. Mourão, J.L.; Pinheiro, V.M.; Prates, J.A.M.; Bessa, R.J.B.; Ferreira, L.M.A.; Fontes, C.M.G.A.; Ponte, P.I.P. Effect of dietary dehydrated citrus pulp and citrus pulp on the performance and meat quality of broiler chickens. * Poult. Sci.* 2008, 87, 733–743. [CrossRef] [PubMed]

13. Kamboh, A.A.; Zhu, W.Y. Individual and combined effects of genistein and hesperidin supplementation on meat quality in meat-type broiler chickens. *J. Sci. Food Agric.* 2013, 93, 3362–3367. [CrossRef] [PubMed]

14. Ahmed, S.T.; Mun, H.S.; Islam, M.M.; Kim, S.S.; Hwang, J.A.; Kim, Y.J.; Yang, C.J. Effects of *Citrus junos* by-products fermented with multistrain probiotics on growth performance, immunity, caecal microbiology and meat oxidative stability in broilers. *Br. Poult. Sci.* 2014, 55, 540–547. [CrossRef] [PubMed]

15. Surai, P.F. *Natural Antioxidants in Avian Nutrition and Reproduction*; Nottingham University Press: Nottingham, UK, 2002.

16. Bakhshalinejad, R.; Akbari Moghadam Kakhki, R.; Zoidis, E. Effects of different dietary sources and levels of selenium supplements on growth performance, antioxidant status and immune parameters in Ross 308 broiler chickens. *Br. Poult. Sci.* 2015, 59, 81–91. [CrossRef] [PubMed]

17. Zoidis, E.; Papadomichelakis, G.; Pappas, A.C.; Theodorou, G.; Fegeros, K. Effects of selenium and cadmium on breast muscle fatty-acid composition and gene expression of liver antioxidant proteins in broilers. *Antioxidants* 2019, 8, 147. [CrossRef] [PubMed]

18. Food and Drug Administration (FDA). Food and Drug Administration Approves Food Additive Petition for Selenium Yeast. In *Food and Drug Administration Veterinarian Newsletter (July/August)*; Food and Drug Administration (FDA): Washington, DC, USA, 2000.

19. Wang, Y.; Zhan, X.; Yuan, D.; Zhang, X.; Wu, R. Influence of dietary selenomethionine supplementation on performance and selenium status of broiler breeders and their subsequent progeny. *Biol. Trace Elem. Res.* 2011, 143, 1497–1507. [CrossRef]

20. Kim, Y.; Mahan, D. Comparative effects of high dietary levels of organic and inorganic selenium on selenium toxicity of growing-finishing pigs. *J. Anim. Sci.* 2001, 79, 942–948. [CrossRef]

21. Attia, Y.A.; Abdalah, A.A.; Zeweil, H.S.; Bovera, F.; Tag El-Din, A.A.; Araf, M.A. Effect of inorganic or organic selenium supplementation on productive performance, egg quality and some physiological traits of dual-purpose breeding hens. *Czech J. Anim. Sci.* 2010, 55, 505–519. [CrossRef]

22. Hassan, F.; Mobarez, S.; Mohamed, M.; Attia, Y.; Mekawy, A.; Mahrose, K. Zinc and/or Selenium Enriched Spirulina as Antioxidants in Growing Rabbit Diets to Alleviate the Deleterious Impacts of Heat Stress during Summer Season. *Animals* 2021, 11, 756. [CrossRef]

23. Cai, S.J.; Wu, C.X.; Gong, L.M.; Song, T.; Wu, H.; Zhang, L.Y. Effects of nano-selenium on performance, meat quality, immune function, oxidation resistance, and tissue selenium content in broilers. *Poult. Sci.* 2012, 91, 2532–2539. [CrossRef]

24. Payne, R.; Southern, L. Comparison of inorganic and organic selenium sources for broilers. *Poult. Sci.* 2005, 84, 898–902. [CrossRef] [PubMed]

25. Dlouhá, G.; Ševčíková, S.; Dokoupilová, A.; Zita, L.; Heindl, J.; Škrivan, M. Effect of dietary selenium sources on growth performance, breast muscle selenium, glutathione peroxidase activity and oxidative stability in broilers. *Czech J. Anim. Sci.* 2008, 53, 265–269. [CrossRef]

26. Ševčíková, S.; Škrivan, M.; Dlouhá, G.; Koucký, M. The effect of selenium source on the performance and meat quality of broiler chickens. *Czech J. Anim. Sci.* 2006, 51, 449–457. [CrossRef]
27. Zhou, X.; Wang, Y. Influence of dietary nano elemental selenium on growth performance, tissue selenium distribution, meat quality, and glutathione peroxidase activity in guangxi yellow chicken. Poult. Sci. 2011, 90, 680–686. [CrossRef]

28. Goliomytis, M.; Kostaki, A.; Avgoulas, G.; Lantzouraki, D.Z.; Stiapi, E.; Zoupoulakis, P.; Simitzis, P.; Deligeorgis, S.G. Dietary supplementation with orange pulp (Citrus sinensis) improves egg yolk oxidative stability in laying hens. Anim. Feed Sci. Technol. 2018, 244, 28–35. [CrossRef]

29. Cason, J.A.; Lyon, C.E.; Papa, C.M. Effect of muscle opposition during rigor on development of broiler breast meat tenderness. Poult. Sci. 1997, 76, 785–787. [CrossRef]

30. Botsoglou, N.A.; Fletouris, D.J.; Papageorgiou, G.E.; Vassilopoulos, V.N.; Mantis, A.J.; Trakatellis, A.G. A rapid, sensitive and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissues, food and feedstuffs samples. J. Agric. Food Chem. 1994, 42, 1931–1937. [CrossRef]

31. O’Fallon, J.V.; Busboom, J.R.; Nelson, M.L.; Gaskins, C.T. A direct method for fatty acid methylester synthesis: Application to wet meat tissues, oils, and feedstuffs. J. Anim. Sci. 2007, 85, 1511–1521. [CrossRef]

32. Sas/Stat. Statistical Analysis Systems, Version 9.1.3; SAS Institute Inc.: Cary, NC, USA, 2005.

33. Yadav, B.; Wennerberg, K.; Aittokallio, T.; Tang, J. Searching for Drug Synergy in Complex Dose–Response Landscapes Using an Interaction Potency Model. Comput. Struct. Biotechnol. J. 2015, 13, 504–513. [CrossRef]

34. Chen, G.; Wu, J.; Li, C. The effect of different selenium levels on production performance and biochemical parameters of broilers. Ital. J. Anim. Sci. 2013, 12, 486–491. [CrossRef]

35. Rama Rao, S.V.; Prakash, B.; Raju, M.V.L.N.; Panda, A.K.; Poonam, S.; Murthy, O.K. Effect of supplementing organic selenium on performance, carcass traits, oxidative parameters and immune responses in commercial broiler chickens. Asian-Australas. J. Anim. Sci. 2013, 26, 247–252.

36. Zdunczyk, Z.; Gruzauskas, R.; Semaskaite, A.; Juskiewicz, J.; Raceviciute-Stupeliene, A.; Wroblewska, M. Fatty acid profile of breast muscle of broiler chickens fed diets with different levels of selenium and vitamin E. Arch. Geflügelk. 2011, 75, 264–267.

37. Heindle, J.; Ledvinka, Z.; Englmaierova, M.; Zita, L.; Tumova, E. The effect of different selenium sources and levels on performance, selenium content in muscle and glutathione peroxidase activity in broiler chickens. Czech J. Anim. Sci. 2010, 55, 572–578. [CrossRef]

38. Fegerson, K. Supranutritional selenium level affects fatty acid composition and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissues, food and feedstuffs samples. J. Agric. Food Chem. 2003, 51, 1177–1180. [CrossRef]

39. Perić, L.; Milošević, N.; Žikić, D.; Kanački, Z.; Džinić, N.; Nollet, L.; Spring, P. Effect of selenium sources on performance and meat characteristics of broiler chickens. J. Appl. Poult. Res. 2009, 18, 403–409. [CrossRef]

40. Lanza, M.; Fasone, V.; Galofaro, V.; Barbagallo, D.; Bella, M.; Pennisi, P. Citrus pulp as an ingredient in ostrich diet: Effects on meat quality. Meat Sci. 2004, 68, 269–275. [CrossRef]

41. Ibrahim, D.; Kishawy, A.T.Y.; Khater, S.I.; Hamed Arisha, A.; Mohammed, H.A.; Abdelaiz, A.S.; Abd El-Rahman, G.I.; Elabbasy, M.T. Effect of dietary modulation of selenium form and level on performance, tissue retention, quality of frozen stored meat and gene expression of antioxidant status in broiler chickens. Animals 2019, 9, 342. [CrossRef]

42. Korzeniowska, M.; Królczewska, B.; Kopeć, W. Effect of dietary selenium on protein and lipid oxidation and the antioxidative potential of selected chicken culinary parts during frozen storage. J. Chem. 2018, 2018, 3492456. [CrossRef]

43. Li, J.; Zhang, L.; Yang, Z.; Zhang, Z.; Jiang, Y.; Gao, F.; Zhou, G. Effects of different selenium sources on growth performance, antioxidative capacity and meat quality of local Chinese Subei chickens. Biol. Trace Elem. Res. 2018, 181, 340–346. [CrossRef]

44. Pappas, A.C.; Zoidis, E.; Papadomichelakis, G.; Fegeros, K. Supranutritional selenium level affects fatty acid composition and oxidative stability of chicken breast muscle tissue. J. Anim. Physiol. Anim. Nutr. 2012, 96, 385–394. [CrossRef]

45. Mikulski, D.; Jankowski, J.; Zdunczyk, Z.; Wroblewska, M.; Sartowska, K.; Majewska, T. The effect of selenium source on performance, carcass traits, oxidative status of the organism, and meat quality of turkeys. J. Anim. Feed Sci. 2009, 18, 518–530. [CrossRef]

46. Van Acker, F.A.A.; Schouten, O.; Haenen, G.R.M.M.; Van Der Vlijh, W.J.F.; Bast, A. Flavonoids can replace α-tocopherol as an antioxidant. FEBS Lett. 2000, 503, 145–148. [CrossRef]

47. Smet, K.; Raes, K.; Huyghebaert, G.; Haak, L.; Arnouts, S.; De Smet, S. Lipid and protein oxidation of broiler meat as influenced by dietary natural antioxidant supplementation. Poult. Sci. 2008, 87, 1682–1688. [CrossRef] [PubMed]

48. Basmacioglu, H.; Tokusoglu, O.; Ergul, M. The effect of oregano and rosemary essential oils or α-tocopheryl acetate on performance and lipid oxidation of meat enriched with n-3 PUFAs in broilers. S. Afr. J. Anim. Sci. 2004, 34, 197–210. [CrossRef]

49. Papageorgiou, G.; Botsoglou, N.; Gavras, A.; Giannenas, I.; Ilidiadis, S.; Botsoglou, E. Effect of dietary oregano oil and α-tocopherol acetate supplementation on iron-induced lipid oxidation of turkey breast, thigh, liver and heart tissues. J. Anim. Physiol. Anim. Nutr. 2003, 87, 324–335. [CrossRef]

50. Pinelo, M.; Manzocco, L.; Nunez, M.J.; Nicolì, M.C. Interaction among phenols in food fortification: Negative synergism on antioxidant capacity. J. Agric. Food Chem. 2004, 52, 1177–1180. [CrossRef]

51. Ghazi, S.; Habibian, M.; Moeini, M.M.; Abdolmohammadi, A. Effects of dietary selenium, vitamin E, and their combination on growth, serum metabolites and antioxidant defense system in skeletal muscle of broilers under heat stress. Biol. Trace Elem. Res. 2012, 148, 322–330. [CrossRef]

52. Ebeid, T.A. Vitamin E and organic selenium enhances the antioxidative status and quality of chicken semen under high ambient temperature. Br. Poult. Sci. 2012, 53, 708–714. [CrossRef]
53. Brewer, M. Natural antioxidants: Sources, compounds, mechanisms of action, and potential applications. *Compr. Rev. Food Sci. Food Saf.* 2011, 10, 221–247. [CrossRef]

54. Goñi, I.; Brenes, A.; Centeno, C.; Viveros, A.; Saura-Calixto, F.; Rebolé, A.; Arija, I.; Estevez, R. Effect of dietary grape pomace and vitamin e on growth performance, nutrient digestibility, and susceptibility to meat lipid oxidation in chickens. *Poult. Sci.* 2007, 86, 508–516. [CrossRef]