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EFFECT OF SOYBEAN OR LINSEED OIL WITH RRR-D-α-TOCOPHEROL OR DL-α-TOCOPHEROL ACETATE ON QUALITY CHARACTERISTICS AND FATTY ACID PROFILE OF TURKEY MEAT*

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Abstract

In this study, the effect of the halved dosage of RRR-d-α-tocopherol (with respect to dl-α-tocopherol acetate) in diets containing oil rich in linoleic or α-linolenic acid (soybean or linseed oil, respectively) on the quality characteristics and fatty acid (FA) profile of turkey meat was studied. The experiment was conducted using 480 one-week-old turkey hens Big 6 line reared until the 16th week of life. The hens in Groups I and II received soybean oil added to their feed mixture, in Groups III and IV linseed oil was the source of supplementary fat. Turkeys in Groups I and III received dl-α-tocopherol acetate, whereas those in Groups II and IV RRR-d-α-tocopherol. No influence of dietary manipulation was observed on the chemical composition of turkey meat. The combined effect of the type of dietary fat and vitamin E source added to the feed was assessed using the color parameters. The addition of natural vitamin E to the feed mixture with linseed oil significantly increased the proportion of PUFA in breast muscle lipids compared with the group receiving soybean oil with this form of vitamin E. The inclusion of linseed oil increased the content of α-linolenic acid and total *n*-3 FA concentration in both muscles, compared with the diet that contained soybean oil. This modification of FA composition led to lower *n*-6/*n*-3 ratio in both the breast and thigh muscles regardless of the dietary vitamin E source. The use of natural form of tocopherol in diets containing linseed oil may help to improve the nutritional quality of turkey meat, especially by enhancing *n-3* PUFA levels with no detrimental effect of lipid addition on the chemical composition and quality of meat.

Key words*:* turkey, soybean oil, linseed oil, tocopherol, fatty acids

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Since poultry meat is consumed widely, modification of its lipid profile could help to improve the nutritional quality of the human diet, especially by enhancing *n*-3 PUFA levels, due to their presumed role in the prevention and therapy of cardiovascular diseases, cancer, and obesity (Lorente-Cebrián et al., 2013; Grasso et al., 2014; McNeill, 2014). Among other possible strategies used to customize FA composition of poultry meat, dietary manipulation has been demonstrated to be very effective (Bou et al., 2009; Zduńczyk and Jankowski, 2013). As the lipid profile of poultry reflects the composition of the bird's diet, alteration to the diet can modify the FA proportion in turkey meat in response to the dietary requirements of consumers (Lessire, 2001; Rymer and Givens, 2005). Also, variation in FA composition has a direct effect on several aspects of meat quality (Wood et al., 2003; Carmona et al., 2008).

The main source of supplementary fat in turkey diets is usually soybean oil; however, the use of linseed oil, which is rich in *n*-3 PUFA (about 60% α-linolenic acid) also shows great promise (Hassan et al., 2011). With a more favorable FA composition: 9% SFA, 19% MUFA, and 72% PUFA, it is expected to be more beneficial than soybean oil (Nuernberg et al., 2005).

However, increasing the degree of polyunsaturation in the animal's diet may accelerate the oxidative deterioration of the meat. Therefore, not only the oil source and their level of inclusion but also adequate inclusion of antioxidants must be considered when formulating PUFA-rich diets for turkeys to be slaughtered for meat. Synthetic dl-α-tocopherol, in practice applied in its acetate form, is commonly used in livestock feeding as a vitamin E supplement to serve as an antioxidant (Rey et al., 2004; Koreleski and Świątkiewicz, 2008; Yu et al., 2008). Nowadays, several precursor forms of tocopherol are used as feed additives in poultry diets. They are active in cells (systemic), but their biological activity varies substantially that results from the isomeric structure and from the chemical form of the compound (Ognik and Wertelecki, 2012). Koreleski and Świątkiewicz (2008) proved that the activity of the RRR-stereoisomer is almost 2 times higher than that of the synthetic form of vitamin E, which suggests that it can be used in half the amount recommended by the NRC (1994) in mixtures for turkey hens. Ognik and Czech (2014), showed that it may be possible to use the natural form of RRR-d-α-tocopherol for diets rich in linoleic and α-linolenic acid (soybean or linseed oil, respectively) as it stimulated the antioxidant defense mechanisms of turkey more effectively than dl-α-tocopherol acetate added to these oils.

Results of previous research indicate that linseed oil is a good candidate for enriching turkey meat with *n*-3 FA (Jankowski et al., 2012). However, to the best of our knowledge, the effects of addition of different forms of vitamin E, into feed containing different dietary oils, on the physicochemical properties of turkey meat remain unexplored.

Therefore, the objective of this study was to compare the effect of the halved dosage of RRR-d-α-tocopherol (with respect to dl-α-tocopherol acetate) in diets containing oil rich in linoleic or α-linolenic acid (soybean or linseed oil, respectively) on the quality characteristics and FA profile of turkey meat. The halved dosage was in accordance with research by Mahan et al. (2000), who suggested that the activity of the natural form of tocopherol in animal tissues is significantly higher than the synthetic form.

Material and methods

Animals and diets

The experiment was conducted using 480 one-week-old turkey hens Big 6 line randomly assigned to 4 experimental groups of 120 turkeys, with 5 replications of 24 birds each. Until the 16th week of life, the birds were kept in cages, 2.5 × 2.5 × 4 m in size, under hygienic conditions recommended for turkeys fattening. The birds in Groups I (control) and II received soybean oil added to their feed mixture. Linseed oil was the source of supplementary fat for Groups III and IV. Turkeys from Group I and III received synthetic dl-α-tocopherol acetate (E 307, according to the European Union Register of Feed Additives EC 1831/2003) at dietary levels of 50 mg/kg (1–9 weeks of life) and 45 mg/kg (10–16 weeks of life), which is consistent with the tocopherol content recommended for turkey hens by the Poultry Feeding Standards (NRC, 1994). Groups II and IV were given another form of tocopherol, i.e., natural form of vitamin E, RRR-d-α-tocopherol (100% activity) in a dose equivalent to the synthetic form, dl-α-tocopherol (i.e. 2.5 mg of the synthetic form = 1 mg of the natural form of tocopherol) at a rate concentration two times lower than in Groups I and III, i.e., 25 mg/kg (1–9 weeks of life) and 22.5 mg/kg (10–16 weeks of life). The turkey hens from all the groups were fed *ad libitum* and had free access to water. The feed mixtures were composed of wheat, corn meal, soybean meal, soybean/linseed oil and maintained isonitrogenous and isoenergetic balances. The diet formulation has been previously described by Czech and Ognik (2014). The feed mixtures were prepared once a week at the farm and kept in a cool and dark place to prevent oxidation. The experiment was conducted with the approval of the Local Ethical Committee (Second Local Ethical Committee for Animal Experiments, 2009). On completion of the rearing period (16 weeks of life), 10 birds from each experimental group (all of the birds from a group were weighed and then chosen for analysis based on mean body weight) were slaughtered by decapitation following the euthanasia protocol of the Local Ethical Committee. During the partial dissection, breast (*M. pectoralis major*) and thigh (*M. iliotibialis lateralis*) muscles were collected and stored at 4°C until examined 48 h postmortem. The influence of soybean or linseed oil combined with RRR-d-α-tocopherol or dl-α-tocopherol acetate on chemical composition, physicochemical properties, color, and FA profile of turkey breast and thigh muscles were examined.

Chemical composition

The chemical composition (dry matter, protein, fat and ash) of breast and thigh muscles was determined according to AOAC methods (2000).

Fatty acid analysis

Lipids from breast and thigh muscles were extracted according to the method of Folch et al. (1957). The FA composition was determined by gas chromatography after conversion of the fats to fatty acid methyl esters (FAME) according to the AOAC method (AOAC, 1990). A gas chromatograph (Varian 450-GC, Varian, CA, USA) with a split–splitless injector, a flame ionization detector, and a 30-m fused silica

capillary column (0.32 mm internal diameter) was used; helium was the carrier gas; injector and detector temperatures were 250°C and 300°C, respectively. After injection, the column temperature was programmed to rise to 200°C, be maintained for 10 min and subsequently increased to 240°C at the rate of 3°C/min and held at this final temperature for 4 min. The amounts of the FA were calculated from the chromatograms and from an external standard containing FAME (F.A.M.E. Mix, C4-C24, No. 18919-1AMP, Sigma-Aldrich Poznań, Poland).

Instrumental color

Breast and thigh muscles were evaluated for instrumental color by using a benchtop spectrophotometer (Color® Premiere 8200, X-Rite Inc., Grand Rapids, MI, USA) following the recommendations of American Meat Science Association (2012). The instrumental parameters were an 8 mm view aperture, D65 illuminant and 10° standard observer. Samples taken for color measurements were 5 cm thick and were covered with a single layer of colorless food wrap before color determination and allowed to bloom for 30 min at 4 ± 1°C. Color measurement followed the Commission Internationale de l'Eclairage (CIE) color convention (1978), with outputs of L^* (lightness), a^* (redness) and b^* (yellowness).

Physicochemical properties

The pH was measured in a slurry made by mixing 10 g of meat sample with 100 mL of distilled water for 1 min using a disperser (T25 Basic ULTRA-TURRAX, IKA, Staufen, Germany). The pH of the resulting suspension was measured by using a digital pH-meter with temperature compensation (CPC-501, Elmetron, Zabrze, Poland) equipped with a combined pH glass electrode (ERH-111, Hydromet, Gliwice, Poland). Water holding capacity (WHC) was measured using centrifugation method (Wierbicki et al., 1962). Drip loss was determined from meat weight loss after 24-h cold storage at 4°C (Honikel, 1998). Cooking loss was determined from percentage loss of meat weight after cooking samples (80 g ± 2 g) in plastic bags immersed in a water bath (PolyScience, Niles, IL, USA) at 80°C for 30 min. For the Warner-Bratzler shear force (WBSF) measurements, cylindrical cores (Ø 1.25 cm), minimum 30 mm long were removed from each cooked sample parallel to the longitudinal orientation of the muscle fibers. Peak force (N) to cut across each piece was determined with a texture analyzer TA-XT plus (Stable Micro Systems Ltd. Surrey, UK) equipped with a V-shaped Warner-Bratzler blade (thickness: 0.9 mm) with a triangular aperture of 60° at a crosshead speed of 100 mm/min. Data were collected with Texture Expert Exceed software (Stable Micro Systems).

Statistical analysis

The experiment was arranged as 2 × 2 factorial randomized block designs with the tocopherol and oil source and their interaction as the main effects. All measurements were made in triplicate. Obtained data were analyzed using Statistica software, version 6.1 (StatSoft, Kraków, Poland). Results were expressed as treatment means and SEM. Compatibility of characteristics distribution with normal distribution was examined with Shapiro-Wilk's test. Significance of the difference between

mean values was estimated by using one-way analysis of variance (ANOVA) assuming the significance level at $P<0.05$ and $P<0.01$.

Results

Chemical composition

Data from Table 1 shows that there were no significant differences between experimental groups with regards to their chemical composition.

Table 1. Chemical composition (%) of turkey breast (*M. pectoralis major*) and thigh (*M. iliotibialis lateralis*) muscles

Parameters	Feeding groups				SEM	Significance		
	Soybean oil		Linseed oil			oil	E	oil × E
	I	II	III	IV				
Breast muscles								
dry matter	26.06	27.41	26.34	26.87	0.102	ns	ns	ns
ash	1.11	1.11	1.09	1.10	0.126	ns	ns	ns
protein	24.19	25.39	24.47	24.89	0.100	ns	ns	ns
fat	0.74	0.88	0.73	0.82	0.007	ns	ns	ns
Thigh muscles								
dry matter	26.32	26.72	26.58	26.63	0.177	ns	ns	ns
ash	0.95	1.05	0.98	0.87	0.108	ns	ns	ns
protein	19.57	20.32	20.08	20.27	0.231	ns	ns	ns
fat	5.73	5.33	5.49	5.47	0.199	ns	ns	ns

Abbreviations: ns – not significant; Groups I and III: turkey hens fed diet supplemented with synthetic dl-α-tocopherol acetate; Groups II and IV: turkey hens fed diet supplemented with natural RRR-d-α-tocopherol.

Fatty acid analysis

The FA profiles are shown in Tables 2 and 3 for breast (*M. pectoralis major*) and thigh (*M. iliotibialis lateralis*) muscles, respectively. The FA found at highest concentration in turkey breast muscle were linoleic acid (C18:2*n*-6) and palmitic acid (C16:0), followed by oleic acid (C18:1*n*-9) and stearic acid (C18:0) (Table 2). For thigh muscle, these FA were C18:1*n*-9 and C18:2*n*-6, followed by C16:0 and C18:0 (Table 3).

In this study, the SFA were approximately 40% in the breast muscle and 35% in the thigh muscle. The breast muscles of birds that were fed with linseed oil and natural RRR-d-α-tocopherol (Group IV) had a higher percentage of total SFA than birds fed with its synthetic counterpart (Table 2). The type of oil administered in the feed mixtures affected the total concentration of SFA in thigh muscles (Table 3).The linseed oil diet led to a significant reduction of SFA level in thigh muscle in comparison with the control (Group I).

Table 2. Fatty acid profile (% methyl esters) of turkey breast (*M. pectoralis major*) muscles

Fatty acids	Feeding groups				SEM	Significance		
	Soybean oil		Linseed oil			oil	E	oil × E
	I	II	III	IV				
SFA (saturated fatty acids)								
C14:0	0.96	0.94	0.96	0.86	0.011	ns	*	*
C15:0	0.19 a	0.21 a	0.18 a	0.15 b	0.006	*	ns	*
C16:0	27.50 a	24.76 b	21.08 c	24.56 b	0.674	**	ns	*
C17:0	0.24	0.18	0.25	0.22	0.008	ns	*	*
C18:0	11.73 b	16.25 a	16.15 a	16.84 a	0.559	*	*	*
C20:0	0.10 b	0.10 b	0.15 a	0.09 b	0.008	ns	ns	*
C21:0	0.05 b	0.15 a	0.04 b	0.03 b	0.012	*	ns	*
∑SFA	40.77 ab	42.59 a	38.81 b	42.75 a	0.515	ns	**	*
MUFA (monounsaturated fatty acids)								
C14:1	0.11 a	0.12 a	0.16 b	0.16 b	0.006	*	ns	*
C15:1	1.27	1.22	1.29	1.40	0.018	*	ns	*
C16:1*n-7*	0.21 b	0.26 ab	0.23 b	0.40 a	0.019	*	*	*
C17:1	0.11	0.15	0.13	0.14	0.005	ns	*	*
C18:1*n-7*	2.24 a	1.63 c	2.06 b	1.59 c	0.075	ns	**	*
C18:1*n-9*	26.29 a	23.29 a	20.20 b	18.05 b	0.917	**	ns	*
C20:1*n-5*	0.01	0.01	0.01	0.02	0.001	ns	ns	ns
C20:1*n-7*	0.13	0.16	0.14	0.14	0.004	ns	ns	*
C20:1*n-9*	0.14	0.17	0.15	0.14	0.005	ns	ns	ns
∑MUFA	30.51 a	27.01 b	24.37 bc	22.04 c	0.931	**	ns	*
PUFA (polyunsaturated fatty acids)								
C16:3*n-3*	0.04 b	0.04 b	0.04 b	0.08 a	0.005	**	ns	*
C18:2*n-6*	28.25 a	27.16 ab	24.62 c	26.16 bc	0.445	**	ns	*
C18:3*n-3*	0.85 b	0.80 b	3.47 a	3.01 a	0.324	**	ns	*
C20:2	0.31 b	0.38 a	0.29 b	0.31 b	0.009	*	*	*
C20:3*n-3*	0.02	0.04	0.05	0.05	0.003	ns	ns	*
C20:3*n-6*	0.01	0.01	0.01	0.01	0.006	ns	ns	ns
C20:3*n-9*	0.27	0.30	0.27	0.28	0.005	ns	ns	ns
C20:4*n-6*	2.27 b	2.31 b	4.18 a	3.98 a	0.246	**	ns	*
C20:5	0.17 b	0.20 ab	0.23 a	0.18 b	0.008	ns	ns	*
C22:5	0.16 a	0.18 a	0.03 b	0.16 a	0.015	*	*	*
∑PUFA	32.35 ab	31.42 b	33.19 ab	34.22 a	0.908	**	ns	*
∑UFA	62.86 a	58.43 b	57.56 b	56.26 b	0.515	ns	**	*
∑*n-3*	0.91 b	0.88 b	3.56 a	3.14 a	0.333	**	ns	*
∑*n-6*	30.53 a	29.48 b	28.81 bc	30.15 ab	0.051	ns	ns	ns
n-6/n-3	33.55 a	33.50 a	8.09 b	9.60 b	0.547	**	ns	*

Abbreviations: Groups I and III: turkey hens fed diet supplemented with synthetic dl-α-tocopherol acetate; Groups II and IV: turkey hens fed diet supplemented with natural RRR-d-α-tocopherol; ns – not significant; UFA – unsaturated fatty acids.

a, b, c – values in rows with different letters differ significantly at $P<0.05$ (compared to group I – control).

*$P<0.05$.

**$P<0.01$.

Table 3. Fatty acid profile (% methyl esters) of turkey thigh (*M. iliotibialis lateralis*) muscles

Fatty acids	Feeding groups				SEM	Significance		
	Soybean oil		Linseed oil			oil	E	oil × E
	I	II	III	IV				
SFA (saturated fatty acids)								
C14:0	1.00 a	0.77 b	0.97 a	0.92 ab	0.035	ns	*	*
C15:0	0.19	0.20	0.16	0.20	0.005	*	*	ns
C16:0	27.01 a	26.92 a	21.87 b	22.96 b	0.685	**	ns	*
C17:0	0.24	0.20	0.20	0.20	0.005	ns	ns	ns
C18:0	9.22 ab	7.91 b	9.66 a	10.56 a	0.324	*	ns	*
C20:0	0.12 ab	0.12 ab	0.16 a	0.10 b	0.006	ns	*	*
C21:0	0.02	0.02	0.01	0.01	0.002	*	ns	ns
C22:0	0.03	0.00	0.03	0.02	0.003	ns	*	ns
C23:0	0.21 a	0.01 b	0.00 b	0.00 b	0.023	*	*	*
∑SFA	38.04 a	36.15 ab	33.06 c	34.97 bc	0.578	**	ns	*
MUFA (monounsaturated fatty acids)								
C14:1	0.13 b	0.14 b	0.10 b	0.19 a	0.009	ns	**	*
C15:1	0.18 a	0.20 a	0.14 b	0.20 a	0.007	ns	**	*
C16:1	0.02	0.02	0.06	0.06	0.005	**	ns	ns
C17:1	0.13	0.15	0.13	0.15	0.004	ns	ns	ns
C18:1*n-7*	3.17 a	2.39 b	1.76 c	2.03 bc	0.160	**	ns	*
C18:1*n-9*	31.07 b	31.15 b	33.94 a	33.27 ab	0.467	**	ns	*
C20:1*n-7*	0.32 b	0.36 b	0.42 a	0.41 a	0.011	*	ns	*
C22:1	0.02	0.01	0.03	0.05	0.004	*	ns	ns
∑MUFA	35.04	34.42	36.58	36.36	0.426	*	ns	ns
PUFA (polyunsaturated fatty acids)								
C16:3*n-3*	0.08	0.09	0.11	0.08	0.003	ns	ns	ns
C18:2*n-6*	24.54	27.12	24.75	23.94	0.634	ns	ns	ns
C18:3*n-3*	1.50 b	1.59 b	4.79 a	4.02 a	0.393	*	ns	*
C20:2	0.18 b	0.20 a	0.16 c	0.18 b	0.004	*	*	*
C20:3*n-3*	0.20	0.19	0.24	0.23	0.007	*	ns	ns
C20:4*n-6*	0.08 b	0.10 b	0.16 a	0.10 b	0.009	*	ns	*
C20:5	0.14	0.15	0.15	0.14	0.004	ns	ns	ns
C22:2	0.02	0.00	0.00	0.00	0.003	*	*	ns
C22:4*n-6*	0.04 a	0.00 b	0.00 b	0.00 b	0.004	*	*	*
C22:5	0.14 a	0.00 b	0.00 b	0.00 b	0.016	*	*	*
∑PUFA	26.92	29.44	30.36	28.69	0.613	ns	ns	ns
∑UFA	61.96 c	63.86 b	66.94 a	65.05 b	0.575	**	ns	*
∑*n-3*	1.78 b	1.87 b	5.14 a	4.33 a	0.769	**	ns	*
∑*n-6*	24.66	27.22	24.91	24.04	0.052	ns	ns	ns
n-6/n-3	13.85 a	14.56 a	4.85 b	5.55 b	0.321	**	ns	*

Abbreviations: Groups I and III: turkey hens fed diet supplemented with synthetic dl-α-tocopherol acetate; Groups II and IV: turkey hens fed diet supplemented with natural RRR-d-α-tocopherol; ns – not significant; UFA – unsaturated fatty acids.

a, b, c – values in rows with different letters differ significantly at $P<0.05$ (compared to group I – control).

*$P<0.05$.

**$P<0.01$.

Feeding linseed oil to turkeys caused a significantly lower proportion of MUFA in breast muscle lipids compared with groups receiving soybean oil (Table 2). No significant differences were observed for the total MUFA content in thigh muscles between the feeding groups (Table 3). The dietary influence on the concentration of oleic acid was not as strong in thigh muscles as it was in breast muscles. There were no significant differences between the total MUFA content of turkey thigh meat with respect to the form of vitamin E and interaction between fat source and tocopherol form (Table 3).

The addition of natural RRR-d-α-tocopherol to the feed mixture with linseed oil (Group IV) significantly increased the proportion of PUFA in breast muscle lipids compared with group receiving soybean oil with this form of vitamin E (Group II), which was primarily due to the increase in C18:3*n*-3 and C20:4*n*-6 (Table 2). Statistically significant differences in the content of PUFA in thigh muscles between the groups fed either soybean or linseed oil-enriched diet were not established (P>0.05).

The effect of dietary linseed oil on increased α-linolenic acid and total *n*-3 FA concentration in both muscles examined is statistically significant. This modification of FA composition led to lower *n*-6/*n*-3 ratio in both the breast (from 33.55 to 8.09) and thigh (from 13.85 to 4.85) muscles. C18:3*n*-3 was preferentially incorporated into breast and thigh muscles of turkeys fed with linseed oil (P<0.05) compared to groups receiving soybean oil-enriched diet.

Instrumental color

The results of statistical analysis displayed that CIE *L*a*b** color parameters of both muscles were significantly (P<0.01) influenced by the fat source and its combined effect with the form of vitamin E (Table 4).

Table 4. Color coordinates of turkey breast (*M. pectoralis major*) and thigh (*M. iliotibialis lateralis*) muscles

Parameters	Feeding groups				SEM	Significance		
	Soybean oil		Linseed oil			oil	E	oil × E
	I	II	III	IV				
Breast muscles								
L*	48.29 a	47.41 a	48.58 a	49.81 b	0.178	**	ns	**
a*	0.18 ab	–0.35 a	0.50 bc	0.77 c	0.086	**	ns	**
b*	7.53 c	6.47 a	7.32 bc	6.76 ab	0.089	ns	**	**
Thigh muscles								
L*	44.91 a	43.82 a	46.37 b	46.66 b	0.177	**	ns	**
a*	4.36 a	4.52 a	4.68 a	6.14 b	0.140	**	**	**
b*	9.70 bc	10.14 c	9.13 ab	8.58 a	0.128	**	ns	**

Abbreviations: Groups I and III: turkey hens fed diet supplemented with synthetic dl-α-tocopherol acetate; Groups II and IV: turkey hens fed diet supplemented with natural RRR-d-α-tocopherol; ns – not significant.

a, b, c – values in rows with different letters differ significantly at P<0.05 (compared to group I – control).

* P<0.05.

** P<0.01.

Higher *L** values were found in muscles from turkeys fed the mixture with linseed oil. Same was true with regard to *a** values. The addition of the synthetic form of vitamin E caused an increase of *b** value of breast muscles of turkeys fed with soybean oil (Group I).

Physicochemical properties

The physicochemical parameters of breast (*M. pectoralis major*) and thigh (*M. iliotibialis lateralis*) turkey muscles are shown in Table 5.

Table 5. Physicochemical properties of turkey breast (*M. pectoralis major*) and thigh (*M. iliotibialis lateralis*) muscles

Parameters	Feeding groups				SEM	Significance		
	Soybean oil		Linseed oil			oil	E	oil × E
	I	II	III	IV				
Breast muscles								
pH	5.64 a	6.01 c	5.95 c	5.80 b	0.025	ns	*	ns
WHC (%)	7.12	7.91	4.38	6.60	0.748	ns	ns	ns
drip loss (%)	1.76	1.53	2.07	1.04	0.147	ns	*	ns
cooking loss (%)	14.78 ab	14.66 ab	15.53 b	12.65 a	0.330	ns	*	*
shear force (N)	53.97 b	36.10 a	43.84 ab	32.58 a	1.340	*	**	**
Thigh muscles								
pH	5.89 a	5.93 ab	6.11 b	6.09 b	0.015	**	ns	ns
WHC (%)	9.44 b	11.19 b	7.44 b	2.73 a	1.040	*	ns	*
drip loss (%)	1.22	1.12	1.10	0.94	0.085	ns	ns	ns
cooking loss (%)	22.61	22.47	23.84	19.41	0.537	ns	*	*
shear force (N)	60.77 c	41.47 ab	51.10 bc	37.65 a	1.530	*	**	**

Abbreviations: Groups I and III: turkey hens fed diet supplemented with synthetic dl-α-tocopherol acetate; Groups II and IV: turkey hens fed diet supplemented with natural RRR-d-α-tocopherol; ns – not significant.

a, b, c – values in rows with different letters differ significantly at $P<0.05$ (compared to group I – control).

* $P<0.05$.

** $P<0.01$.

The addition of different forms of vitamin E (dl-α-tocopherol or RRR-d-α-tocopherol) significantly affected ($P<0.05$) the pH values of breast muscles. The highest pH was recorded in muscles from Groups II (soybean oil + RRR-d-α-tocopherol) and III (linseed oil + dl-α-tocopherol acetate). The administration of synthetic vitamin E (Group I) contributed to a significant decrease of this parameter. In contrast, the addition of dl-α-tocopherol to a feed mixture with linseed oil (Group III) caused a significant increase in pH, compared with Group IV. Groups III and IV of thigh muscles were characterized by higher ($P<0.05$) pH values than the control (Group I). Thus in these two groups (Groups III and IV) this effect resulted from the application of linseed oil, but not from different forms of tocopherol.

In this study, dietary treatment did not affect WHC of *M. pectoralis major* ($P>0.05$). Unlike in breast muscles, certain influence was observed in thigh muscles.

The thigh muscles of birds fed with soybean oil were found to have the highest water holding capacity of 9.44% in Group I and 11.19% in Group II and also did not differ from Group III.

There was no significant effect of dietary treatment on drip loss of breast and thigh muscles. The addition of different forms of vitamin E (dl-α-tocopherol or RRR-d-α-tocopherol) did not also affect cooking loss of thigh muscles. The administration of natural vitamin E (Group IV) contributed to a significant decrease of this parameter in comparison with Group III of breast muscles.

Higher shear force values were noted in muscles from turkeys fed the mixture with the addition of synthetic vitamin E, the differences were the most pronounced for groups fed soybean oil (Groups I and II).

Discussion

In the current experiment, there were no significant differences between experimental groups with regards to the chemical composition of the meat that determine its nutritional value. This is consistent with the results of previous studies which did not show any influence of dietary lipid source on chemical composition of poultry meat (Bianchi et al., 2009; Schiavone et al., 2010). The average concentrations of dry matter, ash, protein, and fat in turkey breast and thigh muscles are similar to those reported by other authors (Sarica et al., 2011; Rusinek-Prystupa et al., 2014). Proximate content data are also in agreement with National Nutrient Database for Standard Reference (USDA, 2016).

This investigation showed that whatever the diet, turkey thigh muscles compared with breast muscles contain less SFA and more unsaturated fatty acids (UFA) due to higher MUFA percentage. Similar results were obtained by Komprda et al. (2002). The proportion of palmitic acid (C16:0) increased in meat from turkey fed with soybean oil in comparison with those fed diets supplemented with linseed oil. These results are in agreement with the findings of Jankowski et al. (2012), who reported that the levels of palmitic acid decreased significantly in broiler breast muscle supplemented with linseed oil compared with groups supplemented with soybean oil. The major MUFA detected in breast muscle and affected by the dietary oil was C18:1*n*-9. The concentration of oleic acid in the breast meat of turkey fed with soybean oil diet was significantly higher than of those groups fed with linseed oil. This observation is similar to the findings of Abdulla et al. (2015), which indicated that breast meat from broilers fed a diet containing linseed oil had lower levels of C18:1*n*-9 compared with birds fed soybean oil. Thigh deposition of PUFA varied from 26.7% to 30.4% and breast deposition ranged from 31.4% to 34.2% in groups fed with different oil sources and had not been significantly affected by the form of vitamin E administered. These results are similar to observations of Nam et al. (1997) who indicated that breast muscles contained more total PUFA than the thigh muscle.

Inclusion of dietary linseed oil resulted in increasing the content of α-linolenic acid and total *n*-3 FA concentration in both muscles examined. This modification

of FA composition led to lower *n*-6/*n*-3 ratio in both the breast and thigh muscles. C18:3*n*-3 was preferentially incorporated into thigh muscles of turkey fed linseed oil compared to groups receiving soybean oil-enriched diet. Delezie et al. (2010) and Jankowski et al. (2012) also observed a significant increase in α-linolenic acid and total PUFA levels in muscles of turkey fed with linseed oil when compared with soybean oil. Although C18:3*n*-3 may be used in metabolic processes of elongation and desaturation, no significant effect of dietary treatment was observed on long chain *n*-3 PUFA. As arachidonic acid (C20:4*n*-6) content in breast muscles was significantly higher in groups receiving linseed oil, it seems that in turkeys fed linseed oil, the desaturase and elongase activities seem to be more focused on the synthesis of C20:4*n*-6 but not long chain *n*-3 PUFA (Nuernberg et al., 2005). Concentration of long-chain PUFA (C20:4*n*-6, C20:5, and C22:5) was greater in breast muscles than in thigh muscles. These results are in agreement with those reported by other authors who found a higher deposition of long-chain PUFA in breast muscle compared with thigh (Gonzalez-Esquerra and Leeson, 2000; Crespo and Esteve-Garcia, 2001). Differences in tissue FA profile may result from different roles of FA in these tissues or from their different phospholipid contents. The PUFA are mainly incorporated into phospholipids, which are in a higher proportion in breast than in thigh muscles (Cortinas et al., 2004). In this study, docosahexaenoic acid (C22:6*n*-3) was detected neither in the breast nor in the thigh muscles.

Color is an important characteristic of poultry meat which influences consumers' purchasing decision as well as provides final product satisfaction (Fletcher, 2002). Previous studies have also indicated that dietary lipid sources may modify the meat color parameters (Bianchi et al., 2009). In the study by Mercier et al. (1998), meat from birds fed soybean oil was redder than meat fed tallow or rapeseed oil. No significant influence of the vitamin E form on a^* values suggests that both the synthetic and the natural forms of tocopherol are equally effective in protecting oxymyoglobin against oxidation in breast muscles.

The pH value reflects the rate of postmortem glycolysis and is a key indicator of meat quality. The different fat sources in the diet did not affect the meat pH values of breast muscle, and these results are in agreement with those from previous studies (Mercier et al., 1998; Bianchi et al., 2009). Results of pH measurements for thigh muscles were higher than those of breast muscles which corresponded with results reported by other researchers for turkey meat (Mercier et al., 1998; Voutila et al., 2009; Karwowska et al., 2010).

Drip loss is an important quality trait for the meat processing industry and also the consumer. In this study, the drip loss of turkey breast and thigh muscles was not affected, and indicated that soybean or linseed oil with RRR-d-α-tocopherol or dl-α-tocopherol had no detrimental effect on this quality (Table 5). WHC and drip loss values observed for thigh muscles corresponded to the higher pH values in these samples. Moisture loss is significantly affected by pH (Huff-Lonergan and Lonergan, 2005). The higher the pH, the stronger the water holding capacity of the meat and lower the drip loss that occurs, which has been confirmed by this study. In relation to drip loss, the results obtained in this work are similar to those reported by Jankowski et al. (2015) who observed no significant effect of dietary fat on drip loss.

In this study, there was no effect of fat source on cooking loss (Table 5). Moreover, whatever the composition of the experimental diet, the cooking loss in thigh muscles was higher than in breast muscles, which is in line with the results of Damaziak et al. (2013). Cooking loss values observed in our study for breast muscles were lower than reported by Mikulski et al. (2012). This is beneficial for the consumer as the meat was able to retain water during the cooking, and also tended not to be withdrawn.

An increase in cooking loss was accompanied by an increase in WBS values which is used as an indicator of meat tenderness (Table 5). These results are in agreement with those of Zhuang and Savage (2013) who observed that muscles with higher cooking loss have higher WBSF values than muscles with low cooking loss. Whatever the muscle type, there was a significant effect of fat source and form of tocopherol as well as their combined effect on WBSF values. The inclusion of linseed oil and RRR-d-α-tocopherol in a feed mixture contributed to a decrease in WBSF value (Table 5). According to Wood et al. (2003) the possible explanations for a positive effect of lipid on tenderness include the presence of neutral lipid in fat cells within the perimysium, which could have a physical effect of separating muscle fiber bundles thus beginning the process of tenderization by "opening up the muscle structure".

The results of this study suggested that the replacement of soybean oil with linseed oil in turkey diets allows maintaining comparable physicochemical properties of breast and thigh muscles. No effect of dietary manipulation was observed in the fat, protein, and ash concentration in meat from any of the groups. A combined effect of dietary fat and vitamin E source was observed on the color parameters. Vitamin E form did not affect PUFA content in breast and thigh muscle which proved that both the synthetic (dl-α-tocopherol) and natural (RRR-d-α-tocopherol) variables evaluated in this study were equally effective in inhibiting the peroxidation of the oxidative-labile PUFA. Groups fed with linseed oil had significantly lower levels of SFA in thigh muscles (Group III), especially palmitic acid (C16:0). The inclusion of linseed oil increased the content of α-linolenic acid and total *n*-3 FA concentration in both muscles, compared with the diet that contained soybean oil. The modification of FA profile was also reflected in the *n*-6/*n*-3 FA ratio which in the muscles of birds fed with linseed oil was significantly lower than in turkey hens receiving soybean oil in their feed mixture regardless of the vitamin E form. The use of RRR-d-α-tocopherol in diets containing linseed oil may help to improve the nutritional quality of turkey meat, especially by enhancing *n-3* PUFA levels with no detrimental effect of lipid addition on the chemical composition and quality of meat.

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