EFFECT OF VITAMIN E SUPPLEMENTATION ON INTRA- AND INTERMUSCULAR FATTY ACID COMPOSITION OF AWASSI LAMBS

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ABSTRACT

This research was carried out to determine the effects of vitamin E supplementation on inter- and intramuscular fatty acid composition in meat of Awassi lambs. Lambs were divided into two groups, control (CG) and experimental (VG), at the beginning of the fattening period. The CG and VG lambs were fed the same concentrate and hay. The VG also received a supplement of 45 mg vitamin E (DL-α tocopheryl acetate) per lamb per day for the 75-day fattening period prior to slaughter. After slaughtering, carcasses were stored at 4 ± 0.5C for 24 h. Then, M. longissimus dorsi *(LD) muscles were excised from carcasses, and the intra- and intermuscular fats from LD muscles were used as study material. Results showed that vitamin E supplementation had no significant effect on fatty acid composition in intra- and intermuscular fats (*$P > 0.05$*). Fatty acid content in intramuscular fats were different than those in intermuscular fats (*$P < 0.01$*) except for lauric (C_{12}), linoleic ($C_{18:2}$) and linolenic ($C_{18:3}$) acids (*$P > 0.05$*). Total saturated fatty acids in the intramuscular fats were lower than in intramuscular fats (*$P < 0.01$*). In*

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addition, the majority of fatty acids, both intramuscular and intermuscular, in Awassi lambs were oleic ($C_{18:1}$), palmitic (C_{16}) and stearic (C_{18}) acids.

INTRODUCTION

One of the basic principles of animal nutrition is to produce high quality meat. For this reason, the diet is very important, and different diet combinations have been used for farm animals. Vitamin E has frequently been used in animal nutrition to improve meat quality. It cannot be synthesized by the animal body, and is present in green plants and animal products (Aksoy *et al.* 2000; Macit *et al.* 2003 a, b). Vitamin E supplementation in the diet of livestock has a positive effect on fattening performance, carcass and meat quality characteristics (Hill *et al.* 1989), with the vitamin E-treated group receiving a supplement of 45 mg vitamin E per lamb per day for the 75-day fattening period. Institut National de Recherche Agricole [(INRA)], Jarrige (1988) recommended 5 to 10 mg vitamin E per kilogram dry feed for ruminants. The Agricultural Research Council (ARC 1980) suggests a minimal requirement between 10 and 15 mg/kg dietary dry matter. However, higher levels of vitamin E likely improve performance and meat quality traits of livestock. Because of its antioxidant activity, vitamin E in the muscle is taken into consideration because of its role in reducing lipid oxidation by preventing formation of free radicals, improve color stability and reduce the drip loss of fresh and frozen meats during display, and extends shelf-life (Morrisey *et al.* 1994; Schaefer *et al.* 1995; Dufrasne *et al.* 2000; Gatellier *et al.* 2001; Macit *et al.* 2003 a, b; Salvatori *et al.* 2004). The susceptibility of muscle to lipid oxidation can be reduced by antioxidants, and α-tocopherol is a highly effective chain-breaking antioxidant (Wilson 1987). It exerts a protective effect on the unsaturated fatty acids in tissues in both domestic and laboratory animals (Barja *et al.* 1996; Yilmaz *et al.* 1997; Salvatori *et al.* 2004).

Fatty acids are involved in various "technological" aspects of meat quality (Wood *et al.* 2004). The effect of fatty acids on shelf-life is explained by the propensity of unsaturated fatty acids to oxidize, leading to the development of rancidity, as display time increases (Wood *et al.* 2004; Renerre 2000). So far, there has been no attempt to study the effect of vitamin E supplementation on fatty acid composition of meat from Awassi lambs. Hence, the present study was conducted with the objective of determining the effect of vitamin E supplementation (VG, 45 mg vitamin E per lamb per day) to diet of Awassi lambs on saturated and unsaturated fatty acid composition in intra- and intermuscular fats from LD muscles, and to determine the main differences of fatty acid composition on intra- and intermuscular fats.

MATERIALS AND METHODS

The experiment was conducted at the Application and Research Farm of the College of Agriculture, Atatürk University, Erzurum, and involved fat tailed Awassi male lambs born in the 2000 lambing season. Lambs were divided into two groups, control (CG, n = 18) and experimental (VG, n = 18), at the beginning of the fattening period. The CG and VG lambs were fed with the same concentrate and hay. In addition, the VG received a supplement of 45 mg vitamin E (DL-α tocopheryl acetate) per lamb per day during the 75-day fattening period. Concentrate feed was composed of barley (42%), corn (24%), soybean meal (10%), wheat bran (4%), molasses (8%), sunflower meal (8%), premix (0.05%), salt (0.95%) and dicalcium phosphate (3%). The concentrate mixture had 91% dry matter, 13.3% crude protein, 10.5% crude fiber, 3.2% ether extract, 55.9% nitrogen free extract and 2.550 MJ ME/kg. Grass hay was fed at 300 g per lamb per day during the fattening period for both groups. Grass hay was 91.7% dry matter, 6.1% crude protein, 27.5% crude fiber, 2.7% ether extract and 46.13% nitrogen free extract.

After the 75 day fattening period, the lambs were conventionally slaughtered (CG: 18 male lambs; VG: 18 male lambs), pelted, eviscerated and split into halves. After evisceration, carcasses were held at 4 $\pm$ 0.5C for 24 h. The *M. longissmus dorsi (LD)* muscles were excised from carcasses, and the intra- and intermuscular fats from them were used as study material. Intra- and intermuscular fat samples were collected from each of the *M. Longissimus dorsi*. The intramuscular fats were collected from the same points of all the muscles (thoracic 13-15, 3.0 - 5.0 cm thick steaks). The exterior fat of thick steaks was used as intermuscular fat (thoracic 13-15), no subcutaneous fat was included.

The intra- and intermuscular fats were extracted from the samples using ether extraction (Unsal 1996; Nas *et al.* 2001; Gökalp *et al.* 2001). Samples were dried at 40C prior to ether extraction, and petroleum ether with low boiling temperature (40 - 60C) was used for lipid extraction (Aksu and Kaya 2002).

Methyl esters of fat samples were prepared with borontrifluoride-methanol (BF_3-methanol) used to determine the fatty acid composition. Fat sample (0.15-0.20 g) was added to 5 mL 0.5 N methanolic-NaOH in flasks, then incubated at 100C for 10 min in a boiling water bath. After saponification, 5 mL of BF_3-methanol was added to the sample and boiled for 2 min, then 5 mL of heptane was added and boiled for another 1 min. The balloon with samples was removed from the water bath and cooled on the bench. Sample mixture was transferred into 25 mL volumetric flasks. The esterified samples in volumetric flasks were adjusted with saturated NaCl on the shaker. One milliliter of the heptane phase from the upper layer of the volumetric flask was used to determine fatty acids composition (Morrison and Smith 1964). Fatty acids were analyzed by gas

chromatography (Perkin Elmer Instrument Auto System XL Gas Chromatograph) with a capillary column (SGE, 60 m × 0.25 mm ID-BP × 70, 0.25). The temperature was increased from 150C to 250C at a rate of 2C/min) and separated compounds were detected using a FID detector (H_2 and dry air) at 240C, using helium gas (1 mL/min, 150 kPa) and an injection block temperature of 250C.

Data obtained from this study were analyzed using the SPSS Package Program (SPSS 1996). Data were analyzed using a *t* test for determination of differences in both groups (VG and CG), and in intra- and intermuscular fats. The results of the statistical analysis are shown as mean values ± standard deviation in tables.

RESULTS AND DISCUSSION

Initial weight, final weight, daily weight gain and feed conversion efficiency were 31.8 ± 1.40 kg, 45.5 ± 1.37 kg, 183 ± 13 g and 7.6 for CG, 32.5 ± 1.45 kg, 46.7 ± 1.42 kg, 189 ± 15 g and 7.0 for VG, respectively. Vitamin E supplementation had no statistically significant effect on animal performance traits, but improved feed conversion efficiency by 8.1%.

The average daily feed intake per animal per day was 1394 g (concentrate = 1054, grass hay = 340) and 1327 g (concentrate = 1011, grass hay = 316) for CG and VG, respectively. The results of the present study consistently indicated that dietary vitamin E supplementation had no effect on fattening performance traits of lambs.

The saturated and unsaturated fatty acid compositions determined in intra- and intermuscular fats from control and vitamin E supplemented Awassi male lamb groups are summarized in Table 1. The effect of vitamin E supplementation on fatty acid composition of intramuscular fats was not significant ($P > 0.05$). The saturated fatty acid composition in intramuscular fats showed that the proportions of capric, lauric, margaric and arachidic fatty acids were less than 3%. There was no difference in the concentrations of saturated fatty acids of vitamin E supplemented groups compared with the control. Although the content of arachidic acid in the control was numerically higher than that in vitamin E supplemented group, the difference between groups was not statistically significant ($P > 0.05$) (Table 1). Fatty acids have very different melting points, therefore, variation in fatty acid composition has an important effect on firmness or softness of the fat in meat, especially the subcutaneous and intermuscular fats (carcass fats) but also the intramuscular (marbling) fat. The ability of unsaturated fatty acids, especially those with more than two double bonds, to rapidly oxidize, is important in regulating the shelf-life of meat (rancidity and color deterioration) (Wood *et al.* 2004). Salvatori *et*

al. (2004) point out that using Vitamin E supplementation of lambs diet (Ile de France × Pagliarola lambs and Gentile di Puglia × Sopravissana lambs) had no effect on fatty acid composition of lipids of *Longissimus dorsi* muscle.

Palmitic (28.52 ± 1.88%) and stearic (18.64 ± 1.75%) acids were the largest component in the saturated fatty acid fraction in intramuscular fats. Oleic acid constituted the highest proportion (44.62 ± 1.08%) of unsaturated fatty acid content in intramuscular fats. Vitamin E supplementation had a relatively positive, but nonsignificant, effect on the proportion of total unsaturated fatty acids in intramuscular fats. Although the content of linoleic and linolenic fatty acids in control samples was numerically higher than those of vitamin E supplemented samples, the difference between groups was not statistically significant ($P > 0.05$) (Table 1). Enser *et al.* (1996) reported that the average percentages of palmitic and stearic acids from saturated fatty acids and oleic acid from unsaturated fatty acids in lamb meat were 22.5%, 18.1% and 32.5%, respectively. In another study, Enser *et al.* (1998) determined that palmitic (20.9%) and stearic (17.5%) acids from saturated fatty acids and oleic (30.3%) acid from unsaturated fatty acids were high in LD muscles of lambs. They also indicated that the myristic, palmitoleic, linoleic and linolenic acid contents of LD muscles from lamb carcass were 3.99%, 2.19%, 3.24% and 0.02%, respectively. Furthermore, Bas and Morand-Fehr (2000) reported that palmitic (22.5%), stearic (15.6%) and oleic (40.4%) acids were dominant in intramuscular fats of lamb meat. The results of our study agree with the findings of the previous studies. The results of the present study confirmed the data reported by Unsal *et al.* (2004). Except for margaric acid in intramuscular fats, no significant effect of vitamin E supplementation (45 mg vitamin E per lamb per day for the 75-day) on fatty acid compositions of intramuscular fats obtained from LD muscles of Morkaraman lambs was found in the study of Unsal *et al.* (2004).

The effect of vitamin E supplementation to the diet of Awassi lambs on fatty acid composition in intermuscular fats was not statistically significant ($P > 0.05$). The amount of myristic, palmitic and margaric acids in vitamin E supplemented samples and the amounts of stearic acid in control samples were relatively high. The most remarkable difference between control and vitamin E supplemented samples occurred in the proportion (3%) of stearic acid. The proportion of oleic acid (42.17 ± 1.47%) in the unsaturated fatty acid component of intramuscular and intermuscular fats was higher than those of other unsaturated fatty acids. While the proportion of palmitoleic acid in intermuscular fats of control samples was lower than that of vitamin E supplemented samples. In contrast, the proportions of oleic and linoleic acids in control samples were comparatively higher than those of vitamin E supplemented samples. In general, the amount of total saturated fatty acids (52.02 ± 2.28%) in intermuscular fats was greater than the amount of unsaturated fatty acids

(47.97 ± 2.28%) (Table 1). Enser *et al.* (1996) indicated that the proportions of lauric, myristic, palmitic, stearic, palmitoleic, oleic, linoleic and linolenic fatty acids in lamb adipose tissue were 0.37%, 4.11%, 21.9%, 22.6%, 2.40%, 28.7%, 1.31% and 0.97%, respectively. In the present study, the effect of vitamin E on fatty acid composition of intermuscular fats from LD muscles was found insignificant. Our findings pertaining to fatty acid composition of intermuscular fats are comparable with those results, except for stearic fatty acid, of Unsal *et al.* (2004).

TABLE 1.
FATTY ACIDS COMPOSITION IN INTRA- AND INTERMUSCULAR FATS OF LD MUSCLES OF LAMBS

Fatty Acid	Intramuscular		Intermuscular	
	Control	Vitamin E	Control	Vitamin E
Saturated fatty acids (%)				
Capric	0.17±0.03	0.16±0.06	0.24±0.08	0.37±0.19
Lauric	0.09±0.04	0.09±0.11	0.10±0.03	0.09±0.08
Myristic	2.98±0.45	2.97±0.91	3.47±0.63	4.20±2.18
Palmitic	28.64±1.79	28.41±2.23	29.54±1.82	31.73±3.65
Margaric	0.86±0.16	1.14±0.56	1.96±0.88	2.74±0.31
Stearic	18.52±2.19	18.76±1.52	15.95±2.87	12.67±3.17
Arachidic	0.35±0.31	0.20±0.40	0.36±0.44	0.79±0.59
Total saturated	51.61±0.90	50.97±1.64	51.62±2.80	52.43±1.96
Unsaturated fatty acids (%)				
Palmitoleic	1.64±0.33	2.03±0.84	3.25±1.16	4.55±1.18
Oleic	44.15±1.14	45.09±0.91	42.91±1.52	41.43±1.14
Linoleic	3.54±0.81	1.91±0.57	2.48±1.25	1.43±0.20
Linolenic	0.07±0.13	0.01±0.02	0.005±0.01	0.00±0.00
Total unsaturated	48.42±0.90	49.04±1.64	48.39±2.80	47.57±1.96

Comparing of intra- and intermuscular fats in samples, there were differences between intra- and intermuscular fats in terms of the proportion of the fatty acids. The amounts of total saturated fatty acids both intramuscular and intermuscular were higher than unsaturated fatty acids (Table 2). In addition, there were differences between intra- and intermuscular fats in the amounts of

saturated and unsaturated fatty acids ($P < 0.01$), and the amounts of the total saturated fatty acids of the intramuscular fats were lower than in the intermuscular fats (Table 2). Velasco *et al.* 2004 reported that the amount of the saturated fatty acids in the intermuscular fats (51.42 - 55.96%, *m. longissimus dorsi*) was lower than that in subcutaneous fat (55.01 - 64.25%) in lambs. Similar results were reported by Unsal *et al.* (2004). Murphy *et al.* (1994) pointed out that the feeding system influences the lipid content of the meat and the proportion of intramuscular fat in meat.

TABLE 2.
MEAN VALUES OF FATTY ACIDS IN INTRA- AND INTERMUSCULAR FATS

Fatty Acid	Intramuscular	Intermuscular	P
Saturated fatty acids (%)			
Capric	0.17±0.04	0.31±0.15	*
Lauric	0.09±0.07	0.08±0.04	Ns
Myristic	2.98±0.67	3.83±0.86	*
Palmitic	28.52±1.88	30.62±1.94	*
Margaric	1.00±0.41	2.35±0.74	**
Stearic	18.26±1.73	14.31±3.30	**
Arachidic	0.28±0.22	0.58±0.29	*
Total saturated	51.29±0.49	52.02±0.40	**
Unsaturated fatty acids (%)			
Palmitoleic	1.87±0.65	3.90±1.28	**
Oleic	44.62±1.08	42.17±1.47	**
Linoleic	2.22±0.73	1.83±0.74	Ns
Linolenic	0.04±0.03	0.003±0.00	Ns
Total unsaturated	48.72±0.49	47.98±0.41	**

P: Probability
*P<0.05
** P<0.01
Ns. P>0.05

The amount of capric ($P < 0.05$), myristic ($P < 0.05$), palmitic ($P < 0.05$), margaric ($P < 0.01$), arachidic ($P < 0.05$) and palmitoleic ($P < 0.01$) acids in intermuscular fats was higher than that in intramuscular fats. The amounts of stearic and oleic acids were low in the intermuscular fats ($P < 0.01$). But, there were no differences between intra- and intermuscular fats in the amounts of lauric, linoleic, and linolenic acids ($P > 0.05$) (Table 2). The majority of fatty acids in both intramuscular fats and intermuscular fats in the present study were oleic, palmitic and stearic acids. Rowe *et al.* (1999) and Bas and Morand-Fehr (2000) reported similar results in the fatty acid composition of the adipose depots of lambs. Bosi *et al.* (2000) reported that different levels (0, 100 and 200 mg/kg) of vitamin E supplementation to the diets of pigs have significant effects on fatty acid composition of Parma Ham. Similar studies performed by other researchers (Enser *et al.* 1996, 1998; Bas and Morand-Fehr 2000) demonstrated that vitamin E has significant effects on the palmitic, stearic, linoleic fatty acids of intramuscular neutral lipids and on total saturated fatty acids in livestock. In addition, the effects of different raw materials added to lamb diets on fatty acid composition of lamb meat have been determined to be significant (Enser *et al.* 1996, 1998; Bas and Morand-Fehr 2000; Unsal *et al.* 2004).

In this study, the effect of 45 mg vitamin E supplementation per lamb per day during the 75 day fattening period on fatty acid composition was not statistically significant. It may suggest that an increase in vitamin E dose in diets of livestock or extension of the fattening period of animals needs to be tested in the future studies for their effects on the fatty acid composition in muscles.

REFERENCES

AKSOY, A., MACIT, M. and KARAOGLU, M. 2000. *Animal Nutrition.* Atatürk Univ. Publ. No: 220. Erzurum, Turkey.

AKSU, M.I. and KAYA, M. 2002. Effect of commercial starter cultures on the fatty acid composition of pastirma (Turkish dry meat product). J. Food Sci. *67*(6), 2342–2345.

ARC. 1980. Nutrient Requirement of Ruminant Livestock, p. 351, CAB, International, Wallingford, UK.

BARJA, G., CADENAS, S., ROJAS, C., PEREZ-CAMPO, R., LOPEZ-TORRES, M., PROT, J. and PAMPLONA, R. 1996. Effect of dietary vitamin E levels on fatty acid profiles and nonenzymatic lipid peroxidation in the Guinea pig liver. Lipids *31*, 963–970.

BAS, P. and MORAND-FEHR, P. 2000. Nutritional factors on fatty acid composition of lamb fat deposits. Livestock Production Sci. *64*, 61–79.

BOSI, P., CACCIAVILLANI, J.A., CASINI, L., LO FIEGO, D.P., MARCHETTI, M. and MATTUZZI, S. 2000. Effects of dietary high-oleic acid sunflower oil, cupper and vitamin E levels on the fatty acid composition and the quality of dry cured parma ham. Meat Sci. *54*, 119–126.

DUFRASNE, I., MARCHE, C., CLINQUART, A., HORNIC, J.L., VAN EENAEME, C. and ISTASSE, L. 2000. Effects of dietary vitamin E supplementation on performance and meat characteristics in fattening bulls from Belgian Blue Breed. Livestock Production Sci. *65*, 197–201.

ENSER, M., HALLETT, K., HEWITT, B., FURSEY, G.A.J. and WOOD, J.D. 1996. Fatty acid content and composition of English beef, lamb and pork at retail. Meat Sci. *42*(4), 443–456.

ENSER, M., HALLETT, K., HEWITT, B., FURSEY, G.A.J., WOOD, J.D. and HARRINGTON, G. 1998. Fatty acid content and composition of UK beef and lamb muscle in relation to production system and implications for human nutrition. Meat Sci. *49*(3), 329–341.

GATELLIER, P., HAMELIN, C., DURAND, Y. and RENERRE, M. 2001. Effects of a dietary vitamin E supplementation on colour stability and lipid oxidation of air- and modified atmosphere-Packaged Beef. Meat Sci. *59*(2), 133–140.

GÖKALP, H.Y., KAYA, M., TÜLEK, Y. and ZORBA, O. 2001. *Guide for Quality Control and Laboratory Application of Meat Products*, 4th Press, Atatürk Univ. Publ. No: 751. Faculty of Agric. No: 318. Erzurum, Turkey.

HILL, G.M., STVART, R.L., UTLEY, P.R. and REAGAN, J.O. 1989. Vitamin E effects on finishing steer performance. J. Anim. Sci. *68*, 557–567.

JARRIGE, R. 1988. Alimentation des Bovins et Ovins et Caprins, p. 471, INRA, Paris, France.

MACIT, M., AKSAKAL, V., EMSEN, E., AKSU, M.I, KARAOGLU, M. and ESENBUGA, N. 2003a. Effects of vitamin E supplementation on performance and meat quality traits of Morkaraman male lambs. Meat Sci. *63*, 51–55.

MACIT, M., AKSAKAL, V., EMSEN, E., ESENBUGA, N. and AKSU, M.I. 2003b. Effects of vitamin E supplementation on fattening performance, non-carcass components and retail cut percentages, and meat quality traits of Awassi lambs. Meat Sci. *64*, 1–6.

MORRISEY, P.A., BUCKLEY, D.J. and SHEEHY, P.J.A. 1994. Vitamin E and meat quality. Proc. Nutr. Soc. *53*, 289.

MORRISON, W.R. and SMITH, L.M. 1964. Preparation of fatty acid methyl esters and dimethyl acetals from lipids with boron fluoride-methanol. J. Lipid Res. *5*, 600–608.

MURPHY, T.A., LOERCH, S.C., MCCLURE, K.E. and SOLOMON, M.B. 1994. Effects of restricted feeding on growth performance and carcass composition of lambs subjected to different nutritional treatments. J. Anim. Sci. *72*, 3131–3137.

NAS, S., GÖKALP, H.Y. and UNSAL, M. 2001. *Vegetable Oil Technology*, 4th Press, Pamukkale Univ. Publ. Faculty of Engineering. No: 005. Denizli, Turkey.

RENERRE, M. 2000. Oxidative processes and myoglobin. In *Antioxidants in Muscle Foods*, (E. Decker, C. Faustman and C.J. Lopez-Bote, eds.) pp. 113–133, John Wiley, New York.

ROWE, A., MACEDO, F.A.F., VISENTAINER, J.V., SOUZA, N.E. and MATSUSHITA, M. 1999. Muscle composition and fatty acid profile in lambs fattened in drylot or pasture. Meat Sci. *51*, 283–288.

SALVATORI, G., PANTALEO, C., DI CESARE, G., MAIORANO, F., FILETTI, F. and ORIANI, G. 2004. Fatty acid composition and cholesterol content of muscles as related to genotype and vitamin E treatment in crossbred lambs. Meat Sci. *67*(1), 45–55.

SCHAEFER, D.M., LIU, Q., FAUSTMAN, E. and YIN, M. 1995. Supranutritional administration of Vitamins E and C improves oxidative stability of beef. Amer. Inst. Nutr. S1792.

SPSS. 1996. SPSS for Windows Release 10.01, SPSS Inc., Chicago, IL.

UNSAL M. 1996. Some properties of fresh tail fat treated with different technological process and determination of some changes in some properties during storage under various conditions. Ph.D. Thesis. Atatürk Univ. Graduate Institute of Science, Erzurum, Turkey.

UNSAL, M., AKSU, M.I. and KAYA, M. 2004. Effect of Vitamin E Supplementation on Intramuscular and Intermuscular Fatty Acid Composition of Morkaraman Lambs. Turk Vet. Anim. Sci. *28*(3), 563-568.

VELASCO, S., CAÑEQUE, V., LAUZURICA, S., PÉREZ, C. and HISIDOBRO, F. 2004. Effect of different feeds on meat quality and fatty acid composition of lambs fattened at pasture. Meat Sci. *66*(2), 457–465.

WILSON, R.L. 1987. Vitamin, selenium, zinc, and copper in the action in free radical protection against ill-placed iron. Proc. Nutrition Soc. *46*, 27–31.

WOOD, J.D., RICHARDSON, R.I., NUTE, G.R., FISHER, A.V., CAMPO, M.M., KASAPIDOU, E., SHEARD, P.R. and ENSER, M. 2004. Effects of Fatty Acids on Meat Quality: A Review. Meat Sci. *66*(1), 21–32.

YILMAZ, O., CELIK, S. and DILSIZ, O. 1997. Influences of intraperitoneally and dietarily administered vitamin E and selenium on the lipid composition, in reproductive organ of male animals. Biological Chem. *378*, 425–430.