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Effect of vitamin E supplementation on growth performance, carcass characteristics and intramuscular fatty acid composition of *Longissimus dorsi* muscle in 'Tan' sheep

Tianzhang Zhao[1,2], Hailing Luo[1*], Yuwei Zhang[1], Kong Liu[1], Huina Jia[1], Yanfei Chang[1], Lijuan Jiao[1], and Weimin Gao[1]

The beneficial effects on meat quality of adding vitamin E to diets have been extensively studied in cattle and lamb. However, how supplemental vit E affects the performance and meat quality of 'Tan' sheep has not been reported. Thirty-five male lambs of 'Tan' sheep (20-30 d after weaning) with similar body weight were randomly divided into five groups of seven each to receive a basal diet plus five levels of vit E supplementation: 0 (control group, CG), 20, 100, 200, and 2000 IU d^{-1} $lamb^{-1}$. The results showed: 1) no differences were observed in animal growth performance between CG and vit E treated groups (VG) ($P > 0.05$); 2) vit E supplementation levels over 200 IU d^{-1} $lamb^{-1}$ dramatically suppressed subcutaneous fat deposition and similarly that above 100 IU d^{-1} $lamb^{-1}$ considerably reduced drip loss and pH 24 h of *Longissimus dorsi* (LD) muscle in VG lambs compared to those of CG ($P < 0.01$), but with no significant effect on other carcass characteristics ($P > 0.05$); 3) although vit E supplementation generally did not affect the fatty acid composition of intramuscular lipids in LD muscle, the percentage of n-6 polyunsaturated fatty acids (PUFA) and the ratio of n-6/n-3 PUFA were significantly enhanced ($P < 0.05$) and an increasing tendency ($P < 0.1$) for both total PUFA proportion and the ratio of PUFA/saturated fatty acids (SFA) was also observed in 'Tan' sheep lambs treated with vit E. In conclusion, vit E supplementation of male 'Tan' sheep lambs did not influence growth performance, significantly reduced subcutaneous fat deposition, drip loss, pH 24 h and tended to improve fatty acid profile of LD muscle.

Key words: Carcass characteristics, growth performance, vitamin E.

INTRODUCTION

In 1922, Evans and Bishop firstly discovered that vitamin E in wheat (*Triticum aestivum* L.) germ oil played an important role on reproduction of rats. After that, a number of research studies were conducted to study on vitamin E in various areas of biology. Recently, in addition to the commonly recognized role of vitamin E as a highly effective antioxidant in lipid oxidation (Dufrasne et al., 2000), ruminant nutritionists also found that supplemental vit E had positive effects on the performance of feedlot ruminant and the quality of their meat products (Turner et al., 2002; Macit et al., 2003b; Álvarez et al., 2008). Compared with beef, lamb probably has a higher antioxidant requirement to extend its shelf life and that is because lamb contains more long-chain poly unsaturated fatty acids (PUFA) (International Institute for Refrigeration, 1964; Enser et al., 1996), which is susceptible to oxidation and is considered to be one of the main factors to induce meat to oxidative rancidity when meat is exposed for a long time on a shelf (Sherbeck et al., 1995). Vitamin E, usually as all-rac-α-tocopherol acetate, is a highly effective chain-breaking antioxidant which can reduce the susceptibility of muscle to lipid oxidation (Salvatori et al., 2004). The beneficial effects on meat quality of adding vit E to diets have been extensively studied in lamb (Álvarez et al., 2008; Kasapidou et al., 2009; 2012) and the mechanism for that may be related to two facts: (1) vit E could exert a protective effect on meat PUFA against peroxidation. Morrisey et al. (1994) indicated that the presence of vit E within muscle cell membranes reduced lipid oxidation, improving the quality characteristics of meat such as color, flavor, texture and nutritional value, and also extending its shelf-life. (2) vit E could somehow modify the biohydrogenation pathways of dietary PUFA in rumen and consequently indirectly improve the fatty acid composition of meat products. Pottier et al. (2006) reported that inclusion of dietary vit E at 12 000 IU d^{-1} could result in a shift in rumen PUFA biohydrogenation toward production *trans*-11 C18:1 rather than *trans*-10 C18:1. In addition, Hou et al. (2012) found that vit E supplementation could accelerate the ruminal biohydrogenation of C18:1 and affect conjugated linoleic acid (CLA) level in rumen fluid *in vitro*.

[1]China Agricultural University, College of Animal Science and Technology, Beijing, 100193, P.R. China.
[*]Corresponding author (luohailing@cau.edu.cn).
[2]Bio-Technology Department, Wulanchabu Vocational College, Wulanchabu, 012000, P. R. China.
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Our previous studies had proved that moderate level (200 IU d^{-1} $lamb^{-1}$) of vit E supplementation could improve fatty acid composition of LD muscle in 'Boer' goat (Luo et al., 2010) and 'Aohan' fine-wool sheep (Ge et al., 2011). 'Tan' sheep, a special local sheep breed, is celebrated for its meat that is authorized by the government as a geographically symbolic product (AGI2008-07-00061) in Ningxia province, China. However, it is very limited for the available data to evaluate the effects of supra-nutritional supplementation of vit E on meat quality of 'Tan' sheep.

Therefore, the objectives of the present study were to investigate the effects of increasing dietary concentrations of vit E on growth performance, carcass characteristics, and intramuscular fatty acid composition of *Longissimus dorsi (*LD) muscle in Tan sheep lambs.

MATERIALS AND METHODS

Animals

'Tan' sheep is a particular fur-purpose breed of sheep raised mainly in the Ningxia Hui Autonomous Region, northwest of China, with high quality meat under unfavorable environmental and feeding conditions, and its products are often exported to Middle Eastern countries. Accordingly, the 'Tan' sheep industry is of significant economic importance for a large area of northwestern China.

The work described in this paper was conducted in accordance with the requirements of the Animal Care and Use Committee of China Agricultural University.

Experiment design and dietary treatments

Thirty-five male lambs of 'Tan' sheep at the age of 4-mo ± 10 d (i.e., 2 wk after weaning, initial body weight; BW = 18.75 ± 1.62 kg) individually housed in shaded pens (1.0 m × 1.1 m) and allowed visual contact with each other and water was supplied *ad libitum*. Lambs were assigned on the basis of body weight (BW) to one of five dietary treatments being a control diet without added vit E (CG) and four additional diets (VG) containing 20, 100, 200, and 2000 IU d^{-1} $lamb^{-1}$ of vit E (α-tocopheryl acetate), respectively. These dose levels were 0, 1, 5, 10, and 100 times that of the NRC (1985) feeding standard, which was chosen according to our previous studies (Luo et al., 2010; Yan et al., 2010; Ge et al., 2011; Liu et al., 2012).

All diets with roughage to concentrate ratio at 50:50 (DM base) were formulated to meet all nutrient requirements for the growing lambs (NRC, 1985). Experimental diets were mixed biweekly to minimize oxidation of vit E. Upon mixing, feed samples were collected and saved (-20 °C) for later analysis according to procedures of AOAC (1990) for DM, crude protein (CP) and ether extract (EE). Additionally, samples were analyzed for neutral detergent fiber (NDF) and acid detergent fiber (ADF) according to Van Soest et al. (1991) to determine dietary composition (Table 1). The experiment lasted for 130 d, first 10 d for adaptation and the following 120 d for experiment.

Lambs were weighed before the morning feeding at the beginning and, thereafter, weekly throughout the study. Lambs average daily gain (ADG) was calculated by subtracting initial from final BW and then dividing by the duration of study. Lambs were offered the diets twice daily at 07:00 h and 17:00 h, with the sequence of roughage firstly and then concentrate. Lambs had *ad libitum* access to feed and free access to clean water throughout the study. The amounts of feed offered and refused were recorded daily for each lamb to determine feed intake.

Slaughtering procedure and carcass characteristics

At the end of the experiment, all animals were slaughtered at a commercial abattoir after being fasted for 24 h as reported previously (Ponnampalam et al., 2001). Carcasses were immediately weighed to obtain the hot carcass weight. Then, carcasses were cut into halves along the midline and the right sides were dissected and measured for total lean, subcutaneous fat, fat depth, and rib-eye area as described by Awawdeh et al. (2009). *Longissimus dorsi* (LD) muscle pH was measured between the 12^{th} and 13^{th} ribs 45 min and 24 h postmortem using a portable pH meter (Schott L 6880, Lab Star pH, Mainz, Germany). Dressing proportion was calculated as the hot-carcass weight proportion of the fasted BW. Loin samples (25 mm thick) were collected 24 h postmortem and kept at 4 °C until drip loss analysis. Drip loss was determined 48 h postmortem via the bag method (Lanza et al., 2003). Finally, *Longissimus thoracis* (LT) muscle was then cut out from the left side of each carcass and samples were taken and kept at -20 °C until analyzed for intramuscular lipids and fatty acid composition of LD muscle.

Chemical analyses

Intramuscular lipids. The content of intramuscular lipids in LD muscle was determined as crude fat in a Soxhlet apparatus by extraction with petroleum-ether as the fat solvents (XT 15i, ANKOM Technology, Macedon, New York, USA).

Table 1. Ingredients and chemical composition of experimental diets.

Ingredients (DM basis)	Ratio (%)	Chemical composition	of DM
Corn silage	50.00	Metabolizable energy, MJ kg^{-1}[(b)]	8.95
Corn	27.81	Crude protein, %	12.30
Soybean meal	13.00	Ether extract, %	5.08
Wheat bran	4.93	Neutral detergent fiber, %	48.77
Shelled sunflower meal	2.11	Acid detergent fiber, %	33.89
Sodium chloride	0.68	Vitamin E, mg kg^{-1}[(c)]	3.42
Calcium carbonate	0.23	Ca, %	0.51
Calcium hydrophosphate	0.11	P, %	0.36
Premix[a]	1.13		

[a]Content per kilogram of premix: 100 000 IU vitamin A, 20 000 IU vitamin D3, 60 IU vitamin E, 1 g Fe, 1 g Mn, 0.78 g Zn, 0.27 g Cu, 0.012 g Se, 0.01 g I.

[b]All values are analyzed except metabolizable energy; metabolizable energy content was calculated based on tabular values (NRC, 1985).

[c]Levels indicated are background levels without the addition of synthetic α-tocopheryl acetate.

Fatty acids. The measurement of intramuscular fatty acid composition was conducted in the Ministry of Agriculture Feed Industry Center (MAFIC) of China. The extraction and transmethylation of fatty acids from LD muscle were carried out following the procedures provided by MAFIC. The remaining portions of LT were minced and freeze-dried, then samples weighing about 0.15 g were placed into a screwed tube and homogenized with 4 mL 1:10 (v/v) mixture of chloroacetyl-methanol (now with the current use, slowly put 1 chloroacetyl into 10 methanol to prevent splash explosion). After adding 1 mL internal standard (1 mg mL^{-1} C11:0) and 1 mL hexane, the screwed tubes were put into 80 °C water bath for standing 2 h and thereafter were cooled down at room temperature. The mixture was added with 5 mL 7% K_2CO_3, well oscillated and centrifuged in 1200 r min^{-1} for 5 min. About 1 ~ 2 mL supernatant was transferred into injection vial to be analyzed on gas chromatography, which was performed on a gas chromatograph (GC-6890N, Agilent, Santa Clara, California, USA) apparatus equipped with a DB-23 type capillary column (60 m × 250 μm × 0.25 μm) and flame ionization detector. Direct injection on the column was performed with 1 μL samples. The GC conditions were: N_2 as the carrier gas with a flow rate of 2 mL min^{-1}; split mode injection 20:1; injector temperature 260 °C and flame ionization detector temperature 270 °C; initial oven temperature 180 °C for 15 min, then increased at 1.5 °C per min to 220 °C, and held at 220 °C for 10 min; the oven temperature was 190 °C. Fatty acids were identified by comparison of the retention times with known standard mixtures of fatty acid methyl esters (NU-VHEK, USA) and quantified by adding methyl-undecanoic acid as an internal standard prior to hydrolysis of tissues or lipid extracts.

Results were expressed as mg g^{-1} of muscle for total fatty acids (TFA) and as percentage of TFA for each fatty acid. The proportion of PUFA (C18:2n-6; C18:3n-6; C18:3n-3; C20:3n-6; C20:4n-6; C20:5n-3; and C22:6n-3), monounsaturated (MUFA) (C14:1n-7; C16:1n-7; C18:1n-9; C18:1n-11; and C20:1n-9) and saturated (SFA) (C8:0; C10:0; C12:0; C13:0; C14:0; C15:0; C16:0; C17:0; C18:0; C20:0; C21:0; and C22:0) fatty acid contents were calculated.

Statistical analysis

The individual animal was the experimental unit. Data were analyzed according to *t* test for determination of differences between control and vitamin treatment groups, and ANOVA for determination of differences among all treatments using the GLM procedure of SAS (SAS Institute, 2002) with concentration of dietary vit E as the independent variable. Statistical differences between means were tested using Duncan's multiple range tests (Duncan, 1955).

RESULTS AND DISCUSSION

Animal performance

Growth performance parameters of lambs from CG and VG are shown in Table 2. The initial weight, final weight, daily DM intake per animal in a day (DMI) and feed conversion ratio did not differ between control and vitamin treatment groups. The ADG were found to be 122.02 g for lambs from CG and 126.19, 110.12, 109.52, and 107.74 g for lambs from VG group corresponding to vit E supplementation level of 20, 100, 200, and 2000 IU d^{-1} $lamb^{-1}$, respectively. This result indicated that vit E supplementation levels over 100 IU d^{-1} $lamb^{-1}$ tended to suppress the growth of Tan sheep lambs compared with those fed a control diet ($P < 0.1$), which is consistent with the finding of Wulf et al. (1995), who reported that lambs fed on concentrates added 1000 mg all-rac-α-tocopheryl acetate d^{-1} had a lower weight gain ($P < 0.05$).

Vitamin E plays an important role in the development

Table 2. Effect of vitamin E supplementation on performance of 'Tan' sheep lambs.

	Dietary vitamin E added levels (IU d^{-1} $lamb^{-1}$)[1]					
Performance[3]	0 (CG)	20 (VG20)	100 (VG100)	200 (VG200)	2000 (VG2000)	p[2]
DMI, kg d^{-1}	0.75 ± 0.028	0.72 ± 0.091	0.73 ± 0.033	0.75 ± 0.084	0.72 ± 0.056	NS
	CG	0.75 ± 0.028	0.75 ± 0.028	0.75 ± 0.028	0.75 ± 0.028	
	P	NS	NS	NS	NS	
Initial BW, kg	16.14 ± 1.82	16.21 ± 1.82	16.29 ± 1.75	16.21 ± 1.65	16.14 ± 1.73	NS
	CG	16.14 ± 1.82	16.14 ± 1.82	16.14 ± 1.82	16.14 ± 1.82	
	P	NS	NS	NS	NS	
Final BW, kg	30.79 ± 1.58	31.36 ± 1.60	29.50 ± 1.94	29.36 ± 3.02	29.07 ± 2.67	NS
	CG	30.79 ± 1.58	30.79 ± 1.58	30.79 ± 1.58	30.79 ± 1.58	
	P	NS	NS	NS	NS	
ADG, g d^{-1}	122.02 ± 10.95	126.19 ± 8.91	110.12 ± 13.79	109.52 ± 14.38	107.74 ± 23.38	*
	CG	122.02 ± 10.95	122.02 ± 10.95	122.02 ± 10.95	122.02 ± 10.95	
	P	NS	*	*	NS	
FCR, %	6.29 ± 1.77	6.10 ± 1.24	6.66 ± 1.51	6.34 ± 1.11	6.15 ± 0.66	NS
	CG	6.29 ± 1.77	6.29 ± 1.77	6.29 ± 1.77	6.29 ± 1.77	
	P	NS	NS	NS	NS	

[1]CG: control group; VG: vitamin E treatment group.
[2]NS: non significant; *$P < 0.1$;**$P < 0.05$; ***$P < 0.01$.
[3]DMI: DM intake; BW: body weight; ADG: average daily gain; FCR: feed conversion ratio.

of the immune system of young animals (Kolb and Seehawer, 1998) and the recommended minimal requirement of vit E is lying between 10 and 15 mg kg^{-1} dietary DM by the Agricultural Research Council (ARC, 1980) for normal growth and health of sheep. Gentry et al. (1992) suggested that lambs receiving high levels of vit E supplementation may have a better growth performance. However, the results of the present study indicate that vit E supplementation to the diet of lambs had no significant effect on most growth performance traits, which is supported by the findings of Dufrasne et al. (2000), Macit et al. (2003a), and Maiorano et al. (2007). Differences in vit E effects on lamb growth performance may be ascribed to the factor of studying a different section of animal growth period length. Birch et al. (1994) showed that the beneficial effect of added vit E on growth performance is generally observed in very young animals.

Carcass characteristics

Measurements taken on hot carcasses are summarized in Table 3. Vitamin E supplementation did not have a significant effect on carcass traits in terms of hot carcass weight, LD muscle area (rib-eye area) and pH 45 min of LD muscle in 'Tan' sheep. However, there were significant differences among groups in most carcass characteristics, such as dressing percentage, total lean, subcutaneous fat, fat depth, drip loss and pH 24 h. Vitamin E supplementation levels below 100 IU d^{-1} $lamb^{-1}$ significantly increased dressing percentage and total lean, and those above 200 IU d^{-1} $lamb^{-1}$ significantly decreased subcutaneous fat and fat depth of Tan sheep lambs ($P < 0.01$). In addition, vit E supplementation levels above 100 IU d^{-1} $lamb^{-1}$ considerably reduced drip loss and pH 24 h of LD muscles in 'Tan' sheep lambs ($P < 0.01$). The mean pH values of LD muscles consistently decreased from slaughter time up to 24 h postmortem for lambs in all treatment groups.

In this study, no significant differences among groups were observed for the main carcass indices, such as hot carcass weight, LD muscle area (rib-eye area) and pH 45 min of LD muscles. These results of the present study are consistent with findings of Turner et al. (2002), Macit et al. (2003a), and Maiorano et al. (2007). However, the result of the current study that a moderate level (200 IU d^{-1} $lamb^{-1}$) of vit E supplementation had a suppressing effect on subcutaneous fat deposition in 'Tan' sheep was not reported in other studies involving in different breed of sheep (Turner et al., 2002; Macit et al., 2003b; Maiorano et al., 2007). But our result could be supported by the findings of Birch et al. (1994), who suggested that the suppressing effect of vit E supplementation on fat deposition might be due to vit E stimulation of the immune system, which caused a partitioning of energy away from growth and inhibited lipid catabolism. This hypothesis could be further demonstrated by the result reported above

Table 3. Effect of vitamin E supplementation on carcass characteristics of 'Tan' sheep lambs.

	Dietary vitamin E added levels (IU d^{-1} $lamb^{-1}$)[1]					
Carcass traits	0 (CG)	20 (VG20)	100 (VG100)	200 (VG200)	2000 (VG2000)	p^2
Hot carcass, kg	14.14 ± 0.77	14.89 ± 0.98	14.24 ± 1.16	13.43 ± 1.51	13.78 ± 1.38	NS
	CG	14.14 ± 0.77	14.14 ± 0.77	14.14 ± 0.77	14.14 ± 0.77	
	P	NS	NS	NS	NS	
Dressing proportion, %	45.93 ± 1.62	47.45 ± 2.28	48.28 ± 2.23A	45.71 ± 1.78	47.36 ± 0.91	NS
	CG	45.93 ± 1.62	45.93 ± 1.62B	45.93 ± 1.62	45.93 ± 1.62	
	P	NS	**	NS	*	
Total lean, kg	5.76 ± 0.22	6.34 ± 0.35A	6.72 ± 0.88A	6.23 ± 0.53	6.18 ± 0.61	NS
	CG	5.76 ± 0.22B	5.76 ± 0.22B	5.76 ± 0.22	5.76 ± 0.22	
	P	***	**	NS	NS	
Subcutaneous fat, kg	2.40 ± 0.39a	2.14 ± 0.52a	2.06 ± 0.13a	1.50 ± 0.19bB	1.49 ± 0.20bB	***
	CG	2.40 ± 0.39	2.40 ± 0.39	2.40 ± 0.39A	2.40 ± 0.39A	
	P	NS	*	***	***	
Fat depth, mm	1.86 ± 0.021a	1.85 ± 0.029ab	1.83 ± 0.038ab	1.83 ± 0.032bB	1.76 ± 0.027cB	***
	CG	1.86 ± 0.021	1.86 ± 0.021	1.86 ± 0.021A	1.86 ± 0.021A	
	P	NS	*	**	***	
Rib-eye area, cm^2	13.69 ± 1.47	13.31 ± 1.06	13.17 ± 2.38	13.03 ± 1.30	12.83 ± 1.53	NS
	CG	13.69 ± 1.47	13.69 ± 1.47	13.69 ± 1.47	13.69 ± 1.47	
	P	NS	NS	NS	NS	
Drip loss, %	1.50 ± 0.33ab	1.62 ± 0.26a	1.33 ± 0.27cb	1.22 ± 0.19cb	1.12 ± 0.14cB	***
	CG	1.50 ± 0.33	1.50 ± 0.33	1.50 ± 0.33	1.50 ± 0.33A	
	P	NS	NS	*	**	
pH 45 min	6.21 ± 0.22	6.38 ± 0.17	6.42 ± 0.19	6.42 ± 0.23	6.14 ± 0.26	NS
	CG	6.21 ± 0.22	6.21 ± 0.22	6.21 ± 0.22	6.21 ± 0.22	
	P	NS	*	NS	NS	
pH 24 h	5.85 ± 0.10a	5.77 ± 0.27ab	5.51 ± 0.14cB	5.65 ± 0.13abcB	5.56 ± 0.23bcB	***
	CG	5.85 ± 0.10	5.85 ± 0.10A	5.85 ± 0.10A	5.85 ± 0.10A	
	P	NS	***	***	***	

[2]CG: control group; VG: vit E treatment group.

[2]NS: non significant; *$P < 0.1$;**$P < 0.05$; ***$P < 0.01$.

[a, b, c]Means within the same row with different letters differ significantly according to Duncan's multiple range tests ($P < 0.05$).

[A, B]Means within the same column with different letters differ significantly according to t test ($P < 0.05$).

that vit E supplementation tended to reduce ADG of 'Tan' sheep lambs.

It was unexpected that VG lambs supplemented with 100 IU vit E d^{-1} $lamb^{-1}$ showed better performance than CG lambs in terms of dressing percentage and total lean in the present study. This result was not reported in most previous studies with different breed of sheep (Turner et al., 2002; Macit et al., 2003b; Maiorano et al., 2007). This result indicates that the normal requirement of vit E for growth of 'Tan' sheep lambs may be higher than that of other sheep genotypes. Besides, it was found that drip loss was significantly suppressed by moderate and high levels of vit E supplementation, which was also observed by Morrisey et al. (1994), Mitsumoto et al. (1998), Dufrasne et al. (2000), and Macit et al. (2003a). These results indicate that vit E can suppress drip loss of mutton within a short storage period.

It is well known that the ultimate pH of the muscle is an important contributing factor to meat quality (Maiorano et al., 2007). Higher *Longissimus* muscle pH values at 24 h postmortem produced poor quality meat (Chrystall and Daly, 1996). In this study, although vit E treatment had no effect on pH 45 min ($P > 0.05$), moderate and high levels of vit E supplementation clearly reduce pH 24 h of LD muscles ($P < 0.001$). Cheah et al. (1995) and Castellini et al. (1999) observed that the ability of vit E to stabilize membranes is presumably achieved by decreasing Ca^{2+} release which reduces phospholipase A_2 activity and, hence, phospholipid hydrolysis. Decreased levels of cytosolic Ca^{2+} reduce the rate of postmortem glycolysis resulting in a higher postmortem pH.

Lipid content and intramuscular fatty acid composition of LD muscle

The results of content and fatty acid composition of intramuscular lipids in LD muscle are presented in Table 4. The vit E treatments did not significantly affect the contents of both intramuscular lipids and total fatty acids (TFA) in LD muscle, except for a lower ($P < 0.01$) content of TFA in LD muscle of the VG lambs with 2000 IU d^{-1} $lamb^{-1}$ α-tocopheryl acetate compared to that of CG. These data are in agreement with the findings of Salvatori et al. (2004) and Kasapidou et al. (2012).

Within diets, there were some significant effects of the level of vit E supplementation on fatty acid composition of intramuscular lipids in LD muscle. The moderate levels (100 and 200 IU d^{-1} $lamb^{-1}$) of vit E supplementation considerably ($P < 0.01$) increased the proportions of C8:0, C12:0, C14:0 and C15:0 fatty acids. The lambs from vit E treatment groups with 200 and 2000 IU d^{-1} $lamb^{-1}$ α-tocopheryl acetate had higher ($P < 0.05$) percentages of C16:1, C18:2, C18:3 and C20:3 than those in CG, whereas these levels of vit E supplementation significantly ($P < 0.01$) reduced the proportion of C18:1 in intramuscular lipids of LD muscle. In general, with regard to SFA, although slightly higher proportions of C8:0, C12:0, C14:0, and C15:0 were observed for VG lambs compared to those in CG, the general SFA proportion was not modified by vit E supplementation. Similar results were obtained by Kasapidou et al. (2012) on 'Suffolk' × 'Charollais' wether lambs, who detected no effect of vit E on fatty acid composition of neutral lipids, which are mainly consisted of SFA, in intramuscular lipids of *semimembranosus* muscle. As for MUFA, proportions of C14:1 and C16:1 were significantly increased by vit E supplementation with an inversely effect on C18:1 percentage ($P < 0.05$), which finally resulted in a decreasing tendency for MUFA proportion of LD muscle in VG lambs ($P < 0.1$). This result could be supported by the findings of Hou et al. (2012), who reported that vit E supplementation could accelerate the ruminal biohydrogenation of C18:1 unsaturated fatty acids *in vitro*. For PUFA, the results showed that the proportion of linoleic acid (C18:2n6) was significantly increased ($P < 0.05$) and a similar trend ($P < 0.1$) was also observed for C20:3n6 percentage of LD muscle resulting in a significant increase ($P < 0.05$) in n-6 PUFA proportion and in ratio of n-6 PUFA/n-3 PUFA, but with no significant effect on total PUFA proportion in LD muscle. These results were similar with our previous study on Boer male kids and were also supported by the findings of Salvatori et al. (2004) and Kasapidou et al. (2012). In addition, an increasing tendency ($P < 0.1$) for both PUFA proportion and the ratio of PUFA/SFA in LD muscle of lambs treated with vit E was also detected in the present study. According to these results from the present study, vit E levels did influence some aspects of fatty acid profiles of LD muscle lipids, especially for phospholipid fraction, in 'Tan' sheep lambs, which demonstrated that vit E supplementation may have some beneficial effect on meat quality as protecting intramuscular lipids against oxidation in live sheep. The mechanism for vit E supplementation affecting fatty acid profiles of intramuscular fat may be related with the findings that vit E could modify ruminal pathways of PUFA biohydrogenation in dairy (Pottier et al., 2006; Bell et al., 2006), beef cattle (Juárez et al., 2010; Juárez et al., 2011), and goat (Hou et al., 2012), acting either as an inhibitor of bacteria producing *trans*-10 C18:1 or as an electron acceptor for *Butyrivibrio fibrisolvens* (Pottier et al., 2006).

CONCLUSIONS

In conclusion, vitamin E supplementation to the diet of 'Tan' sheep lambs at a wide range of inclusion rate from 20 to 2000 IU d^{-1} $lamb^{-1}$ showed no differences in growth performance, and relatively affected carcass characteristics with the addition levels over 200 IU d^{-1} $lamb^{-1}$ as significantly decreasing subcutaneous fat deposition, drip loss, and pH 24 h. As for fatty acid composition of intramuscular lipids, vit E supplementation could significantly increase n-6 PUFA proportion and the ratio of n-6/n-3 PUFA and tended to enhance PUFA proportion and the ratio of PUFA/

Table 4. Effect of vitamin E supplementation on content and fatty acid composition of intramuscular lipid in *Longissimus dorsi* muscle of 'Tan' sheep lambs.

	Dietary vitamin E added levels (IU d^{-1} lamb^{-1})[1]					
Fatty acid[3] (%)	0 (CG)	20 (VG20)	100 (VG100)	200 (VG200)	2000 (VG2000)	p[2]
IMF, g 100 g^{-1} DM	12.48 ± 3.32	13.26 ± 2.42	12.43 ± 1.87	11.31 ± 1.31	11.60 ± 3.44	NS
	CG	12.48 ± 3.32	12.48 ± 3.32	12.48 ± 3.32	12.48 ± 3.32	
	P	NS	NS	NS	NS	
TFA, mg g^{-1}	110.78 ± 17.37	114.83 ± 23.14	103.55 ± 23.08	90.19 ± 34.17	79.62 ± 17.83B	NS
	CG	110.78 ± 17.37	110.78 ± 17.37	110.78 ± 17.37	110.78 ± 17.37A	
	P	NS	NS	NS	***	
C8:0	0.022 ± 0.0024b	0.022 ± 0.0015b	0.025 ± 0.0058ab	0.029 ± 0.0046aA	—	**
	CG	0.022 ± 0.0024	0.022 ± 0.0024	0.022 ± 0.0024B		
	P	NS	NS	***		
C10:0	0.056 ± 0.072	0.084 ± 0.093	0.069 ± 0.089	0.092 ± 0.095	0.13 ± 0.10	NS
	CG	0.056 ± 0.072	0.056 ± 0.072	0.056 ± 0.072	0.056 ± 0.072	
	P	NS	NS	NS	NS	
C12:0	0.094 ± 0.019b	0.15 ± 0.034aA	0.13 ± 0.045ab	0.12 ± 0.041ab	0.13 ± 0.028abA	NS
	CG	0.094 ± 0.019B	0.094 ± 0.019	0.094 ± 0.019	0.094 ± 0.019B	
	P	***	*	NS	***	
C13:0	0.017± 0.0017	0.012 ± 0.0031	0.014 ± 0.0085	0.013 ± 0.0028	0.016 ± 0.0024	NS
	CG	0.017 ± 0.0017	0.017 ± 0.0017	0.017 ± 0.0017	0.017 ± 0.0017	
	P	NS	NS	NS	NS	
C14:0	1.84 ± 0.26b	2.32 ± 0.39aA	2.28 ± 0.36aA	1.81 ± 0.34b	2.13 ± 0.40ab	**
	CG	1.84 ± 0.26B	1.84 ± 0.26B	1.84 ± 0.26	1.84 ± 0.26	
	P	**	**	NS	NS	
C14:1*n*7	0.065 ± 0.014b	0.081 ± 0.014ab	0.093 ± 0.027aA	0.066 ± 0.012b	0.078 ± 0.014ab	**
	CG	0.065 ± 0.014	0.065 ± 0.014B	0.065 ± 0.014	0.065 ± 0.014	
	P	*	**	NS	NS	
C15:0	0.23 ± 0.020b	0.31 ± 0.037aA	0.28 ± 0.054ab	0.30 ± 0.045abA	0.31 ± 0.092a	NS
	CG	0.23 ± 0.020B	0.23 ± 0.020	0.23 ± 0.020B	0.23 ± 0.020	
	P	***	*	***	*	
C16:0	24.24 ± 0.97	24.98 ± 1.40	25.03 ± 1.56	23.67 ± 1.31	23.84 ± 1.40	NS
	CG	24.24 ± 0.97	24.24 ± 0.97	24.24 ± 0.97	24.24 ± 0.97	
	P	NS	NS	NS	NS	
C16:1*n*7	1.39 ± 0.17b	1.51 ± 0.15ab	1.66 ± 0.17aA	1.52 ± 0.18ab	1.59 ± 0.13aA	**
	CG	1.39 ± 0.17	1.39 ± 0.17B	1.39 ± 0.17	1.39 ± 0.17B	
	P	NS	**	NS	**	
C17:0	0.83 ± 0.35	1.03 ± 0.057	0.96 ± 0.061	0.78 ± 0.50	0.79 ± 0.52	NS
	CG	0.83 ± 0.35	0.83 ± 0.35	0.83 ± 0.35	0.83 ± 0.35	
	P	NS	NS	NS	NS	
C18:0	20.73 ± 0.88	20.01 ± 1.71	19.37 ± 1.56	20.44 ± 1.18	20.74 ± 2.33	NS
	CG	20.73 ± 0.88	20.73 ± 0.88	20.73 ± 0.88	20.73 ± 0.88	
	P	NS	*	NS	NS	
C18:1*n*11t	0.44 ± 0.039	0.42 ± 0.13	0.44 ± 0.067	0.42 ± 0.039	0.40 ± 0.059	NS
	CG	0.44 ± 0.039	0.44 ± 0.039	0.44 ± 0.039	0.44 ± 0.039	
	P	NS	NS	NS	NS	
C18:1*n*9c	42.55 ± 1.31a	41.53 ± 0.82ab	41.74 ± 1.49ab	40.67 ± 1.33bcB	39.84 ± 1.75cB	**
	CG	42.55 ± 1.31	42.55 ± 1.31	42.55 ± 1.31A	42.55 ± 1.31A	
	P	NS	NS	**	***	
C18:2*n*6t	0.078 ± 0.015b	0.071 ± 0.0078b	0.085 ± 0.012b	0.18 ± 0.18ab	0.26 ± 0.18aA	**
	CG	0.078 ± 0.015	0.078 ± 0.015	0.078 ± 0.015	0.078 ± 0.015B	
	P	NS	NS	NS	**	
C18:2*n*6c	3.57 ± 0.73c	3.81 ± 0.56bc	3.73 ± 0.78c	5.07 ± 1.42aA	4.96 ± 1.24abA	**
	CG	3.57 ± 0.73	3.57 ± 0.73	3.57 ± 0.73B	3.57 ± 0.73B	
	P	NS	NS	**	**	
C18:3*n*6	0.17 ± 0.032	0.17 ± 0.018	0.15 ± 0.018	0.19 ± 0.020	0.18 ± 0.027	NS
	CG	0.17 ± 0.032	0.17 ± 0.032	0.17 ± 0.032	0.17 ± 0.032	
	P	NS	NS	NS	NS	
C18:3*n*3	0.21 ± 0.057	0.26 ± 0.052	0.24 ± 0.083	0.29 ± 0.052A	0.29 ± 0.075A	NS
	CG	0.21 ± 0.057	0.21 ± 0.057	0.21 ± 0.057B	0.21 ± 0.057B	
	P	NS	NS	**	**	
CLA-c9t11	0.18 ± 0.034	0.19 ± 0.022	0.19 ± 0.050	0.17 ± 0.039	0.16 ± 0.031	NS
	CG	0.18 ± 0.034	0.18 ± 0.034	0.18 ± 0.034	0.18 ± 0.034	
	P	NS	NS	NS	NS	
CLA-t10c12	0.026 ± 0.017	0.034 ± 0.013	0.043 ± 0.025	0.032 ± 0.012	0.048 ± 0.021	NS
	CG	0.026 ± 0.017	0.026 ± 0.017	0.026 ± 0.017	0.026 ± 0.017	
	P	NS	NS	NS	*	
C20:0	0.14 ± 0.045	0.16 ± 0.033	0.14 ± 0.025	0.16 ± 0.026	0.16 ± 0.016	NS
	CG	0.14 ± 0.045	0.14 ± 0.045	0.14 ± 0.045	0.14 ± 0.045	
	P	NS	NS	NS	*	

Continuation Table 4.

Fatty acid[3] (%)	Dietary vitamin E added levels (IU d^{-1} lamb^{-1})[1]					
	0 (CG)	20 (VG20)	100 (VG100)	200 (VG200)	2000 (VG2000)	p[2]
C20:1*n*9	0.094 ± 0.0062	0.089 ± 0.012	0.10 ± 0.023	0.098 ± 0.020	0.094 ± 0.013	NS
	CG	0.094 ± 0.0062	0.094 ± 0.0062	0.094 ± 0.0062	0.094 ± 0.0062	
	P	NS	NS	NS	NS	
C21:0	0.49 ± 0.086	0.43 ± 0.089	0.49 ± 0.13	0.63 ± 0.18	0.62 ± 0.18	*
	CG	0.49 ± 0.086	0.49 ± 0.086	0.49 ± 0.086	0.49 ± 0.086	
	P	NS	NS	*	NS	
C20:3*n*6	0.17 ± 0.035	0.17 ± 0.033	0.18 ± 0.036	0.23 ± 0.089	0.23 ± 0.065A	*
	CG	0.17 ± 0.035	0.17 ± 0.035	0.17 ± 0.035	0.17 ± 0.035B	
	P	NS	NS	*	**	
C20:4*n*6	1.96 ± 0.58	1.83 ± 0.32	2.17 ± 0.51	2.59 ± 0.89	2.64 ± 0.88	NS
	CG	1.96 ± 0.58	1.96 ± 0.58	1.96 ± 0.58	1.96 ± 0.58	
	P	NS	NS	NS	NS	
C20:5*n*3	0.11 ± 0.058	0.11 ± 0.043	0.12 ± 0.039	0.13 ± 0.064	0.16 ± 0.081	NS
	CG	0.11 ± 0.058	0.11 ± 0.058	0.11 ± 0.058	0.11 ± 0.058	
	P	NS	NS	NS	NS	
C22:0	0.089 ± 0.010	0.12 ± 0.024A	0.093 ± 0.013	0.12 ± 0.044	0.10 ± 0.025	NS
	CG	0.089 ± 0.010B	0.089 ± 0.010	0.089 ± 0.010	0.089 ± 0.010	
	P	**	NS	*	NS	
C22:6*n*3	0.22 ± 0.10	0.17 ± 0.12	0.21 ± 0.040	0.24 ± 0.094	0.26 ± 0.10	NS
	CG	0.22 ± 0.10	0.22 ± 0.10	0.22 ± 0.10	0.22 ± 0.10	
	P	NS	NS	NS	NS	
C≤10	0.078 ± 0.073	0.11 ± 0.093	0.094 ± 0.088	0.12 ± 0.099	0.13 ± 0.10	NS
	CG	0.078 ± 0.073	0.078 ± 0.073	0.078 ± 0.073	0.078 ± 0.073	
	P	NS	NS	NS	NS	
∑*n*-6 PUFA	5.96 ± 1.32b	6.05 ± 0.92b	6.31 ± 1.29ab	8.26 ± 2.45aA	8.28 ± 2.23aA	**
	CG	5.96 ± 1.32	5.96 ± 1.32	5.96 ± 1.32B	5.96 ± 1.32B	
	P	NS	NS	**	**	
∑*n*-3 PUFA	0.54 ± 0.21	0.54 ± 0.20	0.58 ± 0.15	0.66 ± 0.20	0.64 ± 0.29	NS
	CG	0.54 ± 0.21	0.54 ± 0.21	0.54 ± 0.21	0.54 ± 0.21	
	P	NS	NS	NS	NS	
n-6/*n*-3	6.50 ± 1.49b	6.59 ± 1.11b	6.89 ± 1.40b	8.92 ± 2.64a	8.92 ± 2.43aA	**
	CG	6.50 ± 1.49	6.50 ± 1.49	6.50 ± 1.49	6.50 ± 1.49B	
	P	NS	NS	*	**	
∑ SFA	48.76 ± 1.20	49.55 ± 1.50	48.85 ± 2.16	48.11 ± 2.22	48.89 ± 3.34	NS
	CG	48.76 ± 1.20	48.76 ± 1.20	48.76 ± 1.20	48.76 ± 1.20	
	P	NS	NS	NS	NS	
∑ MUFA	44.53 ± 1.22	43.63 ± 0.83	44.03 ± 1.57	42.77 ± 1.48B	41.99 ± 1.85B	*
	CG	44.53 ± 1.22	44.53 ± 1.22	44.53 ± 1.22A	44.53 ± 1.22A	
	P	NS	NS	**	**	
∑ PUFA	6.70 ± 1.52	6.81 ± 1.10	7.12 ± 1.46	9.12 ± 2.63	9.12 ± 2.45A	*
	CG	6.71 ± 1.52	6.71 ± 1.52	6.71 ± 1.52	6.71 ± 1.52B	
	P	NS	NS	*	**	
PUFA/SFA	0.14 ± 0.033	0.14 ± 0.026	0.15 ± 0.035	0.19 ± 0.062	0.19 ± 0.063	*
	CG	0.14 ± 0.033	0.14 ± 0.033	0.14 ± 0.033	0.14 ± 0.033	
	P	NS	NS	*	*	

[1]CG: control group; VG: vit E treatment group; results are expressed as g 100 g^{-1} frozen-dry muscle for intramuscular lipid, as mg g^{-1} of muscle for total fatty acids (TFA) and as percentage of TFA for each fatty acid. Each value is expressed as mean ± SD.

[2]NS: non significant; *$P < 0.1$;**$P < 0.05$; ***$P < 0.01$.

[3]IMF: Intramuscular fat; PUFA: polyunsaturated fatty acids; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids.

[a, b, c]Means within the same row with different letters differ significantly according to Duncan's multiple range tests ($P < 0.05$).

[A, B]Means within the same column with different letters differ significantly according to t test ($P < 0.05$).

SFA in *Longissimus dorsi* muscle of 'Tan' sheep. These results indicate that it is necessary to make a re-evaluation of the currently recommended levels of vit E in sheep diets to meet the requirements of consumers for more healthy meat consumption and that of dealers for modern retailing practices.

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