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Effects of chlorogenic acids-enriched extract from *Eucommia ulmoides* leaves on growth performance, stress response, antioxidant status and meat quality of lambs subjected or not to transport stress

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ABSTRACT

This study was conducted to evaluate the effects of chlorogenic acids-enriched extract (CGAE) from *Eucommia ulmoides* leaves on growth performance, stress response, antioxidant status and meat quality of lambs subjected or not to transport stress. Forty eight weaned male Huzhou lambs (a local breed, average body weight 17.3 ± 1.58 kg) were equally divided into three treatments for a 56 d feeding period and fed the basal diet supplemented with 0 (CGAE0), 1 (CGAE1) or 5 (CGAE5) g of CGAE/kg of the basal diet (dry matter basis). After the feeding trial, eight lambs per treatment were randomly selected, blood sampled and slaughtered without road transport. The remaining 24 lambs were transported for 8 h to simulate stress. After transport, all lambs were blood sampled and slaughtered. Dietary CGAE supplementation did not affect average daily gain, dry matter intake and feed efficiency of lambs. Significant interaction between road transport and dietary CGAE supplementation was found for the glucose concentration ($P < 0.01$) in blood and the pH_{24} value ($P < 0.05$) and malondialdehyde (MDA, $P < 0.01$) content in meat. Lambs fed the CGAE1 and CGAE5 diets had lower ($P < 0.01$) glucose and triiodothyronine (T_3) concentrations, creatine kinase (CK) activity, white blood cell (WBC) count and neutrophil (NEU): lymphocyte (LYM) ratio and higher ($P < 0.01$) LYM count than lambs fed the CGAE0 diet. Lambs fed the CGAE5 diet had higher superoxide dismutase (SOD, $P < 0.01$) activity and total antioxidant capacity (T-AOC, $P < 0.01$) of serum and T-AOC ($P < 0.05$) of liver and lower serum cortisol concentration ($P < 0.01$) and MDA ($P < 0.05$) contents in serum and liver compared with lambs fed the CGAE0 diet. Road transport increased ($P < 0.01$) cortisol, glucose, T_3 and thyroxine (T_4) concentrations, CK activity and WBC count in blood and MDA contents in serum and liver and decreased ($P < 0.05$) SOD activity and T-AOC of serum. Dietary CGAE supplementation decreased pH_{24} value ($P < 0.05$) and MDA content ($P < 0.01$), but increased ($P < 0.05$) cooking loss of meat. In contrast, the opposite was true for the effects of road transport on pH_{24} value ($P < 0.05$), MDA content ($P < 0.01$) and cooking loss ($P < 0.01$) of

Abbreviations: *a**, redness; ADFom, acid detergent fiber expressed exclusive of residual ash; ADG, average daily gain; aNDFom, neutral detergent fiber assayed with a heat stable amylase and expressed exclusive of residual ash; *b**, yellowness; CGAE, chlorogenic acids-enriched extract; CK, creatine kinase; DM, dry matter; DMI, dry matter intake; FE, feed efficiency; GH, growth hormone; GSH-Px, glutathione peroxidase; *L**, lightness; LTL, *longissimus thoracis et lumborum*; LYM, lymphocyte; MDA, malondialdehyde; NEU, neutrophil; PCV, packed cell volume; RBC, red blood cell; SOD, superoxide dismutase; T_3, triiodothyronine; T_4, thyroxine; T-AOC, total antioxidant capacity; WBC, white blood cell

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meat. In conclusion, dietary CGAE supplementation did not affect the growth performance and improved certain stress indicators, meat quality and antioxidant status of lambs, especially for transport-stressed lambs.

1. Introduction

Lamb production has moved from traditionally extensive to intensive system in many parts of the world (Muñoz-Osorio et al., 2017). To improve the production efficiency and protect the fragile ecosystem, lambs are gradually fattened under penned conditions in China (Zhao et al., 2017). In intensive fattening system, some steps or processes can induce various stresses to lambs (Kruger et al., 2016). Weaning is abruptly stressful in the neonates' life, which causes the release of glucocorticoid hormones and results in suppression on growth performance and immune system (Pohl et al., 2015). Moreover, high metabolic rates or other conditions (*e.g.*, environmental factors and transport) can make lambs susceptible to oxidative stress which may result in growth retardation, disease and decreased meat quality (Celi, 2011; Chauhan et al., 2014). Therefore, minimizing the stress involved in intensive lamb fattening system is receiving a great deal of attention, especially through dietary strategies. Several studies have indicated that phytocompounds such as polysaccharides and polyphenols could be used to alleviate the negative effects of stress on fattening lambs due to their antioxidant and anti-inflammatory properties (Zhong et al., 2012; Morán et al., 2012; Kafantaris et al., 2016).

Eucommia ulmoides Oliver (*Eucommiaceae*), called Du-Zhong in Chinese, is a commonly used herb in traditional Chinese medicine, which is also widely used in Eastern Asia (He et al., 2014). The medicinal parts of *E. ulmoides* are its barks and leaves as mentioned in Chinese pharmacopoeia (National Commission of Chinese Pharmacopoeia, 2010). More than 40 compounds exist in *E. ulmoides* leaves, including lignans, iridoids, phenolics, steroids, terpenoids and flavonoids (He et al., 2014; Bai et al., 2015). Among these compounds, chlorogenic acids are one of the main active components, which are phenolic compounds formed from the esterification of trans-cinnamic and quinic acids (Clifford, 2000). Chlorogenic acids have been reported to possess antioxidant, antimicrobial and anti-inflammatory capacities *in vitro* studies and *in vivo* rat and human studies (Liang et al., 2016; Tajik et al., 2017). Previous studies found that *E. ulmoides* leaves or polyphenolic extract from leaves (rich in chlorogenic acids) supplementation improved growth performance and meat quality in pigs (Zhou et al., 2016a, 2016b), broilers (Wang et al., 2012) and fish (Sun et al., 2017). However, no information is known about the potential role of chlorogenic acids in improving the performance and health of lambs, especially for intensive fattening lambs subjected to stress conditions. Therefore, we chose road transport as a source of stress in lambs and designed this study to investigate the effects of transport stress on stress response, antioxidant status and meat quality of lambs and the effects of dietary chlorogenic acids-enriched extract (CGAE) from *E. ulmoides* leaves supplementation on growth performance, stress response, antioxidant status and meat quality of lambs subjected or not to transport stress.

2. Materials and methods

2.1. Animals and diets

All procedures were approved by the Committee for the Care and Use of Experimental Animals of Qingdao Agricultural University (No. 021/2016).

Table 1
Ingredients and chemical composition of the basal diet.

Item	Basal diet
Ingredient (g/kg diet)	
Aneurolepidium chinense hay	300
Ground corn	410
Soybean meal	160
Wheat bran	105
Sodium chloride	5
Minerals and vitamins[a]	20
Chemical composition (analysed, n = 5)	
Dry matter (g/kg feed)	899 ± 11.29
Crude protein (g/kg DM)	176 ± 3.91
Crude fat (g/kg DM)	34 ± 1.86
Neutral detergent fiber (g/kg DM)	404 ± 8.02
Acid detergent fiber (g/kg DM)	205 ± 4.49
Gross energy (MJ/kg DM)	21.98 ± 1.31

[a] Minerals and vitamins were purchased from a commercial company (Continental Grain Corp., Beijing, China) and contained (per kg) 24,000 IU vitamin A, 2500 IU vitamin D_3, 4800 IU vitamin E, 32 g Ca, 11 g P, 5 g S, 65 mg Zn, 50 mg Mn, 120 mg Fe, 25 mg Cu, 0.9 mg Co, 0.8 mg Se.