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# Effects of carvacrol and cinnamaldehyde on intake, rumen fermentation, growth performance, and carcass characteristics of growing lambs☆,☆☆,◊

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**Abstract**

Effects of essential oil compounds (EOC) on feed intake, ruminal fermentation, growth performance, and carcass characteristics were determined using 60 lambs (24.6 ± 0.77 kg initial live weight, LW) fed either a barley- or corn grain-based diet without supplementation (control), or supplemented with 0.2 g/kg (DM basis) of carvacrol (CAR) or cinnamaldehyde (CIN). The experimental diets were arranged as a 2 × 3 factorial with 11-week periods and fed to lambs *ad libitum*. Ruminal pH tended (P=0.06) to be lower and total volatile fatty acid (VFA) concentration was higher (P<0.01) for barley-

*Abbreviations:* AA, amino acid; ADG, average daily gain; CAR, carvacrol; CIN, cinnamaldehyde; DM, dry matter; EOC, essential oil compound; FC, feed conversion; ME, metabolizable energy; VFA, volatile fatty acid.

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*versus* corn-based diets. Addition of EOC reduced (P=0.02) ruminal pH and increased (P=0.03) total VFA concentration *versus* the control. Acetate and propionate molar proportions and ammonia concentration did not differ among treatments. Inclusion of EOC in barley- or corn-based diets did not alter dry matter intake or average daily gain of lambs. Lambs fed the control diets tended (P=0.10) to have lighter livers than those fed diets containing EOC. Neither type of grain nor inclusion of EOC substantially affected sensory attributes of lamb sirloins.


*Keywords:* Carvacrol; Cinnamaldehyde; Ruminal fermentation; Growth performance; Carcass quality

## 1. Introduction

In recent years, plant extracts such as essential oils (EO) have received increased attention as potential alternatives to growth promoters for animal production (Thakare, 2004; Westendarp, 2005). They have been shown to exhibit selective antibacterial activity, and may inhibit degradation of protein in the rumen, thereby potentially increasing the intestinal supply of amino acids (AA) to the animal host (Wallace, 2004). In Europe, use of plant extracts in livestock production has expanded (Van de Braak and Leijten, 1999) after the ban of use of antibiotics and growth promoters, including ionophores, in livestock nutrition (OJEU, 2003).

Essential oils are the volatile, lipophilic compounds extracted from plants by distillation (Westendarp, 2005). They have been used for centuries for their scent, flavour, antiseptic, and/or preservative properties (Burt, 2004). Chemically, EO are variable mixtures of terpenoids that primarily include monoterpenes ($C_{10}$) and sesquiterpenes ($C_{15}$), although diterpenes ($C_{20}$) may also be present. They also include a variety of low molecular weight aliphatic hydrocarbons, acids, alcohols, aldehydes, acyclic esters or lactones and, on occasion, N and S containing compounds such as coumarins and homologues of phenylpropanoids (Dorman and Deans, 2000).

This study was conducted to determine effects of two EO compounds (EOC), carvacrol and cinnamaldehyde, on feed intake, growth performance, ruminal fermentation characteristics, and carcass quality of growing lambs fed corn- or barley grain-based diets that are typical of those used in commercial lamb production in Canada.

## 2. Material and methods

### 2.1. Animals, diets, and feeding

Sixty weaned Canadian Arcott lambs (initial live weight (LW) $24.6 \pm 0.77$ kg) were used in a $2 \times 3$ factorial arrangement of treatments with 11-week periods and fed corn- or barley grain-based diets not supplemented (control), or supplemented with 0.2 g/kg of dry matter (DM) of carvacrol or cinnamaldehyde. Carvacrol (CAR; purity >98%) and cinnamaldehyde (CIN; purity >99%) were provided by Phodé S.A. (Albi, France). Animals were cared for in accordance with guidelines of the Canadian Council on Animal Care (CCAC, 1993). Lambs were penned by treatment group for 1 week and then each lamb was assigned to an individual pen ($0.97\,m \times 2.82\,m$) for the study period with *ad libitum* access to feed and

Table 1
Ingredients and chemical composition of the experimental diets fed to lambs

| | Barley-based diets | | | Corn-based diets | | |
|---|---|---|---|---|---|---|
| | Control | CAR[a] | CIN[b] | Control | CAR[a] | CIN[b] |
| Ingredients (g/kg DM) | | | | | | |
| Barley grain, steam-rolled | 699 | 699 | 699 | | | |
| Corn grain, dry-rolled | | | | 613 | 613 | 613 |
| Canola meal | 105 | 105 | 105 | 170 | 170 | 170 |
| Beet pulp | 115 | 115 | 115 | 148 | 148 | 148 |
| Beet molasses | 25 | 25 | 25 | 25 | 25 | 25 |
| Calcium carbonate | 18 | 18 | 18 | 18 | 18 | 18 |
| Megalac (Enertia)[c] | 20 | 20 | 20 | 8 | 8 | 8 |
| Sheep mineral[d] | 13 | 13 | 13 | 13 | 13 | 13 |
| Feed pellet binder | 5 | 5 | 5 | 5 | 5 | 5 |
| Vitamin ADE[e] | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Carvacrol | 0 | 0.20 | 0 | 0 | 0.20 | 0 |
| Cinnamaldehyde | 0 | 0 | 0.20 | 0 | 0 | 0.20 |
| Chemical composition | | | | | | |
| Dry matter (g/kg) | 911 | 910 | 908 | 910 | 910 | 911 |
| Crude protein (g/kg DM) | 137 | 160 | 151 | 147 | 147 | 146 |
| Total NFC[f] (g/kg DM) | 564 | 560 | 547 | 571 | 568 | 584 |
| Ether extract (g/kg DM) | 17 | 24 | 21 | 29 | 30 | 33 |
| aNeutral detergent fibre (g/kg DM) | 199 | 176 | 198 | 174 | 176 | 162 |
| Acid detergent fibre (g/kg DM) | 106 | 94 | 98 | 110 | 104 | 102 |
| Ash (g/kg DM) | 83 | 80 | 83 | 79 | 79 | 75 |
| Gross energy (MJ/kg DM) | 16.2 | 17.1 | 16.3 | 16.2 | 16.5 | 16.3 |

[a] CAR: carvacrol.
[b] CIN: cinnamaldehyde.
[c] ADM Animal Health and Nutrition (Quincy, IL).
[d] Sheep mineral contained (g/kg): NaCl (927.3), S (14), K (9.2), Mg (7.2), Zn (3.3), Cu (0.33), Se (0.014), Co (0.01), Mn and Fe (0.0001).
[e] Contained (IU/g): Vitamin A (10,000), Vitamin D (1000), and Vitamin E (10).
[f] NFC: Non-fibrous carbohydrates, calculated as 1000 − (aNDF + CP + Lipid + Ash).

water at all times. Feed was delivered once daily at 08:00 h. The experimental diets were completely pelleted (Table 1) and formulated for crude protein (CP) and metabolizable energy (ME) contents of 140 g/kg of DM and 8.4 MJ/kg of DM, respectively.

Feed deliveries were recorded daily and refusals were weighed weekly, on an individual lamb basis, to determine feed intake. Samples of offered and refused feeds were collected weekly and dried at 100 °C for 24 h to determine their DM content. Average daily gain (ADG) was determined by weighing the lambs at 7-day intervals throughout the study and by dividing the weight gain (initial LW–final LW) by the number of days (*i.e.*, 7 days). Feed conversion was calculated as the ratio between DM intake and ADG (g of DM intake/g of LW gain).

### 2.2. Ruminal fermentation characteristics

On week 3, 5, 7, and 9 of the study, ruminal fluid was collected from four lambs randomly selected from each treatment group. Samples were collected using an orogastric tube at 2

and 6 h after daily feeding. Rumen fluid was collected into 50 ml plastic tubes and pH was measured immediately (Orion model 260A, Allometrics, Inc., Baton Rouge, LA, USA). Tubes were capped and placed in an ice bucket and immediately transferred to the laboratory.

Ruminal fluid samples were centrifuged ($1000 \times g$, 10 min, +4 °C) and supernatants were collected for later analysis of ammonia ($NH_3$) and volatile fatty acid (VFA) concentrations. For determination of $NH_3$, two supernatant sub-samples of 1.8 ml were transferred to 2.0 ml locking-lid micro-centrifuge tubes (Fisher Scientific, Ottawa, ON, Canada) containing 200 μl of trichloroacetic acid (650 g/l). Tubes were centrifuged at $14{,}000 \times g$ for 15 min at +4 °C in a Labnet centrifuge (Spectrafuge 16M; Labnet International, Inc., Edison, NJ, USA) and supernatants were transferred to 2 ml micro-centrifuge tubes and frozen at −20 °C until analyzed for $NH_3$. For determination of VFA concentration, two 1.6 ml sub-samples of supernatant from the slow-speed centrifugation were acidified by transfer to micro-centrifuge tubes containing 160 μl of meta-phosphoric acid (250 g/l), then centrifuged ($10{,}000 \times g$, 15 min, +4 °C) and stored at −20 °C until analysis.

### 2.3. Carcass characteristics and sensory evaluation

At a LW of ≥45 kg, lambs were slaughtered at a commercial abattoir and carcasses harvested. Liver and rumen weights, carcass yield, and saleable meat yield were recorded. Saleable meat included primal cuts of short cut semi-boneless leg, sirloin, butt tender, short loin bone-in, chine-off rack, square cut shoulder, front shank, and neck; each trimmed to ≤0.64 cm subcutaneous fat as per commercial standards. Sirloins from each carcass were vacuum-packed and transported on ice to the Lacombe Research Centre (Lacombe, AB, Canada) where they were stored frozen at −20 °C until assessed for sensory and palatability attributes by a trained 8-member evaluation panel.

Screening and training of panellists for sensory evaluation of lamb meat were conducted in accordance with American Meat Science Association (AMSA) and National Livestock and Meat Board (1995) guidelines. Standards for aroma training included beet molasses, Megalac (5 g/500 ml filtered water; stirred overnight and filtered through cheesecloth), CAR (standards of 0, 10, 20, and 40 μl in 10 ml of canola oil), CIN (standards of 0, 5, 10, and 20 μl in 10 ml canola oil), and well-aged casein hydrolysate as a standard for "barny" aromatic. CAR and CIN were included in the panel to test for carry-over flavour from the diet to the meat. For flavour training, wheat germ, corn meal, and commercially sourced ground lamb patties were used as standards.

Sirloin samples were transferred to a refrigerator to thaw for 24 h before sensory analysis. For each sample, thawed fat and lean were separated, then re-combined in a wt:wt ratio of 10:90 (fat:lean) to a total weight of 220–250 g. Each sample was coarse ground by passage twice through a meat grinder (model F133; Moulinex, Richmond Hill, ON, Canada), then weighed and formed into two 100 g patties. The patties were cooked on an electric grill (model ED-30B, Garland Commercial Ranges Limited, Mississauga, ON, Canada) to an internal temperature of 71 °C. Both patties from a single sample were cut into sixths and the eight most uniform wedges were transferred to a pre-warmed glass jar and covered with an aluminium lid labelled only with a three-digit identification number. Jars were placed in a 70 °C water bath for 7 min for temperature equilibration, and wedges were served to the panellists in the order of removal from the water bath. Analysis sessions (morning and

afternoon, separated by a 2 h break) were conducted on three separate days. In each session, samples from each dietary group were evaluated in random order by each panellist, with a 30 min break after the 6th sample.

Evaluation was completed using eight-point descriptive scales for juiciness (where 8 = extremely juicy; 1 = extremely dry), lamb flavour intensity (8 = extremely intense lamb flavour; 1 = extremely bland or low lamb flavour), off-flavour intensity (8 = extremely bland or no off-flavour; 1 = extremely intense off-flavour), and residual mouth coating (8 = none detected; 1 = abundant). Overall palatability and flavour desirability were rated on an eight-point hedonic scale (8 = extremely desirable; 1 = extremely undesirable). Juiciness was rated after five or six chews with the molars; flavour desirability, lamb and off-flavour intensity were rated after 6–10 chews; and residual mouth coating and overall palatability were rated prior to expelling the sample. The 10 classes of off-flavours were assessed: none (no off-flavours), barny, bloody, grainy, livery, metallic, off/sour, woolly, other (identity suggested), and unidentified.

### 2.4. Chemical analyses

Dry matter content of feed samples was determined by oven drying at 100 °C for 24 h (method 967.03, AOAC, 1990). Ash content was determined after 5 h of incineration at 500 °C in a muffle furnace (method 942; AOAC, 1990). Feed samples and orts were analyzed for neutral detergent fibre (aNDF) concentration as described by Van Soest et al. (1991) with the use of sodium sulfite and heat stable α-amylase. Acid detergent fibre (ADF) concentration in samples was determined using the method 973.18 of AOAC (1990). Concentration of total N was determined by combustion analysis (Carlo Erba Instruments, Milan, Italy). Lipid was determined by extraction with ether (method 920.39; AOAC, 1990) using a Goldfisch Fat Extractor (Labconco Corporation, Kansas City, MO, USA). Gross energy concentration was determined using an adiabatic bomb calorimeter (model 1241, Parr Instrument Company, Moline, IL, USA). Non-fibrous carbohydrate (NFC) was calculated as:

$$\text{NFC(g/kg DM)} = 1000 - (\text{aNDF} + \text{CP} + \text{Lipid} + \text{Ash})$$

Ammonia concentration was analyzed by the phenol hypochlorite method of Weatherburn (1967). Analysis of VFA used gas liquid chromatography with a 5890 gas chromatograph (Hewlett Packard) equipped with a ZB-FFAP silica capillary column (30 m × 32 mm × 1 μm; Phenomenex, Torrance, CA, USA).

### 2.5. Statistical analyses

Data on feed intake, growth performance, and rumen characteristics were analyzed according to a factorial arrangement using the MIXED procedure of SAS (2007). Means were compared using the least squares mean linear hypothesis test with grain, EOC, week, and interactions included as fixed terms, lamb nested within (Grain × EOC) as a random effect, and week (and time, 2 *versus* 6 h, for rumen samples) as a repeated measure. Initial lamb weight was used as a covariate. Repeated measures analysis with the minimum values of AIC (Akaike's Information Criterion) were used for selecting covariance structure. Unless otherwise specified, treatment effects were declared significant if $P<0.05$.

Data from carcass characteristics and taste panel were analyzed using a model similar to that described above, but excluding week as a repeated measure. Mean values were determined from all trained panellists using the specialized computer software Compusense *five*® (Compusense Inc., Guelph, ON, Canada).

## 3. Results and discussion

### *3.1. Ruminal fermentation parameters*

Lambs fed barley-based diets tended (P=0.06) to have lower ruminal pH (Table 2) compared to those fed corn-based diets (5.66 *versus* 5.83), which is consistent with the higher ruminal total VFA concentration for lambs fed barley compared to those fed corn (107.8 *versus* 90.6 mmol/l). Conversely, Beauchemin and McGinn (2005) reported lower ruminal pH and higher total VFA concentration (P=0.06) for beef cattle fed corn- *versus* barley-based diets, a likely reflection of higher DM intake for cattle fed corn-based diets.

Addition of EOC reduced (P=0.02) ruminal pH which reflected the higher (P=0.03) total VFA concentrations for lambs fed EOC *versus* those fed control diets (103.0 *versus* 91.5 mmol/l). The higher total VFA concentration observed for diets supplemented with EOC suggested that diet fermentability in the rumen was enhanced by addition of CAR and CIN. Such a change may be nutritionally beneficial, as VFA are the main sources of metabolizable energy for ruminants.

Molar proportions of acetate, propionate, butyrate, and valerate were not affected by grain nor EOC, and averaged 48.1, 41.5, 7.1, and 3.5 mmol/100 mol, respectively. The molar proportion of BCVFA was also unaffected by EOC, but was higher for lambs fed barley *versus* lambs fed corn (0.59 *versus* 0.40; P<0.01). This change in BCVFA suggests that degradation of branched-chain AA was reduced by feeding corn *versus* barley. Beauchemin and McGinn (2005) observed that beef cattle fed corn had higher molar proportion of acetate and lower molar proportion of propionate than cattle fed barley, suggesting that corn was less extensively digested in the rumen than barley, which is contradictory to their findings of lower ruminal pH, and higher total VFA concentration, for corn *versus* barley.

The literature on effects of EO or EOC on *in vitro* ruminal fermentation is limited. Cardozo et al. (2005) observed that at pH 7.0 or 5.5, high doses of cinnamaldehyde and oregano oil (*i.e.*, 300 mg/l) strongly decreased total VFA and $NH_3$ concentrations. Busquet et al. (2005) reported no effects of 7.1 mg/day of CAR and CIN on N metabolism parameters (*i.e.*, $NH_3$–N, small peptide + AA, and large peptide) or on total VFA concentrations in continuous cultures maintained at constant pH. Inclusion of EO, or their active components, in *in vitro* incubations frequently results in an increase in the proportion of butyrate (Cardozo et al., 2005; Castillejos et al., 2006; Fraser et al., 2007), but this response did not occur in the current study where the amounts of CIN and CAR ingested were 257 and 274 mg/day, respectively. Assuming a rumen volume of 3 l, the corresponding ruminal concentrations of CIN and CAR would be 85.7 and 91.3 mg/l, respectively, concentrations that are higher than the concentration (*i.e.*, 2.2 mg/l) used by Busquet et al. (2005) in a continuous culture system maintained at constant pH. Consequently, the concentrations of EOC required to alter ruminal fermentation *in vivo* appear to be higher than those for *in vitro* experiments.

Table 2
Ruminal fermentation characteristics in lambs fed barley- or corn-based diets without supplementation (control) or supplemented with carvacrol (CAR) or cinnamaldehyde (CIN)[a]

| | Barley-based diets | | | Corn-based diets | | | S.E. | P value[b] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | CAR | CIN | Control | CAR | CIN | | Grain | EOC | Grain × EOC |
| pH | 5.93 | 5.39 | 5.67 | 5.88 | 5.81 | 5.80 | 0.101 | 0.06 | 0.02 | 0.09 |
| Total VFA (mmol/l) | 97.2 | 110.5 | 115.7 | 85.8 | 90.9 | 95.0 | 4.85 | <0.01 | 0.03 | 0.59 |
| Individual VFA (mol/100 mol) | | | | | | | | | | |
| Acetate | 49.1 | 47.0 | 47.8 | 47.7 | 47.6 | 49.7 | 1.24 | 0.98 | 0.44 | 0.18 |
| Propionate | 39.8 | 41.9 | 42.4 | 40.7 | 40.7 | 37.7 | 1.75 | 0.26 | 0.76 | 0.30 |
| Butyrate | 6.6 | 7.1 | 6.2 | 8.1 | 7.0 | 7.6 | 0.73 | 0.13 | 0.78 | 0.48 |
| Valerate | 3.7 | 3.0 | 2.8 | 2.9 | 4.1 | 4.3 | 0.49 | 0.16 | 0.84 | 0.06 |
| BCVFA[c] | 0.7 | 0.7 | 0.5 | 0.4 | 0.4 | 0.4 | 0.053 | <0.01 | 0.83 | 0.07 |
| *n*-Caproic | 0.15 | 0.26 | 0.31 | 0.21 | 0.25 | 0.33 | 0.079 | 0.70 | 0.24 | 0.91 |
| Acetate:propionate | 1.24 | 1.13 | 1.13 | 1.15 | 1.16 | 1.33 | 0.094 | 0.43 | 0.62 | 0.60 |
| Ammonia (mmol/l) | 0.56 | 0.88 | 0.95 | 1.18 | 1.11 | 0.96 | 0.301 | 0.27 | 0.91 | 0.60 |

[a] Carvacrol (CAR) and cinnamaldehyde (CIN) were supplemented at 200 mg/kg diet DM.

[b] Grain: effect of grain type (barley *versus* corn); EOC: effect of essential oil compounds supplementation (control *versus* CAR and CIN); Grain × EOC: interactive effects of grain type and essential oil compounds supplementation; Grain × Time, EOC × Time, Grain × EOC × Time interactions were not significant for any parameter measured.

[c] Branched-chain volatile fatty acids: iso-valerate + iso-butyrate.

### 3.2. Lamb performance

Neither the source of grain nor EOC supplementation affected DM intake, final LW, or ADG of lambs (Table 3). The DM intake, ADG, and FC reported for lambs in this study were typical of lambs fed a high concentrate diet (Stanford et al., 1998, 1999).

The lack of an effect of grain type on lamb performance was expected since all lambs were fed iso-ME diets and had similar DM intake. Research has been inconclusive when corn and barley are compared in feeding studies. Generally, cattle fed dry-rolled corn have higher intakes, slightly higher gains, but likely no advantage in feed efficiency compared to cattle fed barley (Gibb and McAllister, 2003).

Bampidis et al. (2005) observed no change in DM intake, ADG, and FC when growing lambs were fed diets supplemented with oregano leaves (*Origanum vulgare* L.) providing 144 or 288 mg of oregano oil (850 mg/g of carvacrol) per kilogram of diet DM. There is very limited information on effects of EO or their compounds on growth of ruminants. Benchaar et al. (2006) demonstrated no change in DM intake and ADG of beef cattle fed a silage-based diet supplemented with 2 or 4 g/day of a mixture of EOC consisting of thymol, eugenol, vanillin and limonene. However, the EOC mixture had a quadratic effect on FC with dose of 2 g/day improving feed conversion *versus* a dose of 4 g/day.

### 3.3. Carcass characteristics and saleable meat yield

Liver weight was not affected by grain source, but lambs fed diets supplemented with EOC tended (P=0.10) to have heavier livers than those fed control diets (Table 4). An increase in liver size and the signals involved in the differential contribution of each biochemical contribution due to EO supplementation are still not well understood. Fluharty et al. (1999) reported an increase in liver weight of lambs fed diets supplemented with ionophores (lasalocid) compared to those fed diets containing none. Visceral organ size has been shown to be affected by DM intake (Burrin et al., 1990), which may explain results reported by Fluharty et al. (1999). Rumen weight, hot dressed weight, shrink (water lost), and saleable meat yield were not affected by our experimental diets.

Diets did not alter the weights of primal meat cuts, except that sirloins were heavier when the corn-based cinnamaldehyde diet was fed *versus* the corn-based control diet or barley-based cinnamaldehyde diet (interaction Grain × EOC; P=0.02).

### 3.4. Meat quality evaluation

The juiciness sirloin patties were not affected by the grain source or EOC (Table 5), and inclusion of EOC in lamb diets did not alter the flavour intensity of sirloin patties *versus* the control, but patties tended (P=0.06) to have a higher flavour intensity when lambs were fed corn than when they were fed barley (4.99 *versus* 4.79).

Overall palatability and flavour desirability corresponded with data on flavour intensity with sirloin patties from lambs fed corn tending (P=0.08) to have higher scores than those from lambs fed barley. Mouth coating residues and off-flavours intensity were unaffected by grain type or EOC. The principal off-flavour identified was ‘woolly’ and ‘grainy’. The

Table 3
Dry matter intake, initial and final live weight, average daily gain, and feed conversion of lambs fed barley- or corn-based diets without supplementation (control) or supplemented with carvacrol (CAR) or cinnamaldehyde (CIN)[a]

| Measurement | Barley-based diets | | | Corn-based diets | | | S.E. | P value[b] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | CAR | CIN | Control | CAR | CIN | | Grain | EOC | Grain × EOC |
| DM intake (g/day) | 1357.4 | 1296.5 | 1363.1 | 1221 | 1285 | 1387 | 47.59 | 0.23 | 0.15 | 0.16 |
| Initial live weight (kg) | 25.9 | 24.8 | 24.3 | 22.8 | 24.2 | 25.9 | 1.34 | 0.53 | 0.83 | 0.22 |
| Final live weight (kg) | 45 | 45.6 | 45.6 | 44.2 | 46.9 | 47.8 | 1.32 | 0.27 | 0.39 | 0.50 |
| Average daily gain (g/day) | 288.3 | 309.0 | 312.4 | 303.3 | 308.2 | 313.3 | 11.82 | 0.60 | 0.33 | 0.77 |
| Feed conversion[c] | 4.77 | 4.20 | 4.36 | 4.03 | 4.17 | 4.43 | | | | |

[a] Carvacrol (CAR) and cinnamaldehyde (CIN) were supplemented at 200 mg/kg diet DM.
[b] Grain: effect of grain type (barley *versus* corn); EOC: effect of essential oil compounds supplementation (control *versus* CAR and CIN); Grain × EOC: interactive effects of grain type and essential oil compounds supplementation.
[c] Calculated as mean DM intake/mean average daily gain.

Table 4
Carcass characteristics and meat yield of lambs fed barley- or corn-based diets without supplementation (control) or supplemented with carvacrol (CAR) or cinnamaldehyde (CIN)[a]

| Measurement[c] | Barley-based diets | | | Corn-based diets | | | S.E. | P value[b] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | CAR | CIN | Control | CAR | CIN | | Grain | EOC | Grain × EOC |
| Liver weight (g) | 879 | 991 | 998 | 955 | 1013 | 992 | 41.8 | 0.38 | 0.10 | 0.62 |
| Rumen weight (g) | 5224 | 4984 | 5236 | 4958 | 5601 | 5684 | 224.7 | 0.15 | 0.27 | 0.12 |
| Hot dressed weight (kg) | 23.4 | 23.0 | 22.4 | 22.2 | 23.3 | 23.1 | 0.69 | 0.97 | 0.80 | 0.38 |
| Shrink (kg) | 0.7 | 1.0 | 0.7 | 0.7 | 0.9 | 0.7 | 0.09 | 0.53 | 0.02 | 0.71 |
| Saleable meat yield (kg) | 17.6 | 17.2 | 16.9 | 17.0 | 17.6 | 17.6 | 0.53 | 0.63 | 0.96 | 0.43 |
| GR measurement (mm) | 20 | 20 | 19 | 20 | 19 | 19 | 0.8 | 0.47 | 0.37 | 0.81 |
| Weight of cuts (kg) | | | | | | | | | | |
| SCSBL | 4.7 | 4.8 | 4.6 | 4.6 | 4.8 | 4.7 | 0.14 | 0.93 | 0.52 | 0.87 |
| Sirloin cap-on | 0.62 [x,y] | 0.59 [x,y] | 0.57 [y] | 0.55 [y] | 0.59 [x,y] | 0.64 [x] | 0.024 | 0.89 | 0.70 | 0.02 |
| Butt tender | 0.079 | 0.080 | 0.075 | 0.081 | 0.076 | 0.084 | 0.0036 | 0.48 | 0.76 | 0.22 |
| Short loin, bone-in | 1.8 | 1.8 | 1.6 | 1.7 | 1.7 | 1.7 | 0.09 | 0.94 | 0.48 | 0.41 |
| Chine-off rack | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.06 | 0.54 | 0.74 | 0.83 |
| Square cut shoulder | 4.6 | 4.5 | 4.7 | 4.5 | 4.7 | 4.9 | 0.18 | 0.51 | 0.44 | 0.68 |
| Front shank | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.04 | 0.76 | 0.92 | 0.78 |
| Neck | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.03 | 0.30 | 0.95 | 0.38 |
| Waste | 5.1 | 4.7 | 4.8 | 4.6 | 4.8 | 4.7 | 0.21 | 0.46 | 0.86 | 0.22 |

[x,y] Within a row, means without a common superscript letter differ, $P<0.05$.

[a] Carvacrol (CAR) and cinnamaldehyde (CIN) were supplemented at 200 mg/kg diet DM.

[b] Grain: effect of grain type (barley *versus* corn); EOC: effect of essential oil compounds supplementation (control *versus* CAR and CIN); Grain × EOC: interactive effects of grain type and essential oil compounds supplementation.

[c] GR measurement: body wall thickness between the 12th and 13th ribs, 11 cm off midline; SCSBL: short cut semi-boneless leg.

Table 5
Sensory evaluation of meat of lambs fed barley- or corn-based diets without supplementation (control) or supplemented with carvacrol (CAR) or cinnamaldehyde (CIN)[a]

| Measurement[c] | Barley-based diets | | | Corn-based diets | | | S.E. | P value[b] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | CAR | CIN | Control | CAR | CIN | | Grain | EOC | Grain × EOC |
| Juiciness | 5.55 | 5.32 | 5.37 | 5.59 | 5.42 | 5.54 | 0.117 | 0.30 | 0.23 | 0.85 |
| Lamb flavour intensity | 4.89 | 4.64 | 4.83 | 5.04 | 5.04 | 4.88 | 0.122 | 0.06 | 0.54 | 0.33 |
| Off-flavour intensity | 6.03 | 5.78 | 6.01 | 6.44 | 6.35 | 5.91 | 0.216 | 0.10 | 0.46 | 0.26 |
| Mouth coating residue | 6.36 | 6.45 | 6.42 | 6.50 | 6.40 | 6.26 | 0.065 | 0.66 | 0.32 | 0.08 |
| Overall palatability | 4.63 | 4.50 | 4.59 | 5.15 | 5.04 | 4.55 | 0.230 | 0.08 | 0.39 | 0.36 |
| Flavour desirability | 4.86 | 4.61 | 4.79 | 5.31 | 5.14 | 4.73 | 0.209 | 0.08 | 0.30 | 0.31 |

[a] Carvacrol (CAR) and cinnamaldehyde (CIN) were supplemented at 200 mg/kg diet DM.
[b] Grain: effect of grain type (barley *versus* corn); EOC: effect of essential oil compound supplement (control *versus* CAR and CIN); Grain × EOC: interactive effects of grain type and essential oil compounds supplementation.
[c] GR measurement: body wall thickness between the 12th and 13th ribs, 11 cm off midline.

fact that EOC did not alter palatability or flavour suggests that the compounds examined could be included in the diet without adversely affecting the eating quality of the meat.

## 4. Conclusions

Ruminal VFA concentrations were higher with barley *versus* corn grain-based diets. Inclusion of EOC in the diet caused a modest increase in concentrations of ruminal VFA, but this response did not improve growth or feed efficiency of lambs. Despite their potent odour, EOC could be included in the diet of lambs without adverse effect on the eating quality of the meat.

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