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A supply chain approach to improving the shelf life of lamb meat; vitamin E concentration, electrical stimulation, ageing period and packaging system

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ABSTRACT

This study investigated the effects of vitamin E, electrical stimulation, aging and packaging system on the colour stability of lamb meat. Eighty crossbred wether lambs, 6–8 months old were fed on either vitamin E or control pelleted diet for 31 days prior to slaughter. Half of the carcases from each group were electrically stimulated before being split longitudinally into 2. Each side was randomly allocated 1 of the 4 aging periods (5 days fresh, 10, 20 and 30 days CO_2). Muscle samples were set for retail display, after the respective aging period, colour was measured over 96 h. Supplementing vitamin E nutritionally is likely to lengthen the shelf life of lamb products aged longer than 10 days. Muscle vitamin E concentrations > 3.0 mg/kg are required to increase the shelf life of lamb cuts aged for up to 30 days to 60 h. Medium voltage electrical stimulation did not have a detrimental effect on the display life of aged lamb meat.

1. Introduction

Consumers choose fresh meat on visual appearance rather than eating quality (Renerre, 1990). Meat that is red in colour is considered desirable, whilst brown meat often cannot be sold at the full retail price, resulting in financial loss to the meat retailer. Meat colour changes due to the oxidation of myoglobin, and is represented by the change from the red oxymyoglobin (oxygenated) form, to the brown metmyoglobin form. The rate of this change is the key element of colour stability. This change can be characterised using reflectance spectrophotometry to estimate the relative amounts of the different redox forms of myoglobin; deoxymyoglobin, oxymyoglobin and metmyoglobin. The ratio of reflectance of light at 630 and 580 nm is an estimate of the ratio of oxy/met, sometimes called redness (Hunt, 1980). For values below 3.5 consumers perceive meat to be brown in colour (Morrissey, Jacob, & Pluske, 2008). The oxy/met value declines during retail display and the This benchmark value is often reached within 48 h of meat being sliced for retail display, thus 48 h is a benchmark used by some supermarkets for shelf life of lamb meat.

A range of factors along the supply chain can in combination influence the colour stability of lamb meat. For example, lipid peroxidation causes oxidation of myoglobin and reduces colour stability. Vitamin E supplementation of sheep on farm and aging period after slaughter can both influence lipid peroxidation (Eikelenboom, Hovingbolink, Kluitman, Houben, & Klont, 2000; Wulf et al., 1995). The latter is particularly relevant to meat exported by ship, as shipping times can be excess of 30 days. Australia exports about 321.1 thousand tonnes of sheep meat worth an estimated value of A$1.3 billion each year (Anonymous, 2008).

Packing and storing meat in anoxic conditions will prevent metmyoglobin formation in meat (Faustman & Cassens, 1990). Anoxic conditions can be achieved with either vacuum packaging or modified atmosphere packaging using CO_2. Carbon dioxide also inhibits the growth of a range of microorganisms (Jakobsen & Bertelsen, 2002). Given that both methods provide anoxic conditions, they should have similar effects on colour stability. However, when aging is described in literature, a vacuum pack is typically used, while the effect of aging in high concentration CO_2 atmospheres is not well described. Thus it is appropriate to compare the colour stability of aged product between these two systems.

Studies have shown that supplementing animals with vitamin E slows oxidation of myoglobin and improves colour stability of meat (Wulf et al., 1995). This effect requires a threshold concentration to be reached of about 3.5 mg/kg for both beef (Arnold, Arp, Scheller, Williams, & Schaefer, 1993; Faustman et al., 1989) and lamb meat (Hopkins, Lamb, Kerr, van de Ven, & Ponnampalam, 2013; Jose, Jacob, Pethick, & Gardner, 2016; Ponnampalam et al., 2014). No further benefit for meat colour stability is gained if the concentration of

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vitamin E exceeds 3.5 mg/kg and thus reaching these thresholds should be the target of any supplementation regime.

Studies in lamb (Álvarez et al., 2008; Wulf et al., 1995) have shown that with sufficient vitamin E concentrations the negative effects of aging on colour stability can be avoided. A study in this laboratory found that aging for 21 days had no detrimental effect on colour stability of lamb meat supplemented with vitamin E (Jose et al., 2016). This was also supported by Ponnampalam et al. (2013), who found that colour stability was better for lamb loin aged in vacuum packaging for 4 weeks compared to 5 days when the vitamin E concentration was above the threshold value. From these studies, the impact of vitamin E in the non-aged product was negligible, while 3 to 4 week aged product required sufficient vitamin E. However, these studies did not identify if aging periods of < 3 weeks had the same benefits and requirement for muscle vitamin E.

The majority of lamb processing plants in Australia use electrical stimulation to reduce variation in tenderness (Hopkins, Toohey, Pearce, & Richards, 2008). Many authors have shown that electrical stimulation has no detrimental effect on the colour stability of lamb meat (Jacob, Pearce, & Smith, 2008; Moore & Young, 1991; Toohey, Hopkins, Stanley, & Nielsen, 2008) or beef (Powell, Dickinson, Shorthose, & Jones, 1996). Some of these studies found that stimulation increased the redness at the commencement of the display period by reducing oxygen consumption rate, but this did not change colour stability (Toohey et al., 2008). Additionally, Moore and Young (1991) showed that meat colour was less variable when lambs were stimulated. None of these studies have tested for an interaction between electrical stimulation and vitamin E supplementation.

This study consisted of two experiments:

Experiment 1 was designed to test for any interactions between the vitamin E concentration of muscle, electrical stimulation and aging period. Experiment 2 compared the colour stability of cuts aged in CO_2 packaging to those aged under vacuum.

2. Materials and methods

2.1. Experimental design and procedure

2.1.1. Experiment 1

This experiment was a 2 × 2 × 4 factorial design with the treatments consisting of 2 levels of vitamin E supplementation (Control, vitamin E), 2 levels of electrical stimulation (NES, ES) and 4 aging periods. The lambs were a crossbred genotype (Poll Dorset × Merino), 6–8 months of age, castrated males (wethers) with a live weight of 32.7 ± 0.44 kg (mean ± sem) at the commencement of the experiment.

The feeding treatments consisted of a pelleted ration fed at the rate of 1.6 kg/hd/day for 31 days prior to slaughter. The pellets contained approximately 30% Barley; 3.5% Oats and 28% whole Lupins; with an energy content of 11 MJ/kg metabolisable energy and 18% crude protein.

Prior to the feeding treatments, all had lambs grazed a dry annual pasture, supplemented with lupin grain at the rate of 600 g/sheep/day, together on a commercial farm. Lambs were transported to the Murdoch University farm for the experiment and were drenched with Cydectin© (Fort Dodge Labs) anthelmintic that contained selenium (0.5 mg/ml sodium selenate; administered at the rate of 1 ml/5 kg of body weight) on arrival.

Eighty lambs were used for the experiment. They were stratified according to live weight and allocated to 2 groups of 40 lambs of equal mean live weight for the feeding period. For one group the diet contained no added synthetic α-tocopherol (Control; 5.85 mg vitamin E/kg) and for the other group the diet contained added synthetic α-tocopherol acetate (Vitamin E; 175.7 mg vitamin E/kg). Lambs were fed in groups of 10.

After completion of the feeding treatments, the next phase of the experiment began with slaughter at a commercial abattoir. At slaughter, half of the lambs fed each of the nutritional treatments (n = 40) were randomly allocated to one of the two electrical stimulation treatments (n = 20). The electrical stimulation treated animals were slaughtered first, after which the stimulator was switched off. An electrical impulse was applied to each carcase in the ES treatment for 30 s and had a frequency of 15 hz, pulse width of 2.5 mS and a current of 1.2 A, using a medium voltage post dressing unit. Carcase weights and fat GR measurements were recorded at the abattoir.

Once chilled, each carcase was split longitudinally into 2 equal sides, Each side was randomly allocated to 1 of 4 aging periods (5, 10, 20 and 30 days), with the frequency of pairings of aging treatments together within a carcase being represented equally.

The 5-day aging period represented current industry practice using a gas permeable plastic bag left unsealed. Each side allocated to the 10, 20 & 30 day aging periods was packed in a gas impermeable "mother bag" containing > 99% carbon dioxide with a 2:1 gas to muscle headspace ratio. Target oxygen levels inside the pack were to be < 0.1% and no > 0.15% and thus the bags were flushed and evacuated three times with CO_2 before the bags were finally sealed and stored. After their respective aging periods, the *m.longissimus lumborum* (LL), *m.semimembranosus* (SM) and *m.semitendinosus* (ST) were dissected and samples taken for colour measurement, muscle vitamin E, myoglobin, driploss and ultimate pH. There were 10 sides allocated per treatment group.

2.1.2. Experiment 2

Fourteen lamb loins (LL) were purchased from a commercial abattoir, sourced from the one farm where they received no vitamin E supplementation. Lambs were fed a dry annual pasture prior to slaughter and carcases had an average weight of 21.7 ± 0.49 kg and a GR fat score of 3 (1 = 0–5 mm; 2 = 6–10 mm; 3 = 11–15 mm; 4 = 16–20 mm; 5 > 20). Carcases were electrically stimulated as per experiment 1. The LL was removed from the carcass and each muscle was divided into 3 equal proportions (approximately 100 g each) and were randomly allocated to one of the following treatment groups; Fresh 5 days (Control); CO_2 30 days; vacuum 30 days. Aged groups were packaged in vacuum packs or in close to 99% CO_2 with a 2:1 gas to muscle headspace (as per experiment 1) for 30 days before cutting for retail display, while the fresh group was packaged loosely in air for 5 days before cutting for retail display. Colour was measured after the allocated aging periods. Additional samples were taken for vitamin E analysis.

2.2. Experimental measurements

2.2.1. Colour

Muscles dissected for colour measurements were sliced into 2 cm thick slices, visible fat removed from the meat surface, slices placed on black Styrofoam trays, and over wrapped with oxygen permeable polyvinyl chloride wrap with a thickness of 10 μm. The meat was stored at 4 °C in a refrigerator fitted with cool white fluorescent lights (OSRAM L36W/20, Germany). Colour measurements were made using a Hunter Lab Mini Scan XE Plus (model No. 45/0-L, Hunter Associates Laboratory Inc., Reston VA, USA), Using a 45° illumination/0° viewing (specular component excluded) angle, C set as the light source with the aperture set to 10. A single measurement per sample was taken every 12 h for 96 h, with the first measurement taken at 6 h after the meat was cut.

Surface myoglobin oxidation was predicted from the R630/R580 ratio calculated from the ratio of light reflectance at 630 and 580 nm. Hunt (1980) noted that very little metmyoglobin is present in meat with ratios above 4, however when the meat surface approaches a ratio of 1, metmyoglobin will be the only remaining form present. Thus at ratios below 4 meat will begin to appear brown, therefore a ratio score of 3.5 (Morrissey et al., 2008) was used as a point for comparing myoglobin