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The effect of carbon monoxide pretreatment exposure time on the colour stability and quality attributes of vacuum packaged beef steaks

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ABSTRACT

The effect of 5% CO pretreatments prior to vacuum packaging of beef striploin steaks (*Longissimus thoracis et lumborum*, LTL) on quality attributes, primarily colour stability was investigated. The aim was to determine the optimum pretreatment that would induce the desirable red colour, while allowing discoloration to occur by the end of a 28-day display period (2 °C), so as to not mask spoilage. A range of pretreatment exposure times (1, 3, 5, 7, 9, 15 and 24 h) were applied to steaks using a gas mixture of 5% CO, 60% CO_2 and 35% N_2. The 5 h CO pretreatment exposure time achieved the desirable colour and discoloration reached unacceptable levels ($a^* = 12$, $C^* = 16$) by the use-by date (28 days), thus ensuring consumers' of a reliable visual indication of freshness and addressing concerns about safety. The 5% CO pretreatment had no negative effect on microbiological safety, lipid oxidation, cooking loss and WBSF measurements at the end of storage ($P > 0.05$).

1. Introduction

Meat packaging innovations are driven by an effort to meet increased consumer demand and expectations of high quality. Consumers initially evaluate meat quality at point of purchase based on meat colour, as other quality attributes cannot be assessed prior to meat consumption. Meat colour is perceived by consumers as a strong indication of freshness or wholesomeness (Kropf, 1980). However, for eating experience tenderness is considered the most important palatability attribute (Grobbel, Dikeman, Hunt & Milliken, 2008a; Miller, Huffman, Gilbert, Hamman & Ramsey, 1995). This has highlighted the need for value-added meat packaging technologies which improve colour and tenderness.

Currently the meat industry employs a two-stage packaging system where primals are aged in vacuum packs (VP) ("wet aged") and then transferred to vacuum packaging (VP), vacuum skin packaging (VSP) or modified atmosphere packaging (MAP). Since meat colour is the primary quality trait desirable to consumers, high-oxygen MAP is the most commonly applied second-stage fresh packaging technology used to promote the desirable bright red colour (oxymyoglobin) desirable to consumers. Unfortunately, the disadvantages of this packaging technology include limited shelf life, reduced juiciness and increased oxidation leading to reduced tenderness and promotion of off-flavours. MAP packs are also a more bulky than VSP packs. With increasing demand for more tender aged meat, VP and VSP could be an alternative solution to MAP. VP is an anoxic technology that prevents lipid oxidation, prolongs shelf-life, reduces microbial spoilage and is the most commonly applied ageing method (wet ageing) for the tenderisation of primals. Wet ageing is also more cost effective than dry ageing and produces much higher yields (Obuz, Akkaya, Gök & Dikeman, 2014). More recently Eastwood, Arnold, Miller, Gehring and Savell (2016) showed the potential benefit of cutting steaks and individually ageing steaks in the pack instead of subprimal ageing as consumer panellists preferred steaks aged as individual steaks as opposed to subprimal ageing. However, VP and VSP are still largely limited due to the dark purple appearance (deoxymyoglobin) of the meat. Consumers perceive the purple colour of meat as unattractive and are less likely to purchase meat presented in this form (Carpenter, Cornforth & Whittier, 2001).

Carbon monoxide (CO) induces a bright red colour (carboxymyoglobin) similar to oxymyoglobin but more stable. CO is also naturally synthesised within the human body due to the breakdown of haemoproteins and an average concentration of 1.2–1.5% HbCO is endogenous in non-smokers (European Commission, 2001). CO has a long history of application within the meat industry for its colour stabilizing effect coupled with its antioxidant abilities. In the USA, low concentrations of CO (0.4%) have been GRAS (Generally Recognised As Safe) approved by the FDA and CO is permitted as a primary packaging gas in case-ready packaging systems (FDA, 2004). New Zealand and Australia also regulate low concentrations of CO in centralised packaging systems and it is considered a processing

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aid (Federal Register of Legislative Instruments, 2014). Similarly, Canada also allows the application of 0.4% CO as a secondary packaging gas (USDA-FSIS, 2016). However, in the EU, CO has not yet been approved as a packaging gas even though the application of low concentrations of CO to meat packaging systems have been reported to be consumer friendly and have no toxic effect (Sørheim, Aune & Nesbakken, 1997). An important concern which has been raised by regulatory authorities is that CO might be used to mask meat spoilage so that meat might be sold beyond its sell-by date due to the bright red colour being retained (Cornforth & Hunt, 2008). If spoilage is masked, consumers are led to falsely perceive the meat as fresh and wholesome (Hunt et al., 2004) and this is unacceptable for food safety.

Previous researchers have investigated applying 5% CO pretreatments prior to vacuum packaging (Aspé, Roeckel, Martí & Jiménez, 2008; Jayasingh, Cornforth, Carpenter & Whittier, 2001; O'Connor & Allen, 2011). These researchers applied a 5% CO pretreatment for 24 h to beef steaks prior to vacuum packaging. Spoilage was masked as colour was retained beyond microbiological spoilage. The optimum pretreatment exposure time which allows discoloration to occur by a use-by date of 28 days (2 °C so as to not mask meat spoilage, has not yet been determined. Lentz (1979) reported further research is required to establish the length of exposure of meat to CO. Furthermore, reducing exposure time to CO pretreatment may reduce process time thus increasing profitability, productivity and efficiency if applied in meat packaging plants. The addition of CO pretreatments prior to vacuum packaging may be beneficial to allow a desirable colour to be induced while allowing ageing to occur within the package and increase meat tenderness.

Therefore the objective of this study was to determine the pretreatment exposure time for 5% CO prior to vacuum packaging striploin steaks that would give an attractive red colour that would become unacceptable after 28 days display (2 °C) so as to not mask spoilage. Microbiological analysis, lipid oxidation, tenderness and cooking loss were also examined at 28 days storage to determine if the pretreatment had any effect on meat quality.

2. Materials and methods

2.1. Sample preparation and pretreatment procedure

Two *Longissimus thoracis et lumborum* (LTL) muscles (normal pH 5.41–5.57) were excised from the 10th rib to last lumbar vertebrae from one Charolais-cross (CHX) heifer (21–29 months of age) and obtained from a commercial meat producer. At 6–8 days post-mortem a total of 24 striploin steaks (2.5 cm in thickness) were cut from the two muscles and pooled. To account for any possible systematic differences between the left and right muscles and between steaks due to their position within the muscle, three steaks (one for colour and microbiological analysis, one for cooking loss and WBSF, and one for TBARs) were randomly assigned to each of eight CO exposure treatments; CO1 (1 h), CO3 (3 h), CO5 (5 h), CO7 (7 h), CO9 (9 h), CO15 (15 h) CO24 (24 h), and a control (untreated vacuum packaged steak). Three steaks assigned to the same treatment were immediately vacuum packaged together (New Diamond Vac J-V006W, Heavy Duty Automatic Vacuum Machine, Jaw Feng Machinery Co., LTD, Taiwan; vacuum pressure < 0.01 Torr held for 32 s) in a pouch (5-layer coextruded film with PA/Tie/PE/Tie/PE (OTR: <— 70 cm^3 O_2/m^2/24 h at 23 °C and 50% RH, Versatile Packaging, Ltd., Castleblayney, Co. Monaghan, Ireland) for 30 min as a reducing step to minimise the amount of oxymyoglobin prior to CO pretreatment. The pouch was then filled with the calibration-grade gas mixture of 5% CO, 60% CO_2 and 35% N_2 (Air Products and Chemicals, Inc.,), to give a large (at least 20:1) headspace to meat volume ratio. The pouches were then stored in chill rooms at 2 °C for the allocated CO exposure times. Steaks were then rapidly removed from the pouch to minimise potential O_2 exposure and rapidly individually vacuum packaged using 5-layer coextruded film with PA/Tie/PE/Tie/PE (OTR: <— 70 cm^3 O_2/m^2/24 h at 23 °C and 50% RH, Versatile Packaging, Ltd., Castleblayney, Co. Monaghan, Ireland). This whole experiment was repeated on three separate occasions using a different heifer for each replicate.

2.2. Display and storage conditions

Steaks were randomised and placed in an upright open front-display cabinet (Cronos fan-assisted cabinet, Criosbanc, Padova, Italy) at 2–2.5 °C with permanent fluorescent lighting (600 lx, 58 W deluxe cool white bulbs, temperature of 420 K, Philips, Eastern Electric, Dublin, Ireland) to simulate retail conditions. The display cabinet temperature was monitored at the meat surface on each of three shelves every 5 min using dataloggers (EasyLog-USB, Lascar Electronics Ltd., Salisbury, UK). The display cabinet had four 35 min defrost cycles each day reaching a maximum temperature of (8 °C) for 1 min. The simulated lighting was continuous throughout the display period of 28 days (2–2.5 °C) with an insulated blind which was pulled down throughout storage.

2.3. Instrumental colour analysis

Instrumental colour analysis was carried out using a HunterLab UltraScan Pro (Hunter Associates Laboratory, Inc., Reston, VA) with a viewing port of 25.54 mm and illuminant D_{65}, 10°. The specular component was excluded. Calibration was carried out using a white standard tile (L = 100) and a light trap (L = 0). The white tile was covered with the vacuum packaging film to eliminate any effect on the colour readings (AMSA, 2012). Steaks were measured within the vacuum packages and three independent measurements were taken in separate locations avoiding intramuscular fat, an average was then calculated to obtain CIELab L* (lightness), a* (redness) and b* (yellowness) values. CIELab a* and b* values were used to calculate Hue ($\tan^{-1}(b^*/a^*)$) and Chroma ($C^* = (a^{*2} + b^{*2})^{1/2}$) values (Hunter & Harold, 1987). Surface colour analysis was measured over 28 days of storage (2 °C) at 0, 7, 14, 21 and 28 days.

2.4. Determination of cooking loss

Cooking loss was determined according to the method of Shackelford et al. (1991) LTL steaks which had been displayed in the retail display cabinet for 28 days storage (2 °C) were then removed and frozen (−20 °C) until the day of analysis. Frozen samples were thawed in a circulating water bath (Model No Y-38, Grant Instruments Ltd., Cambridge, UK) set at 20 °C. Once the steaks were thawed, they were trimmed of any fat and the raw weight of each pretreated steak was recorded. Following this, steaks were placed in vacuum bags and cooked in a water bath (Model No Y-38, Grant Instruments Ltd., Cambridge, UK) set at 72 °C, until an internal temperature of 70 °C was reached for each steak. The internal temperature of the steaks were monitored using a temperature probe (Hanna Foodcare Digital thermometer, Hanna Instruments, Eden Way, Pages Industrial Park, Leighton Buzzard, Bedfordshire, LU7 8TZ, UK) which was placed in the geometric centre of each steak. Following cooking, any excess juices and moisture were removed from the steaks and the cooked weight of the steaks was recorded. The percentage cooking loss was determined according to the following equation:

$$\%\text{cook loss} = \left(\frac{X-Y}{X}\right) * 100$$

where X = raw weight of steak and Y = cooked weight of steak.

2.5. Warner Bratzler shear force (WBSF)

Warner Bratzler shear force analysis was carried out on cooked day 28 samples used for the determination of cooking loss which were cooled for 24 h at 4 °C, following the procedure by Shackelford et al.