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Influence of different gas compositions on the short-term storage stability of mother-packaged retail-ready lamb packs

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Abstract

Longissmus dorsi muscles were removed from Suffolk cross-breed lambs (aged 4–9 months) and cut into steaks. Lamb steaks were over-wrapped on trays and placed in vacuum pack bags. Bags were divided into 3 groups and flushed with gas mixtures containing 100:0, 90:10 or 80:20/CO_2:N_2. Mother packed lamb bags were stored for 4 days (T2) and 7 days (T3), respectively, in darkness at 4 °C, prior to retail display. The effect of aerobic packaging alone on lamb meat quality was used as the control (T1). Under retail display, all over-wrapped trays were held under refrigerated conditions (4 °C, 616 lx) for up to 8 days. Steaks were assessed for microbial growth, oxidative and colour stability as well as pH every 2 days. Mother-packing in 100:0/CO_2:N_2 was the most effective way of extending the storage life of retail ready lamb prior to display, particularly over longer storage periods. TVCs for T3 lamb meat using all gas compositions remained below 2.0×10^6 CFUs/g meat up until day 6 compared to day 4 in both T1 and T2 lamb. Lipid oxidation in lamb mother-packed for 7 days occurred at a faster comparative rate than discolouration and microbial growth and was the major determinant of shelf-life. However, under simulated retail display in aerobic packages, TBARS values did not increase significantly. There was no significant difference between Hunter '*a*' values for T3 lamb meat and the control, but T3 meat mother-packed in 100:0/CO_2:N_2 had higher '*a*' values than those of the control and T3 meat packed in other gas compositions. Lamb steaks in T3 previously mother-packed in 100:0/CO_2:N_2 were also significantly ($p<0.05$) higher than those of T2 on day 0. T3 meat also maintained initial colour values over those of the control.

Keywords: Mother packs; Retail-ready; Shelf-life; Lamb

1. Introduction

Current trends in meat processing show a move away from undifferentiated products of ill-defined quality towards well presented products of high quality, as well as a shift from point of sale processing to central processing. Markets still exist for fresh, red meat and consumers will often pay a premium for this freshness (Bailey, Jayas, Holley, Jeremiah, & Gill, 1997). Guaranteeing product freshness has become increasingly difficult because small, retail butcheries are slowly being replaced by large, wholesale, centralised facilities which means that meat may spend a greater period of time in distribution than it did in the past. This reflects the preferences of increasingly discriminating consumers and highlights the need for packaging systems that enhance the storage stability of chilled meat (Buys, 1996). Bulk flushing, master or mother-packing is such a system developed to provide sufficient storage life and subsequent display life for Irish factories to supply retail cuts, in consumer-ready packs, direct to European retail outlets (Cowan, 1998). It involves fresh red meat cuts being placed on polystyrene foam trays and over-wrapped in stretchable, high O_2 permeable PVC film.

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The over-wrapped, trayed products (primary package) are placed in a large mother bag/pouch (secondary package) which is flushed with a selected gas mixture and sealed. In theory during distribution, gas in the secondary package migrates through the PVC into the primary package and produces the necessary bacteriostatic effects to ensure a reasonable shelf-life. At store level, mother bags are opened and primary packages placed directly into retail display cases. The O_2 in the atmosphere then migrates through the permeable overwrapping, causing the meat to bloom.

Although some deterioration of meat will occur in the absence of microorganisms, such as the enzymatic breakdown of tissues, microbial growth is by far the most important factor in relation to the keeping quality of fresh meat (Lambert, Smith, & Dodds, 1991). The principal microbiological objective of preservative packaging is the partial or total inhibition of the rapidly growing pseudomonads (Gill, 1996). Under O_2 depleted atmospheres of N_2 or CO_2 in the mother packing system, the anaerobic conditions created prevent the growth of pseudomonads and on meat of pH < 5.8, anaerobic growth of the faculatively anaerobic enterobacteria and *Brochothrix thermosphacta* are totally inhibited (Grau, 1980, 1981). Thus, flora composed only of low spoilage potential lactobacilli develop in mother packs (Gill, 1996).

Anoxic atmospheres have greater preservative capabilities than high O_2 atmospheres (Gill & Molin, 1991). The overall performance of mother-packed meat could be superior to that of modified atmosphere retail packs, provided that the meat maintains an acceptable appearance for a sufficient period when it is displayed (Gill & Jones, 1994a). This packaging system is currently used mainly for packaging primal cuts. With limited use of vacuum packaging for retail ready product, O_2 depleted packaging has as yet not been used for retail ready product on any substantial scale (Gill, 1996). Advantages of mother-packing include; flexibility which would allow companies to prepare meat for promotions; access to markets for high value cuts such as striploins; reduction of the impact of seasonality. It would also allow the trade to take advantage of an increasing market or conversely to reduce oversupply problems. This is due to the longer storage life which could be particularly important for new product lines and slower selling lines (Cowan, 1998). The objective of this study was to investigate the effect of mother-packing with different gas compositions on lamb meat quality. The mother-packing storage period examined reflected current overland distribution systems in Ireland. To allow for delays occasioned by weekends and statutory holidays, and for the stockpiling which is required to accommodate unpredictable fluctuations in consumer demand, a storage period of 4 and 7 days was examined.

2. Materials and methods

2.1. Chemicals

All chemicals used were 'AnalaR' grade obtained from British Drug House, Poole, Dorset, UK; Sigma Chemical Co., Ltd., Dorset, UK and Rathburn Chemical Co., Ltd., Peableshire, Scotland.

2.2. Meat samples

M. Longissmus dorsi were obtained from factory lambs (4–9 month Suffolk cross-breeds) after carcasses were chilled overnight to 4 °C. The muscles were trimmed of external fat and cut into 1.9 cm (3/4″) steaks using a bandsaw (Band saw Model 1640 Ser 4-14164; Butcher Boy UK Ltd., Lochview Road, Willowyard, Beith, Aryshire KA15 1HB, Scotland).

2.3. Packaging

2.3.1. Over-wrapping (aerobic packaging)

Meat steaks (1.9-cm thick) were selected at random and placed on expanded polystyrene trays (Linpac, Wakefield Road, Featherstone, West Yorkshire, WF 7 5 DE, England) and overwrapped with O_2 permeable (6000–8000 $cm^3/m^2/24$ h at STP) polyvinyl-chloride film (Wrap Films Systems Ltd., Shropshire, England). Packaging trial 1 was used as the control to study the effect of aerobic packaging alone on lamb meat quality (T1).

2.3.2. Mother-packing

Overwrapped meat steaks ($n = 4$) were placed in vacuum pack bags (Cryovac, W.R. Grace Europe Inc., Lausanne, Switzerland) (45 $cm^3/m^2/24$ h at STP) and partially sealed using a Webomatic type D463 vacuum packer (Webomatic Vacuum Packaging Systems, D 463 Bochum 6, Germany) except for a 4 cm opening for gas flushing. The partially sealed bags ($n = 9$) were selected at random, and divided into three groups ($n = 3$) and were flushed with gas mixtures containing 100:0, 90:10 or 80:20/CO_2:N_2 through a snorkel inserted into the opening of the bag for 2 min at (30 l/min) and then immediately sealed completely using the Webomatic type D463 vacuum packer. Packaging trial 2 and 3 were undertaken to study the effect of different gas compositions on mother-packed lamb stored for 4 days (T2) and 7 days (T3), respectively, in darkness at 4 °C, prior to retail display.

2.4. Storage conditions

Mother-pack bags containing over-wrapped lamb steaks were held in a non-illuminated chill at 4 °C for either 4 or 7 days prior to opening and removal of

over-wrapped tray packs. Over-wrapped tray packs were held under refrigerated display (4 °C) conditions using fluorescent light (Osram L30W/76, Natura Delux, Germany) (616 lx) for up to 8 days.

2.5. Determination of microbial load

All microbiological procedures were carried out in a Class 2 hood (Quality Air Systems, Warrington, England). The microbiology of the meat in each mother bag was analysed using a method modified from Holley et al. (1994). Using a sterile scalpel, a composite 2.5 g of meat was aseptically sampled from each steak from each mother bag and pooled to give a total of 10 g. Each 10 g sample was stomached for 2 min at high speed with 90 ml 0.1% sterile water, in a Seward stomacher 400 Laboratory blender (Seward, London SE1 1PP, UK). A 10-fold serial dilution was made using 0.1% sterile peptone water and a 0.1 ml aliquot from the appropriate dilution was plated in duplicate onto four types of pre-poured media.

Total viable counts (TVC) were determined using plate count agar (PCA) with inoculated plates incubated at 35 °C for 48 h. Lactic acid bacteria (LAB) were determined by plating on deMan, Rogosa, Sharpe (MRS) agar and incubating at 35 °C for 48 h. Coliforms were determined using violet red bile agar (VRBA) with inoculated plates incubated at 35 °C for 24 h. Pseudomonads were determined by plating on *Pseudomonas* selective agar (PSA), and plates were incubated at 30 °C for 48 h. Viable numbers were determined from plates bearing 20–200 colony forming units and results were expressed as CFU/g meat.

2.6. Measurement of pH

The pH of lamb steaks was measured using a WTW pH meter 320/Set-1 with an INGOLD type: LoT 406-M6-DXK-S&/25 probe (Wissenschaftlich–Techinische Werkstätten GmbH, D-8236 2 Weilheim; OB, Germany) on days 0, 2, 4, 6 and 8 of retail display. Three readings were taken from each steak for each treatment in the different trials.

2.7. Measurement of oxidative stability

The extent of lipid oxidation was assessed by measuring thiobarbituric acid reacting substances (TBARS) using the method of Tarladgis, Watts, Younathan, and Dungan (1960) as modified by Ke, Ackman, Linke, and Nash (1977). TBARS were expressed as mg malonialdehyde/kg muscle. Lipid oxidation was measured in duplicate from each of the five packs for each treatment in each trial on days 0, 3, 6, 9 and 12.

2.8. Determination of colour

Surface meat colour (Hunter *L*, *a*, *b*, values) was measured using a Minolta Chromameter CR-300 (Minolta Camera Co., Osaka 541, Japan). The '*L*' value measuring white-dark, '*a*' measuring red-green and '*b*' measuring yellow-blue. Hunter '*a*' values of lamb steaks (*M. longissmus dorsi*) were measured through the polyvinyl-chloride film of the over-wrapped pack on days 0, 2, 4, 6 and 8 of retail display.

2.9. Statistical analysis

An initial parametric analysis of the data indicated that the normality and constant variance assumptions were violated. Thus, non-parametric tests were conducted where the observations for each response were ranked in ascending order and the appropriate parametric tests were performed on the ranked data (Neter, Wasserman, & Kutner, 1990). For day 0, one-way ANOVAs were performed on the ranked responses to investigate differences between the 7 groups; control (T1), T2 100:0, 90:10 and 80:20/CO_2:N_2, and T3 100:0, 90:10 and 80:20/CO_2:N_2. Pairwise comparisons of treatment means with the control mean were analysed with Dunnett's test. The level of significance was determined as $p < 0.05$.

For each storage time separately, generalised linear models were used to test for the effect of gas type on colour, TBARS, pH, TVCs, LABs, coliforms and *Pseudomonas* counts. The model fitted to the data consisted of the following effects; gas type, day and day×gas type interaction. In all models, the term of primary interest was the interaction between gas type and day. This interaction term indicated whether the slope of the regression line for days was the same in each gas type, that is, whether the lines were parallel or not. The slope indicated the increase/decrease in average response level for each 1 day increase. All analyses were performed using SPSS for Windows (SPSS, Chicago, IL, USA) version 10.0.

3. Results and discussion

3.1. Microbiology

Total viable counts for over-wrapped lamb control meat (T1) had exceeded the microbiological guidelines for meat maximum limit (Irish Department of Health, 1992) of 2.0×10^6 CFUs/g meat at day 6 of retail display (Table 1). TVCs for lamb previously mother packed for 4 days (T2) using 100:0 and 90:10/CO_2:N_2 were significantly ($p < 0.05$) higher than the control (T1) on day 0. They were also higher throughout the first 6 days of retail display. They remained below the limit up until day

Table 1
Microbiological counts in overwrapped lamb steaks (*M. longissmus dorsi*) under retail display at 4 °C for 8 days previously mother-packed in different headspace compositions and stored in non-illuminated conditions at 4 °C for 0 (T1), 4 (T2) and 7 (T3) days

Bacterial types	Atmosphere (% CO_2:N_2)	Time (days)				
		0 (CFU/g)	2 (CFU/g)	4 (CFU/g)	6 (CFU/g)	8 (CFU/g)
TVC	T1 (0:0)	4.0×10^{2}	2.3×10^{5}	1.2×10^{4}	3.4×10^{6}	6.2×10^{8}
	T2 (100:0)	3.7×10^{5}*	4.0×10^{4}	5.1×10^{5}	2.2×10^{7}	1.8×10^{8}
	T2 (90:10)	1.9×10^{4}*	4.2×10^{4}	7.9×10^{5}	6.0×10^{7}	2.6×10^{8}
	T2 (80:20)	8.9×10^{3}	3.7×10^{4}	1.1×10^{6}	1.1×10^{6}	1.3×10^{8}
	T3 (100:0)	7.9×10^{4}*	3.2×10^{5}	4.0×10^{5}	8.1×10^{5}	4.3×10^{6}
	T3 (90:10)	1.6×10^{4}*	4.0×10^{4}	2.8×10^{5}	6.9×10^{5}	3.7×10^{6}
	T3 (80:20)	2.6×10^{4}*	2.1×10^{5}	1.1×10^{6}	1.1×10^{6}	1.7×10^{8}
LAB	T1 (0:0)	1.7×10^{5}	5.7×10^{4}	8.4×10^{2}	8.7×10^{5}	8.4×10^{7}
	T2 (100:0)	TFTC*	3.8×10^{4}	1.0×10^{5}	5.8×10^{6}	1.3×10^{7}
	T2 (90:10)	TFTC*	1.0×10^{5}	6.6×10^{5}	1.5×10^{7}	2.7×10^{7}
	T2 (80:20)	0.2×10^{4}	1.2×10^{4}	5.5×10^{4}	1.9×10^{5}	9.1×10^{6}
	T3 (100:0)	6.2×10^{4}	2.0×10^{5}	2.8×10^{5}	4.7×10^{5}	5.2×10^{5}
	T3 (90:10)	7.1×10^{2}*	1.1×10^{4}	1.2×10^{5}	4.4×10^{5}	6.4×10^{5}
	T3 (80:20)	2.8×10^{3}	9.4×10^{3}	5.0×10^{5}	7.1×10^{5}	4.8×10^{6}
Coliforms	T1 (0:0)	0.5×10^{3}	1.7×10^{4}	9.1×10^{2}	2.2×10^{4}	4.2×10^{5}
	T2 (100:0)	2.9×10^{4}	3.0×10^{3}	3.9×10^{4}	1.7×10^{6}	1.4×10^{7}
	T2 (90:10)	0.9×10^{3}	3.2×10^{3}	4.2×10^{4}	4.6×10^{6}	2.0×10^{7}
	T2 (80:20)	0.1×10^{3}*	2.8×10^{3}	9.6×10^{4}	2.9×10^{6}	1.0×10^{7}
	T3 (100:0)	0.5×10^{3}	3.1×10^{3}	6.6×10^{3}	8.9×10^{4}	8.7×10^{4}
	T3 (90:10)	1.1×10^{3}	3.5×10^{3}	2.2×10^{4}	4.7×10^{4}	1.7×10^{6}
	T3 (80:20)	1.1×10^{2}*	2.0×10^{3}	7.8×10^{3}	7.0×10^{3}	1.3×10^{6}
Pseudomonas	T1 (0:0)	1.4×10^{4}	3.6×10^{4}	4.7×10^{4}	7.9×10^{3}	5.6×10^{8}
	T2 (100:0)	5.2×10^{3}	2.4×10^{4}	6.6×10^{4}	2.8×10^{7}	1.7×10^{8}
	T2 (90:10)	8.8×10^{3}	8.2×10^{4}	2.7×10^{5}	4.0×10^{7}	2.3×10^{8}
	T2 (80:20)	TFTC*	1.9×10^{4}	1.3×10^{4}	3.4×10^{4}	1.2×10^{8}
	T3 (100:0)	7.7×10^{2}*	1.0×10^{4}	7.7×10^{3}	1.1×10^{4}	7.9×10^{6}
	T3 (90:10)	5.5×10^{2}*	7.8×10^{3}	1.5×10^{4}	5.9×10^{4}	3.2×10^{6}
	T3 (80:20)	2.8×10^{2}*	9.4×10^{2}	4.2×10^{3}	2.5×10^{3}	1.7×10^{5}

Mean values for three analyses.
Mean microbial count value significantly different to control: *$p<0.05$. TFTC, Too few to count.

4 and counts were lower than the control on day 8. TVCs for lamb meat previously mother-packed for 7 days (T3) using all gas compositions remained below the limit up until day 6 compared to day 4 in both T2 and the control. T3 TVCs were also lower, with the exception of 80:20/CO_2:N_2 on day 8, than T2 and the control on days 6 and 8 of retail display. These results suggest that the longer exposure to high concentrations of CO_2 was more effective at inhibiting the microbial population in meat. Farber (1991) found the overall effect of CO_2 on microorganisms was the extension of the lag phase of growth and a decrease in growth rate during the logarithmic phase. T3 lamb meat previously mother-packed in 100:0 and 90:10/CO_2:N_2 had lower TVCs on days 4, 6 and 8 compared to 80:20/CO_2:N_2. This suggests that higher concentrations of CO_2 were more effective at inhibiting microbial growth. These results concur with the findings of Huffman, Davis, Marple, and McGuire (1975) for beef. They found that the longest extension of shelf-life was obtained for beef stored in 100% CO_2 compared to that stored in an atmosphere 20:5:75/CO_2:O_2:N_2.

LAB counts in control lamb meat increased throughout the 8 days of storage. LABs initially represented the highest proportion of the flora examined, however *Pseudomonas* became the dominant flora after day 4 (Table 1). This was also observed in T2 after day 6 and in T3 after day 8 in gas compositions 100:0 and 90:10/CO_2:N_2. Under aerobic conditions, the dominant spoilage organisms in meat are the rapidly growing *Pseudomonas* (Gill, 1982). Under O_2 depleted atmospheres of N_2 or CO_2, the anaerobic conditions prevent all growth of *Pseudomonas* (Gill, 1996). The anaerobic conditions during storage of the T2 meat in mother-packs may have prevented the growth of *Pseudomonas* but upon exposure to air in retail display *Pseudomonas* became the dominant flora due to the return of aerobic conditions. T3 *Pseudomonas* counts were significantly ($p<0.001$) lower in all gas compositions compared to that of the control on day 0 and lower than the control and T2 throughout the 8 days of retail display. T3 LABs also represented the highest proportion of the flora examined up until day 6 in meat previously mother packed in 100:0 and 90:10/CO_2:N_2 compared to day 4

in the control and T2 in all gas compositions. This suggests that the exposure of lamb meat to higher concentrations of CO_2 for a longer period not only delayed *Pseudomonas* growth but reduced their number sufficiently to allow LABs of low spoilage potential to dominate the microbial population of the meat for longer during retail display.

T2 coliform counts in all gas compositions were higher than control on days 4, 6 and 8 suggesting previous mother packing in CO_2:N_2 atmospheres for 4 days had little or no inhibitory effect on coliform growth. Lambert et al. (1991) found anaerobic organisms, such as coliforms were not markedly affected by CO_2, and that their growth may be encouraged by anaerobic conditions and high levels of CO_2. However, T3 coliform counts were lower, with the exception of day 2, compared to those of T2 in all gas compositions throughout the 8 days of retail display with no observed increase in coliform numbers after day 6 in T3 meat previously mother-packed in 100:0/CO_2:N_2. Potent spoilage organisms such as enterobacteria, a portion of the coliform population, must be expected in the spoilage flora of meat when stored under vacuum or N_2 (Gill & Molin, 1991). This suggests that exposure of lamb meat to higher and lower concentrations of CO_2 and N_2, respectively, for a longer period may have partially inhibited coliform growth.

3.2. pH

The pH of T3 meat was generally below pH 5.8, with 90:10/CO_2:N_2 significantly ($p<0.05$) lower than that of the control on day 0. T3 was also slightly lower than T2 meat in all gas compositions throughout the 8 days of retail display. Grau (1980, 1981) found that on meat of pH <5.8 anaerobic growth of the faculative anaerobic enterobacteria was totally inhibited.

3.3. Oxidative stability

TBARS values for lamb meat control (T1) increased but values remained below 2.0 throughout the 8 days of retail display (Table 2). There was no significant difference between TBARS values of lamb meat previously mother-packed in 100:0/CO_2:N_2 throughout the 8 days of retail display. TBARS values for T2 100:0 and 90:10/CO_2:N_2 lamb were lower than 80:20/CO_2:N_2 mother-packed meat on days 2, 4, 6 and 8 of retail display with 100:0/CO_2:N_2 packed meat being the lowest throughout the 8 days. However it must be noted that values for T2 lamb meat in all gas compositions remained below the threshold level of 2.0 (Watts, 1962) throughout the 8 days of retail display.

TBARS values for T3 lamb meat were significantly ($p<0.05$) higher than those of the control and T2 in all gas compositions on day 0 and throughout the 8 days of retail display and only meat previously mother-packed in 100:0/CO_2:N_2 remained below 1.0 up until day 4 (Table 2). However, the TBARS values of both T2 and T3 did not increase exponentially from day 0 to day 8, as would be expected when the pre-packaged meat was displayed under aerobic conditions. Interestingly, the total viable counts for all treatments increased significantly over the display period (Table 1). Therefore, the fact that the TBARS numbers did not increase during retail display may suggest that the MDA produced by the oxidation process was simply utilised as a nutrient source by the microbial flora, which as has been described previously, increased over time in all packs during simulated retail display.

Bell, Penny, and Moorhead (1996) reported that long-term storage of lamb and beef beyond 6 weeks using mother packing was feasible, but it should be noted that these were for primal bulk cuts or whole carcasses and not for retail cuts.

No overall trends were determined for Hunter "*L*" or "*b*" values for Lamb meat in this study.

3.4. Colour

Hunter '*a*' values for T2 lamb previously mother-packed for 4 days in 100:0 and 80:20/CO_2:N_2 were significantly ($p<0.01$) lower than those of the control on day 0 of retail display (Table 3). These T2 day 0

Table 2
Oxidative stability of overwrapped lamb steaks (*M. longissmus dorsi*) under retail display at 4 °C for 8 days previously mother-packed in different headspace compositions and stored in non-illuminated conditions at 4 °C for 0 (T1), 4 (T2) and 7 (T3) days

	Atmosphere (% CO_2:N_2)	Time (days)				
		0	2	4	6	8
TBARS number	T1 (0:0)	0.08±0.0	0.56±0.3	0.40±0.4	0.62±0.1	0.99±0.4
	T2 (100:0)	0.32±0.1	0.41±0.1	0.41±0.1	0.47±0.1	0.50±0.2
	T2 (90:10)	0.56±0.1*	0.54±0.2	0.85±0.2	0.25±0.1	0.58±0.2
	T2 (80:20)	0.40±0.1*	0.61±0.2	0.86±0.1	1.30±0.2	0.81±0.1
	T3 (100:0)	0.82±0.3*	0.97±0.2	1.26±0.2	2.02±0.2	1.19±0.2
	T3 (90:10)	1.50±0.6*	1.38±0.4	1.17±0.2	2.92±0.3	1.33±0.2
	T3 (80:20)	1.01±0.4*	1.43±0.4	0.95±0.2	1.21±0.2	0.85±0.1

Mean TBARS values for three analyses performed in duplicate.
Mean value significantly different to control: *$p<0.05$.

Table 3
Hunter '*a*' values of overwrapped lamb steaks (*M. longissmus dorsi*) under retail display at 4 °C for 8 days previously mother-packed in different headspace compositions and stored in non-illuminated conditions at 4 °C for 0 (T1), 4 (T2) and 7 (T3) days

	Atmosphere (% CO_2:N_2)	Time (days)				
		0	2	4	6	8
Colour	T1 (0:0)	10.51 ± 0.5	8.44 ± 0.3	6.36 ± 0.2	6.87 ± 0.9	6.01 ± 1.1
	T2 (100:0)	6.30 ± 0.2*	7.24 ± 0.3	9.59 ± 0.6	10.21 ± 0.6	5.30 ± 0.5
	T2 (90:10)	6.23 ± 0.2*	6.46 ± 0.2	9.51 ± 0.7	8.56 ± 0.6	4.41 ± 0.3
	T2 (80:20)	6.18 ± 0.3*	7.12 ± 0.4	6.97 ± 0.5	8.55 ± 0.3	4.74 ± 0.4
	T3 (100:0)	10.08 ± 0.3	8.24 ± 0.3	7.16 ± 0.6	6.48 ± 0.5	7.34 ± 0.4
	T3 (90:10)	10.32 ± 0.2	8.42 ± 0.1	7.19 ± 0.3	6.37 ± 0.9	5.72 ± 0.9
	T3 (80:20)	9.73 ± 0.3	7.93 ± 0.2	7.36 ± 0.4	6.88 ± 0.5	5.56 ± 0.3

Mean Hunter '*a*' values for twelve analyses performed 10 times.
Mean value significantly different to control: $*p < 0.05$.

Hunter '*a*' values were comparable to those of day 4 of the control which corresponded to the same sampling day which suggested that the gas compositions in which the meat had been mother-packed for 4 days had no adverse effect on meat colour stability. However these values increased from days 0 to 6 with values higher on day 6 than those of the control. Johansson (1989) showed that the '*a*' value could be used to predict changes in the myoglobin of meat, either during blooming/oxygenation or oxidation of metmyoglobin. Metmyoglobin is reconvertable to deoxymyoglobin, which in turn can be oxygenated to the desired oxymyoglobin, only slowly by enzyme mediated reactions termed metmyoglobin reducing activity (Ledward, 1985). Gill (1996) also found *M. longissmus dorsi* to have a high metmyoglobin reduction activity which may account for this observed increase in Hunter '*a*' values. However this is in disagreement with Moore and Gill (1987) who found that this activity reduces during the storage of muscle. Hunter '*a*' values of T2 lamb meat previously mother-packed for 4 days in 90:10/CO_2:N_2 were higher than T2 lamb previously mother-packed in 100:0 and 80:20/CO_2:N_2 on days 4 and 6 and was comparable to those values of the control on day 0. However there was no significant difference between Hunter '*a*' values of T2 lamb mother-packed in the different gas compositions on day 2. The 90:10/CO_2:N_2 meat increased after day 2 and decreased after day 6 similar to that observed with 100:0 and 80:20/CO_2:N_2 packed meat. Gill (1996) found mother-packs that use equipment which fills the mother bags with gas through a snorkel to be often inadequate in composition. The bag using this technique is exposed to the pressure of the atmosphere throughout the evacuation and gassing operations. Consequently, a volume of air sufficient to prevent the bag collapsing around and crushing the retail trays must remain in the bag at the end of the evacuation phase. Ledward (1970) reported that the colour of beef steaks was degraded by short storage periods under CO_2 or N_2 atmospheres. He concluded that this occurred because the residual O_2 in the normally anoxic atmospheres was scavenged by the meat pigment with the formation of metmyoglobin at the surface of the steaks. Moreover, the extent to which individual bags are filled with air can vary. This can result in the input gas being greatly and variably diluted by the air and indeed O_2 being present in bags at the time of gassing. A small volume of O_2 present in the mother bags may have been responsible for metmyoglobin formation as opposed to keeping the meat in the intended deoymyoglobin state in an O_2 depleted atmosphere during storage. This would account for the initially low Hunter '*a*' values. The metmyoglobin so formed has to be reduced by the metmyoglobin reducing activity of the meat before the steaks can bloom in air to a desirable colour (O'Keeffe & Hood, 1982). Gill and Jones (1994b) found a duration of two days was required for the reduction of sufficient metmyoglobin to allow the meat to develop a desirable colour when exposed to air.

There was no significant difference between Hunter '*a*' values for lamb meat previously mother-packed for 7 days (T3) in all gas compositions and the control (Table 3). T3 100:0/CO_2:N_2 were also significantly ($p < 0.05$) higher than those of T2 on day 0. T3 meat also maintained their initial colour values better than those of the control. T3 meat previously mother-packed in 100:0/CO_2:N_2 had higher '*a*' values than those of the control and T3 meat packed in other gas compositions on days 4 and 8 of retail display. Powell and Cain (1987) found that meat respires during storage due to tissue and microbiological respiration consuming O_2 and producing CO_2. These activities during the longer storage period of T3 may have consumed all of the small volume of O_2 present in the mother bags due to the gassing operation creating a complete anaerobic environment thus allowing metmyoglobin reducing activity to proceed without further metmyoglobin formation. This suggests that meat packaged in higher concentrations of CO_2 for a longer period maintains if not increases the colour stability of lamb.

4. Conclusion

The results show that previous mother-packing in 100:0/CO_2:N_2 was the most effective way of extending the storage life of retail ready lamb prior to display, especially over longer storage periods. Lamb meat previously mother-packed in 100:0/CO_2:N_2 for 7 days maintained their initial colour '*a*' value better than that of conventional over-wrapped meat during retail display. Mother-packing in 100:0/CO_2:N_2 for 7 days also extended the microbial shelf-life of lamb from 4 to 6 days. The 100:0/CO_2:N_2 atmosphere was the most effective at decreasing *Pseudomonas* and coliforms while increasing the numbers of lactic acid bacteria in the total microbial load in lamb prior to retail display. TBARS values for lamb meat were not significantly increased when previously mother-packed for 4 days but mother packs for 7 days showed significantly ($p < 0.05$) higher TBARS when compared to conventional over-wrapped meat. Lipid oxidation in lamb previously mother-packed for 7 days occurred at a faster comparative rate than discolouration and microbial growth and was the major determinant of shelf-life.

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