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Packaging Venison for Extended Chilled Storage: Comparison of Vacuum and Modified Atmosphere Packaging Containing 100% Carbon Dioxide

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ABSTRACT

Thirty red deer *(Cervus elaphus)* stags were slaughtered at three deer slaughter premises (plants A, B, and C) to determine the effects of initial microbial flora on the quality of chilled venison loins stored using three packaging methods: vacuum packaging (VP), modified atmosphere packaging using an ultra-high barrier outer barrier film (CO_2-UHB), and modified atmosphere packaging using a dual aluminized polyethylene outer barrier film (CO_2-MPET), all of which were stored for 6, 12, and 18 weeks at -1 ± 3°C. Carcasses slaughtered in plant B had higher aerobic plate counts than those killed at either plants A or C. Location of slaughter had little effect on loin quality except for drip loss, pH and anaerobic and lactic acid bacteria counts. Oxygen levels increased in the modified atmosphere packages ($P<0.05$) during storage from 12 to 18 weeks (CO_2-UHB, 1%; CO_2-MPET, 0.05%). Loins packaged in CO_2 -UHB exhibited less acceptable surface color than meat packaged in CO_2 -MPET or VP. Aroma, flavor, texture, and acceptability scores decreased ($P<0.05$) when loins were stored over 12 weeks regardless of packaging method. pH values of loins packaged in modified atmosphere packs were lower ($P<0.05$) than those in VP. The regression relationship between percent drip loss and pH was given by % drip = 39.1 -6.49 [Standard error (SE) 1.52] pH. Acceptable display color of steaks cut from the loins, regardless of treatment, decreased as loins were stored from 6 to 18 weeks. These results suggest that vacuum packaged venison loins resulted in meat of acceptable quality after 12 and 18 weeks of chilled storage, and that modified atmosphere packaging contributed no additional benefit.

Packaging methods utilizing high concentrations of CO_2 have been researched in New Zealand to maintain the organoleptic quality of chilled venison *(28)* and lamb *(11)* for periods up to 18 weeks and longer *(11)*. Such storage periods are necessary to allow for consignment assembly, transport to foreign ports, and distribution since it has been estimated that a shelf life of over seven weeks is required for transportation to Britain from New Zealand by sea freight *(20)*. Additional product shelf life would ensure adequate meat quality if delays arose during transportation. Vacuum packaging using barrier-shrink bags can usually maintain the quality of meat of normal ultimate pH and low microbial load for up to 12 weeks at -1°C, but cannot be relied upon when packaging high pH meat *(14)* or meats of high initial microbial contamination *(13)*. Packaging in a CO_2 modified atmosphere has been beneficial with lamb since lamb is particularly difficult to store chilled for extended periods of time because of variations in pH caused by preslaughter washings *(25)*, possible nutritional and post-shearing stress *(26)*, and high fat and bone content.

Carbon dioxide (CO_2) has been found to be a potent inhibitor of spoilage bacteria and has been used to help preserve red meat *(4,9,30)*. For this reason, CO_2 was used in the first shipment of chilled beef from New Zealand to the United Kingdom in 1933 resulting in no traces of microbial spoilage *(18)*. CO_2 is more effective when applied at early stages of bacterial growth, when used at low storage temperatures (approaching 0°C), and when used in high concentrations *(6)*. Gram negative spoilage bacteria are more susceptible to the effects of CO_2 than Gram positive bacteria *(31)*. High concentrations of CO_2, however, discolor meats *(6)*. Brooks *(3)* demonstrated that concentrations of CO_2 over 30% caused increased discoloration, but systems containing up to 20% had little effect on color stability. The proteins in some muscle fibers have been reported to denature upon exposure to high concentrations of CO_2, presumably caused by a rapid fall in surface pH, which resulted in a patina of bleached fibers on the meat surface *(11)*. These disadvantages, however, can be overcome in part, by first packaging the meat in gas permeable bags which mediate the CO_2 and tend to moderate its deleterious effects before exposure to high CO_2 concentrations *(11,13)*.

Increasing worldwide demand for ranched venison has necessitated the exploration of innovative packaging methods. The objectives of this study were *(a)* to determine the microbial quality of deer carcasses processed from three slaughter premises, *(b)* to compare the keeping characteristics of venison using modified atmosphere packages containing 100% CO_2 with conventional vacuum packages, and *(c)* to compare the influences of using two different outer barrier films; ultra-high barrier plastic (UHB) and

dual aluminized polypropylene (MPET) on venison quality. Loin surface color, pH, odor at opening, drip loss, sensory scores, changes in microflora, and color stability were evaluated on loins stored for 6, 12, or 18 weeks at -1 ± 3°C.

MATERIALS AND METHODS

Slaughter

Thirty, 16 month old red *(Cervus elaphus)* stags were slaughtered in lots of 10 at three slaughter premises denoted A, B, and C. All deer carcasses were electrically stimulated (45 V, 45 mA RMS, 90 sec duration) and dressed according to usual methods used within each establishment. Carcasses in plants A and C were placed immediately after dressing into chillers set at 4 and 5°C respectively for 24 h. Carcasses in plant B were conditioned for 9-11 h (depending upon the order of kill) at 10°C prior to chilling at -1°C for 13 h. Boneless loins (*M. Longissimus dorsi*, LD) were removed from nine carcasses at each plant 24 h post-mortem. Loins from the 10th carcass in each lot were to be used as replacements if those from any of the other animals were found to be unacceptable due to physical damage, bruising, miscutting, high pH, etc. Loins from plant B were stripped of epimyseal connective tissue by use of a Townsend skinner prior to packaging. All loins were vacuum packaged, transported to the Invermay Agricultural Center and stored at 4 ± 3°C for 24 h before opening and assignment to the various packaging treatments.

Packaging

Each of the pair of LD muscles from individual deer carcasses was sliced into three 18 cm long portions, with corresponding portions from each side being packaged together in pairs, constituting the experimental units. These were allocated to three packaging treatments (vacuum packaging, VP; modified atmosphere packaging using 100% CO_2 with ultra-high barrier outer barrier film, CO_2-UHB; and modified atmosphere packaging using 100% CO_2 with a dual aluminized polypropylene film as the outer barrier film, CO_2-MPET) and three storage times (6, 12, and 18 weeks) according to a predetermined scheme. Meat was stored at -1 ± 3°C during storage.

Vacuum packaged loins. Loin portions were vacuum packaged individually in Cryovac™ barrier bags (ethylene/vinyl acetate copolymer-polyvinylidene chloride laminate; W.R. Grace, Porirua, New Zealand; OTR = 30-40 ml m^{-2} 24 h^{-1} atm^{-1} at 25°C and 75% RH) using a Supervac chamber vacuum packager (model GK169K SH) to 722 mm Hg and heat shrunk by dipping in a 90°C water bath for 2-3 s. Pairs of vacuum packaged loin portions were kept together.

Modified atmosphere packaged loins. Loin portions were individually vacuum packaged in Cryovac™ E-bags (W.R. Grace, Porirua, New Zealand; OTR = 517 ml m^{-2} 24 h^{-1} atm^{-1} at 0°C and 75% RH; CO_2-TR = 7223 ml m^{-2} 24 h^{-1} atm^{-1} at 27°C and 75% RH) to 722 mm Hg and heat shrunk as above. Paired loin portions were placed inside either a bag made from the ultra-high barrier outer barrier film (CO_2-UHB treatment; Transpak Industries Ltd, Auckland, New Zealand) or dual aluminized polyethylene outer barrier film (CO_2-MPET) treatment; (Transpak Industries Ltd, Auckland, New Zealand) which were evacuated and flushed with 100% food grade CO_2 (New Zealand Industrial Gases, Dunedin, New Zealand) twice before filling with 1 L of CO_2/kg of meat.

Sampling of residual oxygen

Residual oxygen concentration in the head space of the modifed gas packages was analysed using a portable Servomex oxygen analyser (model 570A) by inserting a needle connected to the instrument through a pad of dried silicon glue previously fixed to the outer barrier film. This provided an absolutely gas tight seal *(27)*. Residual oxygen was measured on the first 3 d after packaging and after the designated storage periods.

Determination of pH

The pH of each loin was determined by taking duplicate readings using an Orion spear-tip combination electrode (91-63) and a portable pH meter 24 h post-mortem, prior to cutting and assignment of loin portions to treatments. Readings were also taken from each loin portion (in duplicate) after the designated storage period.

Microbial analysis

Swabs for the determination of aerobic plate counts (APC) were taken from the shoulder (point of shoulder), mid-loin (10th rib; approx. 10 cm from midline), and rear leg (approximately 20 cm from midline) of each carcass after evisceration and prior to chilling by swabbing a 5 cm^2 area using a sterilized wire as a template. Swabs were placed in sterile 0.1% peptone and analyzed using standard plating methods *(19)*. Appropriate dilutions were prepared in duplicate on Plate Count Agar. Shoulders of carcasses from plant B were not sampled.

Ten gram samples were aseptically removed from each LD after arrival at Invermay to determine APC count prior to packaging. Samples were macerated with a stomacher for 2 min in 0.1% peptone. Appropriate dilutions were made in duplicate on Plate Count Agar.

A composite sample of venison weighing 10 grams was taken from the two loin portions in each package unit after storage, and macerated with a stomacher for 2 min in 0.1% peptone. Appropriate dilutions were made on selective media to enumerate lactic acid bacteria (Rogosa media) *(1)*, total aerobes (Plate Count Agar), and total anaerobes (Plate Count Agar). Plates for enumerating total anaerobes and lactic acid bacteria were incubated in BBL Gaspak™ jars at 35°C for 72 h and for 4 d at 35°C, respectively *(1)*. Total aerobic plates were incubated at 35°C for 48 ± 2 h. All enumerations were performed in duplicate. Microbiological counts were reported as $\log_{10}$ CFU/cm^2 or per gram as appropriate.

Objective tenderness evaluation

Two, 2.0 cm thick slices were cut from each loin portion and cooked in a 80°C water bath for 1 h *(32)*. After cooking, samples were blotted dry, wrapped in aluminum foil, and chilled overnight (3°C) before shearing using a MIRINZ Tenderometer. Fifteen samples from each loin portion with a cross-sectional area of 1 cm^2 were sheared to provide adequate assessment of tenderness. Tenderness was reported as N/cm^2 cross-sectional area.

Drip loss

Percent drip loss was determined by dividing the difference between the initial loin portion weight prior to packaging and the weight of the same portion blotted with paper towels after opening and expressed as a percent of the initial portion weight. Drip losses for meat samples stored for 6 weeks were not determined due to faults with the method used.

Sensory evaluation

Loin surface color. Surface color and color acceptability was assessed by three trained color evaluators after loin portions were removed from storage and exposed to the air for 30 min using a 5 point color scale; (5 = bright fresh red venison color, 4 = bright red venison color, 3 = slightly dark or brown, 2 = moderately dark or brown, 1 = extremely dark or brown), and a 3 point color acceptability scale; (3 = purchase with no reservation, 2 = purchase with reservation, 1 = would not purchase).

Color stability. A single 1.5 cm thick slice was removed from each loin unit (n = 24 per storage time), placed on a white molded polystyrene tray, wrapped with poly vinyl chloride (PVC) film (OTR = 11,000 ml m^{-2} 24 h^{-1} at 20°C and 0% RH) and displayed in a portable retail display case held at 3 ± 3°C for 5 consecutive days while illuminated with soft white fluorescent light (1800 lx) for two h/d in a darkened room. Although meat displayed for retail sale would probably be exposed to the light for longer periods of time, this procedure was followed to maintain a consistency of measurement under standard conditions.

Samples were evaluated for degree of off color and color acceptability by a 15 member trained color evaluation panel, made up of personnel at the Invermay Agricultural Centre *(28)*. Panelists had previously been screened for color blindness. Discoloration and color acceptability were scored using a 5 point and 3 point scale as described above. Data were not obtained for the fifth day of display for 12 weeks samples due to logistical problems.

Odor. Odor was assessed immediately upon opening the packages of loin portions from each packaging treatment using a 3 point scale with 3 = no off odor-not objectionable, and 1 = off odor - objectionable, with a 3 member panel made up of individuals experienced with vacuum packaged meat odors. Typical confinement odors associated with vacuum packaged meat were not considered off odors, but putrid or sulphurish odors were considered unacceptable.

Taste panel. Loin portions representing each unit were vacuum packaged after sampling, frozen at -25°C, and shipped to the Meat Industry Research Institute of New Zealand (MIRINZ) for evaluation of aroma, texture (tenderness), flavor, juiciness, and overall acceptability using a 40 member consumer-type taste panel. Panelists rated the samples using 9 point hedonic scales with 9 = could not be better and 1 = could not be worse. Loins were wrapped in aluminum foil and roasted to an internal temperature of 70°C which was monitored using thermocouples attached to an alarm which sounded when the endpoint was reached.

Statistical methods

Experimental units in this study comprised 81 paired loin portions, 3 from each of 9 stags from each of 3 slaughter sites. These were allocated within sites to the 3 package type by 3 storage time factorial treatment structure, such that the main effects of packaging and storage time could be separated from the influence of individual animals.

Data were analyzed by analysis of variance, with site and package within site as the error strata, and with initial pH as a covariate for the analysis of later pH measurements. Data for surface color, sensory traits and tenderness, for which there was evidence of a stag effect, were analyzed by restricted maximum likelihood *(24)* with site, stag within site, and package within stag as random effects and the main effects and interaction of packaging and storage time as fixed effects. Statistical significance was assessed at the 5% level throughout.

RESULTS

Residual oxygen concentration

Oxygen was depleted from an initial mean level of 0.34% immediately after packaging to less than 0.04% (Standard error of the difference between two means [SED] = 0.073) by 48 h after packaging in both CO_2-UHB or CO_2-MPET. Residual oxygen levels in modified atmosphere packs increased with increasing length of storage, but to different levels depending upon the outer barrier film used (Fig. 1). Higher ($P<0.05$) mean oxygen levels were found in meat packaged using CO_2-UHB than that packaged in CO_2-MPET after storage for 12 and 18 weeks.

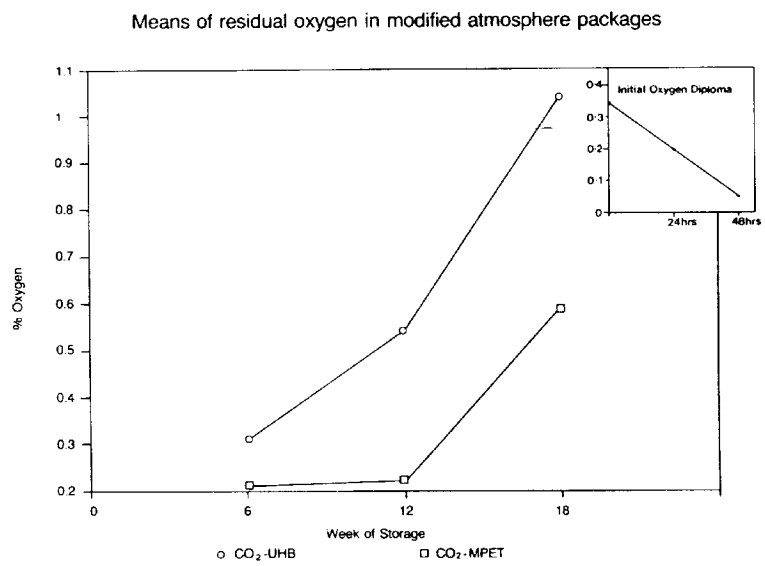

Figure 1. *Means of residual oxygen in modified atmosphere packages (o, CO_2-UHB; ❑, CO_2-MPET).*

Residual oxygen content was higher ($P<0.05$) in both modified atmosphere packages after 18 weeks of chilled storage than at 6 or 12 weeks, resulting in mean values of 1.0% and 0.6% for CO_2-UHB and CO_2-MPET, respectively.

Surface color evaluations

Mean surface color acceptability and discoloration scores were lower ($P<0.05$) in loins packaged in CO_2-UHB outer film than for meat packaged in either VP or CO_2-MPET (Table 1). Although surface color acceptability scores were not significantly affected by storage time for 12-18 weeks, mean surface discoloration scores decreased ($P<0.05$) in meat packaged in the VP and CO_2-UHB treatments stored 12-18 weeks, but increased for meat packaged in CO_2-MPET.

pH

Mean pH values from VP loins were higher ($P<0.05$) than those obtained from loins packaged in CO_2-UHB and CO_2-MPET in all storage periods (except CO_2-MPET at week 6) (Table 1). There was a significant packaging by storage time interaction, with mean pH values increasing ($P<0.05$) to 12 weeks of storage and then decreasing only for loins packaged in VP and CO_2-MPET.

TABLE 1. *Means of panel surface color, color and stability, pH and drip loss by packaging method and storage time.*

	Packaging Method			
	Vacuum	CO_2-UHB	CO_2-MPET	SED[1]
SURFACE COLOR TRAITS				
Color acceptability[2]				
Week 12	3.00	1.85	2.96	0.051*
Week 18	3.00	1.76	3.00	
Discoloration[3]				
Week 12	4.33	2.76	3.97	0.106*
Week 18	4.01	2.06	4.29	
pH				
Week 6	5.58	5.51	5.58	0.02*
Week 12	5.73	5.63	5.63	
Week 18	5.69	5.64	5.56	
DRIP LOSS (%)				
Week 12	1.89	2.19	3.03	0.34*
Week 18	1.77	2.36	3.11	
COLOR STABILITY[4]				Mean ± SD
Week 6	2.8	2.7	2.8	2.8 ± 0.06
Week 12	1.6	1.6	1.7	1.6 ± 0.06
Week 18	1.5	1.4	1.7	1.5 ± 0.15

[1]SED = Standard error of the difference between two means.
[2]Scored using a 3 point scale (3 = purchase without reservation; 2 = purchased with reservation; 1 = would not purchase).
[3]Scored using a 5 point scale (5 = bright fresh red venison color; 4 = bright red venison color; 3 = slightly dark or brown; 2 = moderately dark or brown; 1 = extremely dark or brown).
[4]Number of days required to reach a color acceptability of 2 (purchase with reservation).

Drip losses

Drip loss did not vary with storage period; however, mean drip loss was higher ($P<0.05$) for meat in CO_2-MPET than for that packaged in CO_2-UHB which, in turn was higher than for VP (Table 1).

Differences in percent drip loss were also found between slaughter locations, with Plant A 2.24%, Plant B 2.89%, and Plant C 2.06% (SED = 0.24), but there was no evidence of an interaction between packaging treatment and slaughter location.

The regression relationship between meat pH and percent drip loss was given by

Percent drip loss = 39.1 - 6.49 (Standard error [SE] 1.52) pH.

with no significant contribution of packaging, storage treatment, or slaughter location to the model.

Sensory evaluation

Sensory data from the 40 member untrained consumer panel are presented in Table 2. Differences ($P<0.05$) due to packaging method were only found in texture values. Mean texture (tenderness) scores decreased ($P<0.05$) as meat in VP and CO_2-MPET was stored from 6 to 18 weeks, but scores for CO_2-UHB did not change significantly during chilled storage. There were small decreases in aroma, flavor, and overall acceptability scores from 6 to 12 weeks of storage, followed by significant decreases to 18 weeks. Overall acceptability scores decreased ($P<0.05$) after each storage period. Juiciness scores were unaffected ($P<0.05$) by either packaging method or storage time.

Odor

Mean odor scores decreased ($P<0.05$) in both the VP and CO_2-UHB treatments after chilled storage up to 18 weeks. Odor scores for CO_2-MPET followed a similar trend but the mean did not differ ($P>0.05$).

TABLE 2. *Means of sensory traits[1], MIRINZ tenderometer values and odor scores of venison by packaging method and length of chilled storage.*

	Week of Storage			
Trait	6	12	18	SED
AROMA	5.36	5.29	4.82	0.065*
TEXTURE[2]	5.86	5.73	5.39	0.091*
FLAVOR	5.29	4.98	4.31	0.087*
JUICINESS	4.68	4.41	4.62	0.162
ACCEPTABILITY	5.01	4.76	4.30	0.092*
TENDERNESS[3] (N/cm^2)	39.6	43.0	40.0	3.04
ODOR				
Package				
Vacuum	-	2.95	2.76	0.077*
CO_2-UHB	-	2.96	2.76	
CO_2-MPET	-	3.00	2.92	

[1]Scored using 9 point hedonic scales with 9 = couldn't be better and 1 = couldn't be worse.
[2]Treatment X storage time interaction.
[3]MIRINZ Tenderness reported in Newtons/cm^2.

Objective tenderness

MIRINZ tenderness scores were not significantly affected by either storage time or packaging method.

Color evaluation

Six weeks. Color scores of venison loins decreased ($P<0.05$) after 6 weeks of storage from values over 4.7 (corresponding to bright fresh red venison color) to values as low as 1.8 (corresponding to moderately dark or brown)

after 5 d of display (Fig. 2). Color deterioration was similar for loin slices from each packaging treatment except that those packaged in CO_2-UHB tended to deteriorate and exhibit lower color scores from the third day of display onwards.

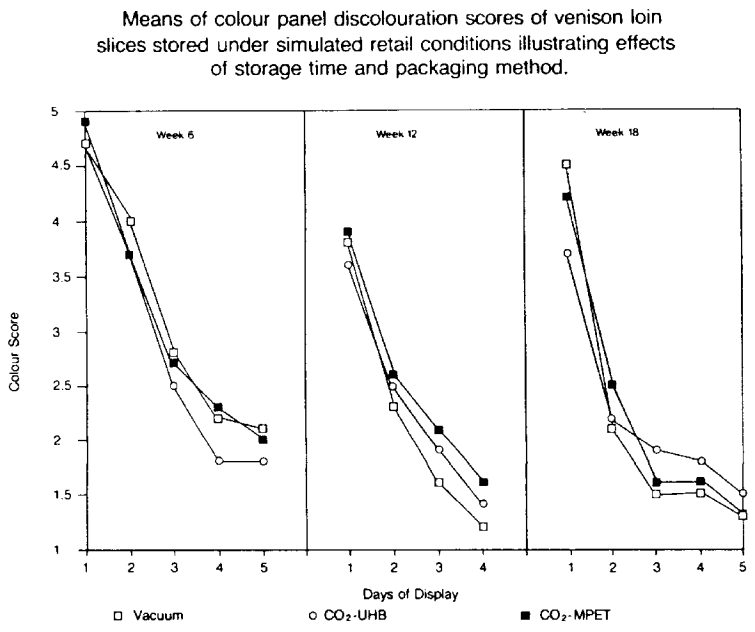

Figure 2. *Means of color panel discoloration scores of venison loin slices stored under simulated retail conditions illustrating effects of storage time and packaging method. (Vacuum, ❑; CO_2-UHB, o; CO_2-MPET, ■).*

Twelve weeks. Meat sampled after 12 weeks storage resulted in similar trends except that initial color scores were lower than those observed at 6 weeks storage. Loins packaged in VP packages exhibited lower color scores after 2 or more days of display than either modified atmosphere package treatments.

Eighteen weeks. Loin slices from CO_2-UHB stored for 18 weeks had lower ($P<0.05$) initial color scores which deteriorated less, resulting in significantly higher color values after 2, 3, 4, and 5 d of display than VP or CO_2-MPET.

Panelists also assigned color acceptability scores from which the number of days of acceptable display (defined as an acceptability score of 2 - purchase with reservation) could be calculated (Table 1). This corresponded to a color score of approximately 3.0 (slightly dark or brown). Loin samples stored for 6 weeks could be displayed for 2.8 d before reaching marginal color acceptability, but display time was reduced to 1.6 d after 12 weeks and 1.5 d after 18 weeks. It was observed that venison slices stored 18 weeks had acceptable color when sliced, but that the desirability of the color deteriorated between the time of cutting and wrapping until the time the panel observed them 3 h later, having been held at 0-2°C in the interim. A 3 h delay was necessary to fit the schedule of the color evaluator panelists so that they could examine the steaks at 24 hr intervals.

Microbial evaluation

Carcass counts. Aerobic plate counts obtained by swabbing three locations selected on each deer carcass did not vary significantly with sampling site on the carcass (Table 3). However, deer slaughtered at Plant A exhibited lower ($P<0.05$) mean aerobic plate counts with smaller ranges than those from deer processed in the other plants.

TABLE 3. *Mean and range of the aerobic plate count of deer carcasses slaughtered at three locations.*

	Carcass Site		
	Shoulder	Mid-Loin	Leg
SLAUGHTER LOCATION	($\log_{10}$ CFU/cm^2)		
(A)	0.05 (0-1.04)	0.07 (1-1.30)	0.12 (0-1.20)
(B)	1.52 (0-4.73)	1.48 (0-3.20)	nd
(C)	0.99 (0-4.00)	1.32 (0-5.20)	0.85 (0-3.18)
SED at same level of carcass site = 0.395*			
SED at same level of location = 0.293			

nd - not determined.

Pre-packaging loin counts. The mean and range of aerobic plate counts ($\log_{10}$ CFU/cm^2) by site for loins samples immediately prior to packaging are as follows: location A, 1.34 (0-3.20); location B, 2.55 (0-5.61); location C, 1.23 (0-3.83) SED = 0.547. Loins obtained from Plant B had a higher mean and wider range of APC counts than those obtained from either Plant A or C. Loins from Plant B were the only ones which were mechanically stripped of epimyseal connective tissue.

Effect of storage time and packaging method. Recoverable aerobic microorganisms increased ($P<0.05$) with storage time in all packaging treatments from values around $\log_{10}$ 2 after 6 weeks up to $\log_{10}$ 4 to 5 CFU/ g after 18 weeks (Table 4). Location of slaughter did not significantly affect aerobic counts. Highest aerobic counts were observed in VP at each storage period; aerobic counts of loins stored in the modified atmosphere packages did not differ from each other ($P>0.05$).

Recoverable anaerobic bacteria counts increased ($P<0.05$) for VP and CO_2-UHB as loins were stored from 6 to 18 weeks, but decreased slightly for CO_2-MPET ($P>0.05$) after 18 weeks storage. Vacuum packaged loins had the highest anaerobic counts at each storage period. A significant slaughter location effect indicated that loins obtained from Plant B ($\log_{10}$ 2.57 CFU/g) had lower recoverable anaerobic counts than loins from Plants A or C ($\log_{10}$ 3.13 and 3.39 respectively).

Lactic acid bacteria counts were initially low (less than $\log_{10}$ 1.0 CFU/g) and increased significantly after 12 and 18 weeks of storage, except for meat packaged in CO_2-MPET counts decreased after 12 weeks of storage. Significant effects due to packaging method were not apparent until 18 weeks, where CO_2-MPET exhibited the lowest lactic acid bacteria counts.

DISCUSSION

Surface discoloration. It is essential that virtually all residual oxygen be removed from packages of unfrozen meat if long shelf life is required *(20)* since low concentrations of residual oxygen (4 mm Hg) have been found to accelerate myoglobin oxidation resulting in the formation

TABLE 4. *Mean and range of microflora by method of packaging and length of storage on chilled venison.*

Bacteria	Method of Packaging		
	Vacuum	CO_2-UHB	CO_2-MPET
AEROBES	(log CFU/g)		
Week			
6	2.70 (1.83-4.11)	1.73 (0-2.67)	1.94 (0-2.71)
12	4.08 (2.79-6.38)	3.43 (1.54-4.51)	3.33 (1.48-6.23)
18	5.53 (4.36-6.56)	4.43 (2.54-6.20)	3.88 (2.53-4.95)
SED	0.482*		
ANAEROBES[1]			
Week			
6	2.44 (1.23-3.76)	1.15 (0-2.08)	1.34 (0-3.23)
12	3.89 (1.66-6.00)	3.64 (2.46-6.00)	3.02 (1.15-5.43)
18	5.22 (3.82-6.59)	4.10 (2.18-5.91)	2.46 (0-4.70)
SED	0.582*		
LACTIC ACID BACTERIA[1]			
Week			
6	0.45 (0-2.20)	0 (0)	0.47 (0-2.98)
12	2.65 (0-5.86)	2.10 (0-6.00)	1.65 (0-3.18)
18	4.06 (0-6.51)	3.04 (0-4.91)	1.34 (0-4.04)
SED	0.773*		

[1]Significant slaughter location effect ($P<0.05$).

of brown metmyoglobin *(8)*. Anoxic conditions remain in vacuum and modified atmosphere packages initially containing 100% CO_2 as long as the utilization of residual oxygen through scavenging by tissue respiration or bacterial growth is greater than the ingress of oxygen through the bacterial growth is greater than the ingress of oxygen through the packaging film into the bag. Oxygen consumption by meat tissues has been estimated at 4 μ/cm^2d at 1°C over the first 2 d of packaging, decreasing to levels as low as 0.01 $\mu g/cm^2/d$ after storage from 4 to 7 d *(17)*. Thus, most vacuum packages of meat should be exhausted of oxygen during the first few days of storage. Residual oxygen levels can increase after the initial depletion stage in modified atmosphere packages if oxygen ingress surpasses oxygen consumption. Residual oxygen of CO_2-UHB exceeded 0.5% by 12 weeks storage and increased to over 1.0% after 18 weeks (Fig. 1). This resulted in venison with detectable surface discoloration (Table 1).

During long term chilled storage it is advantageous to use containment films of low oxygen and CO_2 permeability to maintain an anoxic environment so a flora of lactobacilli can be maintained *(13)*. Although oxygen levels as high as 0.69-1.12% have been found in vacuum packaged beef, these levels do not seem to cause severe color problems *(27)*.

pH effects. Venison packaged in modified atmospheres (100% CO_2) has previously been found to have significantly lower pH values than that which has been vacuum packaged *(28)*, which is probably due to the dissolved CO_2 in the meat fluids *(16)*. Surface color deterioration in this study seems more a consequence of oxygen ingress than changes in pH, since only venison packaged in CO_2-UHB exhibited significant surface discoloration.

The pH of venison in all package treatments decreased from a peak after 12 weeks of storage. This may be the result of a build up of lactic acid produced by the increasing population of lactic acid forming bacteria.

Drip losses. It is well known that the water-holding capacity of meat is strongly affected by pH *(15)*. The strong negative relationship between drip loss and pH indicates that meat aged in vacuum packages (with higher pH values) tended to exude less drip than meat packaged in modified atmospheres. Differences in drip loss with slaughter location were presumably caused by the mechanical stripping of the epimyseal connective tissue of loins obtained from Plant B. The cutting action of the Townsend skinner apparently caused sufficient cell damage to allow the exudation of intracellular fluids and increase the amount of purge. Excessive drip losses have been recognized as a disadvantage associated with using CO_2 modified atmosphere packaging methods, but can be overcome by using pads to absorb the free drip *(11)*.

Sensory traits. Although none of the venison samples were rated over 6 (like slightly) during sensory evaluation by the consumer panel (apparently due to unfamiliarity with venison), the data can still be useful in indicating trends in venison palatability due to storage time and packaging method. Greater differences in palatability scores were found due to storage time than due to packaging method. Changes in aroma, flavor, odor, and acceptability scores uniformly indicate that the maximum storage time for chilled venison lies between 12 and 18 weeks in vacuum and modified atmosphere packages. Longer storage times seem inappropriate under the present conditions.

Color stability. Color stability of slices of venison taken from loins stored in vacuum and modified atmosphere packages displayed under standardized conditions decreased with long periods of chilled storage *(28)*. This has been attributed to the decreased effectiveness of intracellular reducing systems as the meat is held for extended periods *(2)*. The loss of metmyoglobin reducing activity has been attributed to the fall of tissue pH during onset of rigor mortis, depletion of substrates, and co-factors required for biological reductions, and complete loss of mitochondrial structure and integrity *(23,10,8)*.

Microbiological traits. Low initial microbial counts are necessary to help ensure low contamination levels of psychrotrophic spoilage bacteria to successfully store meat for extended periods of time *(12)*. The use of inverted dressing (hanging the carcass by its front legs and pulling the hide downwards from head to tail - Plant A) resulted in very low carcass APC counts when compared to carcasses pelted by traditional methods. Aerobic plate counts, however, increased as the venison loins were excised, packaged, and transported prior to preparation for the packaging study. Loins from Plant B had significantly higher APC counts than those from the other plants presumably because of the stripping of the epimyseal connective tissue prior to packaging. The use of such skinning practices

(silver-siding) is widespread among deer processors in New Zealand and produces very attractive cuts, but care needs to be taken when skinning individual muscles so that they are not overtly contaminated.

Growth of recoverable aerobic bacteria was not hindered by the low storage temperature nor by the high CO_2 environment in any of the packages; however, the composition of the flora, although not determined in this particular study, probably has changed. Other workers *(21,5)* have found that the percentage of recoverable pseudomonads in the microflora decrease and the percentage of recoverable lactic acid bacteria increase with storage time in vacuum and modified atmosphere packaged meat respectively. Also, since the aerobic counts in this study closely parallel the anaerobic counts, it appears both methods are enumerating the same bacteria which are for the most part facultative species of lactic acid bacteria not strict aerobic spoilage bacteria. Consequently, unless aerobic plate counts are accompanied with the identification and assessment of the proportions of the colonies of bacteria present, it provides little information about the changes in recoverable organisms which are likely to proliferate on meat packaged in vacuum and modified atmospheres.

Both the low storage temperatures (-1°C) and the high concentrations of CO_2 in the packages allowed the increase in populations of lactic acid bacteria *(22,7,14)* as storage was increased to 18 weeks. Fewer lactic acid bacteria were recovered from CO_2-MPET packages than from the other packaging treatments. The reasons for this are not readily apparent. The consequence of lower recoverable lactic acid bacteria from CO_2-MPET seemed slight since palatability and odor scores were not significantly different within a given storage period due to packaging method.

Location of slaughter. In summary, location of slaughter did not affect any measures of meat quality except pH and drip loss. The pH could have been affected by different degrees of stress inflicted at each of the slaughter premises by different handling procedures. Percent drip loss could have been affected by stress also, since it is related to pH, as well as by desinewing. The narrow range of pH values, however, indicate that stress related effects, although significant in some cases, are not of a magnitude which is likely to cause adverse problems, larger effects due to slaughter location were found in microbial counts on carcasses and loins prior to packaging. Although APC counts for carcasses and loins were in acceptable ranges, exemplary hygienic practices need to be considered in the pelting, preparation and transportation of loins destined for long-term chilled storage. Had the loins been overtly contaminated or stored at elevated temperatures, the results of this study may have been different.

Packaging treatment. There were significant associations between method of packaging and loin surface color, pH and drip loss, and color stability during display. These results depended upon *(A)* whether the meat was packaged in vacuum packages vs CO_2 modified atmospheres (pH and drip loss) or *(B)* whether the meat was packaged in vacuum packages or in the modified atmosphere using UHB or MPET outer bags (surface color). No clear trends were found in differences in color stability for loins packaged by the various methods.

Although pH and drip loss were affected by packaging method, other quality indicating factors, particularly sensory scores, were not. Therefore, other criteria, including visual appeal, economic considerations, and experience of labor force need to be evaluated to determine which method should be used to package chilled venison.

Length of storage. Increasing the length of storage reduced sensory and odor scores indicating maximum acceptable shelf life lies between 12 and 18 weeks. Color stability scores also decreased indicating that chilled venison has limited display life if offered for sale in retail situations after being stored for extended periods.

CONCLUSIONS

Changes in spoilage flora, palatability, surface discoloration, and color stability must be considered when choosing economical methods to preserve chilled venison for periods of time sufficient for export. Ultra-high barrier (UHB) outer bag films are not recommended for the chilled storage of venison loins if surface color is to be used as a quality indicating factor; however, no other quality measurements were adversely affected by CO_2-UHB. As in previous studies *(28)*, color acceptability under retail display conditions deteriorated as meat was held from 6-18 weeks losing approximately 1 d of acceptable display for each 6 week storage period. Palatability and odor scores decreased after 12 weeks of storage indicating that maximum storage times were approximately 12 weeks. Modified atmosphere packaging confers little additional shelf life to chilled venison loins; since the pH of venison loins varied slightly and none were excessively high, and since boneless venison loins can be fabricated commercially with low levels of initial contamination ($<\log_{10}$ 2.5 CFU/g). Therefore, on the grounds of cost and suitability of product, we would suggest vacuum packaging as the preferred method at the present time as long as the venison is stored at -1°C. In comparison however, lamb may be well suited for packaging in modified atmospheres since lamb cuts are too small for anything other than partial boning and vary greatly in ultimate pH *(29)*.

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