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Sensory and Physiochemical Comparison of Traditional Bone-In Dry-Aged Beef Loin with Bone-Less Dry Ageing and Ageing Using a Moisture Permeable Bag

Maurice G. O'Sullivan[1*], Malco C. Cruz-Romero[2], Joseph P. Kerry[2*]

[1]Sensory Group, School of Foodand Nutritional Sciences, University College Cork, Cork, Ireland
[2]Packaging Group, School of Foodand Nutritional Sciences, University College Cork, Cork, Ireland
Email: *maurice.osullivan@ucc.ie, *Joe.Kerry@ucc.ie

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Abstract

Beef loins, were de-boned and left unpackaged (n = 12) or packaged using dry-ageing bags (n = 12). A third batch (n = 12) were not boned out and unpackaged. Loins were aged in a chill at 2˚C, with steaks (2.54 cm) tested on days 0, 7, 14 and 21 for % yield, colour, texture, pH, cooking losses and microbiological status. Sensory affective analysis and a novel descriptive method (Ranking Descriptive Analysis) were also performed. The dry aged samples had significantly ($P < 0.05$) higher moisture losses followed by dry-ageing bag samples and bone-in samples. The bone-in samples scored lower for appearance at 21 days, were juicier, but had more off-flavour. Dry aged beef scored significantly higher than the bone-in samples for overall acceptability, but were not significantly better than the dry-ageing bag samples which had reduced moisture losses and greater tenderness. Microbiologically all treatments performed similarly. There were no significant differences in trim losses between dry-aged samples with or without the use of ageing bags. The sensory methods utilised allowed samples to be assessed hedonically and descriptively in real time without the necessity to freeze samples and without reverse storage design.

Keywords

Sirloin, Tenderloin, Beef, Dry-Aged, Package, Sensory, Affective, Novel, Rapid, Descriptive, Texture

1. Introduction

Fresh beef products often are aged to enhance palatability characteristics associ-

ated with various retail and wholesale cuts [1]. Aging involves storing the meat at refrigerated temperatures for usually 21 days or more which in turn optimises the palatability characteristics of the meats such as tenderness, juiciness, and flavour [2] [3] [4]. There are two methods of aging: wet aging, the most common, is storing beef cuts in vacuum packages and dry aging refers to storing beef carcasses or wholesale cuts without any type of protective packaging [1]. Wet-ageing is the aging method used by about 95% of US producers of beef products [4]. Traditional dry aging exposes unpackaged meat directly to cooler conditions with strict temperature, humidity, and air-flow control [5]. Dry aging is a more costly procedure that requires a significant amount of time and space, elicits a high amount of shrink, and generates a significant amount of excess dried waste—termed in the industry as "crust"—that must be trimmed [1]. However, the increased sensory quality of dry aged beef compared to wet aged allows this product to be sold at a higher premium. Dry-aging is employed as producers believe it enhances overall palatability while creating a premium price for beef products [6]. Wet-aged beef has a sour and strong bloody/serumy flavour, whereas dry-aged beef has a beefy, brown roasted flavour that is considered desirable [4]. Assessors are more familiar with wet- than dry-aged flavours, but when assessors recognized or preferred the dry-aged flavour profile, they were willing to pay more for this product [1] [7] [8] [9]. Also, aging of fresh beef for retail and foodservice has become essential to meet the high demands and expectations of an exceptional eating experience [7]. Dry-aging has been a successful process used by some high-end restaurants and specialty outlets to meet the needs of assessors who prefer this unique product [1]. Foodservice has capitalized on the perceived value of dry-aged beef products and has been able to merchandise these products at premium prices [7].

If aging could occur in a highly moisture-permeable bag, however, it may be possible to "dry-age" beef in a package and have it be more tolerant to more variable cooler conditions. Such methodology could potentially decrease trim loss and microbial contamination, thus maximizing yields [5]. Previously researchers [5] found that dry aging of beef in a highly moisture-permeable bag was feasible, positively impacted on yields and reduced microbial spoilage, with no negative impact on product quality. Additionally, some researchers [9] have found that leaving the bone on the beef loin during ageing decreased the amount of flavour development, perhaps by limiting the loss of moisture during aging and the resultant "concentration" of flavour components [9].

Much of the research conducted comparing wet and dry aged beef has been undertaken using assessors ([1] n = 77, [7] n = 80 - 91) and the research comparing these ageing regimes to those incorporating moisture permeable bags and bone-in samples have used trained panellists [9] n = 6; [10], n = 6. Sensory Acceptance Testing is a hedonic sensory methods used to determine the degree to which products are liked and has been applied to various product including meats [11]-[17], dairy products [18]-[29], salads, [30] [31], Bakery products [32] [33] and beverages [34] [35] [36] [37] [38]. Thus the objective of the present

study was to directly compare the sensory acceptability, using sensory acceptance testing, of traditional bone-in dry aging to de-boned dry aged loins and de-boned dry aged loins in moisture permeable bags (dry-ageing bag), in the same study. Additionally, a flash profiling descriptive analysis technique [39]-[46] called Ranking Descriptive Analysis [47]-[52] was performed as well as % yield, microbial and physiochemical changes after 0, 7, 14 and 21 days at 2˚C. Previous studies have used meat from frozen beef. All samples tested in the present study were unfrozen and tested in real time at the experimental time points as freezing is not a process step usually utilised for dry ageing of beef in the meat industry because of potential deleterious effects on quality. A more sophisticated approach of undertaking descriptive analysis, without the necessity of freezing, and to prevent assessor bias is to incorporate reverse storage design. Reversed storage design can be performed by staggering product times, so that all products with different storage times are evaluated on the same day [53]. Byrne, O'Sullivan, Bredie and Martens [54] undertook a similar strategy in a descriptive sensory profiling test of warmed-over flavour in meat patties. However reverse storage design does not lend itself easily for routine sensory quality monitoring programmes. Thus, the strategy employed in the presented study displays a real time sensory monitoring system to assess sensory attributes (hedonic and descriptive) without the necessity of freezing samples and without the complexity and difficulty of employing reverse storage design.

2. Materials and Methods

2.1. Meat Samples, Packaging and Storage

18 Beef heifers (Hereford Crosses), aged 17 - 20 months, were slaughtered at a local abattoir on the same day according to EU Council Directive 93/119/EC. The carcasses used in this study originated from animals which were grass pasture fed in the absence of concentrates, as it is standard practice in Ireland during Spring/Summer/Autumn period. Muscles were removed from carcasses 0 days post-mortem. One set of primal beef cuts (n = 12), containing the top sirloin and tenderloin muscles as defined by standard Irish and UK butchering practices, were fully de-boned and packaged in the factory using the permeable dry-ageing bags (Tublin® 88 10, TUB-EX ApS, Denmark). The bags were composed of 50 µm thick polyamide mix (water vapour transmission rate 5000 g/50 µ/m 290/24 h at 38˚C and 50% relative humidity). The second batch of primal beef cuts were also de-boned, but left unpackaged. The third batch of samples were not boned out and left unpackaged. All samples were placed intact on wire mesh shelving in to a chill room at 2˚C and 3 sets of samples from each treatment were sacrificed on nominated test days (D0, D7, D14 and D21) for all analyses throughout storage. All primals were cut in to 1 inch (2.54 cm) prior to analysis.

2.2. Instrumental Texture Analysis—Warner-Bratzler Shear Force

Two steaks of 1 inch thickness were prepared from the dry aged beef dry-ageing

bag aged beef and bone in aged beef after storage at 2˚C for D0, D7, D14 and D21 days for tenderness analysis. These steaks were cut at 90 degrees to the length of the muscle fibres, wrapped in aluminium foil and cooked in an electric forced convection oven, which was preheated to 200˚C, to a core temperature of 70˚C. The core temperature was monitored using a Testo 110 with type NTC probe (Testo Ltd., UK). After cooking, steaks for shear force determination were stored in a cooler at 2˚C overnight before coring. At least twelve 1.27 cm diameter cores from each steak were removed parallel to the longitudinal orientation of the muscle fibres. The cores were sheared perpendicular to the muscle fibres orientation using a Texture Analyser TA-XT2i (Stable Micro Systems, UK) with a Warner-Bratzler shear device and crosshead speed set at 3 mm/s. The considered parameter was the maximum shear force in Newtons. Results were expressed as the mean shear force value ± standard deviation.

2.3. Instrumental Measurement of Colour

The surface colour of beef steaks was measured according to the CIE L × a × b × colour system using a Minolta CR 300 colorimeter (Minolta Camera Co. Ltd., Osaka, Japan). The chroma meter was calibrated on the Hunterlab colour space system using a white ceramic tile (C: $Y = 93.6$, $x = 0.3130$, $y = 0.3193$), (Minolta calibration plate). Six readings were taken per sample on each measurement day at each time point of retail display.

2.4. Measurement of Muscle pH

The pH of the muscle was recorded using a portable pH meter (Mettler Toledo, MP 125, Switzerland). The pH of the beef steaks was taken by making a small scalpel incision in the muscle and inserting a glass electrode approximately 1 cm into the muscle. A total of three readings were taken per each steak and averaged for statistical analysis.

2.5. Microbiological Analysis

Microbiological analyses of beef joints stored under different packaging (Aerobic, and Dry-ageing bag) conditions at 2˚C were performed in triplicate on each measurement day. In order to obtain a representative sample, a number of subsamples were taken aseptically using sterile forceps and scalpels from different parts of the carcass into a sterile stomacher bag, pooled and thoroughly mixed and 10 g of the pooled meat samples were weighted aseptically into a stomacher bag in a vertical laminar-flow cabinet and a primary 10-fold dilution was performed by addition (90 ml) of sterile maximum recovery diluent (Oxoid, Basingstoke, U.K.). Following homogenisation in a stomacher for 3 min, homogenates were serially diluted 10-fold in maximum recovery diluent solution, and 1 ml of each appropriate dilution was inoculated on duplicated plates in the centre of compact dry-total count plates (20 cm^2) (Nissui Pharmaceutical, Co. Ltd., Japan) for enumeration of total mesophilic aerobic bacteria following in-

cubation at 37˚C for 48 hours.

Total coliforms and *E. coli* were enumerated on Brilliance *E. Coli*/Coliform Selective Agar (Oxoid) following incubation at 37˚C for 24 hr. Oxoid *Brilliance E. coli*/coliform Selective Agar is a chromogenic medium for the detection and enumeration of *E. coli* and other coliforms (important hygiene indicators) from food. Chromogenic agents within the medium are used to detect the *β*-glucuronidase activity of *E. coli* and the *β*-galactosidase activity of coliforms (including *E. coli*), allowing them to be clearly differentiated on the culture plate (coliforms—pink, *E. coli*—purple).

2.6. Sensory Evaluation

The sensory acceptance test was conducted using untrained assessors (n = 27 - 33) [55] [56] who were regular consumers of beef steak products and had previously consumed and were familiar with dry-aged beef. Assessors assesed the samples presented to them on days 0 (Assessors n = 30), 7 (n = 33), 14 (n = 30) and 21 (n = 27) days. Two steaks of 1 inch thickness were prepared from three separate samples of dry aged beef, packaged dry-aged beef (dry-age bag) and bone in aged beef after storage at 2˚C for D0, D7, D14 and D21. These steaks were cut at 90 degrees to the length of the muscle fibres, wrapped in aluminium foil and cooked in an electric forced convection oven, which was preheated to 180˚C, to a core temperature of 70˚C. The core temperature was monitored using a Testo 110 with type NTC probe (Testo Ltd, UK). The outer surface of meat samples was trimmed prior to sensory analysis. After cooking, Steaks were cut into 2 cm × 2 cm cubes and identified with a three digit codes before immediate serving of the samples to the assessors. The serving order was randomised for each assessor. Assessors were provided with water to cleanse their pallets between samples. The assessors were asked to evaluate the following hedonic descriptors: liking of appearance, liking of flavour and overall acceptability. Additionally the assessors were asked to assess juiciness, tenderness as well as off flavour using ranking descriptive analysis (RDA) [57], a method that can be used for concise focussed descriptive analysis using either trained or untrained assessors. All samples were again presented in duplicate [58]. Samples were also presented coded and randomised. Assessors were also asked to rank steaks according to their preference using the descriptors Unsatisfactory, Good, Very Good and Excellent every day eating quality. The experiment was conducted in panel booths which conform to the International Standards [59].

2.7. Percentage Yield

All intact treatment samples were initially weighed on Day 0 of analysis and then relevant samples returned to the chill at 2˚C. On D7, D14 and D21 sample treatments were re-weighed and the loss in weight was expressed as weight loss [(kg)/initial weight (kg)] × 100. Trim loss was calculated as the weight of loins after trimming in the factory divided by the weight of samples at Day 21 × 100,

in the case of samples using ageing bags, these were removed prior to weighing.

2.8. Data Analysis

ANOVA-Partial Least Squares Regression (APLSR) [52] was used to process the raw data accumulated from the +30 test subjects during the sensory evaluation and physiochemical analysis. The X-matrix was designed as 0/1 design variables for treatment and days of retail display. The Y-matrix was designed as sensory, chemical and instrumental variables. The optimal number of components in the APLSR models presented was determined to be 4 Principal Components (**Figure 1**). PC 3 versus PC 1 is presented; the other PC's did not yield additional information or provide any predictive improvement in the Y-matrix obtained through their examination. The validated explained variance for the model constructed was 34%. And the calibrated variance was 31%. To derive significance indicators for the relationships determined in the quantitative APLSR, regression coefficients were analyzed by jack-knifing (**Table 2**) which is based on cross-validation and stability plots [60] [61]. All analyses were performed using the Unscrambler Software, version 9.7 (CAMO ASA, Trondheim, Norway). **Table 1(b)** presents P-Values from the estimated regression coefficients for the ANOVA-Partial Least Squares Regression (APLSR). Significant P-Values in are in BOLD. The Sign dictates weather the correlation is positively or negatively correlated. Values correspond to mean data, ± corresponds to standard deviation.

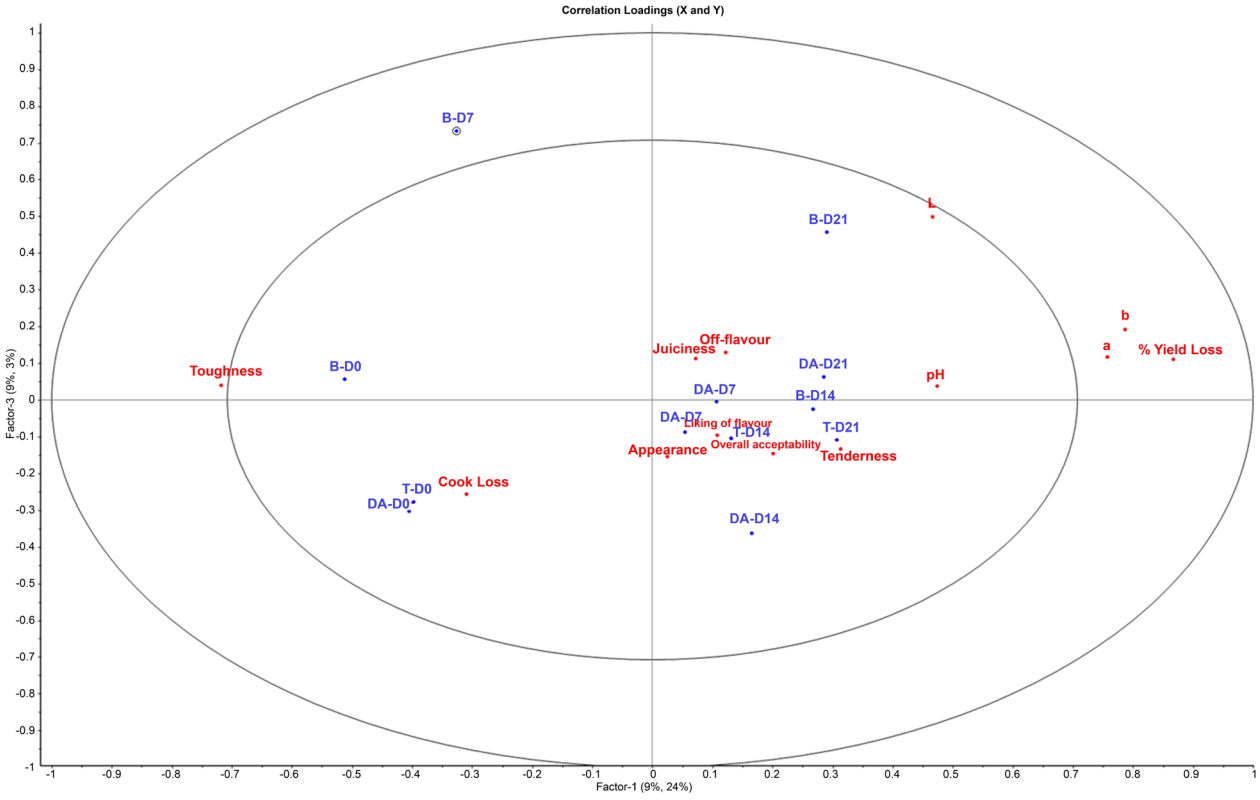


Figure 1. Anova-partial least squares regression plot of the raw sensory data for dry aged, dry-ageing bagaged and bone-in aged striploin steaks after 0, 7, 14 and 21 days storage at 2˚C. PC 1 vs PC 2 presented.

Table 1. Significance of estimated regression coefficients (P values) for the relationships of sensory terms as derived by Jack-knife uncertainty testing for beef steak samples presented with mean sensory data and standard deviations.

Code	Appearance			Liking of flavour			Overall acceptability			Juiciness			Tenderness			Off-Flavour		
	Mean	**SD**	**P Value**	**Mean**	**SD**	**P Value**	**Mean**	**SD**	**P Value**	**Mean**	**SD**	**P Value**	**Mean**	**SD**	**P Value**	**Mean**	**SD**	**P Value**
DA-0	6.66	1.68	−0.111	5.99	1.44	−0.854	5.76	1.26	−0.417	5.00	1.64	−0.904	4.75	2.02	−0.029	0.44	0.65	−0.005
DA-7	5.71	1.42	0.110	6.13	1.36	0.368	5.79	1.31	0.517	4.19	1.77	0.003	5.22	1.35	0.831	0.68	0.92	0.865
DA-14	6.58	1.37	0.183	6.29	1.53	0.127	6.51	1.39	0.085	5.09	1.90	0.692	6.14	1.32	0.048	0.63	0.92	0.595
DA-21	6.76	1.50	0.524	6.26	1.21	0.208	6.52	1.41	0.174	5.39	1.59	0.043	5.51	1.69	0.073	0.55	0.67	0.102
T-0	6.75	1.74	−0.107	6.17	1.54	−0.911	5.53	1.66	−0.461	5.15	2.13	0.418	4.35	2.20	−0.041	0.38	0.82	−0.020
T-7	6.16	1.00	0.105	5.79	1.47	0.466	5.63	1.13	0.604	3.81	1.40	0.001	5.30	1.53	0.819	0.65	0.79	0.666
T-14	6.64	1.68	0.869	5.70	1.61	0.848	6.23	1.63	0.666	5.00	1.87	0.185	5.72	1.74	0.410	0.93	1.21	0.907
T-21	7.01	1.46	0.568	6.26	1.29	0.176	6.06	1.47	0.072	4.57	1.34	0.374	5.79	1.33	0.006	0.84	1.42	0.399
B-O	6.26	1.39	−0.404	5.95	1.29	−0.022	5.46	1.51	−0.001	4.79	1.89	−0.322	4.44	2.15	−0.000	0.41	0.69	−0.077
B-7	5.82	1.41	−0.001	5.52	1.08	−0.014	5.13	1.14	−0.000	5.30	1.49	−0.370	4.14	1.87	−0.000	0.91	1.21	−0.264
B-14	6.45	1.44	0.487	6.59	1.44	0.254	6.54	1.88	0.184	6.04	1.64	0.015	6.05	1.82	0.062	0.79	1.30	0.172
B-21	5.96	1.78	0.656	5.97	1.13	0.788	5.75	1.64	0.853	6.07	1.36	0.000	5.80	1.77	0.486	1.35	1.33	0.050

P-Values are from the estimated regression coefficients from ANOVA-Partial Least Squares Regression (APLSR). Significant P-Values in BOLD. The Sign dictates weather the correlation is positively or negatively correlated. Values correspond to mean data, ± corresponds to standard deviation.

3. Results and Discussion

3.1. Sensory Evaluation

Figure 1 (Treatment X Days) present the ANOVA-Partial Least Squares Regression Plot for each of the treatment samples over time versus the sensory and physiochemical data. Table 1 displays the mean data for sensory (affective and descriptive) evaluations and standard deviations plus the P-values for the regression co-efficients for these data. Table 2 depicts sample coding. In Figure 1 the B-0 and B-7 samples correlate directionally in the upper right hand quadrant of the plot to Toughness (instrumental), DA-0 and T-0 samples correlate directionally in the lower right hand quadrant to cook loss. Samples T-7, T-14, T-21 and DA-7, DA-14 correlate in the lower left hand quadrant of the plot and are directionally correlated to Tenderness, Overall acceptability and Liking of Flavour, whereas B-14 and B-21 and DA-21 were more correlated to Juiciness and Off-flavour. From Table 1 B-0 sample P Values were significantly ($P < 0.05$) negatively correlated to Liking of Flavour, with B-7 and B-0 samples significantly ($P < 0.05$) negatively correlated to sensory appearance. Additionally these two samples were significantly ($P < 0.05$) negatively correlated to Overall Acceptability. Samples DA-0, T-0, B-0 and B-7 were found to be significantly ($P < 0.05$) negatively correlated to Sensory Tenderness whereas DA-14 and T-21 were significantly ($P < 0.05$) positively correlated to Tenderness. Samples DA-7, DA-21, T-7, B14 and B21 were significantly ($P < 0.05$) positively correlated to sensory

Table 2. Assessment of quality of cooked aged beef products by the assessors for each treatment on each successive test day.

Code	Treatment	Days	Unsatisfactory quality	Good everyday eating quality	Better than everyday eating quality	Premium quality
DA-0	Dry-aged	0	5.00	16.00	7.00	2.00
DA-7	Dry-aged	7	3.00	24.00	5.00	1.00
DA-14	Dry-aged	14	1.00	18.00	9.00	5.00
DA-21	Dry-aged	21	1.00	18.00	6.00	5.00
T-0	Dry-aged in bag	0	12.00	10.00	4.00	3.00
T-7	Dry-aged in bag	7	2.00	24.00	6.00	1.00
T-14	Dry-aged in bag	14	3.00	20.00	8.00	2.00
T-21	Dry-aged in bag	21	3.00	15.00	8.00	3.00
B-0	Dry aged with bone	0	7.00	15.00	3.00	5.00
B-7	Dry aged with bone	7	10.00	17.00	6.00	0.00
B-14	Dry aged with bone	14	6.00	13.00	12.00	2.00
B-21	Dry aged with bone	21	6.00	15.00	8.00	1.00

Juiciness. Samples DA-0 and T-0 were significantly ($P < 0.05$) negatively correlated to Off-flavour. B-21 was not significantly ($P = 0.06$) positively correlated to Off-Flavour, but was the most correlated of the treatments. Although none of the samples were significantly correlated to Overall Acceptability samples T-21 ($P < 0.072$) and DA-14 ($P < 0.085$) were the most correlated. Samples B-0 and B-7 were the most negatively correlated to liking of flavour, but in a real world environment assessors would not encounter these products in a retail or restaurant context. This also applies to Sensory Tenderness where none of the samples over 7 days of aging were considered too tough. This is an interesting finding considering the time and expense incurred in aging meat for 21 days. None of the treatments were correlated to Off-Flavour, but B-21 was the most correlated of the treatments. Perhaps this is due to the presence of bone during the ageing process. DeGeer *et al.* [9] postulated that leaving the bone on the loin during dry ageing decreased the amount of flavour development, perhaps by limiting the loss of moisture during aging and the resultant "concentration" of flavour components.

As well as determining the significant correlations of products to the sensory terms, as performed above, the significant correlations between products for sensory terms were also determined for each test day and denoted by superscript letters on Table 1. The dry-ageing bag samples (T-21) and the dry aged beef samples (DA-21) scored significantly higher for appearance (Table 1) on D21 compared to bone in aged beef. The dry-ageing bag aged beef scored the highest for appearance of the treatments, but compared to the dry aged beef were not significantly different. No significant differences were also observed for "liking

of flavour" (Table 1) for any of the treatments on all days of analysis except on D14 where the "liking of flavour" of the bone in aged beef (B-14) was significantly higher than the dry-ageing bag aged beef (T-14), but not significantly different to the dry aged beef (DA-14).

For sensory evaluated juiciness (Table 1) the bone-in dry aged beef scored significantly ($P < 0.05$) higher that the dry-ageing bag and dry aged beef on D7, D14 and D21 (B-7, B-14, B-21). For sensory evaluated Tenderness (Table 1) dry-ageing bag aged beef (T-7) and the dry aged beef (DA-7) scored significantly ($P < 0.05$) higher for tenderness compares to bone-in aged beef on day 7 (B-7). All other days were not significantly different between treatments. Off flavour (Table 1) was significantly ($P < 0.05$) higher for the bone-in aged beef on day 21 (B-21) compared to the dry-ageing bag aged beef (T-21) and the dry aged beef (DA-21). Overall acceptability was significantly ($P < 0.05$) higher for dry aged beef on Day 21 (DA-21) compared to bone-in aged beef. The dry aged beef and dry-ageing bag aged beef scores for Overall acceptability were not significantly different.

Table 2 also displays the preference of assessors for each treatment on each successive test day using the terms unsatisfactory, good, very good and excellent eating quality to describe the products. For all treatments unsatisfactory and good eating quality decreased from D0 to D21 while very good and excellent eating quality scores increased, which reflects the increase in eating quality of all products during aging. The dry aged beef had the lowest unsatisfactory scores by D21 and the highest good, and excellent eating quality scores. The dry-ageing bag aged products had the next highest excellent eating quality scores. Similar scores were observed for good and very good eating quality for dry-ageing bag and the bone in dry aged beef. The bone in dry aged beef had the highest unsatisfactory scores by D21.

In summary the results from this study show that that the dry-ageing bag and dry aged beef samples after storage at 2˚C for 21 days scored higher than the bone in aged beef for appearance. The bone in aged samples were juicier, but had more off-flavour (D21). The dry-aged (DA-14) and dry-aged in bag (T-21) samples were the most correlated to Overall acceptability. These sensory assessor findings are in partial agreement with DeGeer *et al.* [9], who investigated different dry-aging methods (unpackaged and in a dry-ageing bag), two loin-cut styles (bone-in shell loins and boneless strip loins), and two aging times (21 and 28 days). These authors found that dry aging in a bag produced dry-aged flavour equal to that achieved with traditional dry aging. These data are also in agreement with previous researchers [5], who found the no differences for most quality traits studied for traditional dry aging and aging in a bag which demonstrated the effectiveness of the novel dry-aging method. Some researchers [9] also postulate that leaving the bone on the loin decreased the amount of flavour development, perhaps by limiting the loss of moisture during aging and the resultant "concentration" of flavour components. Differences between the other flavour

traits were either small or not significant. The results of the current study are also in partial agreement with this finding in that bone in samples (B-21) on D21 had significantly more off-flavour than the other treatments and had significantly less Overall acceptability than the dry aged samples. However the flavour of the dry-ageing bag samples (T-14) were significantly ($P < 0.05$) less liked than the bone in samples (B-14) on D14.

Researchers [10] have reported that overall tenderness, flavour, and off flavour intensity were not affected ($P > 0.05$) by any treatment of the beef aging treatments studied (wet-aged, dry-aged and dry-aged in bag). These authors also reported that using a trained sensory panel ($n = 6$) revealed few, if any, differences among dry, vacuum and special bag aging and state that that it is unlikely that assessors could detect any differences. Dikeman *et al.* [10] used steaks for the sensory evaluation that were frozen at −40˚C until just before evaluations by a trained sensory panel. The data from the presented study, on unfrozen beef, clearly disagrees with this statement as assessors detected clear differences between the treatments which were in fact more similar than those used in Dikeman's [10] study. Additionally, the assessors used in the presented study could clearly grade the quality of each of the treatments on each test day (**Table 2**).

3.2. Physiochemical Analysis-Texture (Tenderness)

Figure 1 and **Table 3** display the data for beef primal mean shear force values in Newtons with the design variable toughness. As can be seen from this figure the mean texture values decrease for all treatments on successive test days as the treatments move away from the varia be Toughness (instrumental) on the APLSR plot. No significant differences were observed between treatments on Day 0. All treatments were significantly ($P < 0.05$) negatively correlated to toughness on days 7, 14 and 21 for DA and T and for B14 and B-21. Overall, dry-ageing bag samples displayed the lowest mean shear force values on Days 14 (T-14) (19.92 N) and 21 (T-21) (22.6 N). For Day 7 and Day 21 dry-age bag and dry aged samples were significantly ($P < 0.05$) lower than bone in samples. Destefanis *et al.* (2008) [62] investigated the relationship between beef assessor tenderness perception and Warner-Bratzler shear force values (WBs). These authors concluded that WBs values > 52.68 N and <42.87 N allow classification of tough and tender beef in a sufficiently reliable way. Therefore from this study we can conclude that the by D21 all samples were very tender, but dry-ageing bag samples were the most tender followed by dry aged samples. These results are in disagreement with the findings of several other researchers [1] [5] [7] [8] [9] who have reported no or minimal differences in WBSF for a variety of aging treatments. DeGeer *et al.* [9] did not find differences in WBSF values between experimental treatments including shell (bone in) and strip loins (bone less) aged with and without ageing bags. Perhaps this was due to the fact that in DeGeer's study [9] samples were initially frozen then thawed and not presented fresh as in the presented study. Shanks, Wulf, and Maddock [63] showed that

Table 3. Significance of estimated regression coefficients (ANOVA values) for the relationships of physiochemical data as derived by Jack-knife uncertainty testing for beef steak samples presented with mean data and standard deviations.

Code	L Value			a Value			b Value			Toughness (N)			pH			% Yield Loss			% Cook Loss		
	Mean	SD	P Value	Mean	SD	P Value	Mean	SD	P Value	Mean	SD	P Value	Mean	SD	P Value	Mean	SD	P Value	Mean	SD	P Value
DA-0	34.00	3.45	−0.000	20.59	3.05	−0.000	10.40	1.74	−0.000	54.54	13.88	0.000	5.49	0.04	−0.446	NA	NA	NA	NA	NA	NA
DA-7	39.34	1.93	0.079	27.51	1.64	0.001	15.52	0.94	0.000	24.53	6.00	−0.000	5.45	0.04	0.003	3.02	0.40	0.899	26.17	2.27	−0.005
DA-14	39.33	1.59	0.327	24.44	2.68	0.036	13.88	1.54	0.112	23.14	8.34	−0.007	5.48	0.04	0.406	6.31	0.70	0.168	24.69	0.82	−0.996
DA-21	40.98	1.65	0.250	28.23	2.51	0.008	16.50	1.45	0.010	27.73	12.46	−0.020	5.52	0.01	0.014	9.32	0.91	0.010	23.40	2.62	−0.008
T-0	35.34	3.08	−0.000	20.16	1.42	−0.000	10.15	1.33	−0.000	54.03	11.00	0.000	5.49	0.02	−0.969	0.00	0.00	NA	NA	NA	NA
T-7	39.01	1.66	0.418	27.97	1.46	0.006	15.58	0.94	0.004	25.22	5.16	−0.000	5.43	0.04	0.001	2.31	0.42	0.497	25.11	2.31	−0.000
T-14	39.69	3.23	0.762	24.55	1.88	0.023	13.64	1.43	0.045	19.74	5.01	−0.018	5.47	0.04	0.613	4.70	0.71	0.560	25.44	2.49	−0.330
T-21	40.59	1.51	0.369	27.39	1.69	0.000	15.70	1.02	0.000	22.57	5.16	−0.000	5.57	0.02	0.103	7.03	0.99	0.001	22.88	1.56	−0.125
B-O	37.53	1.13	−0.001	18.65	1.48	−0.000	9.92	1.15	−0.000	58.26	21.83	0.000	5.44	0.01	−0.005	0.00	0.00	NA	NA	NA	NA
B-7	42.87	2.27	−0.026	21.61	1.86	−0.040	12.52	0.99	−0.145	44.61	16.97	0.000	5.45	0.03	−0.081	2.24	0.07	−0.026	23.65	0.55	0.788
B-14	41.08	1.44	0.226	24.47	1.56	0.041	13.90	0.98	0.046	28.81	10.15	−0.020	5.51	0.06	0.000	4.18	0.16	0.000	19.40	0.07	−0.014
B-21	40.90	3.09	0.000	27.91	3.17	0.028	15.60	1.90	0.004	30.03	10.96	−0.067	5.57	0.01	0.006	6.00	0.26	0.000	20.36	1.04	−0.001

P-Values are from the estimated regression coefficients from ANOVA-Partial Least Squares Regression (APLSR). Significant P-Values in BOLD. The Sign dictates weather the correlation is positively or negatively correlated. Values correspond to mean data, ± corresponds to standard deviation.

fewer differences were found in WBSF for steaks that were frozen and thawed before cooking than for never frozen.

3.3. Instrumental Colour Analysis

Table 3 display the hunter "Lab" values for dry aged beef versus dry-ageing bag aged beef versus dry aged bone in striploin steaks after 0, 7, 14 and 21 days at 2˚C. DA-7 and B-21 samples were significantly ($P < 0.05$) positively correlated to L values. DA-7, DA-14, DA-21, T-7, T-14, T-21, B-14 and B-21 samples were significantly ($P < 0.05$) positively correlated to a values and samples DA-7, DA-24, T-7, T-14, T-21, B-14 and B-21 were significantly ($P < 0.05$) positively correlated to b values. For these correlated samples they maintain positive a and b values through-out the study thus maintaining the degree of redness (a value) and yellowness (b value).

Dry-age bag and dry aged samples had significantly lower L values on days 0 and 7 compared to bone-in samples and no significant differences were observed between treatments on days 14 and 21. Dry-ageing bag and dry aged samples had significantly ($P < 0.05$) higher a values on days 0 and 7 compared to bone-in samples and no significant differences were observed between treatments on days 14 and 21. Dry-ageing bag and dry aged samples had significantly ($P < 0.05$) higher b values on day 7 compared to bone-in samples and no significant differences were observed between treatments on days 0, 14 and 21. Therefore

for aging post 14 days no differences were observed for Lab values for any of the ageing treatments.

3.4. pH Changes during Ageing

Table 3 display the pH changes for dry aged beef versus dry-ageing bag aged beef versus dry aged bone-in striploin steaks after 0, 7, 14 and 21 days at 2˚C. pH values were in the range 5.43 - 5.57 for all treatments in the study with general increases over the course of the study for all treatments and were not significantly different between any of the treatments for D0, D7 or D14. By D21 dry-aged in bag samples and bon-in samples had the same ph (5.57) which were significantly ($P < 0.05$) higher than the pH of the dry-aged samples (5.52). This data is in disagreement with Dikeman *et al.* [10] who reported the pH of dry-aged loins was 5.67, which was higher ($P < 0.01$) than samples dry-aged in bag aged 5.61, but we are in agreement with Dikeman *et al.* [10] in that the differences observed though significant are of little practical importance.

3.5. Yield Loss during Ageing

Table 3 displays the % moisture loss of each of the treatments over the 21 days of the study. Samples DA-21, T-21 and B-14 and B-21 were significantly ($P < 0.05$) correlated to % Yield loss. The dry aged samples had significantly ($P < 0.05$) higher moisture losses followed by the dry-age bag and then the bone in aged beef on days 7, 14 and 21. The dry-ageing bag and bone-in samples were not significantly different on days 7 and 14, but the bone-in samples had significantly ($P < 0.05$) lower losses compared to dry-age bag and dry-aged samples on Day 21 where the dry aged beef lost the most (9.21%) followed by the dry-aged bag samples (~6.82%) and then the bone in dry aged beef (5.95%). Statistical analysis of this data displayed that the dry aged samples had significantly ($P < 0.05$) higher moisture losses followed by the dry-age bag samples and then the bone in dry aged beef on days 7, 14 and 21. The dry-age bag samples and bone-in samples were not significantly different on days 7 and 14, but the Bone-in samples had significantly ($P < 0.05$) lower losses compared to dry-age bag samples samples on Day 21. The dry age samples had significantly higher ($P < 0.05$) moisture losses on days 7, 14 and 21 compared to the other treatments. These results are again in partial agreement with DeGeer *et al.* [9] who found that bone-in shell loins will have about 10% - 12% higher yields of dry-aged product than boneless strip loins regardless of the aging method. Dry aging in a bag creates positive effects on yields, with no negative effects on product quality. Trim loss, data not shown, was not significantly different between aged samples using ageing bags or without.

3.6. Cooking Losses during Ageing

Cooking losses (Table 3) were significantly ($P < 0.05$) negatively correlated to DA-7, DA-21, T-7, B-14 and B21. Overall cooking losses were less for bone-in

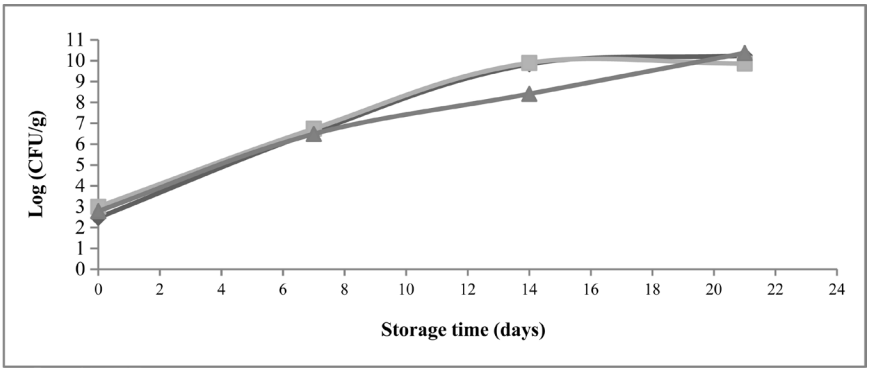
samples on Days 7, 14 and 21 compared to the dry-ageing bag and dry aged samples. Cooking losses (**Table 3**) were lower on all days and significantly ($P < 0.05$) lower for bone-in samples on Days 14 and 21 compared to the dry-ageing bag and dry aged samples which were not significantly different. These results are in agreement with Ahnström *et al.* [5] who reported similar cooking loss for dry-age bag samples and dry-aged samples. However the present study disagrees with DeGeer *et al.* (2009) [9] and Dikeman *et al.* [10] who reported higher cooking losses with dry-age bag samples compared to dry aged samples.

3.7. Microbiological Changes during Ageing

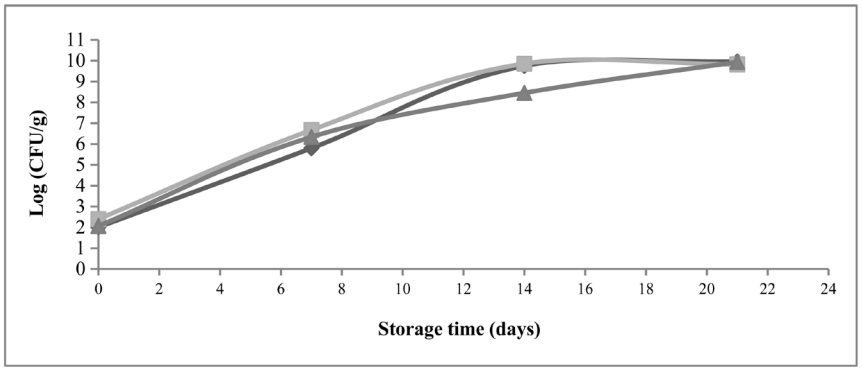
Microbiological standards and guidelines give guidance on the types of micro-organisms and their number that can be considered acceptable or unacceptable or unsafe in a food product. The following recommended microbiological limits for aerobic plate counts as applied to raw chilled meat: $m = 10^6$ or 6 log (CFU/g of meat) (acceptable limit) and $M = 10^7$ or 7 log (CFU/g of meat) (Unacceptable limit) (ICMSF [64]; European Commision [65]). For this study the limit of acceptability was set to 6 log (CFU/g of meat). Concerning Enterobacteriaceae the recommended microbiological limits are: $M < 2.5$ log (CFU/g) or $M = 2.5$ log (CFU/g of meat).

Changes in the aerobic mesophilic counts (AMC), psychrotrophic bacteria and total coliforms on beef primals during storage under different packaging systems at refrigeration temperature (2˚C) are shown in **Figures 2(a)-(c)**. The limit of shelf-life stability was set in terms of AMC. Initially, higher microbial counts were obtained in boneless samples than in boneless samples packaged in dry-ageing bag or bone-in carcass samples. The limit of aerobic mesophilic bacteria (10^6 CFU/g) for chilled meat reported by ICMSF [64] and European Commision [65] was not exceeded in all meat samples on day 0 indicating good quality meat products; however, growth resumed in all samples during storage. The results of the microbiological analysis indicated that the limit of acceptability in terms of aerobic mesophilic bacteria for meat samples stored packaged in dry-ageing bag at refrigeration temperature was reached at days 8 compared to a shelf life of only 7 days for boneless and bone-in samples stored aerobically.

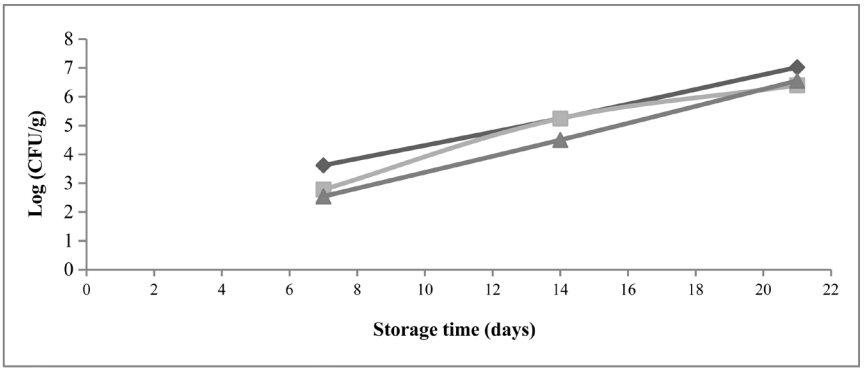
The microbial load on carcasses stored at refrigeration temperature for up to 21 days ranged from 7.3×10^9 to 2.4×10^{10} CFU·g^{-1} for mesophilic bacteria and from 6.7×10^9 to 9.2×10^9 CFU·g^{-1} for psychrotrophic bacteria. The number of mesophillic bacteria was, on average, 1 log cycle higher than psychrotrophic bacteria in bone-in and dry-ageing bag meat samples; however, no significant differences were noticed in the mesophillic and psychrotrophic bacterial load in boneless samples stored aerobically. The growth characteristics of meat spoilage microorganisms depend on the initial microflora, level of contamination, storage time and temperature [66]. As a general rule, meat acquires an offensive odour when the bacterial flora reaches about 10^7 colony forming units (CFU)·cm^{-2} or per g of sample and when numbers have reached about 10^8 CFU·cm^{-2} meat becomes slimy.



(a)



(b)



(c)

Figure 2. Changes in the (a) aerobic mesophilic; (b) psychrotrophic and (c) total coliform counts on beef carcasses bone-in (♦), boneless (■) and dry-ageing bag (▲) during storage at refrigeration temperature (4˚C). Values are average of 3 different samples assessed in replicate (n = 6).

At day 0, the total coliform load was below 10 CFU/g for all samples; however, growth resumed after seven days storage. At day seven, the surface of bone-in carcass sample was higher that the acceptable limit of 2.5 log CFU/g of sample reported by MIG, 2009 [67]. At day 21 the total coliform in all samples were higher than the acceptable limit 2.5 log (CFU/g of meat) and ranged from 2.6×10^6 to 1.1×10^7 CFU·g^{-1}, bone-in samples having the highest total coliform count. Throughout the storage *E. coli* was not detected in all meat samples. To obtain a good shelf life of the matured beef carcasses it is necessary that the ini-

tial quality of the steak is high, because packaging can only maintain the existing quality of the meat.

At the end of storage, microbiological analysis of the internal part of the carcass after sectioning was carried out. The interior of fresh meat from healthy animals is almost free of bacteria and other microorganisms [67]. All samples had AMC below the acceptability level of 10^6 CFU/g of meat. The mesophillic bacterial load was 6.0×10^3, 3.8×10^4 and 3.1×10^4 CFU/g of meat for bone-in, boneless and dry-ageing bag samples, respectively. The relatively higher content on the mesophillic bacteria was probably due to cross contamination from the surface of the carcass when the sterile knife went through the flesh for portioning. Therefore, to avoid cross-contamination it is recommended that the surface of the carcass is removed before sectioning or portioning. The outer surface of meat samples was trimmed prior to sensory analysis.

From the microbiological point of view, the lowest counts for (**Figure 2(a)**) mesophilic; (**Figure 2(b)**) psychrotrophic and (**Figure 2(c)**) total coliform counts were found for dry-aged bag samples on D14 (T-14). The other treatments did not differ on days 0, 7 and 21. These results are general agreement with DeGeer *et al.* [9] who found that, bag dry aging beef had no significant differences in *E. coli*/coliforms and lactic acid bacteria microbial growth than that of traditional dry aging after 21 days.

4. Conclusion

The results from this study show that that the dry-ageing bag and dry aged beef samples after storage at 2˚C for 21 days generally scored higher than the bone in aged beef for Appearance. The bone in aged samples were juicier, but had more off-flavour. The dry-aged (DA-14) and dry-aged bag samples (T-21) scored higher than the bone-in aged samples for overall acceptability and thus were liked more. For Day 7 and Day 21 dry-ageing bag and dry aged samples had significantly ($P < 0.05$) lower shear force values than bone in samples. Overall dry-ageing bag samples displayed the lowest mean shear force values on Days 14 and 21 and thus were the most tender treatments. The dry aged samples had higher moisture losses followed by the dry-ageing bag aged and then the bone-in dry aged beef on days 7, 14 and 21. Thus, dry-ageing bag aged samples were highly acceptable from a assessor perspective and fit the profile of aged beef with reduced moisture and losses and greater tenderness. However, Trim losses were not significantly different between dry aged samples and dry-ageing bag samples after 21 days. From the microbiological point of view, there was no optimal packaging system for maturing beef loins for 3 weeks although dry-aged bag (T-14) samples had the lowest TVC counts on Day 14. The sensory methods utilised allowed samples to be assessed hedonically and descriptively in real time without the necessity to freeze samples and without reverse storage design.

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Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki declaration of 1975, as revised in 2008 (5). No laboratory animals were used in this study.

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