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Assessment of dry-aged beef from commercial aging locations across the United States

Jessica M. Lancaster [a], Jaxon H. Smart [a], Jessie Van Buren [a], Brianna J. Buseman [b], Tanya M. Weber [c], Kizkitza Insausti [d], James A. Nasados [a], Benton Glaze [a], William J. Price [e], Michael J. Colle [a], Phillip D. Bass [a,*]

[a] *Department of Animal, Veterinary, and Food Sciences, University of Idaho, Moscow, ID, 83844, United States*
[b] *Animal Science Department, University of Nebraska, Lincoln, NE, 68583, United States*
[c] *College of Veterinary Medicine, Washington State University, Pullman, WA, 99164, United States*
[d] *Agricultural Engineering School-IS Food, Public University of Navarra, Pamplona, Spain*
[e] *Statistical Programs, College of Agricultural and Life Sciences, University of Idaho, Moscow, ID, 83844, United States*

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ABSTRACT

Modern dry-aging is a culinary-inspired practice that involves storing meat at refrigerated temperatures without protective packaging. The dry-aging process has been observed to create unique flavors. The objective of the current study was to survey commercial dry-aging facility environments and observe palatability differences related to consumer acceptance. Seventy-two bone-in beef strip loins (Institutional Meat Purchase Specification #175) were acquired. Strip loins were randomly assigned to each of ten commercial dry-aging facilities. Additionally, a set of strip loins were wet-aged at the University of Idaho meat laboratory. Strip loins were shipped overnight to respective aging locations and dry-aged for 45-days then returned overnight to the University of Idaho meat laboratory. Strip loins were fabricated into steaks, vacuum packaged, and then frozen until further analyzed. Commercial dry-aging facility cooler conditions were observed to be different ($P < 0.01$) for temperature (0.74–5.26 °C), percent relative humidity (64.87–99.21%), and wind speed (0.56–2.03 m/s). Intrinsic meat quality parameters including pH and water activity were not different ($P > 0.05$) among treatment-locations. Consumer taste panels indicated a difference ($P < 0.01$) in acceptability (6.27–7.24), tenderness (6.65–7.54), and flavor (5.58–6.79) based on aging treatment-location. Overall, the findings indicate that conditions within individual dry-aging facilities aid in producing unique dry-aged beef flavors.

1. Introduction

Aging is the process of storing meat in refrigeration for a period of time to allow for meat to become effected by natural enzymatic activity (USDA-FSIS, 2005). Aging beef often results in improvements in tenderness and flavor desirability, without impacting juiciness of the product (Jeremiah and Gibson, 2003).

Dry-aging is the storage of meat under refrigeration in the absence of protective packaging for an extended period of time (USDA-FSIS, 2005; Perry, 2012). Dry-aged meat products are impacted by a combination of important factors including the length of time the product is aged, temperature at which the product is aged, relative humidity of the aging cooler, and wind velocity within the cooler (Dashdorj et al., 2016). The effect of dry-aging on beef flavor is equivocal in the literature (Warren and Kastner, 1992; Campbell et al., 2001; Sitz et al., 2006; Laster et al., 2008). While dry-aged beef is gastronomically noted for offering unique flavor attributes, it differs from the more conventional wet-aged beef flavor to which many consumers are accustomed (Bauer, 1983; Perry 2012). Additionally, some consumer-based studies have reported no flavor difference between wet-aged and dry-aged beef (Parrish et al., 1991; Sitz et al., 2006; Laster et al., 2008; Oh et al., 2018). Largely, studies have compared wet-aged beef to dry-aged beef treatments to determine whether or not a difference can be detected (Laster et al., 2008; Smith et al., 2008; Dikeman et al., 2013; Berger et al., 2018). Research around dry-aging has featured the effects of temperature, relative humidity, and wind speed, both independently and collectively (Kim et al., 2016; Lee et al., 2017; Ribeiro, 2020). However, few studies have evaluated the effects of multiple commercial aging locations

* Corresponding author.
E-mail address: pbass@uidaho.edu (P.D. Bass).

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(Capouya et al., 2020), cooler parameters, or subsequent impacts on sensory attributes (Oh et al., 2018).

The objectives of this study were to survey environmental parameters of commercial dry-aging facilities from selected regional locations of the United States. Furthermore, the study investigated the effect of dry-aging parameter influences on eating quality (acceptability, flavor, tenderness, and juiciness) of dry-aged beef.

2. Materials and methods

2.1. Product procurement

Commercially available United States Department of Agriculture (USDA) Choice grade *Certified Angus Beef*® brand bone-in strip loins (n = 72; USDA (2020; Institutional Meat Purchase Specification # 175), from a single production date, were sourced from a commercial beef harvesting facility (Wallula, Washington). Strip loins were transported under refrigerated temperatures (2 °C) to the University of Idaho meat lab, Vandal Brand Meats, on the Moscow, Idaho campus of the University of Idaho. Strip loins were weighed, measured (length, width, depth), individually identified, and evenly sorted by weight and calculated surface area across eleven treatment-locations. Six strip loins were shipped overnight to nine different commercial dry-aging facilities each. Strip loins were shipped in insulated shipping containers (Uline Insulated Foam Shipping Kit S-13394, Pleasant Prairie, WI) and were packed with enough icepacks (Uline Cold Pack S-18253, Pleasant Prairie, WI) to maintain a chilled environment (<4.0 °C) for the product being shipped., where strip loins were aged for a 45-day period using the individual facility's standard operating procedure for dry-aging. Furthermore, one set of six strip loins were assigned to be dry-aged at Vandal Brand Meats. An additional set of six strip loins were assigned to a 45-day wet-aging treatment at Vandal Brand Meats. The remaining 6 strip loins represented the unaged product utilized for sensory analysis.

2.2. Cooler conditions

A temperature and humidity logger (Onset® HOBO® temp/RH logger, Cape Cod, MA) accompanied the product to each respective dry-aging location in order to record environmental parameters throughout the shipping and aging periods. Loggers were activated prior to shipping, accompanied the product continuously through shipping and aging, and data were retrieved at the end of the trial by trained personnel at the University of Idaho. Aging facilities measured weekly wind speed using handheld anemometers (866B, HoldPeak, Zhuhai, China) positioned parallel to the cut anterior surface of the strip loin at a distance of 30.5 cm. Upon completion of the aging period, strip loins were individually vacuum packaged and return-shipped overnight in insulated shipping containers to the Vandal Brand Meats. Upon receiving, strip loins were weighed to account for weight loss during aging.

2.3. Fabrication and sample collection

Strip loins were deboned, the exterior dry-aged visible crust was removed on those dry-aged, and each strip loin was cut into ten steaks 2.54 cm thick beginning from the anterior end. Fabricated steaks were systematically assigned to subsequent analysis groups including consumer taste panels, Warner-Bratzler Shear Force, water activity, and additional analyses not reported in this manuscript. Strip loin weights were recorded throughout fabrication to determine yields of saleable product. The posterior face of the first steak cut from the anterior end of the strip loin was allowed 30 min to bloom prior to measuring objective color. Objective color was analyzed using a Nix Pro 2 Color Sensor (Nix Sensor Ltd., Hamilton, Ontario, Canada; D65 Illuminant and 10° observer angle). Two readings were obtained, and the International Commission on Illumination L* (dark to light; 0 = black, 100 = white), a*(green to red; −50 = green, 50 = red), and b* (yellow to blue; −50 = blue, 50 = yellow) measurements were averaged for each of the steaks. The geometric center of the 11th steak removed from the strip loin was used to measure pH and water activity. A puncture type pH meter (Apera Instruments SX811-SS, Columbus, OH) that was calibrated to pH standards of 4.0, 7.0, and 10.0 (Hanna Instruments, Woonsocket, RI) was used to determine pH of the product. Steaks were then vacuum packaged and frozen at −20 °C until further analysis.

2.4. Water activity analysis

Water activity samples were obtained from the 11th steak fabricated from each strip loin to obtain comparable values for all strip loins and locations. A small sample (1.27 × 1.27 cm) was collected from the center of the steak, taking caution to avoid large areas of connective tissue and marbling. The sample was evaluated on an Aqualab water activity meter (model 3te, Meter Group, Pullman, WA) with standards (Meter Group, Pullman, WA) of 1.0, 0.92 and 0.75.

2.5. Mechanical tenderness assessment

Warner-Bratzler shear force (WBSF) was used to assess objective mechanical tenderness of steaks analyzed in the current study. Steaks analyzed for WBSF were tempered for 24 h at 4 °C prior to cooking on a two-sided electric grill (Cuisinart Griddler Deluxe Model GR-150) to a target peak internal temperature of 71 °C. Times were recorded when steaks were placed on the grills, removed from the grills, and upon reaching their peak internal temperatures. Cook time was determined as the difference between when steaks were placed and removed from the grills. Peak internal temperature was recorded using a Type-K thermocouple (Copper-Atkins 93230-K EconoTemp). Steaks were allowed to equilibrate to room temperature prior to coring. A minimum of five cores (1.27 cm diameter) were removed parallel to the muscle fiber orientation from the Longissimus lumborum muscle of each steak. Each core was sheared perpendicular to the muscle fiber orientation using a WBSF machine (G-R Manufacturing, Manhattan, KS) at a cross-head speed of 225 mm/s. Peak shear force (kg) values were used to compute a mean peak shear force value for each steak. Steaks were weighed prior to, and immediately following, cooking to determine the percentage cook loss.

2.6. Consumer taste panels

The study was found to be Exempt by the University of Idaho Institutional Review Board (IRB #19–149). All subjects provided informed, written consent for inclusion prior to their participation in the study. Consumer panelists were informed that the study was investigating dry-aged beef. A minimum of 200 consumer panelists were targeted to assess the samples. Four steaks from randomly selected locations within each strip loin were used for taste panels. Steaks were thawed overnight at 4 °C and subsequently cooked to a medium rare degree of doneness (60 °C). Steaks were prepared on a two-sided electric grill (Cuisinart Griddler Deluxe Model GR-150); grill surface was set at 260 °C. Cook time and cooking loss were recorded. Four separate panels were conducted in accordance with American Meat Science Association guidelines (American Meat Science Association, 2016) targeting a minumum of 50 consumers for each panel; if additional panelists were available for each panel session then additional replicates were assessed in order to add to the control of variation. Panelists were required to be a minimum of 18 years of age and consumers of beef. Within each panel, treatment-location samples were allocated to panelists according to a balanced incomplete block design. Prior to evaluating samples, all panelists received a sample of eye of round steak (Semitendinosus), cooked in the same manner as the strip steaks, as a calibration sample. Each incomplete block represented all locations equally. Panelists were randomly assigned three-digit, blind-coded samples to evaluate in a preselected order to reduce sample order bias. Each sample was evaluated using a 10-point scale where 1 = dislike extremely and 10 = like extremely for the following attributes: overall acceptability, tenderness, juiciness, and flavor of the sample. In addition, consumer panelists were asked to evaluate qualitatively the presence of an off flavor (no/yes) and consumer overall steak eating satisfaction (no/yes). Lastly, consumer panelists were provided with a list of flavor notes (brown/roasted, yeasty, metallic, earthy, nutty, aged cheese, sour, and sweet) and asked to select which were observed if any. Each panelist was provided with a ballot for each sample along with a toothpick, napkin, expectorant cup, cup of room temperature water, and unsalted soda crackers (Nabisco, East Hanover, NJ). Prior to the commencement of the panel, the panelists were provided with verbal instructions on the process and forms. Before sampling, panelists were asked to complete a demographics survey.

2.7. Microbial analysis

The posterior face of each strip loin (5 × 5 cm area) was swabbed at the end of the aging period using sterile cotton swabs and buffered peptone water (3M™, St. Paul, MN). All sampled swabs were vortexed (VWR Vortexer 2 G-550; Scientific Industries, Bohemia, NY), diluted 1:100 with buffered peptone water, vortexed a second time, and subsequently plated. Samples were plated on 3M™ Petrifilm™ Aerobic Count Plates (3M™, St. Paul, MN), and incubated (Model 10–140, Quincy Lab, Inc., Chicago, IL) at 35 °C for 48 ± 2 h for growth of mesophilic organisms. Samples were also plated on 3M™ Petrifilm™ Rapid E.coli/Coliform Count Plates (3M, St. Paul, MN), and incubated at 35 °C for 48 h. Colonies were counted following the 3M™ Interpretation Guides (3M Food Safety, 2017a; 3M Food Safety, 2017b).

2.8. Statistical analysis

A mixed model ANOVA assuming a randomized complete block design with treatment-location as a fixed effect was employed to analyze cooler conditions and intrinsic quality factors. Step-wise regression analysis was used to account for evaluating the variation of cooler parameters. Taste panel data were analyzed according to the predetermined balanced incomplete block design used for sample allocation where treatment-location was assumed as a fixed effect and panelist and the panelist*treatment-location interaction as random effects. Initial analysis also assessed the overall effects of panel and panel*location interactions; however, these were later omitted from the modeling as they showed minimal significance if any of the responses. Following model fitting, differences in least squares means were compared using pair-wise comparisons with a Tukey's Honest Significant Difference adjustment. Plate count data were log10 transformed prior to analysis. The GLIMMIX procedure was used to analyze the qualitative frequency of flavor observances by the consumer sensory panelists. Pearson correlations were used to determine potential associations between cooler conditions and sensory characteristics. Statistically significant p-values were identified at $P < 0.05$. All data were analyzed using SAS version 9.4 (SAS Institute, Inc., Cary, NC).

3. Results and discussion

3.1. Refrigerated aging environmental conditions

Cooler temperatures for the 45-day aging period differed ($P < 0.01$) among aging treatment-locations (Table 1). Aging location H had the lowest average temperature (0.74 °C) whereas location C had the greatest mean temperature (5.26 °C). Additionally, there was a difference ($P < 0.01$) in relative humidity across locations. Location A had the lowest average percent relative humidity (64.87%) and location I had the greatest average percent relative humidity (92.21%). Previous research conducted in laboratory environments has found that the percent relative humidity in a single treatment-location experiment has varied from as low as 49% to as high as 85% (Kim et al., 2013, 2016, 2019; Oh et al., 2018).

Table 1
Least squares mean ± standard error environmental conditions and strip loin evaporative aging loss for aging treatment-locations for a 45-day aging period.

Aging Location	Temperature, °C[a]	Relative Humidity, %[a]	Wind Speed[b]	Aging Loss, %
A	4.09 ± 0.58[bc]	64.87 ± 2.51[d]	1.05 ± 0.08[cd]	13.26 ± 0.01[cd]
B	1.98 ± 0.58[ef]	72.52 ± 2.51[c]	1.13 ± 0.08[cd]	15.46 ± 0.01[ab]
C	5.26 ± 0.77[a]	72.07 ± 3.32[cd]	1.70 ± 0.08[b]	15.74 ± 0.01[ab]
D	2.81 ± 0.58[de]	85.47 ± 2.51[ab]	1.07 ± 0.08[cd]	13.30 ± 0.01[bcd]
E	3.64 ± 0.58[cd]	73.20 ± 2.51[c]	2.03 ± 0.08[a]	15.89 ± 0.01[a]
F	1.67 ± 0.58[fg]	71.38 ± 2.51[cd]	0.94 ± 0.08[de]	14.63 ± 0.01[abc]
G	4.26 ± 0.58[b]	77.22 ± 2.51[bc]	0.75 ± 0.08[ef]	12.95 ± 0.01[cd]
H	0.74 ± 0.58[h]	82.94 ± 2.51[ab]	1.09 ± 0.08[cd]	10.85 ± 0.01[e]
I	1.06 ± 0.58[gh]	92.21 ± 2.51[a]	1.23 ± 0.08[c]	11.62 ± 0.01[de]
J	1.33 ± 0.58[fgh]	82.86 ± 2.51[ab]	0.56 ± 0.08[f]	10.16 ± 0.01[e]
Wet[c]	0.76 ± 0.58[h]	–	–	0.55 ± 0.01[f]
Minimum[d]	0.74	64.87	0.56	0.55
Maximum[e]	5.26	92.21	2.03	15.89

[a-h] Within a trait, means without a common superscript differ ($P < 0.05$).
[a] Parameters recorded via an Onset® HOBO® temp/RH logger at 5-min intervals.
[b] Measured using handheld anemometers on a weekly basis, reported in m/s.
[c] Cooler parameters not included due to protective packaging limiting impact.
[d] Minimum mean observed.
[e] Maximum mean observed.

Average air speed over the 45-day aging period ranged from 0.56 m/s (location J) to 2.03 m/s (location E) and differed by aging treatment-location ($P < 0.01$). The air speed observed in the current study was within ranges of air speeds observed in previously reported dry-aging experiments (Setyabrata et al., 2017; Hulánková et al., 2018; da Silva Bernardo et al., 2020).

As expected, the percent aging weight loss was greater in the dry-aged strip loins compared with wet-aged strip loins ($P < 0.01$). Within the products that were dry-aged, there were differences ($P < 0.01$) in percent aging loss among treatment-locations; however, the majority of treatment-locations in the current study were near the range of 12–14% evaporative loss, similar to those previously reported (Parrish et al., 1991). Additionally, location E had both the greatest average wind speed and percent aging loss while location J had the lowest average wind speed and lowest percentage of aging loss. In agreement with Lee et al. (2019), aging facility locations are unique and can impact final product parameters.

The parameters of temperature, relative humidity, and wind speed, with respect to aging loss accounted for 72.7% of the variation observed. Results of multivariate analyses following a stepwise regression revealed that humidity and wind speed could account for the largest amount of aging loss variation with 46.6% and 25.6% respectively (data not shown). Pearson correlation coefficients of humidity and wind speed as related to aging loss were −0.68 and 0.65 respectively (data not shown). This indicates that as humidity decreases and wind speed increases, an increase in aging loss during the dry-aging of beef strip loins should be observed.

3.2. Intrinsic quality

Intrinsic quality factors for 45 day-aged strip loins are displayed in Table 2. There were no differences detected across aging treatment-locations for the following factors: pH (P = 0.12), water activity (P = 0.08), and the color metrics: L* (P = 0.87), a* (P = 0.36), and b* (P = 0.09). Kim et al. (2013) reported that pH of dry-aged beef was higher than wet-aged beef. However, in agreement with the current study, it has previously been reported that dry-aged and wet-aged beef have similar ultimate pH (Berger et al., 2018; Oh et al., 2018; Kim et al., 2019; Ribeiro, 2020). Although Lee et al. (2019) reported differences in pH of dry-aged beef at 42 days of aging, the raw product differed compared with the current study (Holstein steers vs *Certified Angus Beef*®). Despite the lack of differences between wet-aging and dry-aging locations for water activity in the current study, Ribeiro et al. (2019) reported greater water activity in wet-aged bone-less strip loins compared to product dry-aged for 42 days. The authors of the current study postulate that differences in the current study compared to previous work could be attributed to sampling location. Contrary to the current study, Dikeman et al. (2013), Kim et al. (2019) and Ribeiro et al. (2019) reported differences between wet-aged and dry-aged beef for L*, a*, and b* quantitative color values. The similarity in intrinsic quality factors (pH, water activity, L*, a*, and b*) of the current study suggest a uniform initial raw product and therefore sensory differences post aging can be attributed to aging conditions and locations.

Cook time (P = 0.17) and cook loss (P = 0.41) were not different among aging treatment-locations (data not shown). No difference (P = 0.21) was observed in WBSF values among the wet-aged, negative control, and the dry-aged locations (Table 2). Previous studies have also reported no difference in WBSF of product aged for similar lengths of time (Dikeman et al., 2013; Ribeiro, 2020). In the current study, all steaks (ranging between 1.59 and 2.21 kg WBSF) were well below the tenderness threshold of the USDA Certified Very Tender level of <3.9 kg WBSF (American Meat Science Association, 2016).

Table 2
Least squares mean ± standard error intrinsic quality factors of 45-day dry-aged beef by aging treatment-location.

Aging Location	pH	AW[a]	L*[b]	a*[c]	b*[d]	WBSF[e], kg
A	5.66 ± 0.24	0.99 ± 0.002	37.01 ± 0.71	20.18 ± 0.73	14.81 ± 0.56	1.92 ± 0.14
B	5.68 ± 0.24	0.99 ± 0.002	36.21 ± 0.71	20.46 ± 0.73	13.61 ± 0.56	1.95 ± 0.15
C	5.67 ± 0.24	0.98 ± 0.002	37.01 ± 0.71	21.51 ± 0.73	15.61 ± 0.56	1.59 ± 0.15
D	5.67 ± 0.24	0.99 ± 0.002	37.03 ± 0.71	20.04 ± 0.73	14.68 ± 0.56	2.08 ± 0.15
E	5.65 ± 0.24	0.98 ± 0.002	36.77 ± 0.71	19.19 ± 0.73	13.77 ± 0.56	1.84 ± 0.16
F	5.73 ± 0.24	0.99 ± 0.002	36.16 ± 0.71	19.71 ± 0.73	13.79 ± 0.56	2.19 ± 0.16
G	5.66 ± 0.24	0.98 ± 0.002	35.96 ± 0.71	20.63 ± 0.73	13.99 ± 0.56	1.87 ± 0.14
H	5.66 ± 0.24	0.99 ± 0.002	37.43 ± 0.71	19.40 ± 0.73	14.61 ± 0.56	2.21 ± 0.15
I	5.61 ± 0.24	0.99 ± 0.002	37.03 ± 0.71	21.48 ± 0.73	15.73 ± 0.56	1.97 ± 0.14
J	5.67 ± 0.24	0.98 ± 0.002	36.66 ± 0.71	20.97 ± 0.73	14.50 ± 0.56	1.87 ± 0.15
Wet	5.64 ± 0.24	0.99 ± 0.002	37.56 ± 0.71	20.66 ± 0.73	15.20 ± 0.56	1.83 ± 0.15
Min[f]	5.61	0.98	35.96	19.19	13.61	1.59
Max[g]	5.73	0.99	37.56	21.58	15.73	2.21

[a] AW: Water Activity.
[b] L*: objective color measurement (0 = black; 100 = white).
[c] a*: objective color measurement (−50 = green; 50 = red).
[d] b*: objective color measurement (−50 = blue; 50 = yellow).
[e] Warner-Bratzler Shear Force.
[f] Minimum mean observed.
[g] Maximum mean observed.

3.3. Consumer taste panels

Demographics for taste panel participants are listed in Table 3. In total, 219 consumers completed the evaluation of the dry-aged steak samples. Consumer taste panelists were recruited in the state of Idaho. Over half of the panelists had consumed dry-aged beef prior to participating in the panel; over 90% of the panelists reported that they eat beef twice a week or more. Gender of panel participants were distributed almost exactly in half. Taste panel outcomes are listed in Table 4. Consumers reported differences in overall acceptability of steaks ($P < 0.01$). The wet-aged treatment had the greatest consumer acceptability in the study while location D had the lowest consumer acceptability. Given the vast majority of beef consumed in the United States is wet-aged, consumer familiarity could contribute to the high acceptability rating of the wet-aged beef treatment (Sitz et al., 2006). Alternatively, some previous research has reported consumer sensory panelists found no difference in acceptability between dry-aged and wet-aged beef (Sitz et al., 2006; Laster, 2007; Smith et al., 2014; Oh et al., 2018; S. Kim et al., 2019).

Despite all the samples having mean WBSF values within the threshold of USDA Certified Very Tender, and no observed mechanical differences, consumer panelists identified differences in tenderness between treatment-locations (P = 0.01). Consumers identified the wet-aged steaks and steaks aged at location C as the most tender and steaks from location I as the least tender. Location C was observed to have the highest average aging temperature (5.26 °C) whereas Location I had the second lowest aging temperature (1.06 °C) of the dry-aged treatment-locations. For some time, research has demonstrated that higher aging temperatures allow for a more rapid enzymatic activity resulting in accelerated aging and thereby potentially more tender beef (Dransfield, 1994). There were no identified differences in juiciness among aging treatment-locations for taste panels (P = 0.20). Conversely, Smith et al. (2008) reported consumers preferred the juiciness of wet-aged beef over dry-aged beef. Flavor desirability differences among samples from different aging treatment-locations were identified by

Table 3
Consumer taste panel summary statistics of panelist demographics (N = 219).

	n	%
Age		
18–19	19	8.7
20–29	62	28.3
30–39	42	19.2
40–49	30	13.7
50+	66	30.1
Gender		
Male	111	50.7
Female	108	49.3
Beef meals/week [a]		
0 to 1	21	9.7
2 to 4	87	40.3
5 to 7	76	35.2
8+	32	14.8
Most consumed [b]		
Ground	132	57.6
Roast	16	7.0
Steak	78	34.1
Other	3	1.3
Dry-aged beef [c]		
Yes	114	54.0
No	97	46.0

For [a], [b], and [c], consumers were asked:
[a] Please indicate the number of meals a week in which you consume beef: 0–1, 2–4, 5–7, or 8+.
[b] Please indicate the form in which you most commonly consume beef: ground, roast, steak, or other.
[c] Have you ever consumed dry-aged beef? yes or no.

Table 4
Consumer (N = 219) taste panel least squares mean ± standard error evaluations of 45-day aged steaks by aging treatment-location and unaged steaks.

Aging Location	Acceptability[a]	Tenderness[b]	Juiciness[c]	Flavor[d]
A	7.17 ± 0.20[ab]	7.35 ± 0.18[ab]	6.75 ± 0.18	6.62 ± 0.22[ab]
B	6.82 ± 0.20[abc]	7.20 ± 0.18[ab]	6.64 ± 0.18	6.26 ± 0.22[abc]
C	6.65 ± 0.20[abc]	7.47 ± 0.18[a]	6.76 ± 0.18	6.10 ± 0.23[abc]
D	6.28 ± 0.20[c]	7.35 ± 0.18[ab]	6.88 ± 0.17	5.52 ± 0.22[c]
E	6.52 ± 0.21[abc]	7.06 ± 0.19[ab]	6.65 ± 0.19	5.92 ± 0.23[abc]
F	7.05 ± 0.20[abc]	7.13 ± 0.18[ab]	6.68 ± 0.18	6.59 ± 0.23[ab]
G	6.82 ± 0.20[abc]	7.25 ± 0.18[ab]	6.72 ± 0.18	6.56 ± 0.22[ab]
H	6.44 ± 0.20[bc]	6.79 ± 0.18[ab]	6.65 ± 0.18	6.23 ± 0.22[abc]
I	6.54 ± 0.21[abc]	6.66 ± 0.19[b]	6.52 ± 0.19	5.84 ± 0.24[bc]
J	6.38 ± 0.21[c]	7.05 ± 0.19[ab]	6.78 ± 0.19	5.70 ± 0.23[bc]
Wet	7.26 ± 0.20[a]	7.51 ± 0.18[a]	7.21 ± 0.18	6.86 ± 0.22[a]
Minimum[e]	6.28	6.66	6.52	5.52
Maximum[f]	7.26	7.51	7.21	6.86

[a-c] Within a trait, means without a common superscript differ ($P < 0.05$).
[a] Overall Acceptability Score: 10 = extremely acceptable; 1 = extremely unacceptable.
[b] Tenderness Score: 10 = extremely like; 1 = extremely dislike.
[c] Juiciness Score: 10 = extremely like; 1 = extremely dislike.
[d] Flavor Score: 10 = extremely like; 1 = extremely dislike.
[e] Minimum mean observed.
[f] Maximum mean observed.

consumer panelists ($P < 0.01$). Consumers preferred the flavor of wet-aged steaks and found steaks from location D to have the least desirable flavor. Location D did have the most frequent observances of off-flavors (Table 5) by panelists noting the high instance of specifically cheese, sour, and metallic flavors. Miller et al. (1985) and Lepper-Blilie et al. (2016) reported that dry-aged beef had greater flavor intensity than wet-aged beef although these differences were not consistently observed in the current study. Other studies have also indicated no difference in flavor of dry-aged and wet-aged beef (Sitz et al., 2006; Laster, 2007; DeGeer et al., 2009; Dikeman et al., 2013).

Overall acceptability and identifiable flavor notes reported by consumers are displayed in Table 5. Overall satisfaction of the samples ranged from 56.1% to 87.9% ($P < 0.01$) while the observance of off flavors among treatment-locations ranged from 5.3% to 44.6%. The treatment-location with the greatest overall satisfaction rate was the traditional wet-aged product. Of the dry-aged product, the treatment-location with the greatest overall satisfaction rate was location A; interestingly, location A had the third highest average aging temperature and the lowest recorded average relative humidity. When Pearson correlation coefficients were calculated for the general sensory attributes with relation to aging environment conditions, relative humidity had a significant negative correlation (−0.79; Table 6) to that of overall acceptability as well as flavor. If the relative humidity is low, it can be assumed that a lower fungal microbial growth may be observed leading to a milder flavor which seemed to be more acceptable to the consumer base in the current study.

The observance of cheese ($P < 0.01$), sour ($P < 0.01$), nutty ($P = 0.03$) and yeasty ($P = 0.03$) flavors were different by aging treatment-location. Treatment-locations D and J had some of the highest instances of the previously mentioned off-flavors. Interestingly, treatment-locations D and J also had some of the highest mean relative humidity measurements while their average wind speeds were relatively mild. This may suggest that additional fungal microbial growth may have been observed on the product aged in those locations that resulted in unique flavors detectable by the consumer panels. Meanwhile, consumers reported no differences in the observance of earthy ($P = 0.42$), sweet ($P = 0.46$), and metallic ($P = 0.95$) notes. Trained taste panels using dry-aged beef samples have observed uniqueness of the samples as: beefier flavor (Warren and Kastner, 1992; Smith et al., 2008), less sour notes (Warren and Kastner, 1992), less serum flavor (Warren and Kastner, 1992; Smith et al., 2008), and more musty/putrid notes (Smith et al., 2008) compared with wet-aged samples. In addition, Ribeiro (2020) reported lower humidity (50% relative humidity) had more favorable flavor notes, while product aged at higher relative humidity (70 and 85%) had fewer desirable flavors. Furthermore, product dry-aged at higher humidity had sensory attributes with sourness, rancidity, and oxidation (Smith et al., 2008). Panelists in the present study who indicated an unsatisfied eating experience most often (66%) indicated the reason was the flavor of the product ($P < 0.01$). When

Table 6
Pearson correlation coefficients across refrigerated environment aging parameters and sensory attributes.

Aging Parameters	Sensory Attributes				
	Acceptability[a]	Tenderness[b]	Juiciness[c]	Flavor[d]	Off-Flavor[e]
Temperature	−0.04	0.31	−0.35	−0.02	0.01
Relative Humidity	−0.79**	−0.48	0.23	−0.64*	0.80**
Air Speed	−0.07	−0.04	−0.06	−0.11	−0.02
Aging Loss	−0.30	−0.21	−0.80**	−0.31	0.19

*$P < 0.05$; **$P < 0.01$.
[a] Overall Acceptability Score: 10 = extremely acceptable; 1 = extremely unacceptable.
[b] Tenderness Score: 10 = extremely tender; 1 = not at all tender.
[c] Juiciness Score: 10 = extremely juicy; 1 = extremely dry.
[d] Flavor Score: 10 = extremely flavorful; 1 = extremely unflavorful
[e] Off-flavor: observance of off flavor.

Table 5
Percentage of consumers (N = 219) who noted the following flavors associated with dry-aged beef by aging location and unaged steaks.

Aging Location	Satisfaction	Off-flavor	Cheese	Sour	Nutty	Yeasty	Earthy	Sweet	Metallic
A	81.1[ab]	12.9[ef]	5.2[cd]	3.1[cd]	11.5[b]	5.2[abc]	16.7	8.3	9.4
B	74.2[bc]	22.5[cde]	7.4[bcd]	3.2[cd]	11.6[b]	12.7[a]	12.6	4.2	8.4
C	67.4[cd]	30.0[bc]	13.3[abc]	12.2[ab]	12.2[b]	11.1[ab]	15.6	8.9	11.1
D	59.4[d]	44.6[a]	19.2[a]	15.4[a]	17.3[b]	12.6[a]	18.3	7.7	12.5
E	74.7bc	25.6[cd]	7.0[bcd]	5.8[bcd]	17.4[ab]	3.5[bc]	18.6	4.7	10.5
F	77.7[abc]	20.0[cde]	5.3[cd]	3.2[cd]	9.6[b]	7.4[abc]	25.5	3.2	7.5
G	80.4[ab]	20.9[cde]	5.4[cd]	2.2[d]	18.5[ab]	1.1[c]	25.0	6.5	6.5
H	77.8[abc]	26.4[bcd]	14.1[ab]	9.8[abc]	12.0[b]	11.0[ab]	19.6	10.9	7.6
I	66.3[cd]	26.9[bcd]	18.5[a]	11.1[ab]	16.1[b]	8.6[abc]	22.2	8.6	9.9
J	56.1[d]	38.8[ab]	17.1[a]	12.2[ab]	28.1[a]	12.2[a]	23.2	11.0	9.8
Wet	87.9[a]	14.4[def]	2.2[d]	2.2[d]	12.0[b]	6.5[abc]	14.1	10.9	12.0
Unaged[a]	76.0[abc]	5.3[f]	6.2[bcd]	6.2[bcd]	8.6[b]	3.7[bc]	18.5	11.1	7.4
P - value	<0.01	<0.01	<0.01	<0.01	0.03	0.03	0.42	0.46	0.95

[a-f] Percent observances within a column, lacking a common superscript, differ significantly ($P < 0.05$).
[a] Unaged steaks were frozen upon receiving of product.

panelists reported off-flavors, the percentage of flavor attributes were observed as: yeasty (18.5%; $P < 0.01$), cheese (18.1%; $P < 0.01$), sour (19.3%; $P < 0.01$), metallic (14.2%; $P < 0.01$), and nutty (18.5%; $P = 0.06$). Despite these attributes being noted in tandem with off flavor, the authors of the current study postulate they contribute to other artisanal food products and could be highly sought after by some consumers.

Consumer preferences of products is known to impact acceptability of a number of food products (Fabricant, 1996). While the general United States Pacific Northwest consumer did not favor the distinct flavor notes associated with dry-aged beef, alternative population centers and niche consumers may appreciate more the robustness of unique dry-aged flavors. Furthermore, Terjung et al. (2021) have reviewed over three-dozen papers with regard to dry-aged beef preference and quality and determined that a multitude of dry-aging factors contribute to the overall acceptance of dry-aged beef. Furthermore, Terjung et al. (2021) also deduce that because of the complexity of the interacting factors involved in dry aging (e.g., pH, relative humidity, water loss, etc.) it is possible that some dry-aged beef will result in a less-desirable eating experience compared to the wet-aged counterpart.

The Pearson correlation coefficients of refrigerated environment aging parameters and sensory attributes are displayed in Table 6. Percent relative humidity had a negative correlation with overall consumer panel acceptability (−0.79; $P < 0.01$) and flavor (−0.64; $P = 0.04$), whereas it had a positive correlation with the observance of off flavors (0.80; $P < 0.01$). Ribeiro (2020) reported that an increase in relative humidity can shift sensory attributes from neutral flavor notes (wet aged, 50% relative humidity) to sour and off-flavors (70 and 85% relative humidity). The authors of the current study postulate that microbiological activity, which is often implicated as contributing the unique flavor of dry-aged beef, is going to be higher in the environments that were higher in temperature and relative humidity. The incidence of those unique flavors identified in the study were indeed observed more frequently in treatment-locations where higher mean humidity was present (i.e., D, H, I, and J).

The percent aging loss also had a high negative correlation with sensory juiciness (−0.80; $P < 0.01$). However, results from the consumer taste panel should be interpreted cautiously. Consumers suggested differences in flavor preference of samples, but intensity of flavor was not evaluated in the current study. Additionally, around half of the consumers in the study indicated they had previously consumed dry-aged beef. The relative novelty of flavors to the remaining half of consumer panelists could also be attributed to the taste panel results observed.

3.4. Microbial growth

Aerobic plate count (APC) means were different by treatment-location ($P < 0.01$) and ranged from 0.18 to 4.00 colony forming unit (cfu)/cm^2 (Table 7). Three of the dry-aged locations had aerobic plate counts <1 cfu/cm^2. Campbell et al. (2001) reported that duration of dry-aging did not impact APC, while Ryu et al. (2018) reported increased microorganism growth until day 50 of dry-aging. Berger et at. (2018) and Ribeiro (2020) reported dry-aged beef had lower APC than wet-aged counterparts. In the current study, treatment-location J had a higher APC than the wet-aged treatment. The combination of lower humidity and greater wind speeds is likely contributing to drying of the dry-aged product surface and subsequently resulted in lower APC of some of the dry-aged beef treatment-locations. The coliform plate count means ranged from 0.59 to 4.00 cfu/cm^2 and were different ($P < 0.01$) by treatment-location. However, no *E. coli* were detected on any of the treatment-locations. Location A had the lowest mean plate counts for both APC and coliform assessments and was the only location with plate counts <1 cfu/cm^2 for both parameters measured. Location A also had the lowest relative humidity in the refrigerated aging environment during the study. Meanwhile, location J had the greatest mean plate counts for APC and coliform assessments. Location J also had one of the higher mean relative humidity (82.86%) and the lowest average wind speed (0.56 m/s) observed. Conflicting results have been reported in previous studies on the abundance, or lack of abundance (Ryu et al., 2018), of coliforms on dry-aged beef. The relative dryness of the crust of dry-aged beef may create a hurdle for growth of *E. coli* as illustrated by this study with no *E. coli* detected on the surface of the product.

Table 7
Least squares mean microbial growth of 45-day aged steaks by aging treatment-location.

Aging Location	Aerobic Plate Counts[b]	*E. coli*[a]/Coliform Plate Count[b,c]
A	0.18 ± 0.44^{e}	0.59 ± 0.67^{c}
B	1.11 ± 0.41^{cde}	1.29 ± 0.67^{c}
C	0.35 ± 0.41^{de}	1.04 ± 0.67^{c}
D	1.97 ± 0.41^{bc}	3.60 ± 0.67^{a}
E	0.73 ± 0.41^{de}	2.21 ± 0.74^{abc}
F	0.68 ± 0.41^{de}	1.20 ± 0.67^{c}
G	1.43 ± 0.41^{bcd}	1.44 ± 0.74^{c}
H	2.32 ± 0.33^{b}	3.53 ± 0.67^{ab}
I	2.36 ± 0.41^{b}	2.08 ± 0.74^{abc}
J	4.00 ± 0.41^{a}	4.00 ± 0.74^{a}
Wet	1.33 ± 0.41^{bcd}	1.54 ± 0.74^{bc}
Minimum[d]	0.18	0.59
Maximum[e]	4.00	4.00

[a-e] Within a column, means without a common superscript differ ($P < 0.05$).
[a] Zero *E. coli* were identified.
[b] Plate couts estimated in accordance with 3M™ Interpretation Guides.
[c] Log_{10} colny-forming units/cm.^{2}.
[d] Minimum man observed.
[e] Maximum man observed.

Although molds were not measured or enumerated in the current study, it is strongly believed that the fungal community are likely contributors to the overall dry-aged beef eating experience (Terjung et al., 2021)– predominantly with regard to flavor. Future research will be needed to expand on the knowledge of the influence of microflora on dry-aged beef products.

4. Conclusion

Dry-aging is a meat production process influenced by an array of factors. Temperature, percent relative humidity, and wind speed are all aging conditions that vary across commercial aging facilities. Aging conditions in commercial dry-aging facilities contribute to unique differences in consumer eating preferences. Consumers can identify differences between dry-aged and wet-aged products. Within the dry-aged sector, the aging conditions of the product provide individuality to dry-aged products. Moreover, consumer acceptability of dry-aged beef is likely influenced by previous eating experiences and interpretation of product flavor.

5. Implications for gastronomy

Dry-aged beef is increasing in popularity in the culinary community. However, there is limited understanding of the impacts of aging environment on final product quality, especially in current commercial dry-aging facilities. This research investigates the complexity of dry-aged beef by aging environmental parameters and the implications on consumer acceptance. Largely, dry-aged beef has been grouped into a broad category with little understanding of the variation of the final products. By acknowledging the uniqueness of dry-aged beef, the culinary community has the opportunity to better utilize the products and find a good fit for the dining customer. An understanding of the unique flavor notes allows for marketability of dry-aged beef by location. Additionally, there is an opportunity to celebrate the differences in dry-aged beef similar to coffee, wines, and cheeses.

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Declaration of competing interest

The authors declare no conflicts of interest.

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Abbreviations

°C	Degrees Celsius
cm –	Centimeter
kg –	Kilogram
pH –	measure of acidity (0) to basic (14) where neutral is 7, inverse log of hydrogen ions
WBSF –	Warner-Bratzler Shear Force

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