Article

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The effects of time and relative humidity on dry-aged beef: Traditional versus special bag

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Abstract

The objective of this study was to evaluate the effects of relative humidity (RH) and different dry aging methods on the quality of beef. Sixteen loins, from eight carcasses, were used in this experiment. Each pair of loin was cut into eight sections with equal size, which were evenly assigned to eight treatments, by the combination of two dry aging methods (traditional and highly moisture-permeable special bag), two relative humidity (65 and 85% RH) and two aging times (21 and 42 days). At 85% RH, neither special bag nor the traditional dry aging methods were viable, since samples presented high microbiological counts, mucus and bad odor. At 65% RH, *Enterobacteriaceae* and lactic acid bacteria were not detected in any treatment. The highest aerobic plate count and psychrotrophic count were observed in the samples of the traditional dry-aged process whereas the special bag showed the greatest mold and yeast count. Regarding dry aging in special bag, there was a reduction in the weight loss ($P < 0.05$) and no change in the physical-chemical characteristics ($P > 0.05$) compared to traditional dry aging. The values of pH, moisture and Warner-Bratzler shear force were not affected ($P > 0.05$) by aging method and relative humidity. Thus, the results indicate that high RH should be avoided for both dry aging methods. Furthermore, the special bag dry aging can be considered an alternative to produce dry-aged beef, as it reduces weight losses even at conditions of lower relative humidity.

Keywords

Dry-aged beef, dry aging methods, special bag, relative humidity

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INTRODUCTION

The Brazilian herd is mainly composed by grass-fed Zebu cattle (Ferraz and Felício, 2010), which is known for their lower aging rates. The grass-fed diet does not favor fat deposition on carcasses, which may also compromise beef sensorial quality (Carvalho et al., 2014; Koohmaraie, 1994; Miller et al., 2001; Shorthose and Harris, 1990). However, there are ways to improve sensorial attributes in beef.

Aging is one of the most common methods used, especially to improve flavor and tenderness (Campbell et al., 2001; Sitz et al., 2006), and can be performed either in a vacuum package (wet aging) or without package (dry aging). The wet aging process is the most usual method, due to its convenience in terms of storage and transportation of cuts and low aging

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losses (DeGeer et al., 2009; Li et al., 2014; Savell, 2008). Dry aging has been gaining visibility, due to the development of desirable flavors (Lepper-Blilie et al., 2016; Li et al., 2013; Stenström et al., 2014), such as roasted beef flavor (Campbell et al. 2001; Warren and Kastner, 1992) and umami taste (Li et al., 2014).

Dry aging is considered costly (DeGeer et al., 2009; Miller et al., 1985; Smith et al., 2008), as the process requires a strict control of the aging conditions, such as the temperature, relative humidity and air velocity (Kim et al., 2016; Savell, 2008). In addition, dry aging requires larger spaces in chambers and has higher weight loss compared to wet aging (Dikeman et al., 2013; Oreskovich et al., 1988; Parrish et al., 1991; Warren and Kastner, 1992). Therefore, a new technology of highly moisture-permeable bag (special bag) was introduced to the meat market. This packaging method allows the enhancement of desirable sensorial attributes in meat and increases the process yield (Ahnström et al., 2006; DeGeer et al., 2009; Dikeman et al., 2013; Li et al., 2014) compared to the traditional dry aging. Studies compared the special bag and traditional dry aging methods showed that the special bag technology reduces weight loss and shrinkage, while acts as a barrier protecting the meat from environment conditions, reducing microbial contamination (Ahnström et al., 2006; DeGeer et al., 2009; Dikeman et al., 2013; Li et al., 2014).

Even though there are several studies citing relative humidity on dry aging processes (Campbell et al., 2001; Kim et al., 2017; Ryu et al., 2018; Smith et al., 2008), only one study has been developed to evaluate the effects of different relative humidity on dry-aged beef (Lee et al., 2017). In addition, no other work that evaluated the effects of different relative humidity on the dry aging process using special bag (highly moisture-permeable bag) was found in the literature. Still, in relation to the origin of meat for dry aging, most studies have been done with *Bos taurus* animals, and studies with meat from Zebu animals (*Bos indicus*) are uncommon (Vilella et al., 2019). Thus, this study aimed to evaluate the effects of combination of different aging methods, under different relative humidity and aging time on the physical, chemical and microbiological characteristics of aged beef from grass-fed Zebu cattle.

MATERIAL AND METHODS

Sample collection and aging conditions

Sixteen loins (m. *Longissimus thoracis* et *lumborum*) were collected from eight carcasses (right and left sides) of intact Nellore cattle (24 to 36 months old), at 2 d post-mortem. The carcasses were randomly selected from the same lot, with similar weight (300 ± 22 kg) and fat cover (4 ± 1.2 mm-thick at the 12th thoracic vertebrae). The loins from each carcass were identified, vacuum-packed, placed in cooler boxes with ice and transported to the Meat Laboratory at the University of Campinas.

One steak was removed from the central part of each loin (one from the left and another from the right side) for the raw material characterization analyses: pH, water activity, moisture and fat content and tenderness.

Each pair of loin was deboned and cut into eight sections ($n = 64$). The sections were balanced distributed into eight treatments (Figure 1), according to the combination of two dry aging methods (traditional and in highly moisture-permeable special bag), two relative humidity (65 or 85%) and two aging times (21 and 42 d).

The sections assigned for dry aging in highly moisture-permeable special bag (water vapor permeability 2500 g/50 μ/m2/24h at 38 °C and 50% RH, Tublin® 10, TUB-EX ApS, Denmark) were weighed and vacuum packaged. All loin sections were aged in adapted chambers (model VN50R, Metalfrio 2010©, Brazil) kept at 2 °C and 2.5 m/s of air velocity. The sections were repositioned into the chamber every day for the first 10 d. Afterwards, they were repositioned in the chamber every 3 d, in a quick and hygienic manner to minimize risk of contamination.

Weight loss

Weight loss due to evaporation was determined by weighing the loin sections, before and after aging. After removing the dried surfaces, the sections were weighed again to measure the trimming loss. The results were calculated as percentage from the ratio between the weight lost and the initial weight of the portion. Process loss was the ratio of initial weight before aging and the final weight after trimming.

Microbiological analyses

The microbiological analyses were performed in three out of eight loin sections of each treatment. In a preliminary test, no significant difference was observed between different loin sections. For each section, two samples consisted of 10 g of beef (±2 mm-thick) and with no subcutaneous fat were aseptically collected, one internally (after trimming) and one externally (before trimming). Each sample was homogenized with 90 ml of 0.1% peptone water (Difco, Sparks, USA) in stomacher (Stomacher 400 circulator, Seward, UK) for 2 min at 230 rpm. When necessary, more decimal dilutions were performed in 0.1% peptone water (Difco, Sparks, USA).

Plate count agar (PCA, Acumedia, MI, USA) was used to determine the aerobic plate count (APC) and

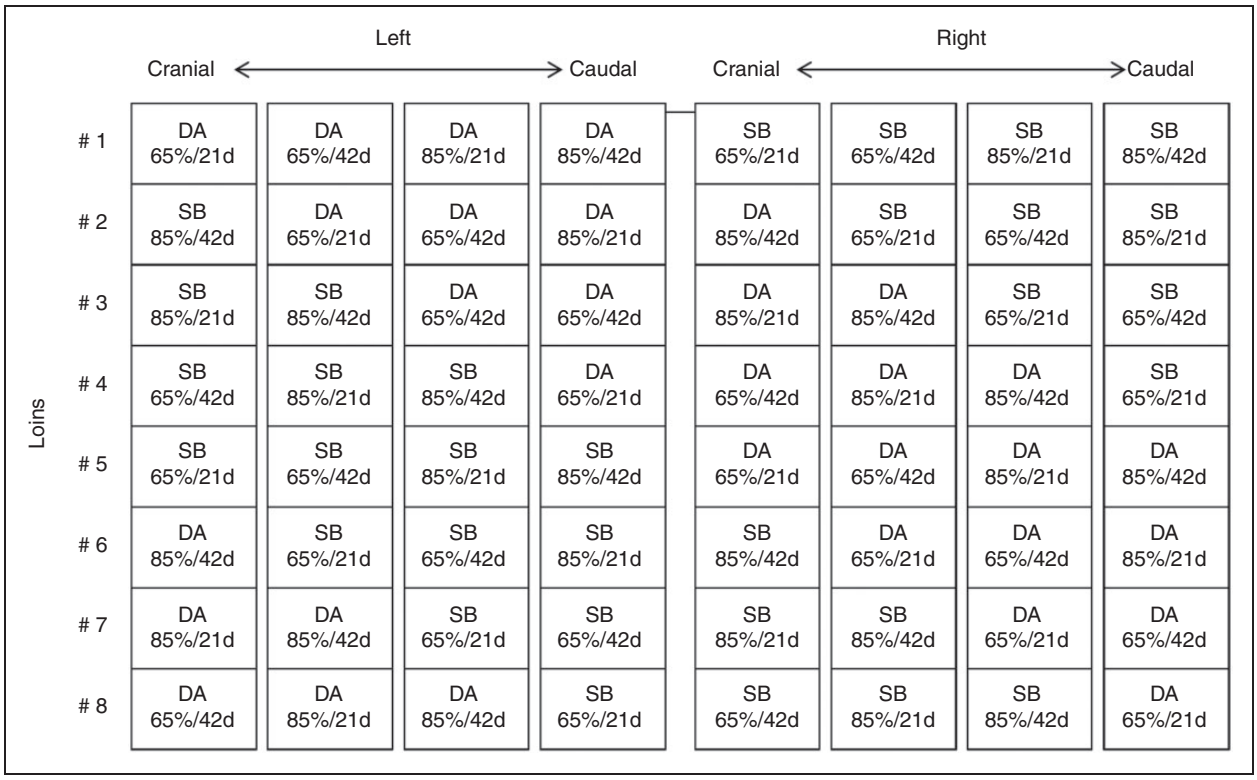

Figure 1. A schematic diagram illustrating the treatment allocation to each section of paired-loins from 8 carcasses based on a balanced complete block design. Traditional dry-aging (DA) and Special bag aging (SB) at two relative humidity (65 or 85%) and two aging times (21 and 42 days).

the psychrotrophics (PSY), with incubation at 35 °C for 48 h (Ryser and Schuman, 2015) and 7 °C for 10 d (Vasavada and Critzer, 2015), respectively. The lactic acid bacteria count (LAB) was performed on Man, Rogosa and Sharpe agar (MRS, Difco), incubated at 35 °C for 72 h in anaerobiosis (Probac, Brazil) (Njongmeta et al., 2015). For *Enterobacteriaceae* (EB), Violet Red Bile Glucose agar (VRBG, Acumedia) with overlay was used (Kornacki et al., 2015). The yeast and mold counts (MYC) were determined on Dichloran Rose Bengal Chlortetracycline agar (DRBC, Acumedia), incubated at 25 °C for 5 d (Ryu and Wolf-Hall, 2015). The molds obtained in the samples were isolated on Czapek Yeast Autolysate agar (CYA) at 25 °C for 7 d and identified by morphological characteristics (Pitt and Hocking, 2009). The Gram staining and catalase test were performed for the confirmation of LAB, *Enterobacteriaceae* and yeast colonies.

pH and water activity

The pH was measured in duplicate by inserting a calibrated potentiometer (MP125 portable pH meter, Mettler Toledo, Brazil) directly into the steak. Water activity (a_w) was determined on a 3 mm-thick sample, collected on the dried surface and internal portion of the loin sections, using the water activity analyzer (Aqualab 4TE, Decagon, Brazil).

Moisture and fat content

The moisture content was determined, in triplicate, by drying lean ground beef in a forced air convection oven, following the AOAC methodology (Association of Official Analytical Chemists, 1990). The fat content analysis was performed in triplicate on the non-aged steak, according to the Bligh and Dyer (1959) methodology.

Warner-Bratzler shear force and cooking loss

The steaks were cooked in an electric oven (FRITOMAQ, Brazil) regulated at 170 °C, until reaching the internal temperature of 71 °C, following the AMSA (2015) procedures. The internal temperature was measured by a Copper-Constantan thermocouple (Omron E5CWL, CSW), inserted into the geometric center of the steak.

After cooking and weighing, the steaks were cooled at room temperature, wrapped in polyvinyl chloride film and then chilled overnight at 4 °C, according to AMSA (2015) protocol. Six cylinders

(1.27 cm-diameter) were removed from each steak using a coring cutter, parallel to the muscle fiber orientation. Each cylinder was sheared in a texturometer (TA-XT plus, Texture Technologies Corp. Stable Micro Systems, UK), equipped with a 1 mm-thick Warner-Bratzler blade (AMSA, 2015).

Each steak was weighed, prior to and after cooking, and the cooking loss was calculated according to the following equation: (raw weight – cooked weight/raw weight) × 100.

Statistical analyses

The initial experimental design for this study was a factorial $2 \times 2 \times 2$ by the combination of two dry aging methods (traditional and highly moisture-permeable bag), two relative humidity (65 or 85%) and two aging times (21 and 42 d) as described in Figure 1 ($n = 8$; 8 animals × 2 carcass side × 4 sections = 46 sections for 4 treatments). The eight treatments were distributed along the two loins from the same animal according to an extended Latin Square design with randomized order of location on the first animal. However, the samples aged at 85% of relative humidity presented signs of deterioration with 21 d of aging, with presence of mucus and a strange odor. Therefore, the samples that would be aged for 42 d had to be discarded (32 from 64 samples were discarded).

Thus, all data obtained in the physical-chemical and instrumental analyses, at 21 d of aging, were analyzed using the factorial variance analysis (ANOVA) from Statistica 10.0 software (StatSoft, USA, 2010) using a model with the fixed main effects of aging methods and relative humidity and the random effect of animal, carcass side and section, with eight replicates. The microbiological results were evaluated by One way variance analysis (ANOVA). The mean values obtained (± SEM) were analyzed by the Tukey test at 5% significance level.

RESULTS AND DISCUSSION

Sample characterization

The non-aged samples had pH 5.39 ± 0.01. The contents of fat and moisture were 3.08 ± 0.30% and 74.94 ± 0.45%, respectively, and subcutaneous fat thickness was 4.17 ± 0.28 mm. Water activity was 0.993 ± 0.001 and instrumental tenderness was 4.48 ± 0.09 kg.

Weight loss

Samples aged at 65% RH presented higher evaporation and process losses compared to samples aged at 85% RH ($P < 0.05$; Table 1).

No differences were observed in the evaporation losses between traditional and special bag dry-aged samples ($P > 0.05$; Table 1). However, trimming and process losses were higher in the traditional dry-aged samples ($P < 0.05$; Table 1) compared to those in special bag.

Literature data on weight losses of traditional dry aging and in special bag are divergent. Dikeman et al. (2013) observed lower evaporation losses and higher trimming losses in samples aged in special bag than in the traditional method; nevertheless, total process losses did not differ. Ahnström et al. (2006) reported that, at 21 days of aging, traditional dry-aged samples presented higher evaporation and trimming losses, compared to the samples aged in special bag. These differences may be explained by conditions of relative humidity, temperature and air velocity used in each of these studies.

There was interaction between the aging method and relative humidity for trimming losses ($P < 0.05$). At 65% RH, no differences were observed in trimming losses for both aging methods ($P > 0.05$). However, at 85% RH, the samples aged in special bag (11.84 ± 0.61%) had lower trimming losses compared to

Table 1. Mean ± SEM of evaporation, trimmings and process losses of traditional and special bag dry-aged samples.

	Evaporation (%)	Trimming (%)	Process (%)
Aging Method			
Traditional (n = 16)	15.10 ± 1.22	18.31 ± 0.85	31.06 ± 1.24
Special bag (n = 16)	14.28 ± 1.12	13.78 ± 0.69	26.03 ± 1.43
P-value	0.20	<0.0001	<0.05
Relative Humidity (RH)			
65% RH (n = 16)	18.91 ± 0.45	16.89 ± 0.62	32.47 ± 0.86
85% RH (n = 16)	10.47 ± 0.44	15.20 ± 1.18	24.62 ± 1.28
P-value	<0.0001	0.10	<0.0001
Method x RH			
P-value	0.36	<0.05	0.26

Evaporation: weight ratio before and after sample aging; **Trimming:** ratio of trimming weight (dried surface) and weight after the dry aging process; **Process:** ratio of initial weight before aging and the final weight after trimming.

traditional dry-aged samples ($P < 0.05$; $18.56 \pm 1.55\%$). In addition, dry aging in special bag at 85% RH also presented lower trimming losses than the same aging method at 65% RH ($P < 0.05$; $15.73 \pm 0.75\%$). Higher values of relative humidity led to an intense formation of mucus on the traditional dry-aged samples and consequently require a deeper removal of the crust surface region. In the process with a special bag, the formation of mucus was less intense due to the protection caused by the plastic bag, even in high relative humidity.

Microbiological analyses

Before aging, no PSY, LAB or MYC were detected on samples (<1 log CFU/g). APC and EB counts were 1.6 and <1.1 log CFU/g, respectively.

After 21 days at 65% RH, LAB counts remained below the detection limit (<1.0 log CFU/g) in both aging processes (Table 2). Low counts of LAB in samples dry aged between 50 and 75% RH were also observed in other studies (Campbell et al., 2001; DeGeer et al., 2009; Hulánková et al., 2018; Li et al., 2013). However, Li et al. (2014) detected 4.4 and 3.2 log CFU/g after 19 days at 75% RH in samples of dry aging bag and traditional dry aging, respectively. In addition, EB was isolated from only one special bag sample, with a count of 1.3 log CFU/g. No recommendations for acceptable EB level for dry aged beef are available. The European criterion for bovine carcass is ≤2.5 log CFU/g (Commission Regulation (EC), 2005). Samples of meat surface of special bag had higher MYC than meat surface samples of the dry-aging process ($P < 0.05$, Table 2). Molds were isolated in 33.3% of dry-aged samples and in 66.6% of samples aged in special bag. However, other studies reported higher yeast counts in traditional dry aging than in dry aging in bags (Ahnström et al., 2006; DeGeer et al., 2009). In our study, all molds were identified as *Aspergillus sydowii*. There is no previous report on this fungal species in dry-aged meat or in the special bag form. This species has been recovered from cured meat and the minimum aw for growth is 0.78 (Pitt and Hocking, 1997).

For the APC and PSY counts, the surface of samples aged in special bag had higher counts of PSY ($P < 0.05$), whereas dry-aged samples presented higher APC ($P < 0.05$). Nevertheless, for both microbial groups and aging methods, counts remained around 4 log CFU/g. Other authors reported APC ≥5log CFU/g, but most studies used higher RH and storage temperature (Gudjónsdóttir et al., 2015; Kim et al., 2019; Li et al., 2013, 2014) have also observed higher counts of APC on the surface of traditional dry-aged samples. After trimming APC was <3 log CFU/g for both treatments. Meanwhile the samples from traditional

Table 2. Microbial counts (log CFU/g ± SEM) in traditional and special bag dry-aged samples for 21 days at 65 and 85% of relative humidity.

	65%				85%			
	Traditional (n = 3)		Special bag (n = 3)		Traditional (n = 3)		Special bag (n = 3)	
Microbial groups	Internal	Surface	Internal	Surface	Internal	Surface	Internal	Surface
APC[1]	2.65 ± 0.21e	4.12 ± 0.06d	2.54 ± 0.16e	1.39 ± 0.21f	5.26 ± 0.14c	9.47 ± 0.13a	3.61 ± 0.23d	7.34 ± 0.08b
PSY[2]	6.22 ± 0.29c	2.88 ± 0.14e	4.61 ± 0.36d	4.22 ± 0.21d	7.21 ± 0.08bc	10.55 ± 0.19a	4.26 ± 0.14d	8.15 ± 0.12b
EB[1]	<1.00 ± 0.00d	<1.00 ± 0.00d	<1.00 ± 0.00d	<1.10 ± 0.10d	3.42 ± 0.23b	7.71 ± 0.27a	<1.10 ± 0.10d	2.58 ± 0.20c
LAB[1]	<1.00 ± 0.00d	<1.00 ± 0.00d	<1.00 ± 0.00d	<1.00 ± 0.00d	5.07 ± 0.11b	8.15 ± 0.34a	2.43 ± 0.15c	5.62 ± 0.11b
MYC[2]	<2.00 ± 0.00d	<2.28 ± 0.28d	<2.00 ± 0.00d	2.97 ± 0.03c	<2.00 ± 0.00d	5.56 ± 0.04a	<2.10 ± 0.10d	4.49 ± 0.11b

APC: Aerobic plate count; **PSY**: Psychrotrophic plate count; **EB**: *Enterobacteriaceae*; **LAB**: Lactic acid bacteria; **MYC**: Mold and yeast count; **Internal**: microbial counts on the internal part (meat) of samples; **Surface**: microbial counts on samples surface. Different letters within the same row indicate significant differences ($P < 0.05$).
[1]Limit of detection: 1 log CFU/g.
[2]Limit of detection: 2 log CFU/g.

dry-aged process showed a significant increase in the PSY count, achieving 6.22 log CFU/g. In addition, no difference ($P > 0.05$) was noted between surface and internal dry-aged beef samples from special bag.

At 85% RH, most samples, both internal and surface, from the traditional dry aged process showed higher counts for all microbial groups compared to samples aged in special bag ($P < 0.05$). APC and PSY reached 9.47 and 10.55 log CFU/g, respectively, on the surface of the traditional dry-aged samples. Although the dry aging process provided the highest counts, a significant microbial growth was also noted in samples aged in special bag, 7.34 log CFU/g for APC and 8.15 log CFU/g for PSY (Table 2). The APC results are similar to those obtained by Li et al. (2014) for dry aging and special bag processes performed for 19 days at 2.9 °C, 8.75 log CFU/cm^2 and 6.57 log CFU/cm^2, respectively. However, values between 3.00 and 5.00 log CFU/cm^2 were reported in other studies conducted in high RH values (87% RH, Ahnström et al., 2006; 85% RH, Hulánková et al., 2018; 91% RH, Li et al., 2013).

Few studies have investigated the effect of relative humidity (RH) during dry aging on the microbial population (Dashdorj et al., 2016). According to Hulánková et al. (2018), some spoilage signal such as off-flavor can be detected in meat with bacteria counts around 7 log CFU/g. However, there is no mention in the literature about the maximum tolerable count for mold and yeast in dry aging beef or other meat. At 85% RH, after 21 days, dry aged samples showed several signs of deterioration, such as discoloration, high viscosity and bad odor (Zagorec and Champomier-Vergès, 2017), with APC and PSY counts >7 log CFU/g (Table 2). Meat spoilage observed in the highest RH may be related to superficial water activity of samples, 0.99 versus 0.95 at 65% RH. The presence of high water activity associated to pH > 5.3 (Table 3) provided a favorable environment for microbial development. The internal portion of aged samples also presented a_w values higher than 0.99 (Table 3). Thus our results demonstrated that both methods at 65% RH and 2 °C, even during a prolonged aging times, keep microbial counts below deterioration levels.

pH, water activity and moisture content

The dry aging method and the relative humidity percentage did not affect the pH values ($P > 0.05$; Table 3). Other studies also found no differences in the pH values between the dry aging process, traditional process, and in highly moisture-permeable bag (Berger et al., 2018; Stenström et al., 2014).

The samples aged at 85% RH had higher internal and external a_w values ($P < 0.05$; Table 3) compared to those aged at 65% RH. Regarding the dry aging method, samples in special bag presented higher internal a_w values ($P < 0.05$; Table 3) than traditional dry-aged samples. However, the dry aging method did not affect the external a_w values ($P > 0.05$; Table 3). Water activity is one of the most important factors that control microbial growth in food (Lewicki, 2004). In the case of the dry aging process, the reduction of water activity on the product surface, together with the low temperature, are the factors that control the microbiota, since the meat is exposed to oxygen, different from the wet aging (vacuum). Lower values of water activity on the surface of the meat tend to provide greater conservation, increasing shelf life (da Silva et al., 2019). In the case of changes on product's internal water activity, it can modify the speed of lipid oxidation and the releasing of free amino acids, peptides, and the breakdown of ribonucleotides, that would have an effect on the flavor development (Dashdorj et al., 2016; Karel, 1980; Savell and Gehring, 2018).The aging

Table 3. Means ± SEM of pH, water activity, moisture, cooking loss and Warner-Bratzler shear force of traditional and special bag dry-aged samples.

	pH	Internal a_w	External a_w	Moisture (%)	Cooking loss (%)	WBSF (kg)
Aging method						
Traditional (n = 16)	5.51 ± 0.01	0.9887 ± 0.0006	0.9730 ± 0.0060	73.82 ± 0.33	19.98 ± 0.55	3.40 ± 0.10
Special bag (n = 16)	5.51 ± 0.01	0.9907 ± 0.0004	0.9813 ± 0.0050	73.94 ± 0.28	20.09 ± 0.67	3.39 ± 0.15
P-value	0.90	<0.05	0.08	0.76	0.90	0.26
Relative Humidity						
65% RH (n = 16)	5.53 ± 0.01	0.9889 ± 0.0006	0.9599 ± 0.0046	73.46 ± 0.34	19.62 ± 0.63	3.61 ± 0.12
85% RH (n = 16)	5.49 ± 0.01	0.9905 ± 0.0004	0.9944 ± 0.0015	74.30 ± 0.21	20.45 ± 0.57	3.18 ± 0.11
P-value	0.23	<0.05	<0.0001	<0.05	0.35	0.19
Method x RH						
P-value	0.58	0.72	0.11	0.18	0.69	0.58

Internal a_w: Water activity of the loin internal part; **External a_w:** Water activity of the loin external surface; **WBSF:** Warner-Bratzler shear force.

method did not affect the moisture content ($P > 0.05$; Table 3). Ahnström et al. (2006) also found no difference in the moisture content of traditional and special bag dry-aged samples. Still, at 65% RH the samples presented lower moisture content compared to those aged at 85% RH ($P < 0.05$; Table 3). Several authors (Ahnström et al., 2006; Degeer et al., 2009; Li et al., 2014; Savell, 2008; Stenström et al., 2014; Warren and Kastner, 1992) reported that the development of the characteristic flavor of dry aged meat is due to the concentration of aromatic compounds and free amino acids due to water loss through evaporation. Thus, one of the objectives of the dry aging process is to reduce the product's moisture, thereby ensuring higher sensory notes for attributes such as nutty, buttery, blue cheese and umami (Campbell et al., 2001; Li et al., 2014; Warren and Kastner, 1992). Juiciness is other sensory characteristic that can be affected by the moisture loss. For few authors, the moisture loss during the dry aging process can concentrate the fat and increases juiciness (Berger et al., 2018; Campbell et al., 2001).

Cooking loss and Warner-Bratzler shear force

The aging method and RH did not affect the cooking loss ($P > 0.05$; Table 3). This result was expected as the samples had similar values of moisture content (Table 3), therefore the samples had similar amounts of water available to be lost during the cooking procedure. Berger et al. (2018) and Ahnström et al. (2006) also reported no differences in cooking loss of traditional and special bag dry-aged samples. On the other hand, Dikeman et al. (2013) and DeGeer et al. (2009) found higher cooking losses in samples aged in special bag than in traditional dry aging. These divergences could be explained by the different RH and temperature conditions used in the studies (Dikeman et al., 2013).

No differences were found in the Warner-Bratzler shear force values due to the aging method and RH ($P > 0.05$; Table 3). It is well known that aging increases the beef tenderness, and time and temperature are the most important factors during this process (Khan et al., 2016). In the current experiment, the treatments were aged for the same time and temperature, therefore no differences were expected in the shear force values, regardless of the aging method and RH. Other authors also found no differences in shear force values of traditional and special bag dry-aged beef (Ahnström et al., 2006; Berger et al., 2018; DeGeer et al., 2009; Dikeman et al., 2013).

Findings of this study should be considered in light of the limitation related to the sample size, which was based on other experimental studies (Bernardo et al., 2020; Cameron et al., 2020; da Silva et al., 2019; Kim et al., 2016; Li et al., 2014; Vilella et al., 2019) and not explicitly calculated.

CONCLUSION

The results from the current study indicated that aging of beef from Zebu cattle, with low fat cover, resulted in a highly tender product, regardless of the aging method and relative humidity condition. Furthermore, given the conditions used in this study, the use of highly moisture-permeable bag could be considered an alternative to produce dry-aged beef with lower process losses and without changing physical-chemical properties of meat, when compared to traditional dry aging. However, dry aging at 85% RH provided high counts of mesophilic and psychrotrophic aerobic microorganisms, leading to deterioration and making dry aging unviable. Due to this deterioration problem, the experiment was finished at 21 days of aging and the samples assigned for 42 days of aging were discarded and was not possible to evaluate the effects of relative humidity and aging method at 42 days of aging. Therefore, further studies on meat physical-chemical properties at variable and high-controlled relative humidity, related with different aging methods and moisture loss rates are recommended to validate and increase the opportunities for this high-value product. In addition, sensory analyses are suggested to evaluate the consumer acceptability of traditional and special bag dry-aged beef.

RESEARCH ETHICS

This study was approved by the Committee of Ethics in Research in Human Beings from the Faculty of Medical Sciences, State University of Campinas (Protocol Number: 69320317.6.0000.5404).

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DECLARATION OF CONFLICTING INTERESTS

The author(s) declare that there is no conflict of interests and that the research was free of bias.

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