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Postmortem Aging of Beef with a Special Reference to the Dry Aging

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Abstract

Animal muscles are stored for specific period (aging) at refrigerated temperatures, during and after which the living muscles start to convert into meat and thus, attain certain superior properties in the final product. Proteolysis, lipolysis, and oxidation are the major biochemical processes involved during the postmortem aging of meat that affect the tenderness, juiciness, and flavor, as well as sometimes may introduce certain undesirable traits. This review analyzes the role of pre- and post-mortem factors that are important for aging and their effect on the chemical and physical changes in the "dry- and wet-aged meat." Thus, if the meat processing manufacturers optimize the effects of aging for specific muscles, the palatability, color, and the shelf life of the aged meat products could be significantly enhanced.

Keywords: meat, aging, pre- and post-slaughter factors, tenderness, flavor

Introduction

Aging of meat, also known as "ripening" or "conditioning", is a natural process and is useful in improving its palatability. On a commercial basis, aging is generally performed by storing the meat under controlled refrigerated conditions to improve several traits of beef that affect consumer satisfaction, such as its tenderness and flavor (McGee, 2004; Piao *et al.*, 2015).

As the tenderness of the meat increases with an increase in the aging time, the time and temperature are two very important factors necessary to obtain a tender product (Mottram, 1998; Nishimura *et al.*, 1995). The tenderness of the aged meat varies with the type of muscles and amount of connective tissue present. This is because different muscles require variable aging periods to achieve appropriate tenderness according to the consumer's expectations (Bratcher *et al.*, 2005; Monson *et al.*, 2005).

Aging improves the flavor, mouthfeel, and juiciness of

beef (Irurueta *et al.*, 2008). Aged beef possesses a peculiar salty or roasted flavor in comparison to the unaged beef (Bruce *et al.*, 2005; Gorraiz *et al.*, 2002). It has been reported that slaughtering results in an interruption of the circulatory system, thus, leading to accumulation of metabolic by-products in muscles and consequently decreasing the pH, which in turn causes favorable changes in the flavor of the beef (Yancey *et al.*, 2005). The level of lipid oxidation increases as the aging time is increased, thus, resulting in the release of products that react with the protein degradation products and impart an intense flavor to the aged beef.

The color of the meat surface and its stability are critical parameters governing the marketability of fresh beef. Furthermore, the internal color of the cooked meat is used as an indicator for the degree of doneness and point of consumption (Suman *et al.*, 2014). Vitale *et al.* (2014) observed lower color stability in *longissimus thoracis* (LT) muscles of Friesian beef after 14-21 d of wet aging in comparison to 0-8 day-aged samples and attributed this difference to the myoglobin and lipid oxidation. The denaturation of proteins during aging results in a lighter color and reduced water activity in aged beef (Jayasooriya *et al.*, 2007).

The two commercial types of aging for beef are dry

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aging and wet aging. In dry aging, the meat is placed in a refrigerated room without any packaging, while in wet aging, the meat is vacuum-packed and stored (Smith *et al.*, 2008). The time for beef aging varied considerably with temperatures and an extended time has been reported to enhance the textural and flavor properties of the meat (Leroy *et al.*, 2003). However, optimal time for dry aging is 14-21 d while for wet aging 7-10 d at specific temperature (0-1°C). Dry-aged beef possesses a beefy and roasted flavor, which differs from the flavor of wet-aged beef, which is bloody and metallic in nature (Campbell *et al.*, 2001; Warren and Kastner, 1992). Various studies have been conducted on the palatability of aged beef, a number of which have shown that aging makes the meat tender (Parrish *et al.*, 1991; Warren and Kastner, 1992); however, a disagreement exists in these studies about the palatability aspect. Campbell *et al.* (2001) concluded that dry aging for a minimum of 14 d improves the palatability characteristics of meat compared to vacuum aging, and that the development of these attributes in the meat are sufficient to offset the increased expenses incurred due to dry aging. Dry-aged meat products have more characteristic flavor in comparison to wet-aged or un-aged products (Diles *et al.*, 1994; Warren and Kastner, 1992). However, no difference or decrease in the palatability attributes, other than tenderness, was observed (Savell *et al.*, 1978). Hodges *et al.* (1974) observed an increase in the beef flavor intensity in the 15-d dry-aged USDA Choice short loin in comparison to the control, while USDA Standard short loin showed a lower beef flavor intensity compared to the control. A higher moisture loss during the dry aging process makes it more expensive and hence, makes the availability of dry-aged meat possible at specialty shops only rather than ordinary food stores (Stenstrom *et al.*, 2014). A new bag technology that possesses a very high water vapor transmission rate has been introduced in dry aging in order to achieve beef with equal sensorial qualities compared to the dry aging process under less harder conditions. Ahnstrom *et al.* (2006) have conducted dry aging of beef for 14 and 21 d using the traditional dry aging and bag aging techniques and observed no differ-

ences in the flavor and meat physicochemical qualities. However, there was a significant decrease in the weight and trim loss for bag-aged samples. Xin *et al.* (2013) also produced dry aged beef using dry aging bag under controlled conditions without negative effects on sensory and quality attributes. These findings were in line with DeGeer *et al.* (2009) who stated non-significant differences in sensory of conventional and in bag dry aged beef. However, dry aging in bag has positive effect on yields. A summarized quality comparison of dry- and wet-aged beef is presented in Table 1.

Lipolysis, proteolysis, and oxidation are some of the biochemical reactions that occur during postmortem aging. Proteolysis includes the breakdown of myofibrillar proteins that release peptides and amino acids, which act as water-soluble flavoring precursors (Spanier *et al.*, 1997) responsible for the taste properties and flavoring characteristics of the meat (Koutsidis *et al.*, 2008). These products react with the reducing sugars and contribute to the meat flavor (Imafidon and Spanier, 1994). Further, the free fatty acids released due to the degradation of lipids result in the production of peroxides, which react with peptides to form the aroma compounds (Zhou and Zhao, 2007).

The quality of beef product depends on a number of pre- and post-mortem factors. Pre-mortem factors that affect the quality of the final aged product include the breed, genetics, gender, energy level of the diet of the animal, and, most importantly, the type of muscle selected for the aging process (Monson *et al.*, 2005). Water is expressed during the aging process, resulting in an increase in the trim, weight, and cooking losses (Jayasooriya *et al.*, 2007). The objective of this review is to provide insights into the beef dry aging process and to emphasize on the factors that influence aging. This article also discusses the future implications of the new emerging technologies in the field of postmortem aging.

Physicochemical Changes during Postmortem Aging

The postmortem storage and processing conditions af-

Table 1. Quality comparison of dry- and wet-aged beef

Parameters	Dry aging	Wet aging
Tenderness	Improved (Campbell *et al.*, 2001; Sitz *et al.*, 2006; Warren and Kastner, 1992)	Improved (Parrish *et al.*, 1991; Sitz *et al.*, 2006; Warren and Kastner, 1992)
Flavor	Flavorsome (Campbell *et al.*, 2001; King *et al.*, 1995; Warren and Kastner, 1992)	Mostly unchanged (King *et al.*, 1995)
Yield	Low (Laster *et al.*, 2008; Smith *et al.*, 2014)	High (Laster *et al.*, 2008; Smith *et al.*, 2014)
Cost	High (Sitz *et al.*, 2006)	Slightly higher (Sitz *et al.*, 2006)

fect the flavor and tenderness of the meat (Perry, 2012), and are important for improving the final quality of the product (Honkavaara *et al*., 2003). Animal slaughtering results in an interruption in the cell control systems, and enzymes are produced that start attacking different cell molecules indiscriminately, thus, turning large flavorless molecules into smaller flavorsome fragments (McGee, 2004). The proteins are broken down into savory amino acids and fats, into corresponding aromatic fatty acids that contribute to the characteristic nutty and meaty flavor of the dry-aged meat. Furthermore, these breakdown products react with other ingredients during cooking and enrich the aroma of the meat by producing new flavoring molecules. Aged beef possesses a strong, savory, and roasted odor compared to the un-aged beef, which has a weak and bland odor. Certain flavor notes like fatty, beefy, brothy, sweet, and caramelly are increased by aging the beef for up to 14 d, while some undesired flavors like painty, cardboard, bitter, and sour also get introduced during aging (Bruce *et al*., 2005; Gorraiz *et al*., 2002; Spanier and Miller, 1993). The interruptions in the circulatory system upon slaughtering result in the accumulation of lactic acid and a drop in the pH, which facilitates these changes in the flavor. Presence of a lower pH (5.4) activates endogenous enzymes, like cathepsins B and L and thiol proteinases (which hydrolyze more peptide bonds in comparison to any other proteases), which are intracellularly redistributed during aging (Spanier *et al*., 1990; Spanier *et al*., 1997). These enzyme activities are independent of the changes in the temperature, and cathepsins B and L retain their high activity even at cooking temperatures (70°C). The production of flavoring compounds in the meat is influenced by the redistribution of enzymes and their activity due to the combined effects of postmortem aging and cooking.

The μ- and m-calpains responsible for postmortem textural changes increase the rancid, sour, and salty flavors of the meat by producing certain peptides. Bauer (1983) has stated in his study that glutamic acid content was observed to more than double during the 7 d of aging (9 mg/100 g on day 4 to 21 mg/100 g on day 7). Furthermore, the microbial breakdown of proteins also contributed to glutamic acid production. Production of carbonyls resulting from lipid oxidation was increased during aging and may contribute toward the development of considerably undesirable flavors. A longer aging period of 35 d may increase the metallic flavor of the meat, as aging for more than 21 d decreases the flavor identity (Yancey *et al*., 2005). Moreover, microbial degradation of lipids also has

a significant role in increasing the concentration of flavor precursors during the aging process. The aging conditions influence the meat flavor; for instance, a high-oxygen environment results in the production of burnt and toasted off-flavors. A more 'aged beef' aroma is attributed to the presence of derivatives of 2-methyl-3-furanthiol (Rowe, 2002). Dry aging results in a more intense beef flavor in comparison to vacuum or carbon dioxide packed aging (Jeremiah and Gibson, 2003; Sitz *et al*., 2006). The inosine-5'-monophosphate (IMP) concentration is found to decrease during aging, with a simultaneous increase in inosine and hypoxanthine concentrations (Kato *et al*., 1987). Further, higher concentrations of IMP and its degradation products, were found to be present at around 72 h of postmortem aging, thus, indicating that postmortem metabolism precedes by about 2 d post-slaughter. The proteolytic enzymes are responsible for the breakdown of muscle proteins into smaller fragments, resulting in rigor mortis during the process of conversion of muscles into meat (Miller *et al*., 1997).

Quality Characteristics of Aged Meat

Aging contributes to the structural changes and flavor development of cooked meat (Koohmaraie and Geesink, 2006). Significant alterations were observed in the contents of various chemical constituents like sugars, organic acids, peptides, free amino acids, and nucleotide metabolites during meat aging. Campo *et al*. (1999) have stated that the overall flavor intensity and livery flavor development in the meat increased throughout the aging process, as also previously proposed in the study by Smith *et al*. (1978). The formation of peptides during the postmortem aging leads to the development of flavor precursors and evolution of flavors (Etherington, 1987; Koohmaraie *et al*., 1988). The inter-reactions of the flavor precursors and their reaction with other compounds results in the formation of new flavor compounds (Bailey *et al*., 1989). Aging carried out for 10 d also results in an increase in the acid flavor, as described by Spanier *et al*. (1997). The umami, butter fried taste, and tenderness in the meat were found to increase with an increase in the presence of free amino acids and other beef flavor precursors that are produced as a result of a high degree of proteolysis associated with longer aging periods (Koutsidis *et al*., 2008). Daszkiewicz *et al*. (2003) have observed a better taste in the beef samples of m. *longissimus lumborum* that were conditioned at 0-2°C and stored for longer periods of time (10-14 d) in comparison to those conditioned for 3-7 d.

This study indicates the positive effects of aging on the organoleptic properties of beef (Daszkiewicz *et al.*, 2003). Jeremiah and Gibson (2003) observed an increase in the tenderness, flavor intensity, and desirability of beef ribs and short loins that were aged for a period of four weeks. The beef aged for 7 d also showed an enhanced aftertaste and characteristic flavor (Gorraiz *et al.*, 2002). Further, the amount of volatile compounds derived from fatty acid degradation showed an increase in the products produced because of lipolytic enzyme activity.

The aging of meat affects the color composition of beef, as aged beef has brighter and slightly red color due to the enzymatic changes that result from the breakdown of certain proteins (Gasperlin *et al.*, 2001; Jayasooriya *et al.*, 2007). The maintenance of red color in the beef is considered to be an important parameter while deciding the quality of marinated meat and is also a quality criteria decided by the consumer. The fresh red color of meat is presumed to correlate with its freshness and is therefore given utmost importance, as all the variations in the muscles are reflected through its color. The myoglobin content in the muscles is a measure of the meat color and depends on several technological and biochemical factors. The color of the meat products that are subjected to the same internal temperatures varies significantly, thus, posing difficulties for the meat industry to fulfill consumer expectations. The factors responsible for variation in the meat color may include meat pigment content, pH, protein denaturation, and cooking temperature (Trout and Schmidt, 1984). Aging results in protein hydrolysis, which produces different amino acids that may result in an increase in the pH (Gasperlin *et al.*, 2001; Jayasooriya *et al.*, 2007). Moreover, the aging time affects the instrumental color parameters in *longissimus dorsi* muscles (Boakye and Mittal, 1996).

Comparison of the Yield and Quality Traits

The moisture loss during fabrication, packaging, and processing of meat is a major cause of quality change, and since meat is sold on weight basis, it is necessary to select a product that has high water-holding capacity. Water-holding capacity and color are often related to the final pH, and these factors are utilized by the packers as a quality indicator of meat. The enzymatic reactions of certain endogenous enzymes result in a decrease in cooking loss, as the holding time is increased. The water holding capacity of meat is increased by the presence of collagenase enzymes that fragment the connective tissues and myofibrillar proteins and, thus, are responsible for improving the water-holding capacity of the meat (Bruce *et al.*, 2005). The cooking temperature and rate of cooking influence cooking losses because protein coagulation and a reduction in the protein network occur at a temperature of 70°C. A rapid increase in the internal temperature to 70°C results in lower cooking loss and production of juicier meat in comparison to slowly cooked meat at the same temperature. Higher temperatures result in rapid coagulation of proteins on the beef surface, and a sudden formation of this layer on the surface decreases the cooking losses due to dripping and evaporation (Lawrie, 1998). Laster *et al.* (2008) studied the comparison of dry and wet aging (35 d) of the USDA Choice and Select meat cuts with respect to the retail cutting yields and consumer sensory attributes. They observed that dry-aged sub-primal cuts had lower saleable yields and an increased processing time. Furthermore, the consumers were unable to distinguish the variations in the sensory attributes in the meat produced by the two types of aging processes. In a similar study, Smith *et al.* (2014) compared the dry and wet aging for US Choice and US Select beef by assessing the retail cutting yield and consumer palatability evaluation during the 35 d of aging process. They revealed a lower saleable yield and an increase in the cutting time for dry-aged steaks compared to the wet-aged steaks. However, consumers were unable to determine any differences between the dry- and wet-aged steaks at different periods of aging.

Relative humidity (RH) significantly influences the saleable yield of the meat, and various RH values have been reported in the literature for beef dry aging process. Campbell *et al.* (2001) studied dry-aged beef in a cooler with 75% RH. Parrish *et al.* (1991) studied the aging process with RH ranging from 80% to 85%, and Warren and Kastner (1992) stored meat products at 78±3% RH; on the other hand, Ahnstrom *et al.* (2006) used an 87±2.6% value for RH. The compounds responsible for flavor development build up during the process of dry aging, resulting in an improved flavor of the dry-aged meat products. On the contrary, shrinkage results in reduced saleable yield of the product, which suggests that the ultimate price of the steaks need to recuperate this loss. Parrish *et al.* (1991) have reported that cooler shrinkage ranges from 3.31% to 4.74% for ribs and 14-d dry-aged loins and 4.54% to 6.53% for ribs and 21-d dry-aged loins. In addition, the trim loss from these cuts after 21 d of dry aging ranged from 5.06% to 6.55%. In comparison, the companion ribs and loins that were wet-aged for 21 d showed no shrinkage and had trim losses ranging from 0.55% to 1.17%.

Oreskovich et al. (1988) reported that at the end of 7 d of aging, the striploins that were dry-aged exhibited 4.62% shrinkage, which was significantly higher in comparison to the steaks packaged in polyvinyl chloride films (2.93%) and vacuum-packed steaks (0.55%). Ahnstrom et al. (2006) conducted a study to compare the moisture losses in normal dry aging and moisture permeable vacuum bag aging processes. They observed no weight loss differences between the dry-aged (6.5%) and vacuum bag-aged (6.3%) processes for striploins after 14 d. However, striploins that were dry-aged for 21 d showed significantly greater weight loss compared to the vacuum bag-aged striploins aged for the same period of time (i.e., 10.2% vs. 8.8%, respectively). However, trim losses were significantly high in 21-d dry-aged meat. Sensory traits and shear force did not differ among the aforementioned four different aging treatments, which suggest that the use of highly moisture-permeable bags may provide an alternative to the normal and unprotected dry aging process.

The major financial losses in the beef industry could be attributed to cooking, which results in the loss of several essential minerals and vitamins, ultimately deteriorating the nutritional quality of the beef (Muchenje et al., 2008). Cooking is an essential parameter for sensory perception and is a process of heating the beef at elevated temperatures, which breaks down proteins and make it more palatable and tender (Garcia-Segovia et al., 2006). Losses occur in all types of cooking methods, including roasting and boiling (Shilton et al., 2002). Meat scientists and technologists have paid less attention to cooking losses, which result in weight reduction in beef during the cooking process (Vasanthi et al., 2006), either through dripping, thawing, and/or evaporation (Obuz et al., 2004).

Factors Influencing Postmortem Aging

Pre-slaughter factors

A meat product is considered acceptable by a consumer based on its nutritional values, sensory characteristics, accessibility, and impact on the health (Azzurra and Paola, 2009). The breed of the animal, its sex, diet, live weight, and their interactions influence the meat quality, fat deposition, and fatty acid composition of the meat (Campo et al., 1999; De Smet et al., 2004).

The breed of the animal has a significant influence on the meat tenderness and flavor development, and this factor should be taken into consideration throughout the aging process, while assessing the consumer preferences for beef (Monson et al., 2005). The breed and slaughter weight of

the animal affects the rate of sensory changes that occur during the process of vacuum aging (Campo et al., 1999). Monson et al. (2005) have recommended the consumption of Limousin meat that has been aged for a shorter time (21 d), while the Blonde d'Aquitaine, Holstein, and Old Brown Swiss meats obtained an optimum consumer acceptance when vacuum aged for longer periods i.e., between 21 and 35 d. These differences between the breeds may be attributed to the quantity and solubility of collagen, fatness, and the activities of calpain and calpastatin enzymes. Whipple et al. (1990) considered the calpastatin activity as a major cause for the differences observed between Bos taurus and Bos indicus meat, since Bos indicus meat showed higher inhibitory activities of calpastatin. The genetic differences in beef tenderness were found to be associated with the variation in the rate and extent of muscle postmortem proteolysis (Shackelford et al., 1991; Wulf et al., 1996). Ba et al. (2013) dry-aged beef samples for 29 d and concluded in their study that the breed of the animal (Hanwoo vs. Angus) had a significant impact on the meat quality parameters, sensory characteristics, and presence of volatile flavor compounds.

Gorraiz et al. (2002) studied the impact of aging time on the volatile compounds, odor, and flavor of the beef obtained from Pirenaica and Friesian bulls and steers. They observed that the beef obtained from bulls had a stronger liver-like odor and flavor, while the meat harvested from heifers possessed a characteristic fatty flavor and aftertaste. The Friesian breed exhibited a stronger flavor and aftertaste in comparison to the Pirenaica breed, which was further enhanced due to aging. Seideman et al. (1982) have reported that red steer meat is juicier compared to that of the bulls. The rib roasts from the steers were tenderer, juicier, flavorful, and received higher overall palatability scores in comparison to the rib roasts from bulls (Forrest, 1975). In most cases, the meat obtained from young bulls (17 mon old) showed variations in tenderness compared to the meat obtained from steers (Burson et al., 1986; Dikeman et al., 2013). Morgan et al. (1993) observed a high calpastatin concentration in muscles from bull carcasses, thus, resulting in less proteolysis by calpain and an increased shear force in the bull meat.

The feed of the animal also affects the carcass conformation and physicochemical and sensory parameters of meat, such as proximate composition, fatty acid profile, meat tenderness, and color (Li et al., 2014). Sami et al. (2004) observed that intensively fed bulls possessed higher fat and lower moisture contents compared to the extensively fed bulls. Furthermore, these results were in confir-

mation with the earlier findings by Vestergaard *et al.* (2000), who reported a 50% higher intramuscular fat content for intensively fed bulls. The higher intramuscular fat content decreases the muscle resistance toward shearing, as in the case of soft fat dilute fibrous tissues (Wood *et al.*, 1999). Xie *et al.* (1995) assessed the palatability and lipid composition of crossbred Wagyu beef fed for 90 and 170 d and subsequently aged for 2, 4, and 10 d postmortem. They observed that feeding for a longer period of time (170 d) tended to increase the shear force and decrease the tenderness in the beef. The beef obtained from the animals that were fed for longer periods of time (170 d) required longer aging time (10 d), while the beef harvested from animals that were fed for 90 d achieved an optimum palatability attribute within 4 d of postmortem aging.

The pre-slaughter stress in the animals may result from a number of factors such as handling, restraints, weather conditions, novelty of the environment, hunger, thirst, and fatigue (Apple *et al.*, 2005; Fazio and Ferlazzo, 2003; Grandin, 1997; Mormede *et al.*, 2002). There is a rapid release of catecholamines in the pre-slaughter stressed animals, resulting in glycogen depletion (Lacourt and Tarrant, 1985) and high ultimate pH, thus leading to darker colored meat (Kannan *et al.*, 2002). The secretion of catecholamines significantly changes the energy metabolism (lipolysis and glycogenolysis) in muscles and affects gluconeogenesis (Kuchel, 1991). An increased secretion of glucocorticoids, produced because of fear in the animals, amplifies the mobilization of energy induced by the catecholamines (Dantzer, 1994). Furthermore, the stress in the animals caused due to the transport time required to reach the processing units adversely affects meat sensory qualities and tenderness of the beef (Villarroel *et al.*, 2003).

Post-slaughter factors

The postmortem aging of meat depends upon a number of factors like temperature, air velocity, relative humidity (RH), and UV light. The optimum period for postmortem aging is also an important factor that influences and imparts better texture and flavor to the meat. Various research groups have used different combinations of temperature, RH, and aging time for postmortem aging process, as shown in Table 2.

Although dry aging for a period of 14-35 d seems to be more beneficial in the development of required characteristics, there is no prescribed threshold level beyond the 14-d period to define the beef as "dry-aged" (Silva *et al.*, 1999). Postmortem aging has been shown to cause optimum changes in the tenderness of beef, but it does not ensure uniformity in the tenderness (Geesink *et al.*, 1999). The rate with which the aging process occurs (Bowling *et al.*, 1987) and the type of muscles present also influence the time of aging. The tenderloin and loin muscles require shorter postmortem aging time, as these are soft muscles containing lesser amount of connective tissues (Hwang *et al.*, 2003). On the other hand, the round muscles contain higher amounts of collagen, thus, require longer postmortem aging time in order to become tender (Joseph, 1996). Air velocity also affects dry aging, as an adequate airflow is required for the removal of moisture from the meat. An increased air velocity causes increased moisture loss leading to shrinkage and resulting in greater weight and trim losses (Miller *et al.*, 1985).

The type of muscle fibers also affect the aging and the time required for it, as the muscles rich in connective tissue require comparatively longer time for aging (Huff and Parrish, 1993). The level of metabolic enzymes and ATPase activity also differ among different types of muscle

Table 2. Postmortem dry aging conditions

Temperature (°C)	Relative humidity (%)	Aging time (d)	References
-0.6	78±9.3	35	Laster *et al.*, 2008
0-1.0	80-85	14-21	Parrish *et al.*, 1991
0-4.0	75.00	21	Campbell *et al.*, 2001
1.0	NR	30	Sitz *et al.*, 2006
1.0	83±11	35	Smith *et al.*, 2008
1.6	NR	13	Stenstrom *et al.*, 2014
1.0±1.0	87±7	28	Smith *et al.*, 1978
2.0	NR[1]	14	Jiang *et al.*, 2010
2.5-2.6	87±2.6	14-21	Ahnstrom *et al.*, 2006
2.9	91.00	21	Li *et al.*, 2013
2-5	85-90	40	Lorenzo, 2014
3.1-3.6	78±3	14	Warren and Kastner, 1992
4.0±1.1	98.10	35	Smith *et al.*, 2014

[1]NR, not reported in paper.

fibers. A direct relationship has been considered to be present between meat tenderness and type IIB muscle fibers, as it is known that fast twitch glycolytic fibers carry out glycolysis during early postmortem aging (Totland *et al.*, 1988). A rapid pH decline is observed in the muscles containing higher percentage of type IIB fibers in comparison to the ones containing higher percentage of type I fibers. Higher percentages of glycogen and lactate at around 45 min postmortem are associated with a high percentage content of type IIB and lower percentage content of type I muscle fibers, thus, resulting in higher drip loss and a pale color in the early postmortem meat (Lefaucheur, 2010). On the other hand, a rapid pH decline was observed in mixed fiber types of psoas muscles compared to the glycolytic longissimus muscles and oxidative semispinalis muscles.

The natural proteolytic enzyme system is one of the major factors responsible for meat tenderization (Koohmaraie, 1990). The calpains, more particularly μ-calpains, are involved in the degradation of costameres and loss of cytoskeletal integrity during the initial 48 h of postmortem aging (Boehm *et al.*, 1998; Geesink and Koohmaraie, 1999; Zamora *et al.*, 1996). However, lower levels of proteolysis have been observed during this period, which showed a subsequent increase between 3 and 14 d. Further, this has also been associated with a substantial drop in the activity of μ-calpain by 20% after 24 h of postmortem aging (Boehm *et al.*, 1998). The primary postmortem action of m-calpain in synergy with an increase in the ionic strength (Zamora *et al.*, 1996) and a drop in pH results in substantial denaturation of myofibrillar proteins, which become easier targets for other proteases. However, the possible impact of other protease systems such as cathepsin B and proteosome 6 is also important in achieving the desired tenderness in beef. The cathepsin enzyme systems are found to be same in all the muscles regardless of any differences in the species. The endogenous inhibitor of the m- and μ-calpains is the calpastatin enzyme, and its activity is influenced by the type of species, breed, gender, and other genetic variations among the animals (Koohmaraie, 1992; Shackelford *et al.*, 1991). An augmented postmortem proteolysis was observed in white muscles in comparison to the red ones within different species (Bickerstaffe, 1996; Lefaucheur, 2010), thus, suggesting an increase in the calpain/calpastatin ratio in the white muscles.

The postmortem aging has profound effect on improving beef palatability; however, breeding, feeding, processing, and preparation also play an important role in consumer satisfaction. Thus, pre- and post-slaughter factors should be given due consideration while setting up postmortem aging process parameters.

Emerging Technologies in Postmortem Aging

Postmortem aging is aimed toward achieving flavorsome and tender meat. The desired consistency of meat tenderness could be achieved by incorporation of freezing and thawing method or freezing and thawing involving an additional aging period. These methods can be incorporated for the normal commercial products to improve the meat tenderness (Grayson *et al.*, 2014). Meat tenderness is mainly governed by the presence of calpastatin, and studies have shown that this enzyme is sensitive to cold storage and loses its activity during freezing. Thus, thawing and aging process could allow calpain to be more active, resulting in greater proteolysis and improved tenderness (Koohmaraie *et al.*, 1995).

The pulsed electric field processing of frozen-thawed beef significantly affects the microstructure of muscles resulting in an improvement in beef tenderness [20.13% reduction in Warner-Bratzler shear force (WBSF) in comparison to frozen-thawed control]. This processing also influences the water-binding and water-holding capacities of beef (Faridnia *et al.*, 2014). On the other hand, Liu *et al.* (2015) suggested that controlling the pre-rigor temperature of Chinese yellow cattle carcasses between 12°C and 18°C (-11±1°C, 0.5 m/s for 2 h, holding for 10 h and then 1±1°C, 0.5 m/s for 48 h postmortem) under commercial conditions can significantly improve beef tenderness. They concluded that stepwise chilling treatment significantly decreased the WBSF and improved the myofibril fragmentation index. Bolumar *et al.* (2014) applied the electrohydraulic shock wave treatment to improve the tenderness of beef loin steaks and concluded that hydrodynamic pressure processing or shock wave treatment significantly tenderizes the meat (18% reduction in WBSF) by modifying the microstructure of the muscle fibers. The modification of the microstructure of muscle fibers offers more number of sites for the action of endogenous proteolytic enzymes. Bekhit *et al.* (2014) concluded that physical methods can significantly affect meat tenderization. However, no generic solution could be presented, as these methods vary tremendously in achieving the degree of tenderization that range from no effect to over-tenderization depending on the type of muscle fibers.

The aforementioned methods and other physical technologies applied for meat tenderization could be used syn-

ergistically with the aging process to shorten the required aging period, thus, speeding up the process and increasing the profit margin. However, further investigations are required to determine the optimum level of physical processing and aging time necessary to obtain meat products with improved quality characteristics.

Conclusion

Postmortem aging process changes the structural, quality, and sensorial characteristics of meat. Since dry aging is performed aerobically, it results in significant weight and trim losses; however, it predominantly improves the beef flavor. Flavor development in meat is a result of lipid peroxidation, Maillard reaction, and inter-reactions of lipid oxidation and Maillard oxidation products. A number of pre- and post-mortem factors and conditions during aging affect the quality characteristics of the aged beef. The new bag technology has a great potential in dry aging process, as it combines the concept of vacuum and dry aging methods. Thus, flavorsome meat could be produced with minimum weight and trim losses. The emerging physical technologies employed for achieving meat tenderness could also be used in conjunction with the aging process to obtain the exact tenderness and flavor of the meat and meat products desired by the consumer. Future research in the field of postmortem aging should be focused on the applications of the new emerging physical technologies in the stages prior to aging, in order to shorten the aging time and achieve the desired characteristics in the aged meat.

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