DRY AGING APPLICATION IN HOME TYPE REFRIGERATORS

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ABSTRACT

DRY AGING APPLICATION IN HOME-TYPE REFRIGERATORS

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Since the popularity of meat aging applications is increasing from day to day in commercial cases or in restaurants, consumers are more aware of the quality enhancement obtained by aging and are more willing to apply aging at home by using their existing refrigerator. For this reason, it was aimed to examine the possibility of dry aging in home-type refrigerators. The combined effects of dry aging conditions (air flow rate and aging period) in a specially designed compartment of home-type refrigerators on meat quality were studied. Paired boneless rib steaks fulfilling US Choice degree standards (n = 48) were obtained from calf carcasses having maturity of A class. Rib steaks taken from carcasses were randomly assigned to one of twelve aging treatments (0.50 m/s ; 0.75 m/s ; 1.00 m/s fan speed and 7, 14, 21 or 28 days of aging period) and kept at temperatures of 0 ± 0.5 °C and humidity averaged 80 ± 4 % during the total aging period. As a novel analysis method, image processing was used for shrinkage analysis and NMR relaxometry was applied to examine internal changes. Besides, microbial analysis (total aerobic bacteria, yeast and mold populations), pH change, water holding capacity (WHC), Warner-Bratzler Shear Force (WBSF), moisture content, trim and cook loss, weight loss, color change, peroxide, p-Anisidine and

TBARs values were examined to determine physical and chemical changes during aging period. According to the findings; for chemical analysis, time effect was dominant when compared to fan speed effect. Besides, after 21 days a sharp rise was observed in terms of TBARS and p.A.V meaning that rate of oxidation increased after 21 days. NMR T1 and T2 relaxation times were also affected from aging at different conditions and correlated with WHC and moisture content. For physical analysis, both fan speed and aging time were effective on physical quality and with increasing time and fan speed, yield decreased causing economic loss. From another aspect, water holding capacity had the top value on 21 days of aging. In addition, Aerobic plate count pressed in upon limit value in case of 28 days of aging.

Keywords: Rib steak, Dry aging, Home-type refrigerator

ÖZ

EV TİPİ BUZDOLAPLARINDA KURU YAŞLANDIRMA YÖNTEMİNİN UYGULANMASI

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Yüksek Lisans, Gıda Mühendisliği Bölümü

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Et yaşlandırma uygulamalarının ticari alanda ve restoranlarda bilinirliğinin ve tüketiminin günden güne artmasıyla birlikte; tüketiciler kuru yaşlandırmanın et kalitesinde sağladığı önemli artışın farkına vararak, evlerinde kullandıkları mevcut buzdolaplarını yaşlandırma yapmak üzere kullanabilmeyi istemektedir. Bu sebeple, yapılan çalışmada kuru yaşlandırma işleminin ev tipi buzdolabında uygulanabilirliği sorgulanmıştır. Bu çalışmanın amacı, kuru yaşlandırmada kullanılan farklı uygulama koşulların (farklı fan hızı ve yaşlandırma süresi) ev-tipi buzdolabı içinde tasarlanan yaşlandırma bölmesinde depolanan et kalitesi üzerindeki etkisini incelemek ve ölüm sonrası et kalitesini en fazla arttıracak optimum koşulları bilinen ve yeni geliştirilen analiz yöntemlerini kullanarak bulmaktır. Dana karkaslarından elde edilen ve her bir yaşlandırma koşulu için eşli olarak depolanan kemiksiz antrikot örnekleri (n=48), US Choice derecesi standartlarını karşılayacak ve A sınıfı olgunluğa sahip olacak şekilde seçilmiştir. Dana karkaslarından alınan antrikot parçaları, rastlantısal olarak 12 farklı yaşlandırma koşullarından biri (0.50 m/s; 0.75 m/s; 1.00 m/s fan hızı; 7, 14, 21 veya 28 günlük yaşlandırma süresi) için seçilmiş ve seçilen yaşlandırma süresine göre yaşlandırma süresi

boyunca 0 ± 0.5 °C sıcaklıkta ve 80 ± 4 % bağıl nemde depolanmıştır. Yeni gelişen analiz yöntemleri arasında olan görüntü işleme metodu, büzüşme miktarının incelenmesinde kullanılırken; bir diğer özgün analiz yöntemi olan NMR tekniği ise et dokusunun iç yapısında meydana gelen değişikliklerin incelenmesi için kullanılmıştır. Bunun yanısıra; mikrobiyal gelişim (toplam aerobik bakteri, küf-maya gelişimi), pH değişimi, su tutma kapasitesi, kesme kuvveti, nem içeriği, verim, kesme ve pişirme kaybı, toplam ağırlık kaybı, renk değişimi, yağ oksidasyonunu incelemek amacıyla peroksit, p-anisidin ve TBARs değerlerindeki değişim yaşlandırma işleminin bittiği günde analiz edilmiştir. Analiz bulgularına göre; kimyasal kalite analizleri kapsamında, zaman etkisi fan hızı etkisine göre çok daha önemli bulunmuştur. Ayrıca kuru yaşlandırma sırasında, 21. günden sonra TBARS ve p.A.V değerlerinde ani bir artışın olduğu gözlemlenmiştir. Bu durum, oksidasyonun hızlandığını göstermektedir. Ağırlık kaybı analizleri kapsamında hem fan hızı hem de yaşlandırma süresi etkili görülmüş, artan fan hızı ve zaman ile birlikte verimin düştüğü gözlemlenmiştir. Bu durum ekonomik kayba sebep olabileceği için tüketici bakış açısından oldukça önemlidir. NMR Analizleri sonuçlarına göre, T1 and T2 relaksasyon süreleri farklı yaşlandırma koşullarında değişkenlik göstermiş ve bu süreler su tutma kapasitesi ve rutubet miktarı ile ilişkili bulunmuştur. Mikrobiyolojik analizler sonucunda ise, 28. günde toplam aerobik bakterinin en yüksek değere ulaştığı ve limit değeri bulduğu belirlenmiştir.

Anahtar kelimeler: Antrikot, Kuru yaşlandırma, Ev-tipi buzdolabı

To My Beloved Family

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TBARS	Thiobarbituric acid-reactive substances
p.A.V	p-Anisidine Value
P.V	Peroxide Value
WBSF	Warner–Bratzler Shear Force
C^*	Chroma
CFU	Colony Forming Unit
APC	Aerobic Plate Count
YM	Yeast and Mold
WHC	Water Holding Capacity
MC	Moisture Content
MDA	Malondialdehyde
TCA	Trichloroacetic acid
GLM	General Linear Model

CHAPTER 1

INTRODUCTION

1.1 Aging of Meat

The most important reason why aging is applied to fresh cut meats is improving the palatability characteristic of the product. Also, aging procedure has become a key role for the high expectations and demands of today's industry for both retail and foodservice (George, 2009). In order to increase meat's palatability features like flavor, juiciness and tenderness storing it at cooled conditions is achieved by aging procedure. It is obvious that most important palatability indicator for the customers is tenderness and aging contribute to tenderness of meat and products (Smith, 2007). It is comprehended that series of enzymatic reactions occur during aging process and they lead to significant deviations in the muscle fibers and collagens. With tenderness being an important characteristic of meat, it decreases instantly after cutting process (6-12 hours along) and continues to increase up to 11 days; after which there is no increase (Epley, 1992).

Taylor et al., (1995) argued that although it is known that Z-disk degradation of the myofibrillar structure takes place to enhance tenderness during long term aging, it does not occur during the first 3-4 days of postmortem aging. Proteolysis of muscle proteins which is a process conducted by proteinases (calpains and L, H, D, and B cathepsins) lead to great number of free amino acids and high amount of small peptides occur. Muscle tissue lipids are primarily degraded by high intensity of lipolysis reactions to free fatty acids which then form to volatile compounds due to secondary lipid oxidation. (Page et al., 2002). Calpain causes changes after slaughter in myofibrils which are related with enhanced tenderness and it is initiated by Ca^{2+} (Koohmaraie,

et al, 1988). Calpain activity is set out by an endogenous inhibitor which is named Calpastatin. According to the studies of Johnson et al., (1990) and Wulf et al., (1996)**,** it appears that there is a positive relationship between calpastatin levels and meat toughness that affects the final quality of meat after post mortem aging process.

Different fatty acid, peptide and amino acid alterations are observed in the aging process which is caused by lipolytic and proteolytic enzymes and these alterations bring about various tenderness and flavor ranges. Amount of carbonyl can be increased by lipid oxidation reactions which can contribute to any off-flavor associated with beef aging (Yancey et al., 2005).

Beefs which do not undergo aging processes are labeled as lacking in characteristic meat flavor and having a metallic taste. In contrast, aged beefs are labeled as having a "gamy" taste. Eleven days of aging period results in a real beef flavor because in this duration flavor of beef increases sufficiently. It is certain that during aging process a loss in the weight of beef due to dehydration of fat and lean can be observed in this duration. The reason why an amount of weight loss which is worth to consider occurs during aging is the lean of carcass which is known as the meat part without bone and trimmable fat that consisted of 70% water. The weight loss is rarely associated with air flow rate, temperature and relative humidity. 2% or 3% proportion of carcass' weight is lost due to humidity slightly after slaughter. After this change, aging process causes 1-1.5% shrinkage in tissues in about 7 days period. Carcasses which have a large fat external cover will lose less moisture than carcasses which have a small amount of fat cover **(**Epley, 1992**).** In addition, during his experiments Epley (1992) observed 18% trim and shrink loss from loins aged 14 days in a 36° F cooler.

Today two methods of aging which are dry and wet aging exist. In wet aging, subprimals are stored in vacuum packages, while in dry aging no protective layer or packaging is used and storing conditions are controlled instead (George, 2009). Both dry and wet aging results in flavor development and

tender meat (Warren and Kastner, 1992; Miller et al., 1997; Campbell et al., 2001). When taste of products are compared, there are differences between two methods like dry aged products have roasted flavor while wet aged products have bloody/serumy and sour flavor which is not desirable (Warren and Kastner, 1992). Dry aging delivers unique palatability characters with high weight loss due to excessive trim and shrinkage. In contrast, wet aging allows retailers, packers and processors to use vacuum techniques to prevent weight loss related with excess trimming and shrinkage. Thus wet aging is most common method for aging**.** Both aging methods achieve increased tenderness, but develop quite different flavor profiles (Campbell et al., 2001; Warren and Kastner, 1992).

Dry aging has become a widely used method for butchers to tenderize and preserve beef for centuries. Method of dry aging is a bit expensive due to control of air flow, relative humidity and temperature in order to reach optimum moisture loss. Besides, due to evenly distributing requirements, in dry aging much space is required compared to wet aging. Wet aging products can be stacked and boxed in process thus, less space and conditioning is required. As dry aging time is extended, fabrication loss, trimming time, and amount of trim increases (Campbell et al., 2001). Since most subprimals are vacuum-packaged before cutting into steaks or roasts, wet aging can also take place during shipping (George, 2009).

For elegant restaurants and food service businesses dry-aged products are preferred as priority. Consumers who are pleased with these products in the U.S. demand to have the same taste in their home country. After this demand, elegant restaurants in Indonesia, Korea, Taiwan and Japan started to offer dry-aged products. USMEF (U.S. Meat Export Federation) has received inquiries from many international customers about the opportunity for the U.S. beef industry to offer dry-aged beef cuts (George, 2009).

1.2 Dry Aging

Dry aging is a method of aging without packaging and requires storage at refrigerated temperatures for one to five weeks in order to preserve beef subprimals, primals and carcasses. Special taste of dry-aged beef can only be achieved with dry aging process which allows biochemical and natural enzymatic processes to improve tenderness of beef. Web sites, sales brochures and popular articles are keen on supporting and propagating dry-aged beef with some mottos which are describing advantages of dry-aged beefs over wet-aged beefs. Some examples of these mottos are "earthy and nutty," "mellow and intense," "superior in taste and tenderness," "superb in taste and texture," and "buttery and rich." The question of "which method is better in flavor and taste; dry aging or wet aging?" is still being argued by both customers and producers. Developments in packaging and vacuum techniques which create a new era in aging technology come along with that argue in 1960s. After wet aging method is improved and spread, it has become internationally popular for shipping beef products due to its commercial advantages. Moreover, wet aging become so popular that 90% of the beef marketed was produced with this method in the beginning of 1980s. The reason behind this popularity is the fact that wet aging methods are preventing trim loss and shrinkage which ends up with economic benefits for both retail/foodservice and packer/processor sectors (Savell, 2008).

It is known that sensory tenderness is increased in 14 days period after slaughter but Warner–Bratzler shear values and tenderness scores continue to improve slightly from 14^{th} day through 35^{th} day (Campbell et al., 2001; Laster et al., 2008; Smith et al., 2008). Besides, according to comparison tests dry-aged beefs are scored better than wet-aged beefs despite the huge amount of juiciness evaporative moisture. As dry-aging time was extended, cutting yields, trimming time, and amount of trim increased (Campbell et al., 2001; Laster et al., 2008; Parrish et al., 1991; Smith et al., 2008).

Perry (2011) states that the action of enzymes on the protein changes characteristics flavour and texture of meat during aging. After slaughter of beef, live cells stop functioning and a fast conversion of cells starts. This conversion involves enzymes to attack large and flavorless cells and molecules and turning them into smaller and flavored ones. With this process; fat molecules are transformed into aromatic fatty acids and proteins are transformed to savory amino acids. These relatively small products are forming the intense nutty and meaty taste of beef. Cooking of beef also causes new molecules which are important for aromas enrichment to form with the further attraction of these molecules. Toughness of beef also reduces with the effect of muscle enzymes. The enzyme known as calpain is the major candidate to explain tenderization process during post-rigor (Hopkins and Thompson, 2002). This enzyme mainly weakens the supporting proteins that hold the contracting filaments in place.

Conventionally, a dry aging process is completed in 28–35 days period. During this period, beef loses its weight at trimming and moisture at aging time. The reason for ordinary food shop's to prefer wet-aged meat products is that this method makes dry-aged products more valuable and harder to be reached compared to wet-aged products. As a result, dry-aged meat products are sold only in specialized markets, on-line and classy restaurants (Stenström et al., 2013). Dry aging process requires some special conditions which causes problems for producers like ventilation, hygiene and temperature control for storing the meat. Provided that these requirements are not met, a high risk of microbial contamination risk occurs. In order to create a dry protective layer against environmental threats at the meat exterior, effective ventilation is crucial. (Campbell et al., 2001; Oreskovich et al., 1988; Warren & Kastner, 1992).

Recently, there are many discussions regarding spread of dry-aged products and its accessibility. For this purpose, "dry aging at home" and "commercial type of dry aging" methods are considered to be a solution for dry-aged products being such luxury expense. In past years various studies are

performed over packaging technology in aging process and meat and aging conditions are examined particularly.

Ahnström et al., (2006) used a highly moisture permeable bag with a unique technique in aging process to compare it with traditional processes. Experimental procedure was included slicing the beef and storing loins both traditionally and in the experimental bag. In traditional processing, meat is unpacked while experimental bag provides a package at 3 °C for 14-21 days. The results were quite interesting because there was not any difference in sensory attributes, shear force, cook loss, total plate counts, fat, moisture and pH between the two aging treatments. Furthermore, it is concluded that dry aging in a highly moisture-permeable bag is preferable due to its microbial contamination preservation and effect on profits.

Comparison of wet and dry aging for 14, 21, 28 and 35 days is examined in a study performed by Savell et al., (2007). Palatability and retail yields were two major features of wet and dry aged beef cuts for comparison. As a result it is observed that dry-aged short loins increase costs of production, rise total cutting time and thus reduce yield. Moreover, during the experiments of Savell and his friends consumers were unable to determine differences between dry- and wet-aged steaks and for different aging periods.

In another study, Hunt et al., (2009) performed some studies and made related experiments to see the combined effects of two dry-aging methods (unpackaged and in a bag), two loin-cut styles (bone-in shell loins and boneless strip loins), and two aging times (21 and 28 days). It is found that strip loins lose less weight compared to shell loins and aging time strongly influences the total weight loss. Besides, it is proven that unpacked dry aging led to more weight loss compared to dry aging in a bag. Moreover, dry aging in a bag has no bad effect on beef's flexibility and quality, it increases yield and supplies a controllable aging process.

Li at al., (2013) performed a study in order to examine consumer preference and meat quality for beef *gluteus medius* in two different aging mediums after

14 days of aging. First medium is vacuum environment and other is a moisture permeable dry aging bag. After aging processes it is seen that; samples aged in dry aging bags have higher trim losses and aging but lower water content, cooking loss and thawing loss compared to samples which are aged in vacuum. Besides, it is also seen that total amount of bacteria and yeast count is higher in samples aged in dry aging but they have less lactic acid bacteria compared to samples aged in vacuum. Moreover, it is observed that dry aging bag makes a controllable environment possible and it does not affect product's quality or sensory attributes.

George (2009) also conducted a study to improve dry aging process which maximizes shell-life and taste of beefs while traditional safety specifications are preserved during the process. For this purpose, four type of beef cuts which are top sirloin butts, short loins, short ribs and rib eye rolls are designated by international and domestic consumers. After experimental procedure, it is shown that dry aging, freezing and wet aging have not much effect on customer's sense if the steaks are served immediately after dry aging process. Moreover it is also seen that short ribs which are dry aged has relatively high weight loss (approximately 20% of its own weight) and this increases its price.

Smith (2007) studied the effects of aging conditions for retail channel. The aim of this study was to examine determine retail cutting and palatability characteristics related to dry aged beef. In experimental procedure three cutting types which are short cuts, short loins and beef loins are aged wet and dry for 14, 21, 28 and 35 days. According to experimental results, dry aged short loins increase total cutting time and reduce profits compared to wet samples. Furthermore, it is seen that customers are not capable of distinguishing differences of wet and dry aged steaks and aging durations.

As a conclusion, one of three major changes related to aging process is moisture loss which led to % 30 volume losses and an intense taste. Another characteristic of aging process is tenderization. Chemical reactions occur

when required enzymes exist in the beef and they diminish big molecules and structures into smaller ones. When aging process is done properly, an aged beef has more tenderness than fresh beef. As a last and most significant characteristic change, aging gives beef a tasteful flavor. Reason behind this change is enzymatic and bacterial activity which oxidizes big molecules like fat and protein. Properly dry-aged meat will develop deeply beefy, nutty, and almost cheese-like aromas which is unique.

It is known that rate of change in tenderness is proportionally related to the ambient temperature. As the temperature increases, the tenderness changes more rapidly. To achieve the same level of tenderness a meat should be stored at +5°C for 2 weeks or at –0.5°C for 4 weeks. Besides, temperature rise is not always good factor due to the fact that bacterial reproduction rate also increases with increasing temperature. As a result, temperature levels should be as low as possible in order to prevent microbiological contamination. Moreover, there is a bottom limit for temperature because the meat freezes at –1.5°C, therefore the ideal temperature for long-term aging is –0.5°C ± 1°C. If the meat is going to be aged in short term (1-2 weeks +2-3°C ambient temperature is satisfactory. Whichever temperature is selected, the rate of improvement in tenderness is highest during the early stages of aging, and decreases with time (Small, 2010). Another important point is keeping the storage medium in constant temperature to prevent irregularities in aging process. In order to sustain air conditions, passing rooms or another refrigerated areas should built near to aging rooms.

Another important factor determining the aging characteristics is relative humidity (RH %). If relative humidity is low, bacterial reproduction is restricted but it also causes high weight loss in aging processes. Thereby a balance should be set up according to requirements of retail, customer, aging time and quality. Generally relative humidity is chosen between 75% and 85%, except the applications which use 50% relative humidity. Besides, there are several techniques to solve bacterial contamination problem like air filtration systems and UV lighting (Small, 2010).

Storing the meat in a controlled air flow rate condition is very important due to its influence on trim, yield and exterior surface drying rate. The suggested ranges of the most significant parameters; storage temperature, relative humidity and air speed are summarized in Table 1.1.

Table 1.1 Suggested storage temperatures, relative humidity and air velocity range for dry aging, derived from https://www.usmef.org/guidelines-for-u-s-dry-aged-beef-for-international-markets/

	Suggested Range	**Problems encountered when values are too high**	**Problems encountered when values are too low**
Storage Temperature	0 – 4°C	Excessive microbial growth resulting in product spoilage	Aging process ceases as meat is frozen
Relative Humidity	80 – 85%	Excessive microbial growth	Excessive weight and trim loss
Air Flow	0.5 – 2 m/s	Excessive weight and trim loss	Excessive microbial growth resulting in product spoilage

1.3 Meat Quality Parameters

Meat quality is an extensive description of meat perception and properties which includes attributes such as production-related issues related with meat like animal wellbeing, health issues like bovine spongiform encephalopathy, bacterial contamination subjects like *Escherichia coli* 0157, meat palatability

quality, carcass composition and conformation. Sum of all these factors determine the total quality of meat and criticized by consumer. There are several parameters which determine consumer's decision about meat after serving it. Flavor, tenderness, color and freshness level are the most decision making parameters (Boleman et al., 1997).

1.3.1 Tenderness

Flavor, juiciness and tenderness are most important meat quality parameters and the overall assessment of meat quality is done by the consumer under the thumb of these parameters. However, the main source of consumer complaint and the primary cause of failure to repurchase is the variability in eating quality, especially tenderness (Tarrant, 1998; Bindon & Jones, 2001).

A meat with marbled appearance can be seen tenderer while the meat with the fat deposited in the layer around outside is seen as more tough. Marbling is considered to be an important tenderness indicator which is actually less related to meat's tenderness compared to the lack of aging and stress before slaughter. There are also several factors before slaughter like meat treatment, age of animal, breed, stress during the slaughtering, calcium status, protein intake, pasture species effects and their combined effects. The best meat cuts on an animal can be made tough by stress, handled and slaughtered without it becoming stressed, and the meat aged correctly (Allport, 2005).

Mechanical property changes in the connective tissues and muscle fibers are in the basis of muscle to meat conversion. Initially, toughness increases into rigor, then as proteolysis progresses and rigor is resolved, tenderness increases during aging (Taylor et al., 1995).

Many factors influence the tenderness of beef, including postmortem proteolysis, intramuscular fat, connective tissue, and the state of muscle contraction (Belew et al., 2003). It is still not clearly known that which mechanisms are responsible for the tenderness increase after slaughter and there is a high number of researches conducted on it. Rising tenderness of postmortem aging is considered to be resulted from proteolysis of myofibrillar

proteins which attach myofibrils to sarcolemma and ensure inter- and intramyofibril linkage. Proteolysis of these proteins causes weakening of the structures that leads to an increase in tenderness (Koohmaraie, 1996; Sentandreu et al., 2002).

Muscle fibers contract strongly, immediately after slaughter except for the ones who are stretched by meat's own weight like tenderloin. The contracted muscle fiber bunches cause toughness to increase while resisting to shear forces. In contrast, relaxed muscle fibers elongate under stress and become relatively tenderer. Factors affecting general enzyme activity which are an antagonist which tends to inhibit calpain activity, the amount of calpain enzymes present (age and breed dependent), the temperature at which the meat is stored, the time the meat is left to age and their interactions also play an important role in calpain enzyme to destruct the muscle fibers and obtain a tender meat (Allport, 2005).

Beef tenderness can be measured objectively using mechanical means, mainly mechanical shear force, which is a measure of myofibril toughness (Bouton and Harris, 1972). Warner-Bratzler shear force method is the most common way to measure the mechanical shear force. This method was first developed by K. F. Warner in the late 1920s and was developed further by L. J. Bratzler in the 1930s (Wheeler et al., 1996). A core specimen of muscle which has 1.27 cm thickness is sheared with gradually increased force and the break point is recorded by means of kilograms of force. As the force required shearing the meat increases toughness of meat also increases. Several researchers have addressed the need for a standard measurement for evaluating WBSF values.

Morgan et al., (1991) performed a study to investigate average tenderness of beef cuts which are sold in U.S market. Warner-Bratzler shear test is applied to different beef types and results are shown in Table 1.2.

Table 1.2 Top Ten "Tender" and "Tough" Cuts in Shear Force (pounds), derived from Morgan et al., 1991

Tender Cuts	**Shear force**	**Tough Cuts**	**Shear force**
Tenderloin steak	5.7	Top round steak	11.7
Top blade steak	6.7	Eye of round steak	10.3
Top loin steak	7.2	Bottom round steak	9.7
Rib roast	7.3	Rump roast	9.5
Rib steak	7.4	Eye of round roast	9.2
Ribeye steak	7.5	Chuck roll steak	9.2
Chuck roll roast	7.6	Chuck tender steak	9.0
Clod roast	7.9	Top round roast	9.0
Round tip roast	7.9	Bottom round roast	8.9
Top sirloin steak	8.0	Round tip steak	8.9

1.3.2 Color

Meat color is considered as the most influential factor concerning consumer purchasing decisions of fresh meat (Kropf, 1980). When customers are buying meat they can only check product palatability and quality by its color. Thus, basic idea of customers is that cherry-red color of a meat is indicator of its salubriousness and other products are in a bad quality (MacKinney et al., 1966).

USDA quality grades for beef are determined by three basic factors which are color, carcass maturity and marbling (USDA, 1997). Meat color can range from bright cherry-red, dark purplish red, to a brownish-red color (Faustman and Cassens, 1990).

The desirable bright cherry-red color is caused by oxymyoglobin which has a diatomic oxygen molecule attached at the sixth coordination site in the ferrous

heme iron within the myoglobin molecule. The dark purplish color is resulting from deoxymyoglobin activity which is a protein that lacks a ligand at the sixth coordination site in the ferrous heme iron. Also the brownish color is originating from metmyoglobin activity which forms most of the discoloration mechanisms in meat. This mechanism take place when the heme iron oxidizes from the ferrous (Fe^{2+}) state to the ferric (Fe^{3+}) state. After, it is impossible for the heme iron to bind an oxygen ligand at the sixth coordination site and brown color appearance occurs in the meat (Mancini and Hunt, 2005). Greene et al., (1971) reported that meat with as little as 40% metmyoglobin caused meat to be rejected by consumers.

Many researches are performed in order to examine the relationship between tenderness and muscle color of meat. (Jeremiah et al., 1991; Wulf et al., 1997). Jeremiah et al., (1991) showed a correlation of 22% or less between shear force values and subjective or objective color measurements over a 10 year carcass data study.

Wulf et al., (1996) reported that beef carcasses, excluding dark-cutting carcasses, with dark-colored muscle produced steaks with higher shear force values and lower panel tenderness ratings than carcasses with normal colored muscle, and steaks from pale-colored carcasses having a lower shear force value and higher panel tenderness than normal-colored muscle. Wulf et al., (1996) conducted a study and reported that steaks from pale-colored muscles have higher panel tenderness and a lower shear force value compared to normal-colored muscle. Moreover, steaks from dark-colored muscle have a higher shear force and a lower panel tenderness value compared to normal-colored muscles.

In the color assessments of meat there are two methods extensively used which are objective and subjective assessments. A subjective assessment procedure is carried out by a person who is giving a range of numbers to colors starting from the most purplish color and ending at the lightest red color. In contrast, objective assessment is executed with the help of a

colorimeter which senses wavelength absorbance of colors and assigns every shade a specific number. CIE L* a* b* and Hunter Lab values are widespread used forms of color measurement.

1.3.3 Shrinkage and Moisture Loss

When moisture moves away from the meat, many compounds responsible for the flavor becomes concentrated in the composition and a more tasteful product is obtained. Even though moisture loss is a beneficial with regard to flavor, the shrinkage reduces amount of saleable aged meat. Thus, an increase in the prize of dry-aged product is inevitable. Both trim loss (discolored and/or dehydrated lean and fat) and shrinkage (moisture loss) cause substantial losses. Parrish et al., (1991) reported cooler shrinkage ranging from 3.31% to 4.74% for ribs and loins dry-aged for 14 days and 4.54% to 6.53% for ribs and loins dry-aged for 21 days.

As a rapid, economic, consistent, accurate and objective inspection tool computer vision systems have been used increasingly in food related applications for quality evaluation purposes like shrinkage, color change or bruising (Sun, 2000). Image analysis is the process of differentiating the objects which are regions of interest from background and giving quantitative information about rate of change (Krutz et al., 2000).

Different software is prepared for different analysis however in all cases, images of interested samples are collected in computer memory to be analyzed from different aspects like density, color, surface elevation, amount of shrinkage, measurement of shape parameters, presence of defects after they are viewed, processed and measured by software (Sun, 2000). During their experiments, Arhaliass et al., (2003) used image processing technology for the observation of shrinkage phase of melt. In addition, Cortellino et al., (2011) and Gümüs et al., (2011) used advantages of image processing while analysing shape parameters of citrus fruit peel and aquatic foods, respectively. For the analysis of citrus fruit in terms of average fruit length, diameter,

surface area and projection area, Kabas (2010) used image processing to get the advantages of this novel technology.

1.3.4 Water holding capacity

Final quality of red meat in terms of yield and other quality aspects are directly affected by water holding capacity which expresses the ability to retain interior water inside aganist external pressures like heating, pressing or centrifuging. This quality indicator is measured by determination of cook loss and drip loss generally. These loss properties of meat are directly related to number of cuts on sample, position of the cuts, storage temperature after slaughtering, rate of freezing and storage time and metabolic state of animal when alive (Lonergan and Lonergan, 2005).

Water holding capacity is one of the main quality attributes since it directly affects final weight loss after any process like aging and also affects consumer acceptance. Consumer can easily observe weight loss due to evaporation, cooking or any other purge way. According to study of Den-Hertog-Meischke et al., (1997), water holding capacity is affected by physiological factors (amount of pH decrease during post-mortem, muscle type, muscle composition, sex, breed, age), rearing conditions (final activity prior slaughtering, feeding composition, growth period of animal), factors related to slaughtering and following processing (chilling rate, packaging, freezing and thawing, aging, temperature, stunning, electrical stimulation and etc.).

Measuring water holding capacity is a way to determine interaction of proteins with water and protein-water interactions determine functional properties of proteins. Water holding capacity is defined as the ability to prevent water being released from 3-D structure of protein within food. Water retention is critical in scope of protein functionality since it directly affects texture, color, eating quality and other sensory attributes (Zayas, 1997).

1.3.5 Microbiological Quality

Microbiological contamination like bacterial spoilage is prohibited with the control of surface water activity. Therefore, the holding conditions are important to prevent losses due to spoilage. Life of vacuum-packaged meat is dependent on growth of lactic acid bacteria; whereas, dry aging relies on reduction of water activity on the surface to minimize bacterial growth (Small, 2010).

When oxygen is present at the medium *Pseudomonas* grow and help the intense flavor to develop in dry aging process. Besides, in the absence of oxygen *Lactobacilli* who convert lactose to lactic acid grow and help the sour taste and smell to occur in wet aging process. Dry aging restricts bacterial growth and allow beneficial moulds like *Mucor genera, Rhizopus and Thamnidium* to grow up. *Thamnidium* is the most beneficial mould found in the surface of meat and it is proven that *Thamnidium* helps tenderization of meat with the proteases release. *Rhizopus* and *Mucor* moulds have been associated with infections in people and do not provide any favorable characteristics for aging meat ("Aging of Beef ", 2013). The genus Thamnidia, in particular, is known to produce collagenolytic enzymes which greatly contribute to the tenderness and flavor of dry-aged meat ("Dry aged vs. wet aged," 2012).

The process of dry-aging usually also promotes growth of certain fungal (mold) species on the external surface of the meat. This doesn't cause spoilage, but actually forms an external "crust" on the meat's surface, which is trimmed off when the meat is prepared for cooking. In addition to endogenous enzymes (those found naturally in the beef) which help tenderize and increase the flavor of the meat, these fungal species do so as well ("Dry aged vs. wet aged," 2012).

1.3.6. Yield

Dry aging process allows some compounds of meat to evaporate and a distinctive flavor to occur but it result in a lighter aged meat compared to wet aging. Thus, from the point of saleable meat yield wet aging is more preferable. Even though wet aging also has some weight loses while storing the meat with vacuum, it is very little compared to dry aging loses from evaporation and the need to trim the dried and discoloured surface tissue referred to as 'crust' (Small, 2010). Smith et al., (2008) measured evaporative losses on beef short loins of 5.4 to 8.5% for storage periods up to 35 days at 1.0°C and 83% RH. Total quantity of saleable meat with dry aging process is significantly less than with wet aging and exact quantities are shown in Table 1.3.

Table 1.3 Saleable meat yield (%) after wet and dry aging, derived from Smith et al., 2008

Aging method	14 days	21 days	28 days	35 days
Dry-aged	76.5	72.1	71.6	69.8
Wet-aged	87.7	85.3	86.6	87.1

1.3.7 Lipid Oxidation

Meat and meat products contain lipids which determine their characteristics in their structure. Lipids are essential in the sense of juiciness and tenderness properties of meat and they contribute to aroma profile and flavor of meat. However, it is known that reason behind the deterioration of meat is lipid oxidation which starts immediately after slaughter and continues during storage and cooking. To prevent lipid oxidation; vacuuming the air or storing the meat at frozen temperatures are acceptable methods. However, oxidation of lipids may continue even during frozen storage (Weber et al., 2007).

Oxidation is an unstoppable chemical deterioration for the meat and its products. The main targets for oxidation in the lipids are the polyunsaturated fatty acids (PUFAs) and phospholipids that are vulnerable to the action of $HO^{\cdot}$ (Esterbauer et al., 1991). Phospholipids which are rich in poly-unsaturated fatty acids and located at the membrane structure are the starting point of lipid oxidation in meat. Therefore, they are most prone to oxidation. Quality of meat is affected in many ways like color change, drip loss and off-flavor formation during deterioration. Volatile short-chain products occur due to poly-unsaturated fatty acid's degradation and cause off-flavor and off-odour formation. As a result, formation of volatile products strongly influence customer's preferences and lower the demand for meat. Oxidative reactions can also affect the ability of the membranes to hold water and may contribute to drip loss (Jensen, 1998).

Lipid oxidation by-products can be examined in two main categories; 1) primary end products such as hydroperoxides and conjugated dienes; 2) secondary end products such as malondialdehyde, isofurans, hydrocarbons (ethane and pentane included), alcohols, carbonyls (aldehydes and ketones), F2-like compounds, prostaglandin and isoprostanes which are the main reason for off-flavors and rancidity. It is seen that off-flavor generation is caused by n-3 and n-6 fatty acid's oxidation with the help of 2,6-nonadienal, 1,5-octadien-3-one, 2,5-octadien-1-ol, 1,5-octadien-3-ol, 2,4,7-decatrienal, propanal, 2-hexenal, 4-heptenal and 2,4-heptadienal (from n-3 fatty acids) and 2-nonenal, 1-octen-3-ol, hexanal and 4-hydroxy-2-nonenal (HNE) (from n-6 fatty acids) hexanal and propanal (Min and Ahn, 2005).

In early stages of the oxidation, the primary oxidation products, hydroperoxides, accumulates. Later, a high level of secondary products is observed along with low levels of primary products. ("Analytical Methods," n.d.). This theoretical scheme was illustrated in Figure 1.1.

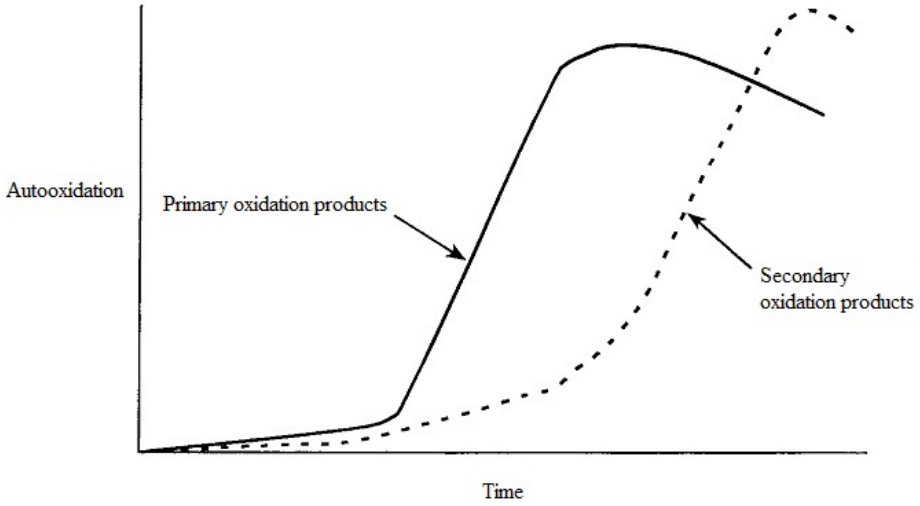

Figure 1.1 Theoretical development of primary and secondary oxidation products as a function of time in lipid oxidation. Adapted from (Frankel, 2005).

In the early stages of oxidation, hydrogen separation from poly-unsaturated fatty acids lead conjugated double bonds to form rapidly. In ındustrial analyses, Peroxide Value (PV) method which measure amount of hydroperoxides existed at the early stages of oxidation is preferred.

There are high numbers of products which occur after decomposition of hydroperoxides and it is hard to detect and measure all of them simultaneously due to rapid chemical transformation, chemical instability and observation difficulties of small compounds. Therefore, measurement methods are determined to focus on a single product or a group of similar products. An important disadvantage for these secondary oxidation product measurements is that at initial stages primary product percentage is high compared to secondary products. Advantage of measurement of secondary oxidation products is the good correlation with sensory analysis, as the measured compounds are the direct cause of the off aromas (Fennema et al., 2007a).

1.4 Nuclear Magnetic Resonance (NMR) Relaxometry

Nuclear Magnetic Resonance (NMR) Relaxometry is a novel technology and enables scientists to analyze interior parts of food samples recently. Analysis can be achieved without any destruction of sample which allows the usage of exactly the same sample during processing or storage. This opportunity eliminates the variance between samples and makes this technique one of the most preferable way of analysis for the food scientists. Other reasons why this novel analysis technique is so popular are related to short analysis period, ease of use and allowing both qualitative and quantitative analysis.

NMR is an assuring technique which allows the determination of fat and moisture content of material which is really critical for food related analysis (Oztop et al., 2010; Wei et al., 2014). NMR Relaxometry is based on determination of T1 and T2 time relaxation times. Short time application of Radio Frequency (RF) waves is essential to create nuclear magnetism and a desirable amount of signal in different planes is created with the help of RF. T1 and T2 are time constants simulating the amount of increase (T1) or decrease (T2) for the signal. T1 value characterizes longitudinal relaxation time while T2 value simulates transverse relaxation time. T1 value of target sample can be determined from exponentially increasing signal curve and T2 value can be calculated from signal curve which is exponentially decreasing. Relaxation spectrum of substance is determined by using T1 and T2 values and proton distribution through substance can be identified. Proton distribution means water and fat content for most of the food products (Hills, 1998; Ersus et al., 2010; Oztop et al., 2012; Wichchukit et al., 2013 and Williams et al., 2011).

Recently, NMR technology is widely used for analysis of poultry, fish and meat samples for the determination of fat and water distribution. It is also found that water holding capacity directly gives idea about sensorial and nutritional quality of meat which almost corresponds to overall quality characteristics (Renou et al., 2003).

After slaughtering and during aging, physical and chemical changes occur in protein structure and water-protein interaction changes affecting the water holding capacity and texture. As a conclusion of these deteriorative effects functional, nutritional and sensorial quality of meat changes during storage and aging. In his research, Renou et al., (2003) studied the effects of freezing on meat quality by using that kind of technology. . Analyzing and differentiating fat, water and muscle tissue was achieved and overall quality was evaluated by images. In another study, Koizumi et al., (2008) analyzed the distribution of fat and muscle tissue in case of frozen meat and during thawing process and results were indicative for quality change.

1.5 Objective of the Study

Recently, people are more aware of the importance of consuming more qualified foods at home by spending less money on it. Since aged and more qualified meats can be consumed only in special restaurants, cost of experiencing that kind of meats is really high and not affordable. Consumers are willing to create their own conditions to get dry aged, which results in more palatable final product. However, there is still no application for home-type refrigerators to provide consumers aging their meat in a reliable and hygienic environment.

Although there are some studies which compare the effects of vacuum and dry aging on eating quality of beef steaks; effects of usage of permeable packaging, muscle type, temperature and humidity in dry-aging, in literature no study is addressing the combined effects of air flow rate and aging period during dry aging in home-type refrigerator (including ionizer inside it). Therefore, main aim of this study was to determine the effects of air flow rate and dry aging period on meat quality.

Since there is no other study addressing dry aging in home-type refrigerators; it is needed to understand the performance of optimum air flow rate and temperature which are given for commercial applications. Besides, since the

consumers wouldn’t be disposed to keep meat sample in their refrigerator for long periods due to the volume loss; different aging periods were also studied to determine the most effective one.

As a novel analysis method, image processing was used for shrinkage analysis and NMR relaxometry was conducted to understand the microstructural changes on the tissue. Besides, microbial analysis (total aerobic bacteria, and yeast and mold populations), pH change, water holding capacity (WHC), Warner-Bratzler Shear Force (WBSF), moisture content, trim and cook loss, weight loss, color change, peroxide, p-anisidine and TBARs value were determined to determine physical and chemical changes during aging period.

CHAPTER 2

MATERIALS and METHODS

2.1 Preparation of Dry Aging Area

For the application of dry aging in home-type refrigerators, Beko T54305 NE 3-door no-frost refrigerator (China product, Arçelik, Eskişehir, Turkey) was used. Multizone compartment of refrigerator which is the middle area of 3-door refrigerator and can be set to temperatures for freezer, fridge and 0°C was used as drying area. This area was chosen for dry aging process since it is isolated from other parts of refrigerator and no external air blows in the aging area unless the door is open. Two loopholes were punctured so as the cold air only flows from these holes inside the aging compartment and no other holes were allowed. An external square shaped fan, 66 mm in width (SDI1820 NMB-Minebea, Tokyo, Japan) was placed back side and in the middle of the compartment so that the desired air flow was obtained homogeneously inside the compartment and through the meat samples. Fans were electrically supplied by an external power source and three different fan speed ranges (0.50 m/s; 0.75 m/s; 1.00 m/s) was managed by adjusting voltage degree. The air was not filtered but the ionizer (TFB-49 Trumpxp, Tianchang TRUMP Electronics, Tianchang City, China) was located just below the fan to sterilize the air sucked by external fan and flowed through (Figure B.1 and B.2). Air movement from other compartments to dry aging unit was prevented so as to prevent contamination from other foods. There was no need to use UV light implementation for air sterilization due to the presence of ioniser.

Low amount of temperature fluctuation, 0 ± 0.5 °C, was provided by new algorithm which controls longer defrosts times and also new assigned cut in

and cut out temperatures abled to conduct the operating time of internal refrigerator fan. Besides, target humidity level of 80 ± 4 % was obtained by placement of a tray full of distilled water and amount of water is specified as 800 ml and kept almost constant during experiments. The diameter and height of the tray, filled with water, was 31 cm and 5cm, respectively. Water level inside tray is kept constant to prevent drastic moisture loss. A wire rack from food compatible plastic material was located in the aging compartment so that bottom of the rib steak was also exposed to flow of cold air and homogenous drying from all sides of meat could be obtained.

2.2 Raw Material Preparation

For all the experiments, twelve calf carcasses obtained from animals aged until 30 months and 2 day post-mortem were purchased from a large commercial processor, Nadir Et Entegre Tesisleri, Eskişehir. Calf carcasses weighing 240 to 280 kg were used in the experiments. From each carcass, rib steak section was removed and totally 3 kg of rib steak was obtained. Three kilograms of rib steaks were divided into two parts to be used in the experiments. All of the carcasses, selected for use as samples for determination of meat quality associated with dry aging at intermediate times (day 7, 14, 21 and 28), were examined carefully to have anterior exposed surfaces that appearing with normal bloomed beef color and were absent of quality defects. Besides, rib steaks were selected from carcasses as having modest 50 or higher marbling degree according to United States Standards for Grades of Carcass Beef (USDA, 1997). Since maturity degree of animals were A and degree of marbling was modest for all carcasses, quality degree of carcasses were graded as CHOICE, according to the USDA Beef Grading Chart, Figure 2.1.

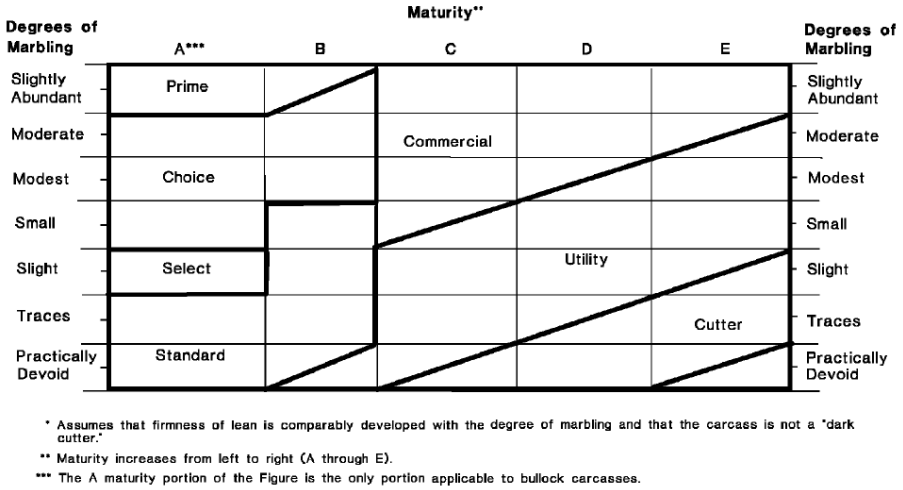

Figure 2.1 USDA Beef Grading Chart

Rib steak samples were vacuum packaged by using CASO vacuum machine (CASO VC-10, Braukmann, Arnsberg, Germany) in processor area and transferred to the Arçelik Food Quality Analysis Laboratory where dry-aging will be applied. Rib steak samples were stored in vacuum environment at 3°C for 2 more days postmortem to simulate the industrial conditions and customer purchasing case. At the end of totally 4 days of post-mortem, rib-steaks were cut into pieces weighing 1500 ± 50 g, and then samples would be ready for aging process. For each aging condition (totally 12), two separate rib steaks having the same appearance, size and weight were placed into the dry aging compartment of refrigerator at the same time. One of the rib steak sample was used for pH analysis, lipid oxidation analysis including peroxide and anisidine value and TBARs value, water holding capacity, trim loss, cook loss, moisture content, weight loss and shear force analysis. On the other hand, the other rib steak sample having weight of 1500 ± 50 g was used for microbial analysis and yield calculation. For the shrinkage analysis by image processing and NMR analysis, , another aging period was started after all experiments were done since the sample shouldn't be damaged differently than other experiments and amount of shrinkage should be calculated by using exactly the same sample. All the rib steak samples were placed in terms of separate aging conditions with different fan speeds (0.50 m/s, 0.75 m/s

and 1.00 m/s) and aging periods (7, 14, 21 and 28 days). One of the rib steak samples having weight of 1500 ± 50 g was used for shrinkage analysis, while the other piece weighing 1500 ± 50 g was used for NMR analysis.

Rib steak samples were directly placed on wire racks in aging compartment and two digital sensors (EBRO EBI, Model No: 25-TH, Ingolstadt, Germany) having the capability of measuring both humidity and temperature was placed in between two rib steak pieces and the middle of aging compartment so that environmental conditions were monitored continually.

2.3 Aging Treatment

The effects of source fan speed (0.50 m/s; 0.75 m/s; 1.00 m/s) and period of aging (7, 14, 21 and 28 days) on microbial load and physical and chemical properties of meat were studied. Aging conditions were summarized in Table 2.1. Aging at each condition was studied with 3 replications and 2 subprimals.

Sections were placed on wire racks in the position that subcutaneous fat surface would be down. Each day of aging, door of refrigerator was opened in order to rotate the sections to minimize location effects and to control humidity, temperature and water level inside monitored by sensors.

Table 2.1 Aging conditions applied during experimental design

# of Experiment	Fan speed for air flow (m/s)	Period of dry aging
1	0.50	7 days
2	0.75	7 days
3	1.00	7 days
4	0.50	14 days
5	0.75	14 days
6	1.00	14 days
7	0.50	21 days
8	0.75	21 days
9	1.00	21 days
10	0.50	28 days
11	0.75	28 days
12	1.00	28 days

2.4 Sampling

At day 0, two rib steak sections were assigned randomly and all the physical, chemical and image analysis were experienced for initial situation. Besides, after 7, 14, 21 and 28 days of aging periods, samples were taken from both ends of rib steak sections and prepared for various analysis.

2.5 Microbial Analysis

For the analysis of total aerobic bacteria, yeast and mold populations, sample was taken after trimming. Initial load of microorganisms was also determined before aging. 25 g of meat samples were removed aseptically from the dorsal subcutaneous fat and ventral lean surfaces of each loin section, placed into stomacher bags (Spiral Biotech, Norwood, MA). Then 225 mL of Buffered Peptone Water were added and stomached for 1 min (Seward Stomacher 400; Seward Medical, London, UK). Appropriate dilutions were made and 0.1 mL of each dilution were plated and enumerated after incubation on Plate Count Agar (37 °C for 48 h) for total bacteria counts and DRBC Agar (Dichloran Rose Bengal Chloramphenicol, 25°C for 5 days) for mold and yeast counts.

After incubation period, number of microorganisms was calculated by using equation (2.1) and logarithm results were debated as final result;

$$CFU\ /g = \frac{number\ of\ colonies\ counted\ \times dilution\ factor}{mass\ plated\ in\ gram} \qquad (2.1)$$

2.6 Physical Analysis

2.6.1 Water Holding Capacity (WHC) and Moisture Content

WHC was determined according to the method described by Kerry et al. (2010). Five samples per batch were analyzed. Approximately 10 g of sample was weighed by using balance (Mettler Toledo MS 6002S, Greifensee, Switzerland) and taken into a glass jar. The jars were placed into a water bath (Memmert WNB 7-45, Schwabach, Germany) for 10 min at 90 °C. After heating, each sample was carefully removed from the jar using a forcept and wrapped in cheese cloth and placed into a 15 ml centrifuge tube each containing cotton wool at the bottom.

The samples were centrifuged (Eppendorf Centrifuge 5702 R, Hamburg, Germany) at 10.000 rpm and at 4 °C for 10 min. The samples were taken out of the centrifuge, the cheese cloth removed and the samples were reweighed. The percentage WHC was calculated using equation (2.2);

$$\% WHC = 1 - \frac{(B-A)\times 100}{M1} \quad (2.2)$$

Where, B is the weight of sample before heating, A is the weight of sample after heating and centrifuging, M1 is the total moisture content of the meat sample;

Measurements of moisture content of samples were performed using moisture analyser (Model No: HB43-S, Mettler Toledo, Greifensee, Switzerland).

2.6.2 Warner–Bratzler Shear Force and Cook Loss

Steaks having size of 20.0± 1.0 cm width, 20.0±1.0 cm length and 5±0.5 cm height were cooked at 163°C in a forced-air convection oven (Binder ED 115, Tuttlingen, Germany) to an internal temperature of 71°C. Internal temperature was monitored by using copper-constant thermocouples and thermocouples were inserted into the geometric center of each steak and connected to a data acquisition unit (Agilent 34970 A, Santa Clara California, United States). After cooking, steaks were overwrapped in polyvinyl chloride film and stored at 2°C for 24 h. Six round cores (1.27 cm diameter) were obtained from each strip steak parallel to the muscle fibers by using manual coring apparatus. Each core was sheared once perpendicular to the muscle-fiber orientation with a Warner–Bratzler shear force (WBSF) apparatus (V-notch blunt blade) connected to a TA Plus Texture Analyser Testing Machine (LLOYD Instruments, West Sussex, UK) operating with a 3 N pre load cell at a crosshead speed of 200 mm/min with an extension limit of 20 mm. Shear force was determined as the maximum (peak) force during shearing and expressed in N. Cooking loss was calculated by the following equation (2.3);

$$Cook\ loss\ (\%) = \frac{weight\ loss\ during\ cooking}{initial\ weight} \times 100 \quad (2.3)$$

2.6.3 Yield, Weight and Trim Loss

Yield of loin sections at the end of aging process is calculated by using the following equation (2.4);

$$Yield\ (\%) = \frac{weight\ of\ dry\ aged\ sample}{weight\ prior\ to\ dry\ aging} \times 100 \quad (2.4)$$

Weights of loin sections were recorded before and after the assigned aging times. The percentage of weight loss during aging was calculated by using following equation (2.5);

$$Weight\ loss\ (\%) = \frac{weight\ loss\ during\ dry\ aging}{weight\ prior\ to\ dry\ aging} \times 100 \quad (2.5)$$

Aged loin sections subsequently were trimmed to remove dry and discolored portions. The percentage of trim loss was calculated by using the following equation (2.6);

$$Trim\ loss\ (\%) = \frac{weight\ loss\ due\ to\ trimming}{untrimmed\ weight} \times 100 \quad (2.6)$$

2.6.4 Shrinkage Analysis by Image Processing

Three refrigerators, having identical dry aging compartments, were used for image processing analysis. At the beginning of the experiment, two of rib steak samples were placed into each of refrigerator differing on fan speed (0.50 m/s, 0.75 m/s, 1.00 m/s). At day 0, images were taken for each sample to keep the initial value of area. Then for each analysis day, samples were placed on shooting board again and photographed before trimming. Shooting board is used for positioning the sample on imaging area and images are

taken from the same angle of aerial viewpoint. The image vision system was consisted of a digital camera (Canon EOS 500D, Melville, NY, USA) with 18-55 mm lens and at manual shooting settings, a power supply (Canon ACK-E5 AC, Melville, NY, USA), a lighting system (led light panels) and a computer (Grundig GNB 1150 B1 N2, Arçelik, TURKEY) as in Figures B3 and B4. The camera was mounted on a stand 30 cm above the base of the shooting tent and light was supplied by led panels, which provided uniform lighting, minimum shadow and glare when photographing the samples. The samples were photographed twice. Images were stored in the computer and image processing Matlab software 7.12.0 (Mathworks 7120 R2011a, Torrance, CA, United States) was used for image acquisition. Green background was used as in the method described by Velioğlu et al. (2010) to enhance the contrast between the background and the object of the interest. Images were collected for day 0, 7, 14, 21 and 28 and analyzed according to the method which uses boundaries of samples. Boundaries were extracted using a threshold-based segmentation method. To analyse the amount of shrinkage, boundary determination algorithm including Percent Surface Area Calculation (PSAC) was used. A simple algorithm was used to calculate total area change indicating shrinkage. The shrinkage percentages were calculated by using the following equation (2.7);

$$Shrinkage\ (\%) = 100 \times \frac{(Area\ of\ initial\ sample - Area\ of\ dried\ sample)}{Area\ of\ initial\ sample} \quad (2.7)$$

2.6.5 NMR Measurements

NMR data were acquired on a 0.5T, 13.52 MHz low resolution system (Spin Track, Russia) with a 16 mm inside diameter coil. T_1 and T_2 relaxation times of the meat samples were measured. T_1 and T_2 experiments were performed by using Saturation Recovery and Carr-Purcell-Meiboom-Gill (CPMG) sequences respectively. CPMG sequence was performed with a relaxation period of 1000 ms, an echo time (TE) of 1000 us, and 64 scans. Saturation

Recovery was applied with delay times changing between 0.01 s and 2 s, and a repetition delay of 2 s.

2.6.6 Color Analysis

The color was measured both prior to aging and after aging treatments by using a colorimeter of Minolta CM-700d spectrophotometer (Konica Minolta Sensing Inc., Osaka, Japan) with 8 mm diameter measuring aperture, illuminant D65, 10° standard observer and CIE L*, a*, b* colour scale. Measuring apparatus was covered with a glass plate and calibration against white color was performed before beef sample measurements for each analysis day (L* = 97.62 ± 0.01, a* = −0.16 ± 0.01, b* = 0.00 ± 0.01). The average of five measurements on the meat surface was calculated and average values were calculated. Chroma was calculated according to equation (2.8);

$$C^* = ((a^*)^2 + (b^*)^2) ½ \quad (2.8)$$

2.7 Chemical Analysis

2.7.1 pH Measurement

Rib steak samples (10 g) were homogenised (1 min, 24,000 rpm) in 90 ml distilled water using homogeniser (IKA Ultra Turrax T25 -Labortechnik, GmbH and Co., Staufen, Germany). The pH of the rib steak homogenates was measured at 20 °C using a pH meter (Inolab, Ph / Cond 720 Weilheim, Germany).

2.7.2 Analysis of Lipid Oxidation

2.7.2.1 Extraction of Lipid

Samples were broken into very small pieces through a Grindomix grinder (Knife Mill Grindomix GM 200 – RETSCH, Haan, Germany) to obtain smaller and homogenous samples. Lipid extraction from meat samples was performed according to the method outlined by Lee et al. (1996). 5 g of sample was homogenised with 50 ml chloroform/ methanol mixture (2/1, v/v) for 2 min in homogenizer (T 25 Digital ultra turrax, IKA). The homogenate

was filtered through fast speed filter paper (12.5 mm id, Whatman No. 1) into a separating funnel and 20 ml of 0.5 % NaCl was added to separate the filtrate into two phases. The mixture was gently shaken and allowed to stand almost 30 min or more until a clear separation was obtained. When clear separation was visible, the methanol-water phase was discharged and the chloroform phase was used for the next steps of analysis. To eliminate all the chloroform from mixture and obtain a pure lipid sample, evaporation was applied by using rotary evaporator (RE 300, Bibby Scientific, Stuart, Staffordshire, United Kingdom) with a vacuum pump (Rocker 400, Rocker Scientific, New Taipei City, Taiwan). Vacuum degree of 40-50 kPa and speed range of 5 for rotation of evaporator flask was selected for the desired amount and speed of evaporation.

2.7.2.2 Peroxide Value

Peroxide value of samples was analyzed according to AOCS Official Method Cd 8-53, Peroxide Value Acetic Acid- Chloroform Method. For the analysis, 1 ± 0.05 g of sample was weighed into a 250 mL erlenmeyer flask with glass stopper. From the 3:2 (v:v) acetic acid- chloroform solution 6 mL was added to sample and the mixture was swirled to dissolve the sample in solution. Saturated potassium iodide (KI) solution was prepared by dissolving an excess of KI in recently boiled distilled water (about 10 gram KI in 6.0 mL of water). Since the solution is unstable when removed from heat, 0.1 mL of saturated KI solution should be added to sample solution immediately. After the addition of KI solution, it was allowed to stand for exactly 1 min with occasional shaking and then 6 mL of distilled water was added immediately to the solution. An iodine color appeared and titration by using digital burette (Digitrate, Jencons, Lutterworth, England) with 0.01 N sodium thiosulfate continued until yellow iodine color has almost disappeared. Starch indicator solution was prepared by making a paste with 1 g of starch and 10 mL of distilled water. While stirring, 100 mL of boiling water was added and boiled for a few seconds. Then, solution was cooled immediately. The color change (turning to blue) was observed after the addition of 0.4 mL of starch indicator

solution. Second titration with 0.01 N sodium thiosulfate was applied under constant agitation to liberate all of the iodine from solvent layer. Addition of 0.01 N sodium thiosulfate as dropwise was continued until the blue color just disappeared. Peroxide value calculation was worked on according to equation (2.9);

$$Peroxide\ Value\ \left(meq.\frac{peroxide}{1000}gsample\right) = \frac{(S-B)\times N\times 100}{mass\ of\ sample, g} \quad (2.9)$$

Where, B is volume of titrant (mL of blank),S is volume of titrant (mL of sample)and N is the Normality of sodium thiosulfate solution.

2.7.2.3 p- Anisidine Value

As a lipid oxidation indicator, p.A.V of samples was analyzed according to AOCS Official Method Cd 18-90. For the analysis, 1± 0.001 g of the sample was weighed into a 25 mL volumetric flask. Sample was dissolved in isooctane and volume was completed to 25 mL with isooctane. Absorbance of sample solution (Ab) at 350 nm was measured with spectrophotometer, using the reference cuvette filled with solvent as a blank. Exactly 5 mL of the fat solution was pipetted into the first test tube and exactly 5 mL of the solvent were pipetted into the second test tube. p-Anisidine reagent was prepared by dissolving 0.25 g of p-anisidine in 100 mL of glacial acetic acid. By means of an automatic pipet, exactly 1 mL of the p-anisidine reagent was added to each test tubes and shaked. After exactly 10 min duration time, absorbance of the solvent (As) was measured in the first test tube at 350 nm by using cuvettes. Solution from the second test tube was used as blank in the reference cuvette. p-Anisidine value was calculated using following equation (2.10);

$$p.A.V = 25\times\frac{(1.2\times As)-Ab}{m} \quad (2.10)$$

Where, As is the absorbance of the fat solution after reaction with the p-anisidine reagent, Ab is the absorbance of the fat solution and m is the mass of the test portion.

2.7.2.4 TBARS Value

Thiobarbituric acid-reactive substances (TBARS) were determined using the method of described by Ulu, H. (2004). Within the scope of method for the malondialdehyde, samples were homogenized by using Waring blender (Model No: 7011HS, Waring Commercial, Torrington, USA) and 15 g of homogenised sample was weighed by using precision balance (Mettler Toledo MS 6002S, Greifensee, Switzerland). Sample was further homogenised with 30 mL of 7.5 % trichloroacetic acid solution for exactly 1 min at 5000 rpm by using Waring laboratory blender. Blend was filtered through Whatman No 1 filter paper. Same procedure was applied for blank which included 15 mL of distilled water and 30 mL of 7.5 % TCA solution. As a second step of TBARS analysis, MDA and TBA complex was composed by applying the following steps. 5 mL of supernatant and sample blank were transferred into test tubes and 5 ml of 20 mM TBA solution (0.72 g TBA+ 250 mL distilled water) was added and final solution was shaked strongly. For the next step; test tubes were held at 85°C for 45 min at water bath (Memmert WNB 7-45, Schwabach, Germany) and after color change was observed at the end of heating operation, test tubes were allowed to cool down at room temperature. Samples were centrifuged for 15 min at 4100 rpm by using centrifuge (Eppendorf Centrifuge 5702 R, Hamburg, Germany) and supernatant parts were collected. They were transferred into glass cuvettes and their absorbance values were measured at 532 nm with spectrophotometer (Biochrom Libra S50 UV/VIS, Biochrom Libra Instruments, Cambridge, UK). Standard curve was used to convert the results of absorbance to μM MDA/ kg muscle. Results were recorded as μM MDA/ kg muscle.

2.8 Statistical Analysis

The structure of whole treatment is composed of 3 ×4 factorial experiments with three different fan speeds (0.50 m/s; 0.75 m/s; 1.00 m/s) and four aging periods (7, 14, 21 and 28 days). Analysis of variance (ANOVA-2 way) was

performed to determine the significant differences between the effects of aging times and fan speeds ($p \leq 0.05$). If significant difference was found, means were compared and grouped by Tukey Method which remains one of the most practical comparison methods in scope of 1-way ANOVA. Interactions that were not significant were removed from the model. $P < 0.05$ was used to separate least squares means when significant differences occurred. Box-Cox transformation was used to ensure normal distribution for analysis of consumer data. General Linear Model (GLM) analysis was used to determine effects of fan speed and aging time on NMR Relaxometry parameters of T_1 and T_2. Pearson correlation tool of Minitab was used to correlate water holding capacity and moisture content with T_1 and T_2 relaxation times. Pearson correlation coefficients and p-values were used to determine change of trend.

CHAPTER 3

RESULTS AND DISCUSSION

In this study, effects of different aging conditions, including variable air flow rates (created by altering fan speed; 0.50 m/s, 0.75 m/s, 1.00 m/s) and aging periods (7, 14, 21and 28 days), on physical (yield, color, weight loss, trim loss, cook loss, shear force, water holding capacity, shrinkage by computer vision, T_1 and T_2 relaxation times by NMR analysis), chemical (pH, p-Anisidine value, peroxide value and TBARS as indicators of lipid oxidation) and microbiological quality (total aerobic bacteria and yeast and mold) of dry aged rib steak samples were investigated.

As an overall evaluation, there were few 2-way interactions in this data set. However, aging time had the greatest number of main effects for all the physical (except for shear force), chemical and microbiological parameters while fan speed had significant effect on p.A.V, weight loss, trim loss, cook loss, yield, WHC, moisture content, L*, a*, C* values and shrinkage results.

3.1 Effects of different aging conditions on chemical quality of dry aged rib steak samples

3.1.1 pH value

Normal beef pH value should be lower than 6.2. Higher pH will be an indicator for microbial spoilage (Lomiwes, 2012). Initial pH values for rib steak samples were 5.4±0.1. This data indicated that all the samples were of normal beef pH at the beginning of the experiments. According to ANOVA, it was observed that at the end of each aging time (7, 14, 21, 28 days) different fan speeds had no significant effect ($p>0.05$) on pH values (Table A.18).

On the other hand, aging time had a significant effect ($p<0.05$) on pH value (Table A.18). According to Figure 3.1, a gradual increase of pH value was observed with increasing aging period for the same fan speed. Similar results for increasing pH with time were observed by Ahnström et al., (2006) and Li et al., (2014). As an overall evaluation, it was observed that any of samples, aged for 7, 14, 21 or 28 days, did not exceed the normal beef pH limit which means that quality is preserved to some extent in terms of pH value.

Change in pH value has been used as a key parameter to determine spoilage degree of most of the food products, especially meat and meat products. This undesirable pH change is directly related to microbial growth within food. Meat products are ideal environments for growing of microorganisms since they are rich in protein and water. Many types of metabolic by-products are produced during growth of microorganisms (mostly by bacteria) and released. NH_3, amines (histamine, cadaverine etc.) and other basic compounds are produced by natural metabolism of spoilage bacteria due to deterioration of amino acids. Since these are basic compounds, they shift pH value to basic side (almost level of 8.0) from pH value of 5.5 which is normal for fresh meat (Ray & Bhunia, 2013). Since target dry aging application was not carried out in vacuum environment, growth of anaerobic bacteria (mainly lactic acid bacteria) which produce acids from metabolism of carbohydrates was not supported in aerobic conditions and pH value increased during aging process.

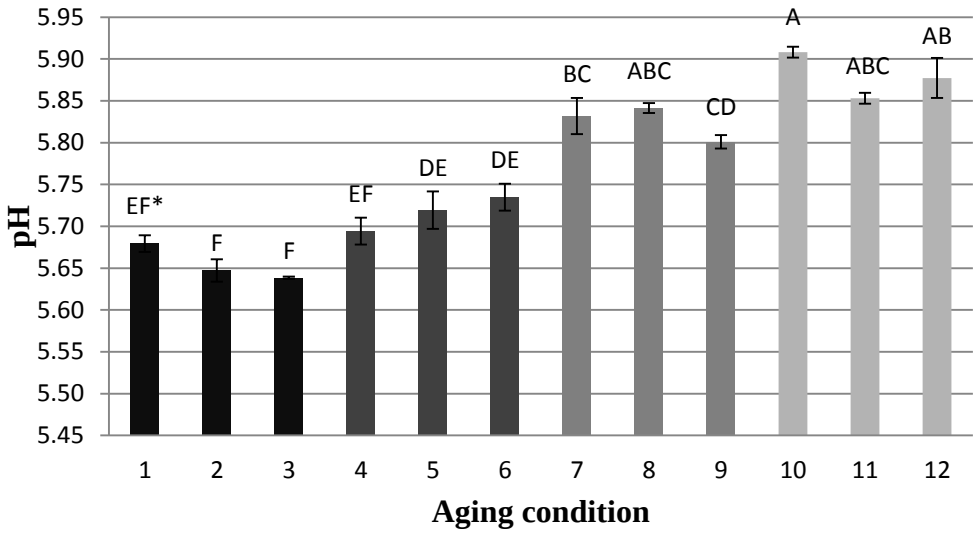

Figure 3.1 pH values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.1.2 TBARS Value

At the beginning of dry aging process, initial TBARS value of rib steak samples were determined to be 0.07±0.2 mg MDA/kg. Effect of using different fan speeds in the range of 0.50-1.00 m/s on TBARS values was not significant ($p > 0.05$) for each aging time (7, 14, 21, 28 days) (Figure 3.2 and Table A.19).

The presence of distinct stepped increase in Figure 3.2 means that aging time had a significant effect ($p < 0.05$) on TBARS value according to ANOVA (Table A.19). Similar results for increasing TBARS value with time were observed by Hunt et al., (2009). For TBARS value, as a secondary oxidation by-product, there is no legal threshold limit exists, however for sense of rancidity it is suggested that the value shouldn't exceed the limit of 1 mg malonaldehyde/kg meat (Jayasingh et al., 2002). As an overall evaluation, it was observed that any of samples, aged for 7, 14, 21 or 28 days, did not

exceed the TBARS limit of uncorrupted meat and it means that quality is preserved to some extent for all fan speeds and aging times.

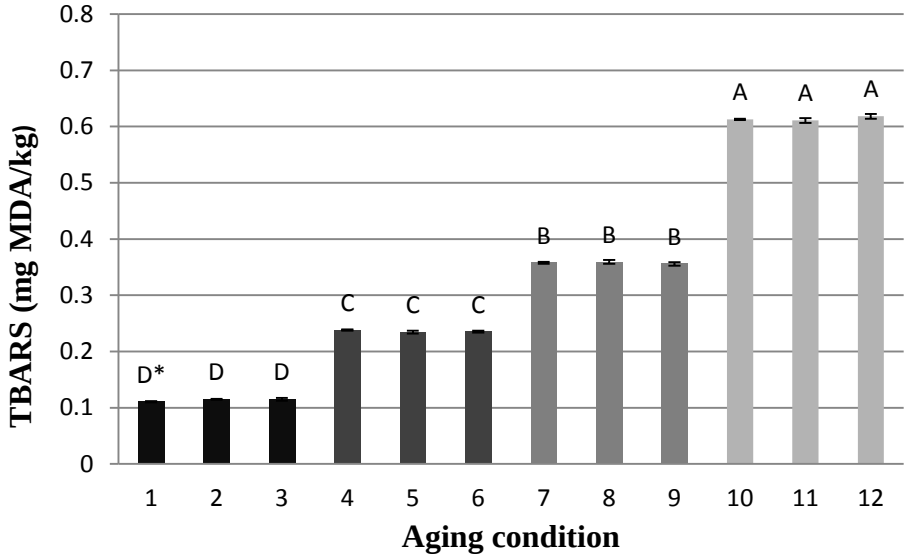

Figure 3.2 TBARS values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.1.3 Peroxide Value (P.V)

Rib steak samples had peroxide values of 0.05±0.2 meq peroxide/100g initially. Peroxide values were not significantly affected from different fan speeds in dry aging ($p > 0.05$) for all aging times (7, 14, 21, 28 days) (Table A.20 and Figure 3.3). Increasing fan speed above 1 m/s may cause increase in P.V value due to increased air flow through samples, which causes oxidation but P.V values of samples were close to each other when air flowing with a velocity between 0.50 and 1.00 m/s was used.

When the samples aged for 28 days was analyzed, it was determined that P.V of rib steak samples were higher than the samples aged for shorter times. The presence of this clear and gradual increase expresses that aging time had a significant effect ($p<0.05$) on P.V according to ANOVA (Table A.20). This clear increase of P.V can be observed also by using Figure 3.3.

Peroxide value is a critical parameter to analyse concentration of peroxides and hydroperoxides which are produced during initial stages of lipid oxidation. The maximum limit for P.V is 1.25 meq. peroxide /100g to prevent consuming deteriorated food (Codex Standard, 1999). As an overall evaluation, it was observed that any of samples, aged for 7, 14, 21 or 28 days, did not exceed this limit which means that quality is preserved to some extent.

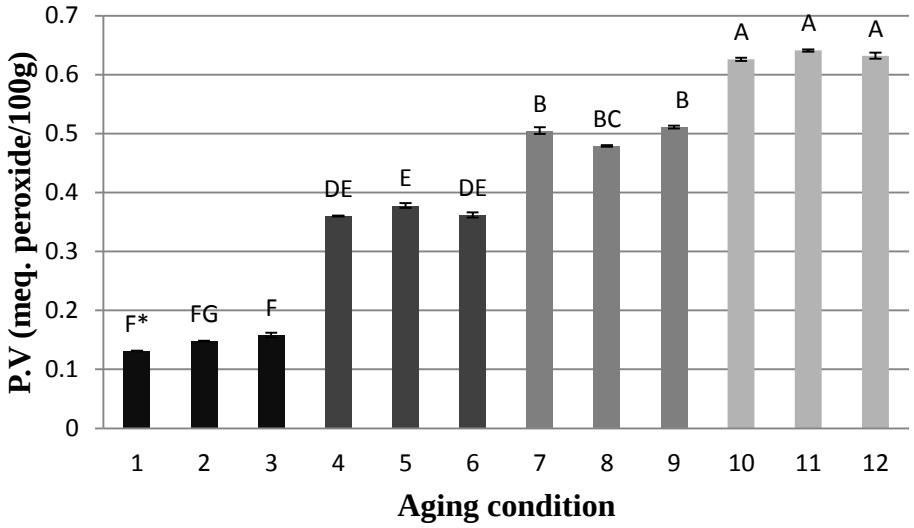

Figure 3.3 Peroxide Values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.1.4 p-Anisidine Value (p.A.V)

Initially, p-Anisidine value of rib steak samples were 0.3±0.07. According to ANOVA, effect of using different fan speed had significant effect ($p<0.05$) for each of aging time (7, 14, 21, 28 days) in terms of p.A.V (Table A.21). However, when Figure 3.4 analyzed it was obvious that for 7, 21 and 28 days of storage there was minimal difference between fan speeds. For 14 days of aging, increased effect of using different fan speed was observed compared to other aging times.

In case of 28 days of aging, p.A.V of rib steak samples were higher than p.A.V of samples aged for 7, 14 or 21 days and the presence of this clear and stepped increase means that aging time had a significant effect ($p<0.05$) on p.A.V according to ANOVA (Table A.21). Also according to Figure 3.4, a gradual rise with increasing aging period and a sharp increase of p.A.V after 21 days of aging was obvious which is parallel with the results of TBARS value. For p.A.V, there is no threshold limit for meat products to evaluate and decide deterioration degree. However, 21 days of aging was the most acceptable aging period in terms of p.A.V level due to sharp increase in p.A.V after this time.

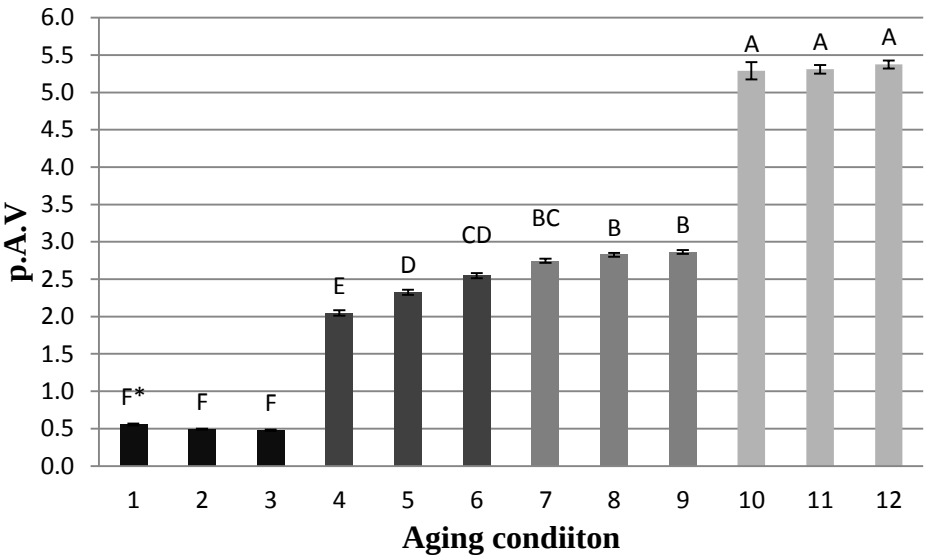

Figure 3.4 p-Anisidine values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days.. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.2 Effects of different aging conditions on physical quality of dry aged rib steak samples

3.2.1 Weight loss

There was significant difference between the fan speed of 0.50 m/s and 1.00 m/s for aging periods of 14 and 21 days (Figure 3.5 and Table A.22). These data was parallel with the studies of Samuelsson et al., (2005). Fan speed directly related to air flow rate through surface of dried samples. Higher fan speeds increased the rate of moisture diffusion from the sample.

Aging time had a significant effect ($p<0.05$) on weight loss (Table A.22). These data agreed with those of Ahnström et al., (2006), Hunt et al., (2009).

There was a sharp increase in weight loss between 7 and 14 days of aging (Figure 3.5). After 14 days, diffusion of moisture from the interior area of the sample to the surface becomes more difficult due to increase in crust thickness.

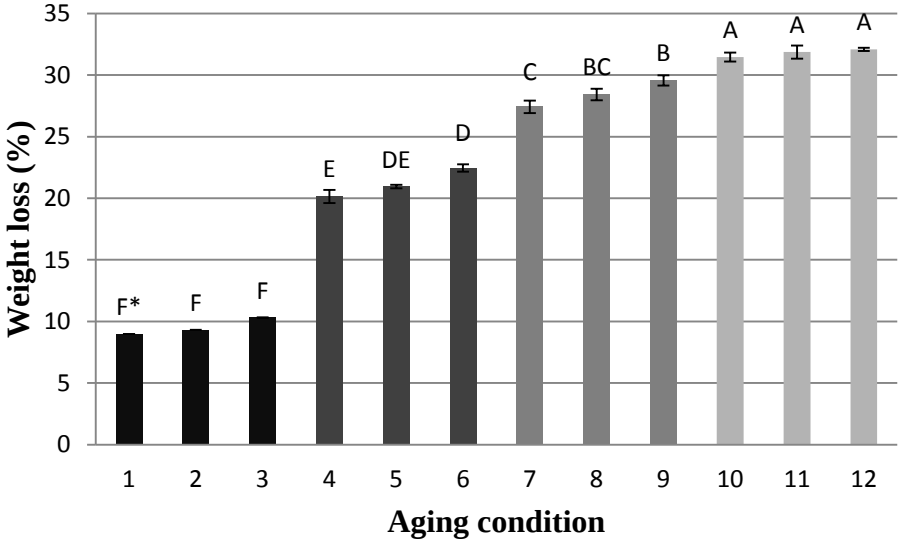

Figure 3.5 Weight loss values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.2.2 Trim loss

For the trim loss analysis of dry aged rib steak samples, greatest trim loss values were obtained for the fan speed of 1.00 m/s for the same aging period. According to ANOVA, effect of using different fan speeds is significant ($p<0.05$) for all aging times of 7, 14, 21 and 28 days (Table A.23). Amount of trim at the end of aging, is directly related to thickness of crust formed by through air flow. Higher air flow rates increased the rate of moisture loss from the surface and resulted in the formation of thicker crust. For this reason,

as fan speed increased trim loss values also increased gradually as in Figure 3.6.

Aging time had also a significant effect ($p<0.05$) on trim loss (Table A.23). It was determined that trim loss of rib steak samples increased as aging time increased. Similar results were obtained by Ahnström et al., (2006) and Hunt et al., (2009). The greatest trim loss value was observed for 1.00 m/s fan speed and 28 days of aging.

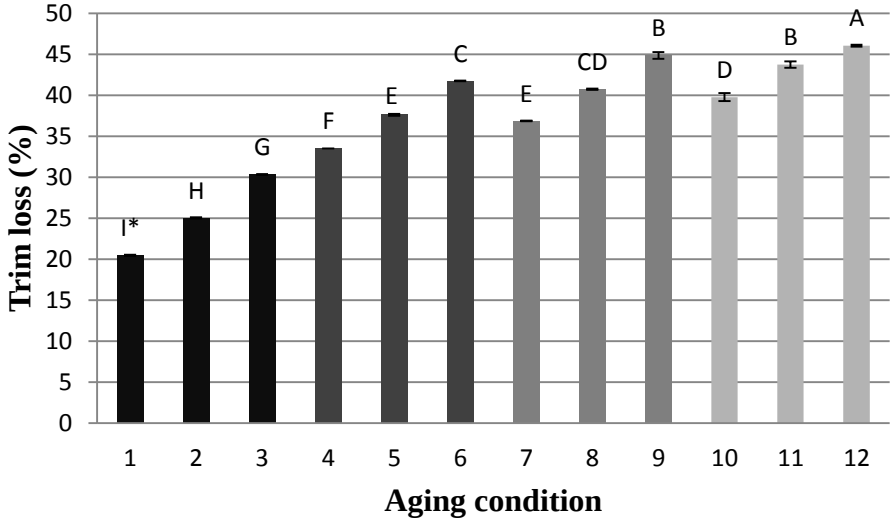

Figure 3.6 Trim loss values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.2.3 Yield

Dry aging is a costly process compared to other aging options. In order to obtain desired sensory attributes and quality aspects expected from dry aging, a period of time is certainly necessary. However, during this period shrinkage occurs on samples due to direct air flow through on and amount of yield decreases. Amount of yield is directly related to economy of aging process and considered by consumers as one of the most important criteria.

The lowest yield values were obtained for the fan speed of 1.00 m/s for the same aging periods. Effect of using different fan speeds is significant ($p<0.05$) for all aging times of 7, 14, 21 and 28 days (Table A.25). These data agreed with results of Samuelsson et al., (2005). Percentage of yield at the end of aging, is directly related to moisture loss and thickness of crust formed by through air flow since crust portion of sample was cut and rest of the sample is used for yield calculation. Higher air flow rates increase moisture loss and thickness of crust. For this reason, as fan speed increases yield values also decreases gradually as in Figure 3.7.

Lower yield values were observed as aging time increased. Aging time had a significant effect ($p<0.05$) on yield value (Table A.25). These data agreed with those of Ahnström et al., (2006), Hunt et al., (2009) and Savell (2008). The lowest yield percentage was observed for 1.00 m/s fan speed and 28 days of aging. Similar trend was observed in variation of weight loss and trim loss with respect to aging time since both of them are resulted from water diffusion (Figure 3.5 and 3.6, respectively).

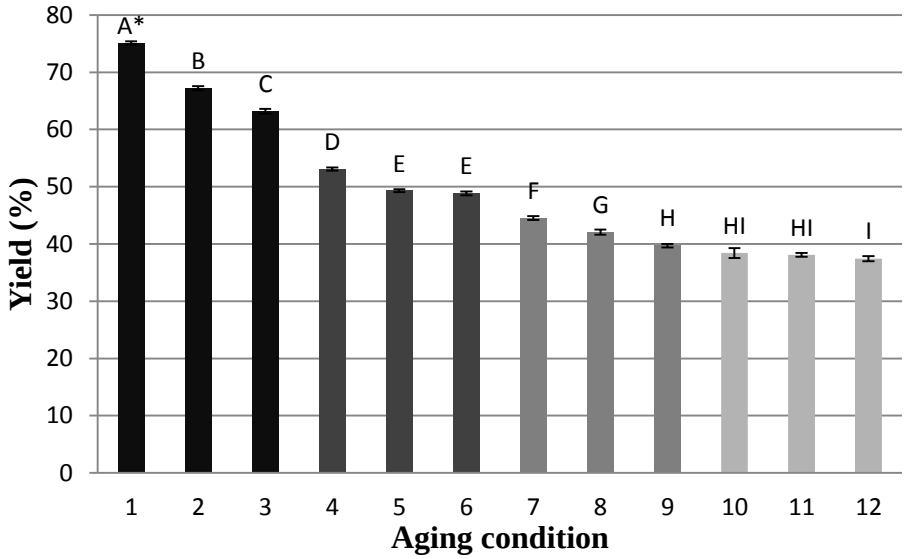

Figure 3.7 Yield values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.2.4 Water Holding Capacity (WHC)

Water holding capacity is a critical parameter to decide about final quality of dry aged rib steak samples from the view point of consumers. Because it is directly related to drip and cook loss and this loss of water can be realized by consumers during storing and cooking, it is considered an economic loss. For this reason, the ability of fresh meat to retain its water inside has become one of the most important quality criteria.

Before starting aging process, initial values of WHC were measured as 35.0±1.5. Effect of using different fan speeds had significant effect on WHC ($p<0.05$) (Table A.26). According to Figure 3.9, it was observed that 0.75 m/s fan speed is ideal for retaining and even increasing WHC values.

The presence of increase with aging time expressed that aging time had a significant effect ($p<0.05$) on WHC value according to ANOVA (Table A.26). It was determined that WHC of rib steak samples increased with aging (Figure 3.8).

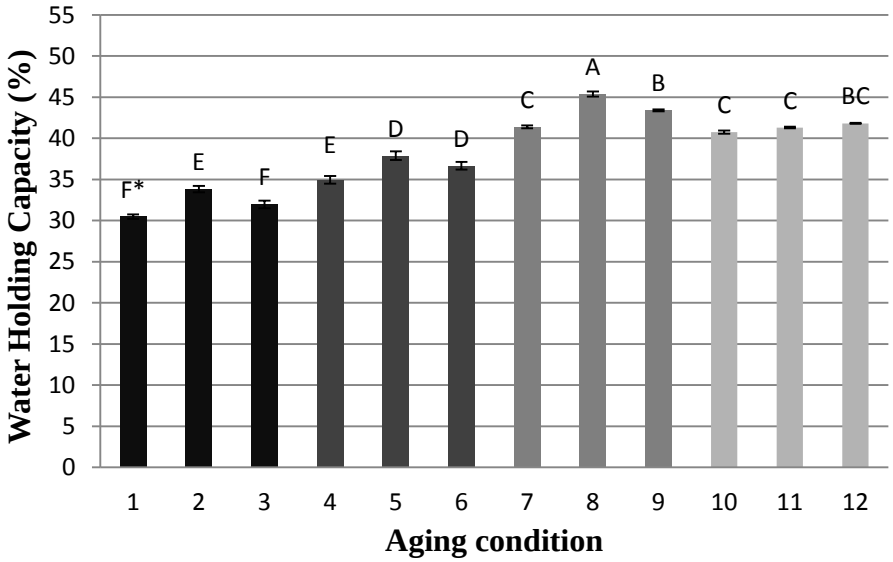

Figure 3.8 WHC values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.2.5 Cook loss

Measuring cook loss is one of the way to determine water holding capacity. Before starting aging process, initial values of cook loss were measured as 22.2 ±1.3 %. In scope of cook loss analysis of dry aged rib steak samples, effect of using different fan speeds had significant effect ($p<0.05$) (Table A.24). According to Figure 3.9, it was observed that 0.75 m/s fan speed is ideal for decreasing amount of water loss during cooking.

A decline in cook loss was observed with aging (Figure 3.9). Aging time had a significant effect on cook loss ($p<0.05$) (Table A.24). These data agreed with results of water holding capacity. As an overall evaluation, the lowest amount of cook loss and the highest amount of WHC were observed for 21 days of aging in case of using 0.75 m/s fan speed (Figure 3.8 and 3.9).

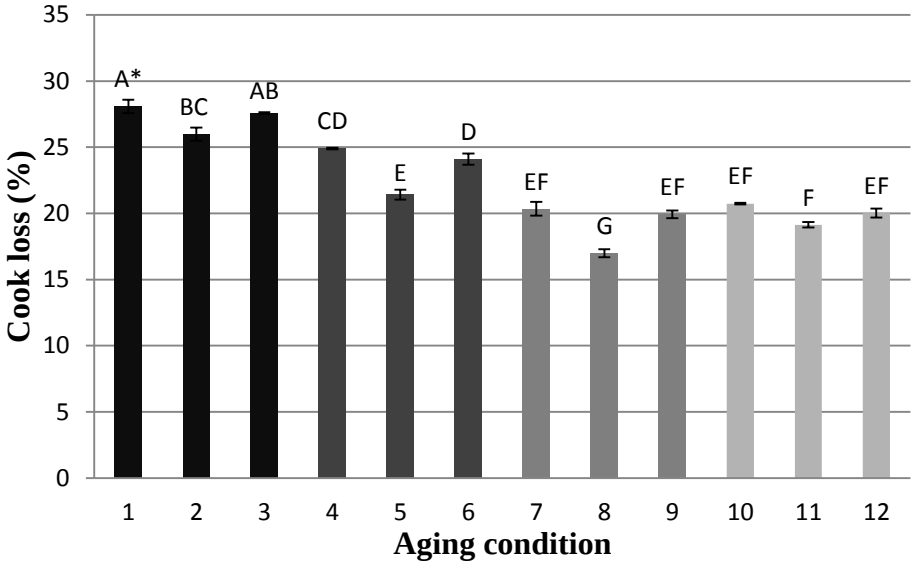

Figure 3.9 Cook loss values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.2.6 Moisture Content

The lowest moisture content values were obtained for the fan speed of 1.00 m/s for the same aging period. Effect of using different fan speed is significant ($p<0.05$), especially for aging time of 14 and 21 days (Table A.27). These data indicated a direct inverse relation with weight loss data. Fan speed directly related to air flow rate through surface of dried samples. Higher fan speeds makes moisture diffusion easier.

Moisture content of rib steak samples decreased as aging time increased. Aging time had a significant effect ($p<0.05$) on weight loss (Table A.27). These data agreed with those of Ahnström et al., (2006).

Decrease in moisture content between 7 days and 14 days of aging was sharp. The reason of this sharp decline is related to crust formation. Since the crust was not thick enough up to 14 days, moisture had a chance to be released from the surface easily. However, after 14 days, resistance to moisture release increased since thickness of crust reached a certain value. For this reason, after 14 days rate of decrease of moisture content was not sharp as in Figure 3.10. and similar trend was observed in weight loss (Figure 3.5).

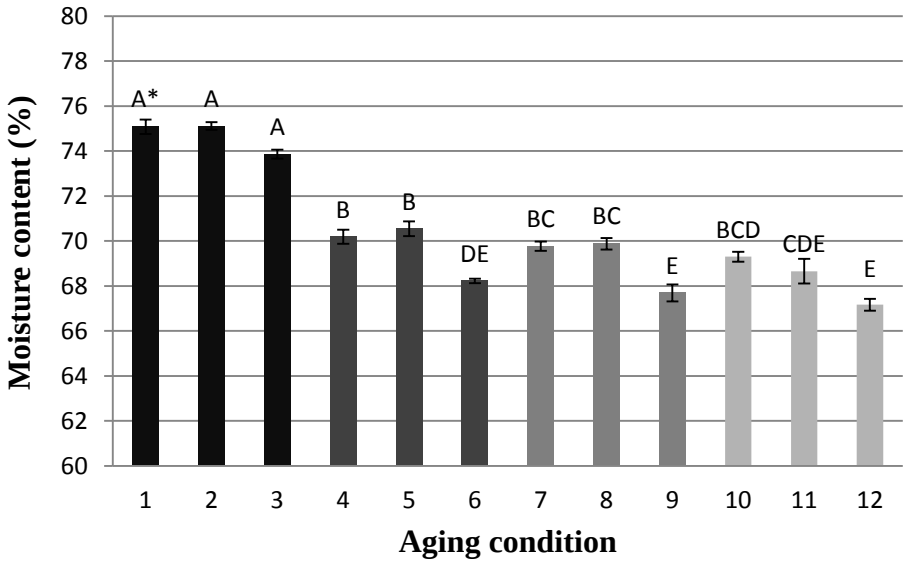

Figure 3.10 Moisture content values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.2.7 Warner-Bratzler Shear Force

Before starting aging process, WBSF values of rib steak samples were measured as 25±1.5 N. It was observed that the effect of fan speeds on WBSF values was not statistically significant ($p>0.05$) for each of aging times (7, 14, 21 and 28 days) (Table A.28 and Figure 3.11). This result agreed with the findings of Samuelsson et al., (2005). The maximum difference between the WBSF values of samples aged at different conditions was around 0.4 N and it was very small to claim a significant difference as in Figure 3.11.

Campbell et al., (2001) stated that in general application of dry aging for long periods improves shear force and tenderness . However, as a counter view, Smith et al. (1978) expressed that similarities for shear force and tenderness after 7 and 14 days are expected since these quality attributes do not change after 11 days of aging. WBSF values were evaluated for different aging times and it was observed that aging time didn't effect shear force significantly ($p>0.05$) (Table A.28 and Figure 3.11). Within the scope of performed experiments, aging times may not be long enough to get a distinct difference in terms of shear force or it was expected to obtain similar shear force values after 11 days period as in previous studies. Similar results were observed by also Ahnström et al., (2006) and Hunt et al., (2009).

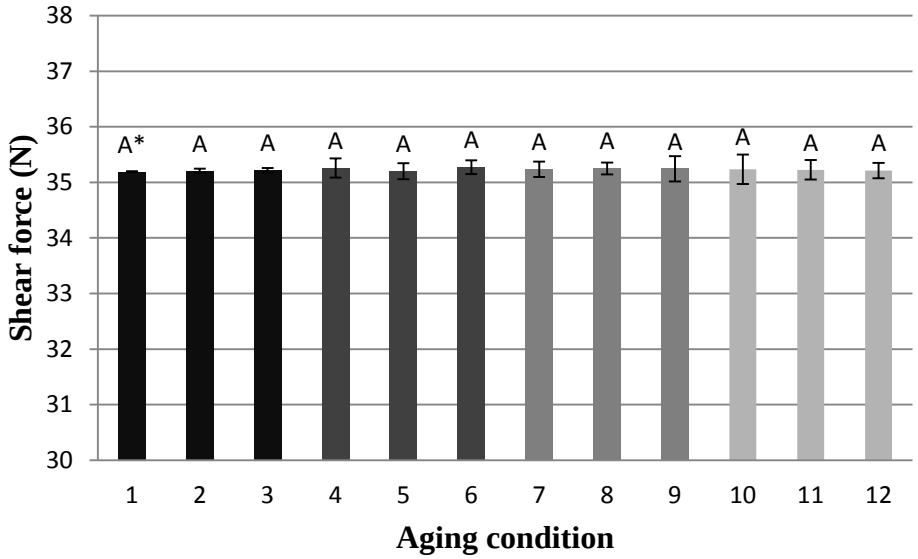

Figure 3.11 WBSF values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.2.8 Color parameters

3.2.8.1 L* value

Color measurements were done after trim was removed. The lowest L* values were obtained for the fan speed of 1.00 m/s for the same aging period. Effect of using different fan speeds is significant ($p<0.05$), especially for the first 7 days of aging, before thickness of crust increased (Table A.29). These data was parallel with the studies of Samuelsson et al., (2005) and in this study, lighter color was associated with greater moisture content bringing about greater lightness and more light reflection. Fan speed directly related to air flow rate through surface of dried samples and affected rate of drying. Drier surface area resulted in darker color in measurements as in Figure 3.12.

The lightness (L*) of rib steak samples reduced significantly during aging (Figure 3.12). The presence of this gradual decrease indicated that aging time had a significant effect ($p<0.05$) on L* value (Table A.29). Aging time directly affected rate of drying and darkness of surface. Besides, higher L* values were directly related to greater reflectance due to higher moisture content.

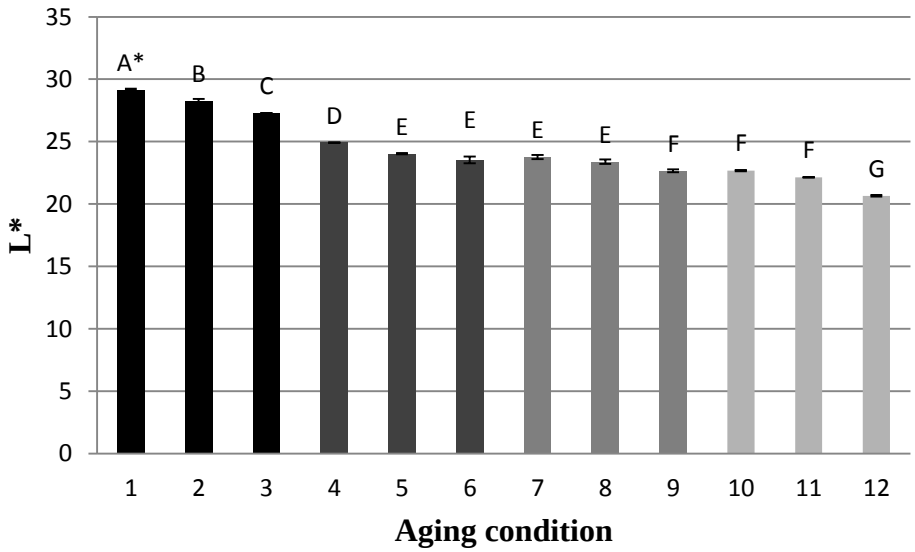

Figure 3.12 L* values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.2.8.2 a* value

In general, in dry aged rib steak samples, the lowest a* values were obtained for the fan speed of 1.00 m/s for the same aging period. Effect of using different fan speeds on color was significant ($p<0.05$) (Table A.30), Similar results were obtained by Samuelsson et al., (2005). Fan speed directly related to air flow rate through surface of dried samples and affected rate of drying. Drier surface resulted in color away from redness as in Figure 3.13.

During aging, a decrease in a* value of rib steak samples were observed (Figure 3.13) and aging time had a significant effect ($p<0.05$) on a* value (Table A.30). Sharp decrease in a* value with aging time during early periods may be due to higher rate of moisture loss during this period and also crust formation. After crust formation, rate of darkening slowed down. This result agreed with the images captured by image process analysis as in Figure B.5-B.7.

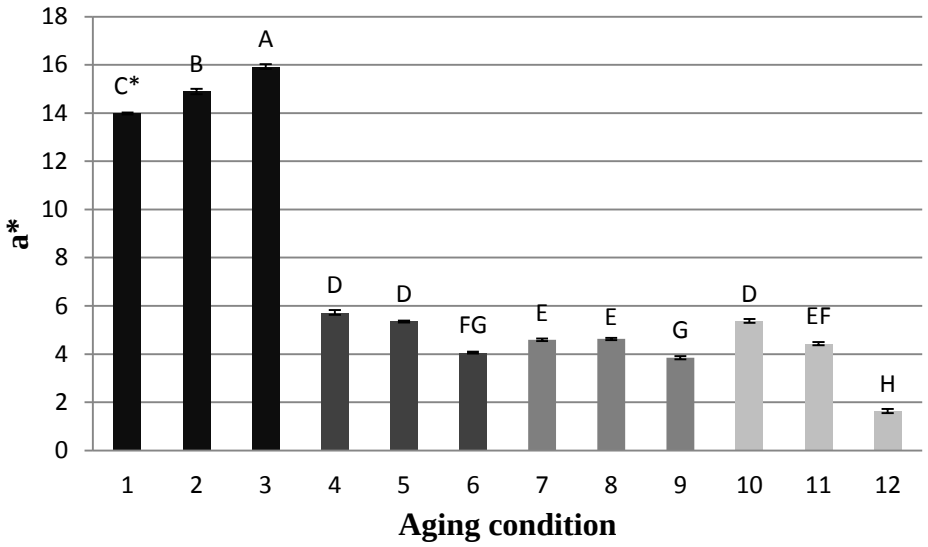

Figure 3.13 a* values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.2.8.3 Chroma (C*) value

Variation of color during aging was also analysed in terms of Chroma (C*) value. Effect of using different fan speeds on C* value was significant ($p<0.05$) (Table A.31). These data was parallel with studies of Samuelsson et al., (2005). Fan speed directly related to air flow rate through surface of dried

samples and affected rate of drying. Drier surface resulted in less pure color (Figure 3.14).

When the data analyzed in terms of different aging times, it was determined that C* value of rib steak samples aged for longer times were lower than the samples aged for shorter times. Aging time had a significant effect ($p<0.05$) on a* value (Table A.31). As in a* values, the decrease in C* value during aging was sharper during the early aging periods due to higher rate of moisture loss and formation of crust. This result agreed with the images captured by image process analysis as in Figure 5-7.

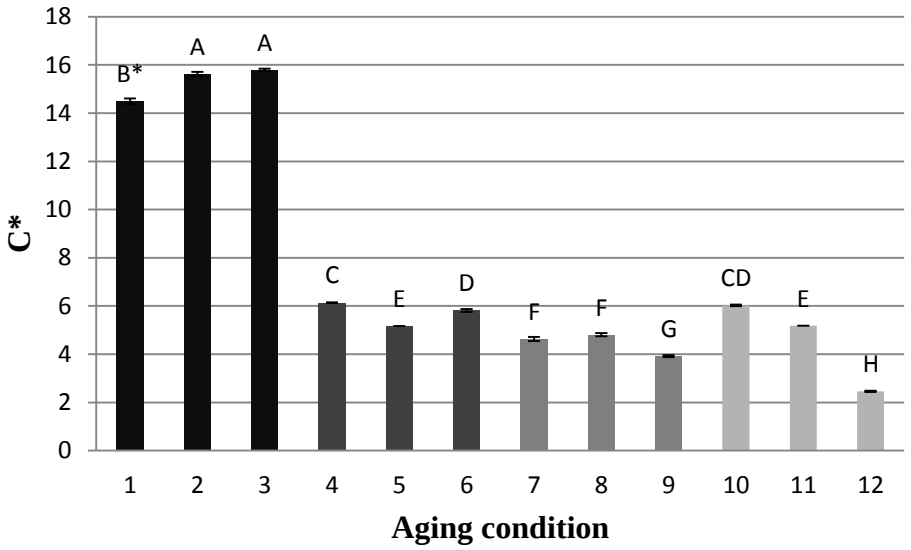

Figure 3.14 C* values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p\leq0.05$).

3.2.9 Shrinkage by Image Processing

For shrinkage analysis images of dry aged rib steak samples were captured for each aging conditions. Then, images were analyzed by software to get the amount of shrinkage values.

The highest shrinkage values were obtained for the fan speed of 1.00 m/s, especially for 7, 14 and 21 days of aging (Figure 3.15). Effect of using different fan speeds had significant effect on shrinkage ($p<0.05$) (Table A.32). These data agreed with yield and weight loss results. Amount of shrinkage was directly related to rate of air flow over the meat surface. As the rate of air flow increased, diffusion of moisture increased resulting in more shrinkage and weight loss, lower L* and yield values (Figures 3.15, 3.5, 3.12, 3.7).

As can be seen in Figure 3.15, shrinkage increased gradually during aging. Aging time had a significant effect ($p<0.05$) on shrinkage value (Table A.32). In the images given in Figures B.5-7, shrinkage of rib steak samples with aging time and air velocity can be seen.

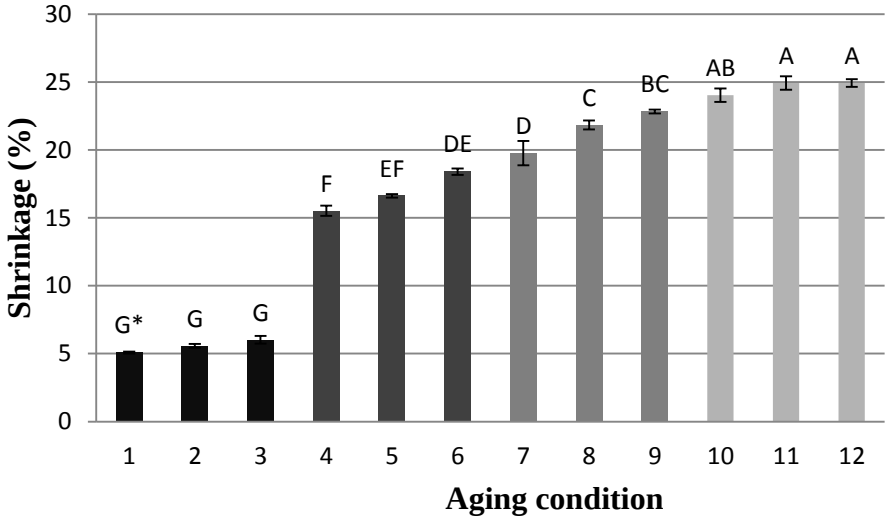

Figure 3.15 Shrinkage values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

A significant amount of correlation between shrinkage and other physical parameters including weight loss, trim loss, yield, moisture content was observed according to Table 3.1. This result means that using shrinkage value instead of other physical parameters is promising.

Table 3.1 Pearson Correlation Coefficients between shrinkage and weight loss, trim loss, yield and moisture content

	Weight loss	Trim loss	Yield	Moisture Content
Coefficient (For shrinkage)	0.992	0.931	-0.977	-0.930
p	0.000	0.000	0.000	0.000

3.3 Effects of different aging conditions on microbiological quality of dry aged rib steak samples

3.3.1 Aerobic Plate Count (APC)

Initially, APC of rib steak samples were 3.0 ±0.3 log cfu/g. Using different fan speeds did not have a significant effect ($p>0.05$) on APC for each aging time (7, 14, 21, 28 days) (Table A.33). The reason might be related to the crust formation. APC analysis was performed in the samples after trimming operation. The dried surface acts as a barrier against contamination. In addition, ionizer used for sterilization of ambient air inside aging area could eliminate the effect of fan speed. Since diffusion of external air towards the inner side of meat samples was restricted, mainly the microorganism present at time zero continued to grow.

Aging time had a significant effect ($p<0.05$) on APC value (Table A.33). A gradual rise with increasing aging period can be seen obviously in Figure 3.16. These findings are in line with studies performed by Hunt et al., (2009) and Ahnström et al., (2006). Results of APC were also parallel with the findings of pH value (Figure 3.1). It was already discussed that the reason for pH increase with time was microbial growth.

In Turkish Food Codex, the log number of APC for raw red meat samples was limited as 6.0 log cfu/g-ml which is used for decision of spoilage (Turkish Food Codex, 2009). Samples aged for 28 days were over-limited at the end of aging process and one of the reason of this result might be initial load of microorganisms (APC). In case of starting with high initial amount, aging for 21 days will be more convenient in terms of food safety.

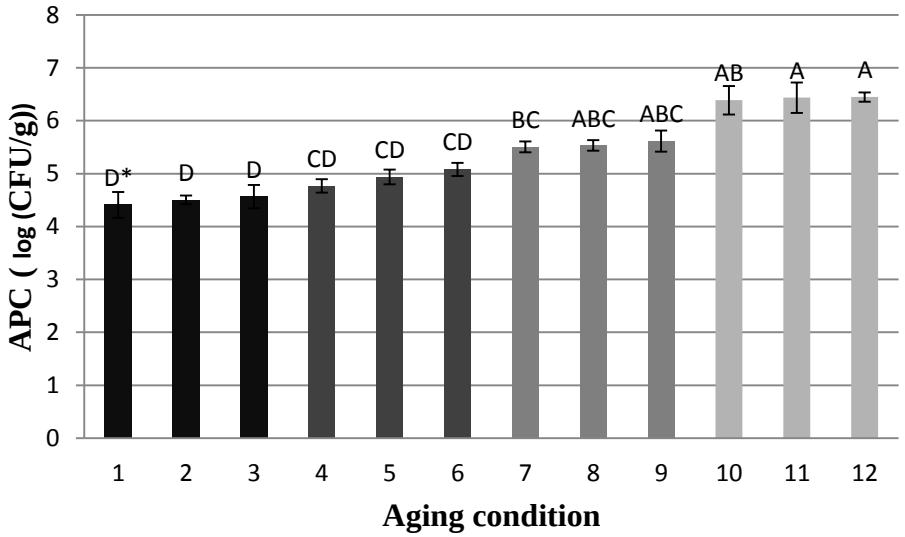

Figure 3.16 Aerobic Plate Count values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.3.2 Yeast and Mold Count

Prior to dry aging, rib steak samples had yeast and mold counts of 3.0±0.05 log cfu/g initially. Using different fan speed rates as 0.50 m/s, 0.75 m/s or 1.00 m/s was not different significantly in terms of its effect on yeast and mold growth ($p>0.05$) for each of aging time (7, 14, 21, 28 days) (Table A.34). As in case of aerobic plate count, the reason for this similarity between different speeds might be related to the crust formation which acts as a barrier

against contamination. Also, ionizer used for sterilization of ambient air inside aging area might eliminate the effect of fan speed rate. Since any other external air can't diffuse inside meat samples, only microorganism occurred at time zero continued to grow. Besides, it was observed that yeast and mold could grow easily compared to aerobic plate count between 21 and 28 days and the reason for this result is lower necessity of water activity for yeast and mold growth. This result is parallel with the findings of Ahnström et al., (2006).

In the case of 28 days of aging, YM of rib steak samples were greater than YM values of samples aged for 7, 14 or 21 days distinctly. Aging time had significant effect ($p<0.05$) on YM value according to ANOVA Table A.34. Also according to Figure 3.17, a gradual rise with increasing aging time was seen obviously. Similarly, in previous studies Hunt et al., (2009) and Ahnström et al., (2006) found that YM value increases with increasing dry aging time if no bag is used.

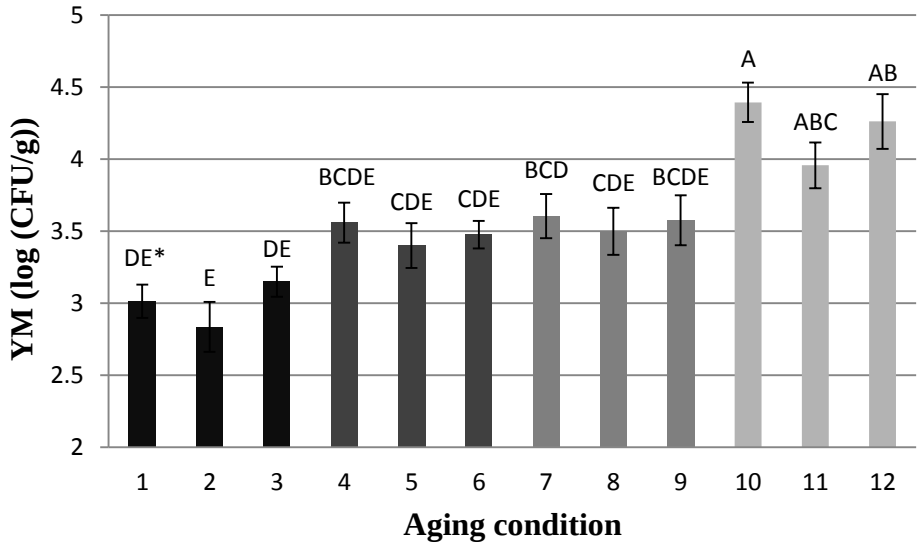

Figure 3.17 Yeast and Mold values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days; **12.** 1.00 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

3.4 NMR Relaxometry Results

T1 and T2 relaxation times of the samples were also measured during the study. Representative T1 and T2 curves for the rib steak samples dried by using 0.50 m/s fan speed for period of 7 and 21 days are given in Figure 3.18 and Figure 3.19, respectively. T1 and T2 curves were fitted both monoexponentially and bi-exponentially. Non-negative least square analysis was also conducted to obtain relaxation spectra but only one obvious peak was detected. For this reason, monoexponential fitting values for the relaxation times were used for interpreting the results. During the analysis of samples stored in condition of 1.00 m/s fan speed and 28 days aging, it was observed that samples are too wrinkled to analyse. For this reason, these samples couldn't be evaluated by NMR technique. Change in T1 and T2 of

the samples with respect to aging condition is also given in Figure 3.20 and Figure 3.21.

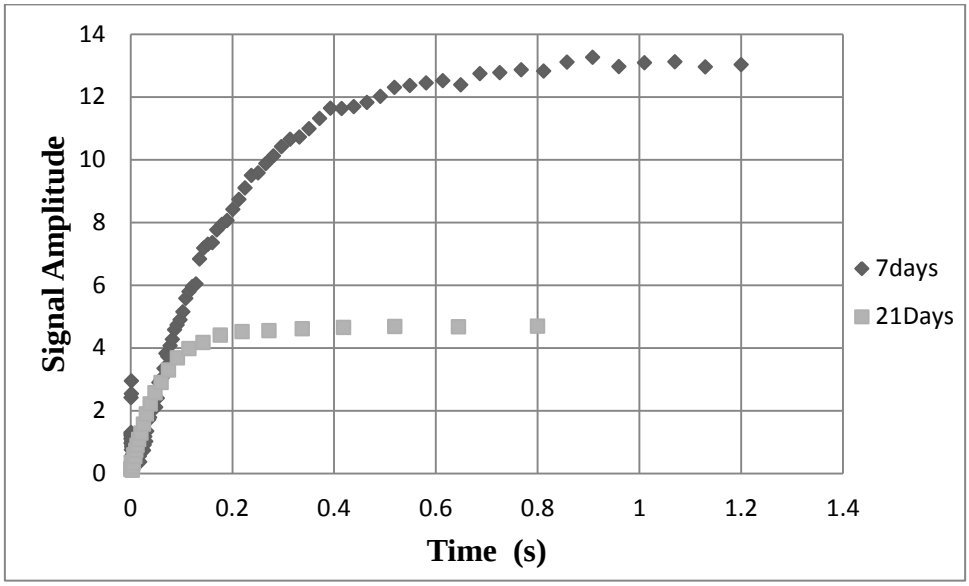

Figure 3.18.Spin-Lattice Relaxation Time (T1) Curves for 7 and 21 days of aging

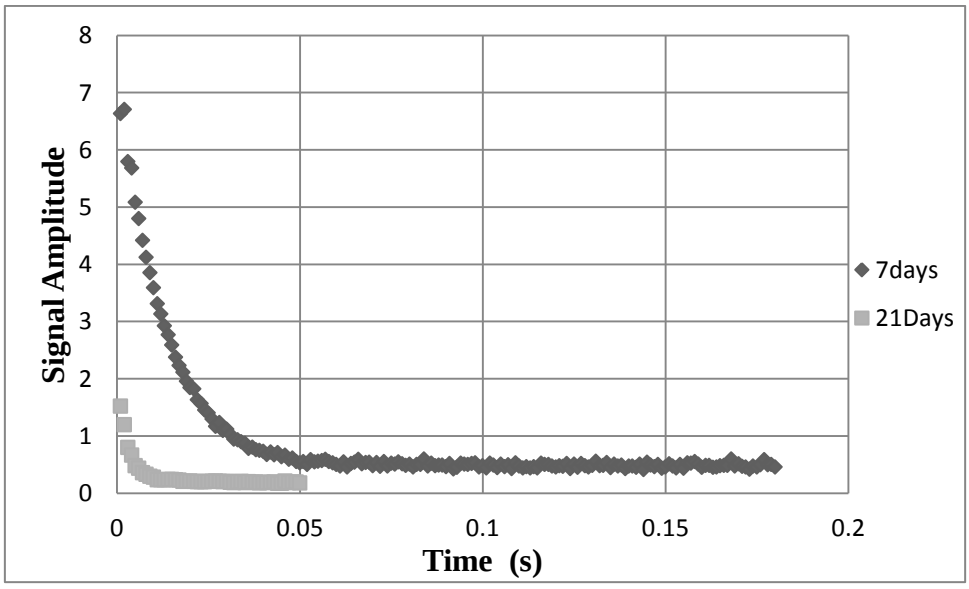

Figure 3.19.Spin-Spin Relaxation Time (T2) Curves for 7 and 21 days of aging

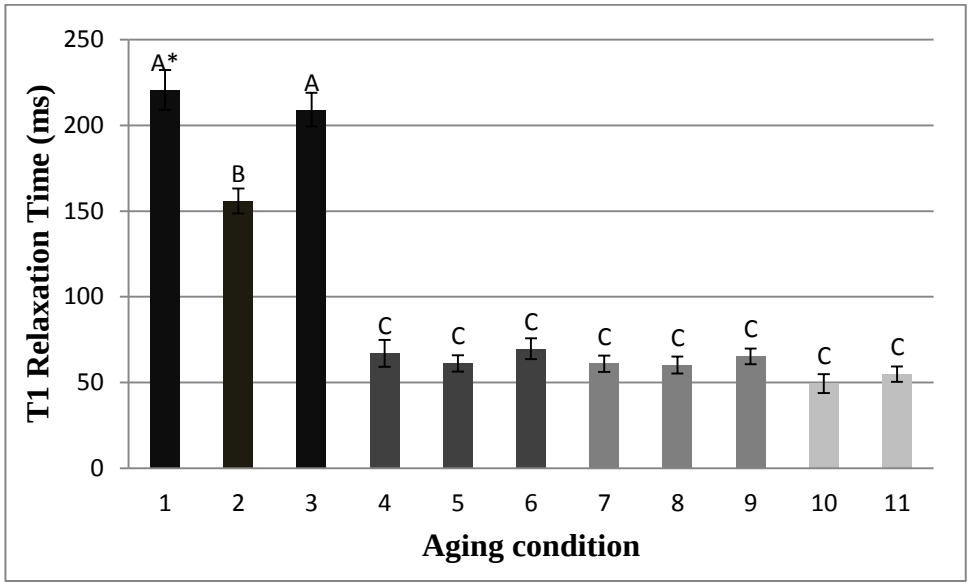

Figure 3.20 Spin lattice (T_1) time values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

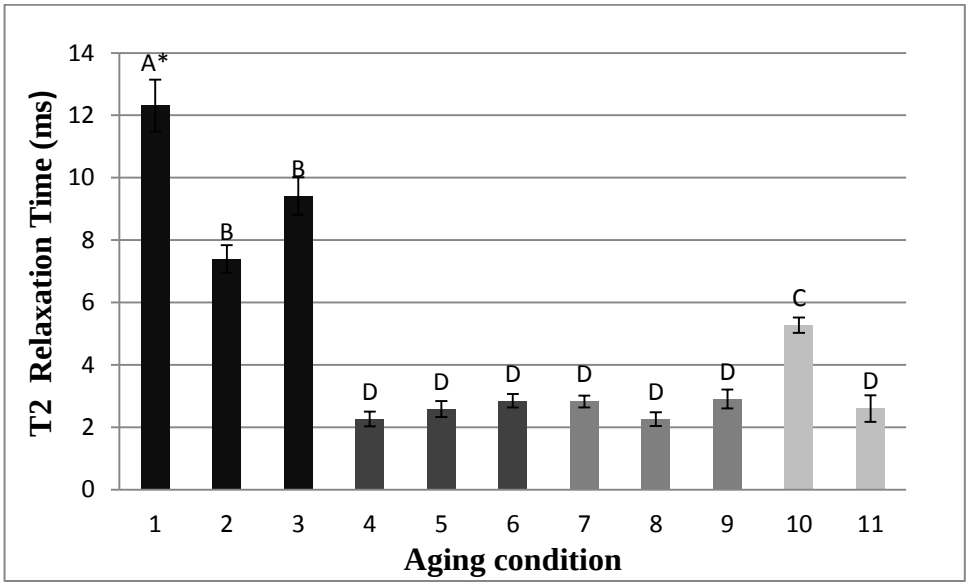

Figure 3.21 Spin-spin relaxation (T2) time values of dry aged rib steak samples stored at different aging conditions. **1.** 0.50 m/s, 7 days; **2.** 0.75 m/s, 7 days; **3.** 1.00 m/s, 7 days; **4.** 0.50 m/s, 14 days; **5.** 0.75 m/s, 14 days; **6.** 1.00 m/s, 14 days; **7.** 0.50 m/s, 21 days; **8.** 0.75 m/s, 21 days; **9.** 1.00 m/s, 21 days; **10.** 0.50 m/s, 28 days; **11.** 0.75 m/s, 28 days. *Means bars with different letters are significantly different ($p \leq 0.05$).

Being sensitive, fast and non-invasive, low field Nuclear Magnetic Resonance (LF-NMR) has been widely adopted as an analytical technique for the characterization of water mobility and distribution in food (Li et., 2014). Many researchers have used NMR to quantify the changes in water distribution and mobility during conversion of muscle to meat, aging , freezing and cooking of meat (Bertram et al., 2002). Figure 3.19 showed that relaxation behavior was best to be explained by a monoexponential behavior .This signal that generated the T2 curve was due to the immobilized water entrapped within the myofibril (Li et al., 2014; Pearce et al., 2011). Our samples did not show the presence of any other proton population due to the echo times used in the study.

The used NMR hardware was limiting the echo time 1000us which automatically eliminated the T2 values less than this value. It was found by

researchers that the other lower proton populations in meat samples were usually associated with the bound water which was integrated closely with polar groups on the surface of muscle protein molecules (Pearce et al., 2011). T2 relaxation times are mostly related with the microstructures of the sample give information regarding the presence of different proton populations in meat samples. In meat the dominant proton population is water and it is affected by the aging process. The other proton population belongs to protons of the protein and water that is strongly bound to the proteins. Fat also contributes to signal but since water protons have limited mobility due to being entrapped in the protein network and it is highly probable that fat protons could be merged with immobilized entrapped water protons resulting a similar relaxation time. Conducting 2D relaxation experiments where T1 and T2 are measured at the same time would be much more helpful to differentiate the protons coming from fat.

T_1 relaxation time (also known as spin–lattice relaxation time) indicates the effectiveness of the magnetic energy transfer between spinning 1H protons and the surrounding lattice. T2 relaxation time (also known as spin–spin relaxation time) is a measure of the effectiveness of energy transfer between neighboring spins, and is expected to be shorter for closer proximity between molecules (Kirtil and Oztop, 2015). Our results showed that both T1 and T2 decreased with increasing aging time due to limited mobility of the protons. In accordance with the findings by Li et al (2014) T2 and also T1 values showed significant correlation with water holding capacity and moisture content. Effect of speed was insignificant both on T1 and T2 ($p>0.05$) whereas 7^{th} day relaxation times were found to be significantly different from the rest ($p<0.05$). Results showed that for monitoring WHC, either T2 or T1 relaxation times were promising as in Table 3.2.

Table 3.2 Pearson Correlation Coefficients between Relaxation Times, WHC and MC

	WHC	**MC**
T2	-0.748	0.855
p	0.008	0.001
T1	-0.828	0.855
p	0.002	0.001

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Change of chemical, physical and microbial properties was investigated after different aging periods for different fan speed rates. When the pH values of rib steak samples were analyzed, it was seen that only aging time had significant effect on pH value. It was observed that any of samples, aged for 7, 14, 21 or 28 days, did not exceed the acceptable beef pH limit (6.2) showing that quality was preserved to some extent in terms of pH which was caused by microbial growth. pH values measured were parallel with the results of APC (aerobic plate count). As logarithmic number of APC increases, pH value increases gradually with time. For TBARS values, it was seen that effect of using different fan speeds was not significant for different aging times (7, 14, 21, 28 days) however, there was a distinct gradual increase for TBARS values with aging time. A sharp increase of TBARS value after 21 days of aging was obvious although any of samples did not exceed the TBARS limit of being uncorrupted. When samples analyzed in terms of P.V, it was determined that effect of using different fan speeds was not significant for each aging time. On the other hand, a gradual increase was observed for P.V with increasing aging time as similar to TBARS value. It was observed that any of samples, aged for 7, 14, 21 or 28 days, did not exceed the P.V limit and it showed that quality was preserved to some extent. As being a final chemical measure, p.A.V results showed that with increasing aging time, oxidation rate increased due to direct air exposure. As an overall evaluation in scope of the chemical properties, 21 days of aging was found as the optimum aging period since after 21 days TBARS value and p.A.V increased sharply.

According to the results of physical analysis; findings of weight loss, moisture content, trim loss, yield and shrinkage were . Both aging time and fan speed had significant effect on final quality. With increasing aging time and fan speed, weight loss, trim loss and shrinkage values raised due to increased amount of air flow directly through the surface of rib steak samples. In addition, moisture content of interior area and yield values decreased due to the same reason related to air circulation through samples. Yield value is directly related to consumer acceptance because as percentage of yield decreases, economic loss increases which is highly critical for consumer aspects. Since a thick crust was formed after aging for long periods, resistance to moisture diffusion occurs from exterior and interior surfaces slowing down surface drying. For this reason there is no significant difference between 21 and 28 days of aging in terms of water releasing properties.

WBSF values were not affected from both different aging times and fan speeds, while color parameters like L*, a* and C* were variable due to different aging conditions. As fan speed and aging time increases, thicker dried surface was formed and this result was reflected as lower lightness, redness and lower purity of color.

According to results of water holding capacity and cook loss, having a certain inverse relation, both different aging times and fan speed had significant effect on these parameters. It was determined that WHC of rib steak samples increased during aging and this results agreed with the results of cooking loss which is a significant indication of capacity of water retaining. WHC was critical for deciding about final quality of end product since it directly gives idea about tenderness and sensory attributes relating muscle composition. As an overall result, the highest amount of WHC and lowest cook loss were observed for 21 days of aging in case of using 0.75 m/s fan speed.

NMR results showed that both T1 and T2 decreased with increasing aging time due to limited mobility of the protons, while effect of speed was insignificant both on T1 and T2. In addition, 7^{th} day relaxation times were

found to be significantly different from the rest. T2 and also T1 values showed significant correlation with water holding capacity and moisture content. Results showed that for monitoring WHC, either T2 or T1 relaxation times were promising.

As the final quality criteria microbiological growth rates, including aerobic plate count and yeast and mold count and were analyzed and it was observed that only different aging times had significant impact on rate of growth. In Turkish Food Codex, the log number of APC for raw red meat samples was limited as 6.0 which is used for decision of spoilage (Turkish Food Codex, 2009). Samples aged for 28 days were over-limited at the end of aging process and one of the reasons of this result might be initial load of microorganisms (APC). When overall increase trend for APC and YM were evaluated; it was seen that after 21 days, a distinct increase occurs in terms of microbial growth continuing until 28 days of aging.

It can be concluded that aging rib steak samples in home-type refrigerators for 21 days will be safer in terms of TBARS, p.A.V, APC and YM values when compared to 28 days of aging. Aging for 21 days with fan speed of 0.75 m/s was necessary to obtain the characteristics of dry aged meat in terms of WHC (indicating desired tenderness and sensory attributes). 21 days of aging was also ideal in terms of weight loss, trim loss, yield, moisture content and shrinkage.

As future study, novel technologies in scope of dry aging could be investigated rather than the traditional one. Water permeable bags can be studied to increase yield and by this way contamination can also be prevented to some extent.

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APPENDIX A

ANOVA TEST TABLES

Table A.1 One-Way-ANOVA test for pH value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	0.310425	0.02822	44.89	0.000
Error	24	0.015089	0.000629		
Total	35	0.325514			

S= 0.02507 R-Sq= 95.36% R-Sq (adj)= 93.24%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	5.8330	0.0373
0.50;14	3	5.6790	0.0277
0.50;28	3	5.9096	0.0111
0.50;7	3	5.6788	0.0173
0.75;14	3	5.7167	0.0389
0.75;21	3	5.8395	0.0102
0.75;28	3	5.8545	0.0111
0.75;7	3	5.6278	0.0231
1.00;14	3	5.7446	0.0278
1.00;21	3	5.7841	0.0141
1.00;28	3	5.8743	0.0414
1.00;7	3	5.6397	0.0023

Pooled StDev= 0.0251

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;28	3	5.90956	A
1.00;28	3	5.87433	AB
0.75;28	3	5.85448	ABC
0.75;21	3	5.83948	ABC
0.50;21	3	5.83305	BC
1.00;21	3	5.78410	CD
1.00;14	3	5.74465	DE
0.75;14	3	5.71670	DE
0.50;14	3	5.67904	EF
0.50;7	3	5.67884	EF
1.00;7	3	5.63971	F
0.75;7	3	5.62783	F

Table A.2 One-Way-ANOVA test for TBARS value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	1.234145	0.112195	5457.32	0.000
Error	24	0.000493	0.000021		
Total	35	1.234638			

S = 0.004534 R-Sq = 99.96% R-Sq(adj) = 99.94%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	0.35757	0.00257
0.50;14	3	0.23810	0.00205
0.50;28	3	0.61273	0.00196
0.50;7	3	0.11053	0.00175
0.75;14	3	0.23443	0.00475
0.75;21	3	0.35917	0.00571
0.75;28	3	0.61083	0.00751
0.75;7	3	0.11463	0.00140
1.00;14	3	0.23527	0.00336
1.00;21	3	0.35563	0.00522
1.00;28	3	0.61807	0.00760
1.00;7	3	0.11500	0.00439

Pooled StDev = 0.00453

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;28	3	0.61807	A
0.50;28	3	0.61273	A
0.75;28	3	0.61083	A
0.75;21	3	0.35917	B
0.50;21	3	0.35757	B
1.00;21	3	0.35563	B
0.50;14	3	0.23810	C
1.00;14	3	0.23527	C
0.75;14	3	0.23443	C
1.00;7	3	0.11500	D
0.75;7	3	0.11463	D
0.50;7	3	0.11053	D

Table A.3 One-Way-ANOVA test for P.V of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	1.165676	0.105971	3294.11	0.000
Error	24	0.000772	0.000032		
Total	35	1.166448			

S = 0.005672 R-Sq = 99.93% R-Sq (adj) = 99.90%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	0.50500	0.00985
0.50;14	3	0.35977	0.00111
0.50;28	3	0.62560	0.00460
0.50;7	3	0.13117	0.00079
0.75;14	3	0.37471	0.00689
0.75;21	3	0.47897	0.00205
0.75;28	3	0.64067	0.00326
0.75;7	3	0.14800	0.00136
1.00;14	3	0.36223	0.00745
1.00;21	3	0.51093	0.00447
1.00;28	3	0.63187	0.00889
1.00;7	3	0.15800	0.00688

Pooled StDev = 0.00567

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;28	3	0.72560	A
0.75;28	3	0.64067	A
1.00;28	3	0.63187	A
1.00;21	3	0.51093	B
0.50;21	3	0.50500	B
0.75;21	3	0.47897	BC
0.75;14	3	0.39471	E
1.00;14	3	0.36223	DE
0.50;14	3	0.35977	DE
0.75;7	3	0.18800	FG
1.00;7	3	0.14807	F
0.50;7	3	0.13117	F

Table A.4 One-Way-ANOVA test for p.A.V of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	107.0519	9.7320	1508.91	0.000
Error	24	0.1548	0.0064		
Total	35	107.2067			

S = 0.08031 R-Sq = 99.86% R-Sq (adj) = 99.79%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	2.7463	0.0496
0.50;14	3	2.0477	0.0599
0.50;28	3	5.2857	0.2029
0.50;7	3	0.5557	0.0216
0.75;14	3	2.3210	0.0575
0.75;21	3	2.82640	0.0444
0.75;28	3	5.3103	0.1006
0.75;7	3	0.4933	0.0078
1.00;14	3	2.5473	0.0607
1.00;21	3	2.8687	0.440
1.00;28	3	5.3740	0.0915
1.00;7	3	0.4793	0.0159

Pooled StDev = 0.0803

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;28	3	5.3703	A
0.75;28	3	5.3157	A
0.50;28	3	5.2840	A
1.00;21	3	2.8640	B
0.75;21	3	2.8210	B
0.50;21	3	2.7487	BC
1.00;14	3	2.5463	CD
0.75;14	3	2.3273	D
0.50;14	3	2.0477	E
0.50;7	3	0.5557	F
0.75;7	3	0.4933	F
1.00;7	3	0.4793	F

Table A.5 One-Way-ANOVA test for weight loss of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	2642.898	240.263	655.16	0.000
Error	24	8.801	0.367		
Total	35	2651.699			

S = 0.6056 R-Sq = 99.67% R-Sq(adj) = 99.52%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	27.418	0.872
0.50;14	3	20.146	0.905
0.50;28	3	31.465	0.628
0.50;7	3	8.979	0.001
0.75;14	3	20.949	0.240
0.75;21	3	28.417	0.811
0.75;28	3	31.864	0.928
0.75;7	3	9.321	0.008
1.00;14	3	22.456	0.512
1.00;21	3	29.556	0.730
1.00;28	3	32.084	0.234
1.00;7	3	10.319	0.040

Pooled StDev = 0.606

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;28	3	32.084	A
0.75;28	3	31.864	A
0.50;28	3	31.465	A
1.00;21	3	29.556	B
0.75;21	3	28.417	BC
0.50;21	3	27.418	C
1.00;14	3	22.456	D
0.75;14	3	20.949	DE
0.50;14	3	20.146	E
1.00;7	3	10.319	F
0.75**;7**	3	9.321	F
0.50;7	3	8.979	F

Table A.6 One-Way-ANOVA test for trim loss of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	2115.338	192.303	1260.70	0.000
Error	24	3.661	0.153		
Total	35	2118.999			

S = 0.3906 R-Sq = 99.83% R-Sq(adj) = 99.75%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	36.866	0.050
0.50;14	3	33.525	0.015
0.50;28	3	39.775	0.858
0.50;7	3	20.482	0.140
0.75;14	3	37.620	0.201
0.75;21	3	40.744	0.133
0.75;28	3	43.755	0.664
0.75;7	3	25.043	0.136
1.00;14	3	41.756	0.047
1.00;21	3	44.841	0.713
1.00;28	3	46.051	0.190
1.00;7	3	30.342	0.089

Pooled StDev = 0.391

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;28	3	46.051	A
1.00;21	3	44.841	B
0.75**;28**	3	43.755	B
1.00;14	3	41.756	C
0.75;21	3	40.744	CD
0.50;28	3	39.775	D
0.75;14	3	37.620	E
0.50;21	3	36.866	E
0.50;14	3	33.525	F
1.00;7	3	30.342	G
0.75;7	3	25.043	H
0.50;7	3	20.482	I

Table A.7 One-Way-ANOVA test for cook loss of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	421.255	38.296	107.08	0.000
Error	24	8.584	0.358		
Total	35	429.839			

S = 0.5980 R-Sq = 98.00% R-Sq (adj) = 97.09%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	20.347	0.894
0.50;14	3	24.894	0.097
0.50;28	3	20.734	0.091
0.50;7	3	28.077	0.886
0.75;14	3	21.410	0.661
0.75;21	3	16.992	0.528
0.75;28	3	19.140	0.366
0.75;7	3	25.986	0.842
1.00;14	3	24.092	0.730
1.00;21	3	19.925	0.499
1.00;28	3	20.021	0.576
1.00;7	3	27.560	0.128

Pooled StDev = 0.598

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;7	3	28.077	A
1.00;**7**	3	27.560	AB
0.75;7	3	25.986	BC
0.50;14	3	24.894	CD
1.00;14	3	24.092	D
0.75;14	3	21.410	E
0.50;28	3	20.734	EF
0.50;**21**	3	20.347	EF
1.00;28	3	20.021	EF
1.00;21	3	19.925	EF
0.75;28	3	19.140	F
0.75;21	3	16.992	G

Table A.8 One-Way-ANOVA test for yield of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	5233.808	475.801	889.76	0.000
Error	24	12.834	0.535		
Total	35	5246.642			

S = 0.7313 R-Sq = 99.76% R-Sq (adj) = 99.64%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	44.546	0.574
0.50;14	3	53.084	0.452
0.50;28	3	38.408	1.525
0.50;7	3	75.118	0.515
0.75;14	3	49.304	0.465
0.75;21	3	42.052	0.784
0.75;28	3	38.097	0.590
0.75;7	3	67.226	0.615
1.00;14	3	48.820	0.590
1.00;21	3	39.705	0.504
1.00;28	3	37.443	0.793
1.00;7	3	63.179	0.708

Pooled StDev = 0.731

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;7	3	75.118	A
0.75;7	3	67.226	B
1.00;7	3	63.179	C
0.50;14	3	53.084	D
0.75;14	3	49.304	E
1.00;14	3	48.820	E
0.50;21	3	44.546	F
0.75;21	3	42.052	G
1.00;21	3	39.705	H
0.50;28	3	38.408	HI
0.75;28	3	38.097	HI
1.00;28	3	37.443	I

Table A.9 One-Way-ANOVA test for WHC (water holding capacity) of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	744.555	67.687	205.25	0.000
Error	24	7.915	0.330		
Total	35	752.469			

S = 0.5743 R-Sq = 98.95% R-Sq (adj) = 98.47%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	41.382	0.310
0.50;14	3	34.939	0.791
0.50;28	3	40.737	0.339
0.50;7	3	30.473	0.443
0.75;14	3	37.879	0.897
0.75;21	3	45.359	0.528
0.75;28	3	41.293	0.178
0.75;7	3	33.824	0.686
1.00;14	3	36.640	0.812
1.00;21	3	43.386	0.180
1.00;28	3	41.809	0.130
1.00;7	3	31.956	0.792

Pooled StDev = 0.574

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.75;21	3	45.359	A
1.00;21	3	43.386	B
1.00;28	3	41.809	BC
0.50;21	3	41.382	C
0.75;28	3	41.293	C
0.50;**28**	3	40.737	C
0.75;14	3	37.879	D
1.00;14	3	36.640	D
0.50;14	3	34.939	E
0.75;7	3	33.824	E
1.00;7	3	31.956	F
0.5;7	3	30.473	F

Table A.10 One-Way-ANOVA test for moisture content of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	250.753	22.796	86.31	0.000
Error	24	6.339	0.264		
Total	35	257.092			

S = 0.5139 R-Sq = 97.53% R-Sq (adj) = 96.40%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	69.770	0.354
0.50;14	3	70.186	0.534
0.50;28	3	69.300	0.377
0.50;7	3	75.081	0.553
0.75;14	3	70.543	0.573
0.75;21	3	69.879	0.438
0.75;28	3	68.654	0.952
0.75;7	3	75.116	0.301
1.00;14	3	68.225	0.165
1.00;21	3	67.690	0.661
1.00;28	3	67.167	0.453
1.00;7	3	73.858	0.351

Pooled StDev = 0.514

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.75;7	3	75.116	A
0.5;7	3	75.081	A
1.00;7	3	73.858	A
0.75;14	3	70.543	B
0.50;14	3	70.186	B
0.75;21	3	69.879	BC
0.50;21	3	69.770	BC
0.50;28	3	69.300	BCD
0.75;28	3	68.654	CDE
1.00;14	3	68.225	DE
1.00;21	3	67.690	E
1.00;28	3	67.167	E

Table A.11 One-Way-ANOVA test for shear force value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	0.0204	0.0019	0.03	1.000
Error	24	1.6297	0.0679		
Total	35	1.6501			

S = 0.2606 R-Sq = 1.24% R-Sq (adj) = 0.1%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	35.235	0.237
0.50;14	3	35.259	0.303
0.50;28	3	35.236	0.456
0.50;7	3	35.192	0.014
0.75;14	3	35.199	0.249
0.75;21	3	35.250	0.186
0.75;28	3	35.225	0.305
0.75;7	3	35.208	0.064
1.00;14	3	35.273	0.218
1.00;21	3	35.244	0.390
1.00;28	3	35.212	0.243
1.00;7	3	35.215	0.074

Pooled StDev = 0.261

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;14	3	35.2731	A
0.50;14	3	35.2586	A
0.75;21	3	35.2498	A
1.00;21	3	35.2444	A
0.50;28	3	35.3264	A
0.50,21	3	35.2349	A
0.75;28	3	35.2251	A
1.00;7	3	35.2153	A
1.00;28	3	35.2122	A
0.75;7	3	35.2076	A
0.75;14	3	35.1994	A
0.50;7	3	35.1915	A

Table A.12 One-Way-ANOVA test for L* value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	221.1671	20.1061	442.30	0.000
Error	24	1.0910	0.0455		
Total	35	222.2581			

S = 0.2132 R-Sq = 99.51% R-Sq (adj) = 99.28%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	23.767	0.289
0.50;14	3	24.923	0.033
0.50;28	3	22.663	0.086
0.50;7	3	29.167	0.142
0.75;14	3	24.027	0.089
0.75;21	3	23.400	0.317
0.75;28	3	22.135	0.028
0.75;7	3	28.272	0.245
1.00;14	3	23.527	0.463
1.00;21	3	22.655	0.188
1.00;28	3	20.649	0.108
1.00;7	3	27.261	0.049

Pooled StDev = 0.213

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;7	3	29.1666	A
0.75;7	3	28.2723	B
1.00;7	3	27.2605	C
0.50;14	3	24.9231	D
0.75;14	3	24.0272	E
0.50;21	3	23.7670	E
1.00;14	3	23.5275	E
0.75;21	3	23.4004	E
0.50;28	3	22.6628	F
1.00;21	3	22.6554	F
0.75;28	3	22.1355	F
1.00;28	3	20.6488	G

Table A.13 One-Way-ANOVA test for a* value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	788.8137	71.7103	4301.58	0.000
Error	24	0.4001	0.0167		
Total	35	789.2138			

S = 0.1291 R-Sq = 99.95% R-Sq(adj) = 99.93%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	4.598	0.095
0.50;14	3	5.727	0.180
0.50;28	3	5.372	0.139
0.50;7	3	13.983	0.073
0.75;14	3	5.353	0.073
0.75;21	3	4.627	0.083
0.75;28	3	4.433	0.121
0.75;7	3	14.893	0.187
1.00;14	3	4.065	0.067
1.00;21	3	3.853	0.110
1.00;28	3	1.637	0.157
1.00;7	3	15.925	0.176

Pooled StDev = 0.129

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;7	3	15.925	A
0.75;7	3	14.893	B
0.50;7	3	13.983	C
0.50;14	3	5.727	D
0.50;28	3	5.372	D
0.75;14	3	5.353	D
0.75;21	3	4.627	E
0.50;21	3	4.598	E
0.75;28	3	4.433	EF
1.00;14	3	4.065	FG
1.00;21	3	3.853	G
1.00;28	3	1.637	H

Table A.14 One-Way-ANOVA test for C* (Chroma) value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	765.3722	69.5793	6806.30	0.000
Error	24	0.2453	0.0102		
Total	35	756.6175			

S = 0.1011 R-Sq = 99.97% R-Sq (adj) = 99.95%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	4.636	0.151
0.50;14	3	6.140	0.016
0.50;28	3	6.024	0.053
0.50;7	3	14.498	0.197
0.75;14	3	5.170	0.006
0.75;21	3	4.809	0.114
0.75;28	3	5.182	0.011
0.75;7	3	15.626	0.145
1.00;14	3	5.814	0.097
1.00;21	3	3.924	0.069
1.00;28	3	2.459	0.047
1.00;7	3	15.795	0.088

Pooled StDev = 0.101

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;7	3	15.795	A
0.75;7	3	15.626	A
0.50;7	3	14.498	B
0.50;14	3	6.140	C
0.50;28	3	6.024	CD
1.00;**14**	3	5.814	D
0.75;28	3	5.182	E
0.75;14	3	5.170	E
0.75;21	3	4.809	F
0.50;21	3	4.636	F
1.00;21	3	3.924	G
1.00;28	3	2.459	H

Table A.15 One-Way-ANOVA test for shrinkage of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	1558.681	141.698	311.72	0.000
Error	24	10.910	0.455		
Total	35	1569.591			

S = 0.6742 R-Sq = 99.30% R-Sq (adj) = 98.99%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	19.767	1.545
0.50;14	3	15.531	0.669
0.50;28	3	24.039	0.852
0.50;7	3	5.089	0.120
0.75;14	3	16.628	0.234
0.75;21	3	21.852	0.578
0.75;28	3	24.935	0.844
0.75;7	3	7.582	0.245
1.00;14	3	18.409	0.410
1.00;21	3	22.838	0.262
1.00;28	3	24.937	0.484
1.00;7	3	10.019	0.498

Pooled StDev = 0.674

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;28	3	24.937	A
0.75;28	3	24.935	A
0.50;28	3	24.039	AB
1.00;21	3	22.838	BC
0.75;21	3	21.852	C
0.50;21	3	19.767	D
1.00;14	3	18.409	DE
0.75;14	3	16.628	EF
0.50;14	3	15.531	F
1.00;7	3	10.019	G
0.75;7	3	7.582	H
0.50;7	3	5.089	I

Table A.16 One-Way-ANOVA test for APC values of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	19.1621	1.7420	17.78	0.000
Error	24	2.3511	0.0980		
Total	35	21.5132			

S = 0.3130 R-Sq = 89.07% R-Sq (adj) = 84.06%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	5.5063	0.1821
0.50;14	3	4.7666	0.2214
0.50;28	3	6.3867	0.4703
0.50;7	3	4.4089	0.4262
0.75;14	3	4.9371	0.2404
0.75;21	3	5.5311	0.1732
0.75;28	3	6.4355	0.4991
0.75;7	3	4.5043	0.1393
1.00;14	3	5.0792	0.2104
1.00;21	3	5.6134	0.3483
1.00;28	3	6.4496	0.1522
1.00;7	3	5.5667	0.3813

Pooled StDev = 0.3130

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
1.00;**28**	3	6.4496	A
0.75;**28**	3	6.4355	A
0.50;**28**	3	6.3867	AB
1.00;21	3	5.6134	ABC
0.75;21	3	5.5311	ABC
0.50;21	3	5.5063	BC
1.00;14	3	5.0792	CD
0.75;14	3	4.9371	CD
0.50;14	3	4.7666	CD
1.00;7	3	4.5667	D
0.75;7	3	4.5043	D
0.50;7	3	4,4089	D

Table A.17 One-Way-ANOVA test for YM value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	11	7.1271	0.6479	9.73	0.000
Error	24	1.5983	0.0666		
Total	35	8.7254			

S = 0.2581 R-Sq = 81.68% R-Sq (adj) = 73.29%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	3.6041	0.3656
0.50;14	3	3.5593	0.2411
0.50;28	3	4.3948	0.2357
0.50;7	3	3.0141	0.2005
0.75;14	3	3.4002	0.2698
0.75;21	3	3.4998	0.2739
0.75;28	3	3.9573	0.2739
0.75;7	3	2.8370	0.2988
1.00;14	3	3.4764	0.1651
1.00;21	3	3.5756	0.2994
1.00;28	3	4.2619	0.3286
1.00;7	3	3.1488	0.1808

Pooled StDev = 0.2581

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;28	3	4.3948	A
1.00;28	3	4.2619	AB
0.75;28	3	3.9573	ABC
0.50;21	3	3.6041	BCD
1.00;21	3	3.5756	BCDE
0.50;**14**	3	3.5593	BCDE
0.75;21	3	3.4998	CDE
1.00;14	3	3.4764	CDE
0.75;14	3	3.4002	CDE
1.00;7	3	3.1488	DE
0.50;7	3	3.0141	DE
0.75;7	3	2.8370	E

Table A.18 One-Way-ANOVA test for T1 relaxation time value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	10	125983	12598	88.33	0.000
Error	22	3138	143		
Total	32	129121			

S = 11.94 R-Sq = 97.57 % R-Sq (adj) = 96.47%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	60.95	8.16
0.50;14	3	67.01	13.65
0.50;28	3	49.40	9.44
0.50;7	3	220.69	20.14
0.75;14	3	61.17	8.15
0.75;21	3	60.25	8.62
0.75;28	3	54.88	7.92
0.75;7	3	155.92	12.52
1.00;14	3	69.35	10.54
1.00;21	3	65.23	7.80
1.00;7	3	209.16	17.01

Pooled StDev = 11.94

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;7	3	220.69	A
1.00;7	3	209.16	A
0.75;7	3	155.92	B
1.00**;**14	3	69.35	C
0.50;14	3	67.01	C
1.00**;21**	3	65.23	C
0.75**;14**	3	61.17	C
0.50;21	3	60.95	C
0.75;21	3	60.25	C
0.75;28	3	54.88	C
0.50;28	3	49.40	C

Table A.19 One-Way-ANOVA test for T2 relaxation time value of dry aged rib steak samples stored at different aging conditions.

Samples: 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging condition	10	356.377	35.638	71.35	0.000
Error	22	10.989	0.500		
Total	32	367.367			

S = 0.7068 R-Sq = 97.01% R-Sq (adj) = 95.65%

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	St Dev
0.50; 21	3	2.827	0.327
0.50;14	3	2.264	0.411
0.50;28	3	5.275	0.430
0.50;7	3	12.310	1.422
0.75;14	3	2.580	0.439
0.75;21	3	2.226	0.377
0.75;28	3	2.598	0.737
0.75;7	3	7.399	0.767
1.00;14	3	2.849	0.373
1.00;21	3	2.907	0.529
1.00;7	3	9.415	1.035

Pooled StDev = 0.707

Grouping information using Tukey Method

Aging condition	N	Mean	Grouping
0.50;7	3	12.310	A
1.00;7	3	9.415	B
0.75;7	3	7.399	B
0.50;28	3	5.275	C
1.00;21	3	2.907	D
1.00;14	3	2.849	D
0.50;21	3	2.827	D
0.75;28	3	2.598	D
0.75;14	3	2.580	D
0.50;14	3	2.264	D
0.75;21	3	2.226	D

Table A.20 Two-Way-ANOVA test for pH value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	0.289473	0.0964911	153.47	0.000
Fan Speed	2	0.001798	0.0008990	1.43	0.259
Interaction	6	0.019154	0.0031923	5.08	0.002
Error	24	0.015089	0.0006287		
Total	35	0.325514			

S = 0.02507 R-Sq = 95.36% R-Sq (adj) = 93.24%

Table A.21 Two-Way-ANOVA test for TBARS value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	1.23398	0.411328	20007.56	0.000
Fan Speed	2	0.00001	0.000006	0.30	0.743
Interaction	6	0.00015	0.000025	1.22	0.333
Error	24	0.00049	0.000021		
Total	35	1.23464			

S = 0.004534 R-Sq = 99.96% R-Sq (adj) = 99.94%

Table A.22 Two-Way-ANOVA test for P.V of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	1.16190	0.387301	12039.33	0.000
Fan Speed	2	0.00065	0.003326	10.13	0.211
Interaction	6	0.00312	0.004520	16.17	0.105
Error	24	0.00077	0.000023		
Total	35	1.16645			

S = 0.005672 R-Sq = 99.93% R-Sq (adj) = 99.90%

Table A.23 Two-Way-ANOVA test for p.A.V of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	106.632	35.5441	5510.97	0.000
Fan Speed	2	0.148	0.0738	11.44	0.000
Interaction	6	0.272	0.0454	7.03	0.000
Error	24	0.155	0.0064		
Total	35	107.207			

S = 0.08031 R-Sq = 99.86% R-Sq (adj) = 99.79%

Table A.24 Two-Way-ANOVA test for weight loss value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	2624.28	874.761	2385.35	0.000
Fan Speed	2	15.61	7.805	21.28	0.000
Interaction	6	3.00	0.501	1.37	0.268
Error	24	8.80	0.367		
Total	35	2651.70			

S = 0.6056 R-Sq = 99.67% R-Sq (adj) = 99.52%

Table A.25 Two-Way-ANOVA test for trim loss value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	269.956	89.9855	2190.27	0.000
Fan Speed	2	3.622	1.8112	44.09	0.000
Interaction	6	7.601	1.2669	30.84	0.000
Error	24	0.986	0.0411		
Total	35	282.166			

S = 0.3906 R-Sq = 99.83% R-Sq (adj) = 99.75%

Table A.26 Two-Way-ANOVA test for cook loss value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	370.298	123.433	345.12	0.000
Fan Speed	2	45.483	22.742	63.59	0.000
Interaction	6	5.474	0.912	2.55	0.047
Error	24	8.584	0.358		
Total	35	429.839			

S = 0.5980 R-Sq = 98.00% R-Sq (adj) = 97.09%

Table A.27 Two-Way-ANOVA test for yield value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	4943.31	1647.77	3081.38	0.000
Fan Speed	2	187.66	93.83	175.46	0.000
Interaction	6	102.85	17.14	32.05	0.000
Error	24	12.83	0.53		
Total	35	5246.64			

S = 0.7313 R-Sq = 99.76% R-Sq (adj) = 99.64%

Table A.28 Two-Way-ANOVA test for WHC value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	689.117	229.706	696.56	0.000
Fan Speed	2	44.289	22.145	67.15	0.000
Interaction	6	11.148	1.858	5.63	0.001
Error	24	7.915	0.330		
Total	35	752.469			

S = 0.5743 R-Sq = 98.95% R-Sq (adj) = 98.47%

Table A.29 Two-Way-ANOVA test for moisture content value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	222.029	74.0095	280.22	0.000
Fan Speed	2	26.825	13.4124	50.78	0.000
Interaction	6	1.900	0.3166	1.20	0.341
Error	24	6.339	0.2641		
Total	35	257.092			

S = 0.5139 R-Sq = 97.53% R-Sq (adj) = 96.40%

Table A.30 Two-Way-ANOVA test for shear force value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	0.00916	0.0030535	0.04	0.987
Fan Speed	2	0.00152	0.0007620	0.01	0.989
Interaction	6	0.00971	0.0016182	0.02	1.000
Error	24	1.62968	0.0679032		
Total	35	1.65007			

S = 0.2606 R-Sq = 1.24% R-Sq (adj) = 0.02%

Table A.31 Two-Way-ANOVA test for L* value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	204.241	68.0804	1497.64	0.000
Fan Speed	2	15.631	7.8157	171.93	0.000
Interaction	6	1.295	0.2158	4.75	0.003
Error	24	1.091	0.0455		
Total	35	222.258			

S = 0.2132 R-Sq = 99.51% R-Sq (adj) = 99.28%

Table A.32 Two-Way-ANOVA test for a* value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	754.789	251.596	15092.13	0.000
Fan Speed	2	8.101	4.050	242.97	0.000
Interaction	6	25.924	4.321	259.18	0.000
Error	24	0.400	0.017		
Total	35	789.214			

S = 0.1291 R-Sq = 99.95% R-Sq (adj) = 99.93%

Table A.33 Two-Way-ANOVA test for C* value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	738.773	246.258	24089.12	0.000
Fan Speed	2	4.751	2.376	232.39	0.000
Interaction	6	21.848	3.641	356.20	0.000
Error	24	0.245	0.010		
Total	35	765.618			

S = 0.1011 R-Sq = 99.97% R-Sq (adj) = 99.95%

Table A.34 Two-Way-ANOVA test for shrinkage value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	1493.20	497.733	1094.95	0.000
Fan Speed	2	52.25	26.124	57.47	0.000
Interaction	6	13.23	2.206	4.85	0.002
Error	24	10.91	0.455		
Total	35	1569.59			

S = 0.6742 R-Sq = 99.30% R-Sq (adj) = 98.99%

Table A.35 Two-Way-ANOVA test for APC value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	18.9519	6.31729	64.49	0.000
Fan Speed	2	0.1540	0.07699	0.79	0.467
Interaction	6	0.0563	0.00938	0.10	0.996
Error	24	2.3511	0.09796		
Total	35	21.5132			

S = 0.2880 R-Sq = 86.00% R-Sq (adj) = 79.58%

Table A.36 Two-Way-ANOVA test for YM value of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Source	DF	SS	MS	F	P
Aging time	3	6.62307	2.20769	33.15	0.000
Fan Speed	2	0.34329	0.17164	2.58	0.097
Interaction	6	0.16069	0.02678	0.40	0.870
Error	24	1.59833	0.06660		
Total	35	8.72538			

S = 0.2581 R-Sq = 81.68% R-Sq (adj) = 73.29%

Table A.37 General Linear Model analysis for T_1 and T_2 values of dry aged rib steak samples stored at different aging conditions.

Samples: 12 different aging conditions including; 0.50 m/s fan speed, 7 days of aging; 0.75 m/s fan speed, 7 days of aging; 1.00 m/s fan speed, 7 days of aging; 0.50 m/s fan speed, 14 days of aging; 0.75 m/s fan speed, 14 days of aging; 1.00 m/s fan speed, 14 days of aging; 0.50 m/s fan speed, 21 days of aging; 0.75 m/s fan speed, 21 days of aging; 1.00 m/s fan speed, 21 days of aging; 0.50 m/s fan speed, 28 days of aging; 0.75 m/s fan speed, 28 days of aging; 1.00 m/s fan speed, 28 days of aging

Analysis of Variance for T_1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Days	3	39816.0	38917.3	12972.4	37.18	0.001
Speed	2	705.1	705.1	352.5	1.01	0.428
Error	5	1744.5	1744.5	348.9		
Total	10	42265.6				

S= 18.6790 R-Sq= 95.87% R-Sq (adj) = 91.74%

Analysis of Variance for T_2

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Days	3	102.304	102.035	34.012	20.16	0.003
Speed	2	7.737	7.737	3.868	2.29	0.196
Error	5	8.435	8.435	1.687		
Total	10	118.476				

S= 1.29883 R-Sq= 92.88% R-Sq (adj) = 85.76%

Grouping information using Tukey Method for T_1

Days	N	Mean	Grouping
7	3	195.2	A
14	3	66.0	B
21	3	60.7	B
28	2	55.1	B

Speed	N	Mean	Grouping
1.00	3	100.3	A
0.50	4	99.5	A
0.75	4	83.0	A

Grouping information using Tukey Method for T_2

Days	N	Mean	Grouping
7	3	9.7	A
14	2	4.0	B
21	3	2.7	B
28	3	2.6	B

Speed	N	Mean	Grouping
0.50	4	5.7	A
1.00	3	4.8	A
0.75	4	3.7	A

APPENDIX B

PICTURES OF ANALYSIS

Figure B.1 Prototype of dry aging unit (Arçelik A.Ş, Eskişehir, Turkey)

Figure B.2 Aging of meat in dry aging unit of refrigerator (Arçelik A.Ş, Eskişehir, Turkey)

Figure B.3 Imaging area for image processing

Figure B.4 The cabinet and lighting system for image processing

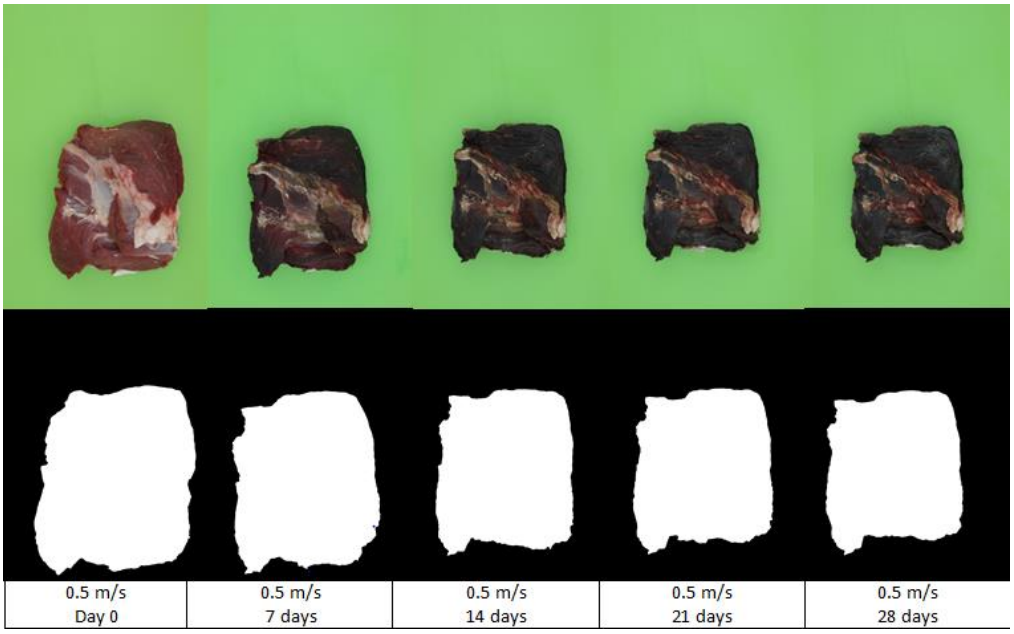

Figure B.5 Rib steak sample images obtained from image process analysis for shrinkage (Fan speed: 0.50 m/s)

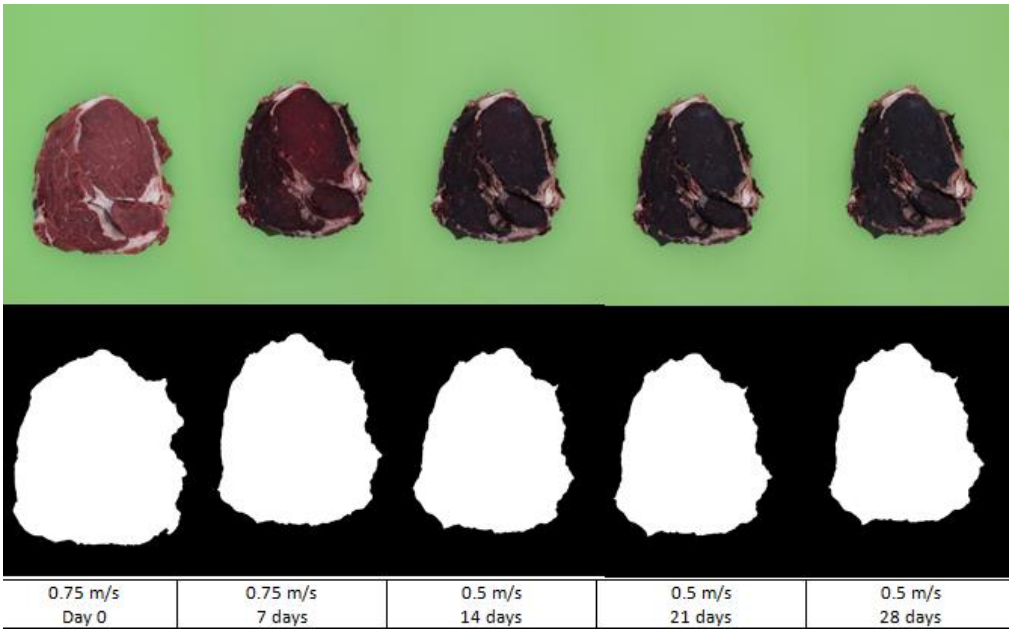

Figure B.6 Rib steak sample images obtained from image process analysis for shrinkage (Fan speed: 0.75 m/s)

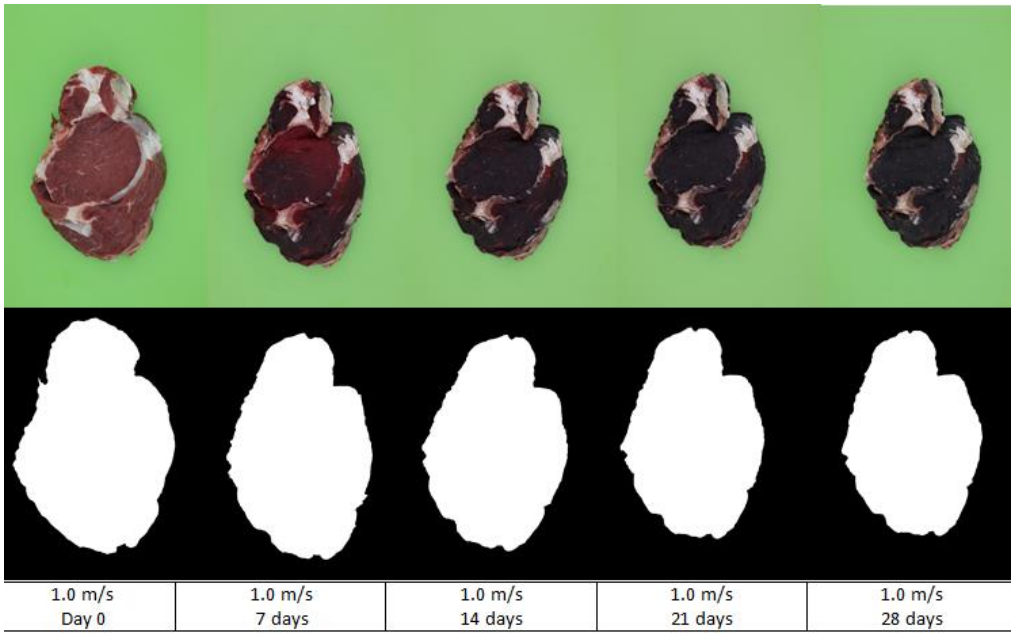

Figure B.7 Rib steak sample images obtained from image process analysis for shrinkage (Fan speed: 1.00 m/s)