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REVIEW ARTICLE

Chilling systems and effect of temperature on tenderness and appearance of meat post slaughter: A Review

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Abstract

Meat quality and its palatability is effected by the chilling process to which carcass is subjected post slaughter. Carcass is chilled post slaughter so that its appearance and tenderness are not compromised and bacterial multiplication can be reduced. Most commonly used carcass chilling systems are conventional carcass chilling in which carcass is chilled at 0ºC -2ºC and very fast chilling (VFC) in which temperature of 0ºC is obtained at core of muscle within 5 hours of slaughter. Temperature at which carcass is cooled post slaughter has critical importance as fluctuations in it can lead to various undesirable conditions like thaw rigor, cold shortening, heat shortening and heat ring which affect consumer's decision to repurchase. This review encompasses the effects of carcass chilling, very fast chilling, thaw rigor, cold shortening, heat shortening and heat ring on appearance and tenderness of meat. Results indicate that VFC offers better carcass characteristics when compared to conventional carcass chilling. Also the undesirable effects of thaw rigor can be reduced with aging of meat and negative effects of cold shortening, heat shortening and heat ring can be controlled by electrical stimulation of carcass.

Introduction

Post slaughter carcass handling starts at abattoirs and continues through the meat processors and market till it finally reaches the consumer. During this process various handling procedures are applied to the carcass which, if not carried out properly can affect the meat quality parameters adversely (Adzitey and Huda, 2012). The way carcass is processed and the temperature at which it is cooled effects meat quality (Warriss, 2000). Biochemical processes occurring in muscle tissue are affected by variations in early post mortem temperature. Most of the enzymes controlling these biochemical reactions are temperature sensitive, so the variation in temperature can affect overall meat quality (Zhu et al., 2011).

Temperature variations due to climate affect the color of meat post slaughter (Gregory, 2010). In earlier times natural means like slaughter of animals in cooler seasons and storing the end product in caves were used for dissipation of heat but with the passage of time use of more sophisticated methods and techniques like refrigeration has evolved and is being used all over the world to accomplish the task of heat dissipation and carcass chilling post slaughter (Savell et al., 2005). The two important ways of cooling carcasses include: Carcass chilling and VFC(Jacob and Thomson, 2012) whereas effects of temperature fluctuations on carcass include heat shortening, cold shortening, thaw rigor and heat ring (Warriss, 2000).

Tenderness, juiciness and flavor are the most important quality attributes of meat which are affected by rate of pH decline and variations in temperature post slaughter (Ajos and Puolanne, 2007). Cooling rate management is critical in carcass processing due to financial and quality considerations. Biochemical processes within muscles that can influence eating quality characteristics and visual appearance of meat are also effected by cooling rate Very fast chillingis much faster than conventional chilling, having potential to reduce bacterial count without deteriorating meat quality parameters. It is done by lowering the temperature of carcass to 0ºC to -1ºC within 5 hours of stunning

(Jacob et al., 2012). The rate of glycogen in muscles post mortem is affected by chilling rate. The weakening of glycolytic enzyme activities at lower chilling temperature before the onset of rigor mortis effects the rate of pH decline that affects the appearance of meat (Li et al., 2012).

The structural changes and biochemical processes that occur in muscles before rigor mortis are influenced by the chilling process applied to the carcass. Variations in tenderness are mainly due to how the carcass is handled before the onset of rigor mortis. Shortening of sarcomere length post slaughter decreases the tenderness of meat (Fernandez and Vieira, 2012). If animals develop hyperthermia due to heat stress or over exercise before slaughter heat shortening ensues and decreases the tenderness of meat (Gregory, 2010) however if temperature falls below 10°C and the pH is > 6.2 cold shortening occurs (Fernandez and Vieira, 2012). Cold shortening makes meat tougher and can be prevented by speeding up the process of rigor mortis (Hopkins et al., 2008).

Freezing is a way to preserve meat for a longer period of time which has been used by many beef producers over the years. But consumer complaints regarding frozen meat have caused a big loss to meat industry (Qi et al., 2012). If muscles are frozen before the onset of rigor mortis thaw rigor can occur (Li et al., 2010) which results in loss of large amounts of drip from frozen meat at thawing making it less tender (Xia et al., 2012) and undesirable to the consumers (Xia et al., 2009). A dark band formation called heat ring can occur due to fast chilling of carcass that negatively affects the appearance of meat (Warriss, 2000). Most of the chilling processes on carcasses are being employed to increase shelf life and reducing shrinkage of muscles with paying less emphasis on maintaining tenderness and color factors along with ensuring food safety standards of final product (Savell et al., 2012).

Chilling procedures to which the carcasses are subjected post slaughter and fluctuations in temperature lead to alterations in the tenderness and appearance of meat. This review comprises the comparison of chilling systems being used and hazardous effects of temperature fluctuations on tenderness and appearance of meat.

1. Carcass Chilling

1.1 Effects of carcass chilling on appearance

Carcass chilling effects meat color (Maggioni et al., 2010). Conventional carcass chilling is done at a temperature of 0-2ºC (Pietrasik et al., 2010). The body temperature of animal at death ranges 37-39ºC. By the end of carcass dressing the temperature at death falls as the heat is lost to the surrounding environment. The rate at which the carcass heat is dissipated to the surrounding environment depends upon circulation of air over the surface area of carcass and thickness of carcass fat layer (Warriss, 2000).

Carcass chilling time is an important parameter in designing a chilling system. Three methods of carcass chilling are being used in broilers which are evaporative air chilling (EAC), air chilling (AC) and water chilling (WC). Results show that these 3 techniques affect pH of meat and juiciness that results in alteration of appearance and tenderness respectively (Jeong et al., 2011a).

1.2 Effects of carcass chilling on tenderness

Chilling can cause tenderization of meat and is more rapid in smaller carcasses as compared to carcasses of large animals (Wiklund et al., 2010a). Scientists have reported that larger parts of the carcass cooled slowly as compared to larger ones and bacterial count is affected by increase or decrease in temperature. Hotter areas of carcass had higher number of bacteria than the colder regions of the same carcass. Therefore carcass chilling is a very important factor to produce quality end product which is tender and has better shelf life (Crowley et al., 2010). However chilling systems for both small and large carcasses are yet to be optimized (Rosenvold et al., 2010).

Back fat thickness measurement is an important factor in beef industry as it indicates nutritional management of the animal and carcass finish. Back fat has its value in carcass chilling as it provides an insulation medium for muscles allowing them to slowly cool down and not causing shrinkage of muscle fiber that decreases tenderness (Zuin et al., 2012). A processing technique related to carcass chilling is spray chilling which is done by intermittent sprays of water during cooling. This technique reduces weight loss of the carcass to approximately 2 % (Wiklund et al., 2010b). In stepwise chilling a pre rigor mortis temperature range of 10ºC -15ºC causes maximum tenderness. This procedure can be implemented commercially as it increases the tenderness of meat (Rosenvold and Borup, 2011).

Processing conditions that include carcass chilling and electrical stimulation have a great impact on tenderness of meat. Electrical stimulation can fasten the onset of rigor mortis so that carcass chilling can be done quickly without reducing sarcomere length that can make meat tougher (Wiklund et al., 2010a). Water chilling reduces carcass temperature more efficiently than AC and EAC however when it came to sensory evaluations AC meat of broiler breast had a better score of juiciness than WC and EAC. Water chilling had the best chilling efficiency but AC has more potential advantages like less water consumption, reduced waste management, a juicier end product (Jeong et al., 2011a) and increased shelf life (Jeong et al., 2011b).

2. Very Fast Chilling

2.1 Effects of VFC on appearance

Color of the carcass gives a clue about the freshness of meat, effecting consumer's preference to purchase. The criteria of VFC is achieving a 0ºC temperature at core of muscle with in five hours of slaughter which, if not obtained can lead to alterations in appearance of meat (Jacob and Thomson, 2012) like formation of dark, firm and dry (DFD) meat which gives an undesirable appearance (Ajos and Puolanne, 2007). Therefore obtaining standard chilling rates for VFC is very important (Jacob and Thomson, 2012) because of financial and quality considerations (Jacob et al., 2012).

Sometimes animals are slaughtered at outdoor facilities for dissipation of body heat when the wind chills and temperatures are below freezing (Rincker et al., 2006), but these practices can cause variations in appearance and can lead to increase in bacterial load which causes food safety concerns. Animal carcasses in commercial slaughter process are cooled rapidly to maintain its appearance and reduce food safety risks due to microbiological proliferation (Jacob et al., 2012). Meat safety is ensured by VFC as bacteria multiplication stops at such a low temperature (Li et al., 2012).

2.2 Effects of VFC on tenderness

The faster cooling rate of VFC reduces the bacterial count without making meat tougher (Jacob et al., 2012). Shortening of sarcomeres that occur due to conventional carcass chilling might not occur due to VFC in which the temperature is kept very cold (-70ºC to -20ºC) and the air moves at very high speed. This process sometimes increases the tenderness of meat (Warriss, 2000) but because of the practical difficulties related with to fast cooling the expected outcome of meat's eating quality due to VFC is still unpredictable (Jacob et al., 2012) moreover, commercial application VFC is somewhat limited (Neto et al., 2013).

3. Thaw Rigor

3.1 Effects of thaw rigor on appearance

Meat palatability is affected by rigor mortis however there is no way by which the whole process of onset and resolution of rigor mortis can be explored. It has been confirmed that ambient temperature effect the process of rigor mortis and struggle at the time of slaughter can also accelerate the process of rigor (Li et al., 2010).

If meat freezes before the onset of rigor then a very large amount of drip is lost at thawing which is called thaw rigor (Warriss, 2000). If meat is frozen before the onset of rigor it exhibits thaw rigor that makes its texture very hard when thawed. Thaw rigor suppression is very important as large amount of drip loss and stiffness of muscles decreases the commercial value of meat (Imamura et al., 2012) so, temperature and thawing process must be controlled to avoid thaw rigor (Cook et al., 2009). Lowering of temperature during storage suppresses thaw rigor but can lead to changes in meat color from red to brown due to formation of metmyoglobin that is oxidized form of ferric or hemin. Therefore thawing and freezing should be optimized for preventing thaw rigor and metmyoglobin formation in meat. A temperature shift technique that prevents thaw-rigor and metmyoglobin formation is storage before thawing at -7ºC and -10ºC for 1 day and 7 days respectively (Imamura et al., 2012).

3.2 Effects of thaw rigor on tenderness

The organoleptic trait that effects consumer's satisfaction is tenderness. Due to thaw rigor development toughening of meat can occur because of sarcomere shortening. Thawed meat is less tender than non-frozen meat, but freezing is the most common method used for meat storage. Microbiological spoilage of meat is demolished by freezing, but fluctuations in temperature during transportation, storage (Xia et al., 2009) and repeated thaw freeze cycles can cause alterations in the tenderness of meat quality that causes financial concerns to the industry (Qi et al., 2012).

Cutting and deboning of meat in slaughtering plants has to be done quickly due to economic and hygienic conditions (Thielke et al., 2005). When muscles are frozen pre-rigor, upon thawing a very severe form of rigor takes place and if thawing is done rapidly meat can suffer from defects due to high temperature. It has been suggested that immediate freezing of carcass after slaughter and then storing it at a temperature below freezing point prevents toughness and thaw rigor development. Moreover tenderness of thaw rigor muscle can be increased by increasing the holding time at -3ºC (Yu et al., 2005).

Thawing and freezing are two opposite processes as in thawing heat instead of being absorbed from product is directed in (Dincer et al., 2009). Thawing of frozen meat has to be done before cooking for restoring foods original quality to the maximum possible extent. Process of thawing takes more time than freezing. Inappropriate thawing may lead to poor quality meat and thaw rigor. When 5 different thawing methods that include lotic water thawing at 9ºC, water immersion thawing at 14ºC, ambient temperature thawing at 20ºC, refrigerated thawing at 4ºC and microwave thawing were observed it was concluded that microwave thawing had the most adverse effects and refrigerated thawing had the least effects on quality loss (Xia et al., 2012). Similarly when results of thawing on meat quality were compared by using three thawing procedures microwave thawing (fast), tap water thawing (moderate) and refrigerator thawing (slow) it was seen that tap water thawing showed the best results for chemical and sensory quality of meat. Therefore it is recommended that thawing of frozen food should take place in a refrigerator or under running water (Dincer et al., 2009). To the best of our knowledge no data is present regarding the effect of cold shortening and heat shortening on appearance and effect of heat ring on tenderness.

4. Cold Shortening

4.1 Effects of cold shortening on tenderness

Development of rigor mortis and changes in pH are temperature dependent (Adzitey and Huda, 2012). When muscles with pH of > 6.2 are cooled to a temperature less than 10ºC cold shortening occurs, making the resultant meat tough after cooking. However attaining a rapid decrease in pH is helpful in decreasing chances of cold shortening (Hoffman et al., 2007).

Cold shortening decreases tenderness which is due to muscle fiber contractions that occur before the onset of rigor (Thompson et al., 2006). Occurrence of cold shortening in broilers increases as the stock density of the flock increases. Farmers increase the stock density for getting increased profits but it can lead to build up of heat which can lead to heat stress. As cooling of shed for removing the effect of high environmental temperature is very expensive so dietary manipulations are done to achieve the required goals. Vitamin E supplementation to broilers with high stock density was found to be useful in removing heat stress which increases the chances of cold shortening to occur after slaughter that lead to a less tender end product (Adebiyi et al., 2011). Muscles which are having large number of white fibers do not undergo cold shortening but pectoralis major muscle of broiler which has almost 100% white fibers underwent cold shortening during commercial air chilling at 0^0C. More data is needed to explain why this muscle got affected by cold shortening despite of having 100% white fibers (Zhu et al., 2011).

Different carcasses in the same chiller can undergo cold shortening that deteriorate the tenderness of meat. Small sized carcasses are more prone to cold shortening however delayed electrical stimulation of leaner and smaller carcasses ensures that cold shortening is prevented (Timar, 2007). Hot- deboned muscles take more time to reach minimum pH than muscles which are left intact on carcass, which can result in cold shortening. However there are no risks of cold shortening occurring in ostrich meat due to rapid decline in pH, because of which hot deboning can be done in ostrich meat with no risks of cold shortening (Polawska et al., 2011).

Toughening due to cold shortening cannot be eliminated by aging of meat (King et al., 2003). A thumb rule to avoid cold shortening is that the temperature of the muscle should be kept high i-e above 10ºC till the pH of meat which is initially 7.0-7.2 at the time of death falls below 6.0 (Hopkins et al., 2008). By clamping the muscle before the onset of rigor mortis early shortening of sarcomeres that decreases tenderness can be prevented (Beermann, 2009). Electrical stimulation can increase tenderness of meat, lowers pH of meat and reduce risks of cold shortening (Adzitey and Huda, 2012).

5. Heat Shortening

5.1 Effects of heat shortening on tenderness

Shortening of sarcomeres that occur at higher temperature is called heat shortening which leads to decreased tenderness and increased toughening of meat (Thompson, 2002). Higher temperature causes rapid decline in pH due to increased activity of glycolytic enzymes and faster glycolytic rates. This rapid decline in pH at higher temperatures can lead to heat shortening (Thompson et al., 2006).

Meat quality is very much affected by the temperature at which it enters rigor mortis (Bekhit et al., 2007). Tenderness is the most important criteria regarding meat selection for consumers as they are ready to pay a higher price for meat if tenderness is ensured (Chambaz et al., 2003). Heat shortening decreases tenderness making the resultant meat tougher and less acceptable to consumers (Mckee et al., 1997). Meat that is kept with temperature and pH range of 10ºC -15ºC and 6.0 – 6.2 respectively gives maximum tenderness values however deviations above or below this can result in heat or cold shortening (Raj et al., 2000). Heat shortening regions lie at pH lower than 6.0 and temperature greater than 35ºC. Over stimulation of carcass due to electrical inputs in slaughter chains and processing equipment can cause meat to enter this region (Thompson, 2002). In summer longer journey to slaughter house has also been reported to result in tough meat due to a heat shortening (Gregory, 2010).

6. Heat Ring

6.1 Effects of heat ring on appearance

A darker band formation called heat ring takes place due to rapid chilling, making meat unattractive in appearance (Warriss, 2000). Studies have shown that in larger muscles there are more chances of heat ring to occur (Ludwig et al., 1997) which is because of the fact that the surface of the muscle that is outside cools more quickly than the surface which is inward when rapid chilling is done (Warriss, 2000).

Handling of animals pre-slaughter is also important as it can lead to variations in meat quality after slaughter. Chances of heat ring to occur are more in animals that are exposed to prolonged stress. Meat from such animals is darker in color and heat ring formation can also occur in their carcasses (Adzitey, 2011). Meat color and texture along with incidence of heat ring is not effected by difference in breed (both cross bred and pure bred) provided if the gender of animals is male (Wheeler et al., 1990). But there are more chances of heat ring occurrence in female cross bred animals as compared to purebred female animals (Shackelford et al., 1991).

The geographical location of the slaughter house and its insulation efficiency effects heat ring occurrence (Miller et al., 1997). Electrical stimulation of carcass improves color, firmness, texture rating (Wheeler et al., 1990) and reduces the incidence of heat ring occurrence (McKeith et al., 1979).

Conclusions

Reported data indicates that VFC is better than conventional carcass chilling as it controls bacterial multiplication more efficiently and reduces the occurrence of cold shortening, but more results regarding the optimization of temperature and time of VFC for different species is required so that a tender end product can be obtained. Thaw rigor, heat ring, cold shortening and heat shortening are unwanted effects of temperature fluctuations on meat quality. Thaw rigor development negatively affects the tenderness and appearance of meat but it can be removed with aging of meat. Heat ring formation negatively affects the appearance of meat whereas cold shortening and heat shortening decrease the tenderness of meat by shortening the sarcomere length of muscle fibers. Thaw rigor, heat ring, cold shortening and heat shortening make meat undesirable to the consumers and effect their decision to repurchase. However electrical stimulation of carcass can help in eliminating or decreasing unwanted effects of heat ring, cold shortening and heat shortening on meat.

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