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Effects of aging/freezing sequence and freezing rate on meat quality and oxidative stability of pork loins

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ABSTRACT

The aim of this study was to evaluate the effect of aging/freezing sequence and freezing rate on quality attributes and oxidative stability of frozen/thawed pork loins (*M. longissimus lumborum*, $n = 6$). Six treatments were prepared by combining 3 aging/freezing sequences (FT, freezing/thawing only; AFT, aging prior to freezing/thawing; and FTA, freezing/thawing and aging) with 2 freezing rates (slow- and fast-freezing). The lowest purge/thaw loss and drip loss were found for AFT, in which fast-freezing reduced total exudate loss ($P < 0.05$). Aging combination (AFT/FTA) decreased shear force of frozen/thawed pork loins, and FTA with slow-freezing caused the lowest shear force ($P < 0.05$). However, aging combination regardless of the sequence accelerated discoloration and lipid/protein oxidation during display ($P < 0.05$). This study suggests that aging prior to freezing coupled with fast-freezing could be an effective way to minimize quality defects of frozen/thawed only meat, particularly water-holding capacity and tenderness.

1. Introduction

Freezing is one of the most common and effective methods to store meat products with extended shelf life. However, quality of frozen/thawed meat, in general, is considered to be inferior to never-frozen fresh meat (Leygonie, Britz, & Hoffman, 2012). Major quality defects of frozen/thawed meat are shown as excessive water loss during thawing/cooking, the acceleration of lipid/protein oxidation, discoloration, and/or occasionally texture issue in consequence of the excessive water loss (Leygonie et al., 2012).

Recently, it has been suggested that a sufficient *postmortem* aging prior to freezing and thawing (AFT) can result in producing frozen meat with superior quality attributes (Coombs, Holman, Friend, & Hopkins, 2017; Kim, Frandsen, & Rosenvold, 2011). Studies found that aging combined with freezing could result in better water-holding capacity (WHC) and tenderness compared to frozen/thawed only meat without aging (Crouse & Koohmaraie, 1990; Hergenreder et al., 2013; Kim et al., 2011; Kim, Liesse, Kemp, & Balan, 2015; Shanks, Wulf, & Maddock, 2002). Given the fact that endogenous proteolytic enzymes associated aging are functional to a certain extent even after freezing/thawing (Crouse & Koohmaraie, 1990), freezing first then thaw/aging (FTA) has been suggested as one possible method to produce frozen meat with equivalent quality to aged/frozen meat, particularly on tenderness (Aroeira et al., 2016; Crouse & Koohmaraie, 1990; Kim & Kim, 2017). In this regard, aging combination with frozen/thawed meat has been mainly investigated in beef and lamb meat products (Aroeira et al., 2016; Kim et al., 2011; Kim et al., 2015; Kim & Kim, 2017). However, the effect of aging combination on meat quality attributes of frozen/thawed pork has not been evaluated, while inferior quality issues of frozen/thawed pork have been consistently identified.

Besides the aging combination for frozen/thawed meat, the extent of the quality deterioration in frozen/thawed meat is initially influenced by freezing rate. The size, distribution, and location of ice crystals are extensively affected by freezing rate (Leygonie et al., 2012; Li & Sun, 2002). Fast-freezing forms small and uniform intracellular ice crystals, leading to a decrease in cryo-damages to muscle cell and structure (Grujić, Petrović, Pikula, & Amidžić, 1993). This in turn could not only improve WHC of frozen/thawed meat (Kim et al., 2015; Kim & Kim, 2017; Kim, Meyers, Kim, Liceaga, & Lemenager, 2017; Leygonie et al., 2012), but also minimize the oxidation of lipid and protein, thereby preventing the damage to muscle cells (Kim et al., 2017; Soyer, Özalp, Dalmış, & Bilgin, 2010).

Since fast-freezing has a considerable positive impact on quality attributes of frozen/thawed meat, it would be reasonable to

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hypothesize that the fast freezing first then thaw/aging could results in positive impacts on meat quality attributes of FTA beef. Furthermore, the effects of aging/freezing sequence combined with freezing rate on quality of frozen/thawed meat have not been fully investigated. Therefore, the objectives of this study was to evaluate the combined effects of aging/freezing sequence and freezing rate on quality attribute and oxidative stability of aged/frozen/thawed pork loins.

2. Materials and methods

2.1. Raw materials and aging/freezing/thawing process

A total of six market weight hogs (average live weight 121.8 ± 16.3 kg) raised at a commercial farming system was slaughtered at the Purdue University Meat Laboratory. Loin muscles (*M. longissimus thoracis et lumborum*) were separated from the same side of pork carcasses at 1 day *postmortem*. The initial pH of pork loins was measured immediately after collection. Each loin muscle was cut into six equal sections (approximately 8 cm × 13 cm × 5 cm), weighed (average weight of 510.7 ± 57.5 g), and individually vacuum-packaged in a Nylon/PE vacuum pouch (thickness of 4 mil, ClarityTM, Bunzl Processor Division, North Kansas City, MO). Six sections from each loin ($n = 6$) were randomly assigned into six treatments, which were a 3 × 2 factorial combinations; three aging/freezing sequences (FT, freezing/thawing only without aging; AFT, aging prior to freezing/thawing; and FTA, freezing/thawing and aging) and two freezing rates (slow- and fast-freezing).

Slow-freezing was conducted in a commercial −20 °C blast freezer, whereas fast-freezing was performed in a liquid nitrogen freezing cabinet (12 CF Cabinet Freezer, RS Cryo Equipment, Inc., Manteno, IL) set at −80 °C as an ambient temperature. The internal temperatures of pork loin sections were individually monitored using type T thermocouples (Omega Engineering, Stamford, CT) connected to an OCTEMP2000 data logger (MadgeTech, Inc., Warner, NH).

FT samples were assigned into either slow- and fast-freezing at 1 day *postmortem*, stored in a −20 °C blast freezer for 8 weeks and 5 days, and thawed in a 1 °C walk-in cooler for 2 days. AFT samples were aged in the cooler for 19 days, slow-/or fast-frozen, stored in the −20 °C blast freezer for 6 weeks, and thawed in the cooler for 2 days. FTA samples were slow-/or fast-frozen at 1 day *postmortem*, stored in the −20 °C blast freezer for 6 weeks, thawed in the cooler for 2 days, and subsequently aged in the same cooler for additional 19 days. A total period for aging/freezing/thawing process was equally assigned as 9 weeks. A schematic figure illustrating sample assignment and aging/freezing/thawing procedure is shown in Fig. 1.

2.2. Aerobic display storage

Once assigned aging, freezing and/or thawing treatments were completed, the pork loin sections were removed from the vacuum bags, blotted with a paper towel and re-weighed. To determine display weight loss, display color and lipid/protein oxidation, one pork chop (2.54 cm of thickness) was obtained from the middle portion of each pork loin section. The pork chop was weighed, individually placed on a commercial soaking absorbent pad in a polystyrene tray and overwrapped with commercial oxygen-permeable polyvinylchloride (PVC) films (thickness of 0.5 mil, Reynolds Food Service Packaging, Richmond, VA). The samples were displayed under a fluorescent lamp (approximately 1450 lx, color temperature = 3500 K, OCTRON® T8 Lamps, Osram Sylvania LTD., Canada) in a 3 °C cooler for 8 days. At the end of display, the pork chops were blotted, re-weighed and used for further chemical analyses.

2.3. Meat quality analysis

2.3.1. Histological observation

For histological analysis, the thin-sliced samples from the aged and/or frozen/thawed pork loin sections were formaldehyde-fixed, embedded in paraffin wax, and sectioned using an ultramicrotome (4 μm thickness; Leica semi-automatic rotary microtome, Leica Co., Wetzlar, Germany). Those sections were stained using a Shandon Harris hematoxylin and eosin Y slide autostainer. The histological characteristics of the prepared sections were observed using a light microscope (Carl Zeiss, Oberkochen, Germany) at 150× magnification.

2.3.2. pH measurement

The pH value of aged/frozen/thawed pork loins was measured in triplicate using an electric pH meter equipped with an insert-type pH probe (HI 99163, Hanna Instruments Inc., Hoonsocket, USA). The pH measurement of samples was conducted at 1 day *postmortem* and after each aging/freezing/thawing treatment.

2.3.3. Water-holding capacity (WHC)

Purge/thaw loss was determined by a percentage weight difference between an initial weight (before vacuum-packaging) and a final weight (after aging/freezing/thawing process) (Kim, Miller, et al., 2017).

Cooking loss was determined according to the protocol as described by Kim, Meyers, et al. (2017), where one pork chop (2.54 cm thickness) was obtained from each thawed pork loin section, weighed, and cooked at 135 °C on a flat top electric griddle (Farberware, Walter Idde and Co., Bronx, NY). Core temperature was monitored by using the digital temperature logger with the thermocouple. When the core temperature reached at 41 °C, the pork chop was flipped to the opposite side and cooked to a core temperature of 71 °C. The cooked pork chop was re-weighed immediately after cooking, and cooking loss was calculated as a percentage weight difference between the initial raw weight and the cooked weight. Total exudate loss was calculated as the sum of purge/thaw loss and cooking loss (Aroeira et al., 2016).

Drip loss was determined according to Honikel drip loss protocol (Honikel, 1998) as described by Kim, Miller, et al. (2017) and calculated as a percentage weight difference between an initial weight and a final weight after 48 h of hanging storage in a plastic container. Display weight loss was determined as a percentage weight difference between day 0 and 8.

2.3.4. Shear force

Six cores parallel to muscle fiber were taken from the cooked loins used for cooking loss determination after cooling below 10 °C, by using a hand-held coring device (1.27 cm diameter). Each core was sheared by a Warner-Bratzler shear attachment on the TA-XT Plus texture analyzer (Stable Micro System Ltd., UK). A maximum force required to shear through each core was recorded, and the peak shear force (N) of six cores per each pork chop was averaged (Kim, Miller, et al., 2017).

2.4. Display analysis

2.4.1. Display color (color stability)

Surface color of pork chops was measured on a daily basis throughout the entire display time, using a Hunter MiniScan EZ colorimeter (Hunter, Reston, VA, USA) equipped with a 25 mm (diameter). The setting for the illuminant was D_{65} source, and the observer was standard 10°. Calibration of the instrument was conducted with black and white calibration tiles, which were covered with PVC film, according to the manufacturer's manual. The CIE L*, a*, and b* values were taken from five random locations of the samples in the PVC-overwrapped packages. Chroma and hue angle were calculated as follows; Chroma = $[(a^{*2} + b^{*2})^{1/2}]$; hue angle = $\tan^{-1}(b^*/a^*)$ (AMSA, 2012).

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