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Pre-rigor temperature control of Chinese yellow cattle carcasses to 12–18 °C during chilling improves beef tenderness

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ABSTRACT

This study evaluates the effects of pre-rigor temperature control on quality traits of Chinese yellow cattle *M. longissimus lumborum* (LL). One stepwise chilling (SC) treatment was used on one half-carcass, involved a fast chilling (−11 ± 1 °C;0.5 m/s) for 2h, then the refrigeration was stopped to hold a core temperature of 12–18 °C until 10h postmortem, followed by a 1 ± 1 °C chilling (0.5 m/s) to 48h postmortem. The other half-carcass was conventional chilled at 1 ± 1 °C (0.5 m/s) until 48h as control chilling (CC). Quality attributes were evaluated at 1, 7 and 14 days. The SC treatment resulted in decreased WBSF and increased myofibril fragmentation index compared with control. SC-treated LL at 7d postmortem had a lower WBSF than those of CC-treated at 14d. This pre-rigor temperature controlled chilling is a realistic alternative for the beef industry in China to ensure adequate tenderness and shorten aging time.

1. Introduction

Tenderness is considered to be the most important quality trait in beef (Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Platter et al., 2003; Savell et al., 1989). In China, cattle have always been used as draught animals in history, and the development period of beef cattle industry was quite short. In the present, yellow cattle in China, account for about 80% of beef produced (Zhou et al., 2001), faced with poor feeding and management regimens and produce tough meat (Kong, Diao, & Xiong, 2006). Many studies have been conducted on the improvement of beef tenderness by applying some carcass handling procedures such as electrical stimulation, alternative chilling regimes, hot-boning, pelvic suspension, or controlled aging (Bayraktaroglu & Kahraman, 2011; Hou et al., 2014; Kim et al., 2013; Pinto Neto, Bearaquet, & Cardoso, 2013).

The process of chilling has a great impact on tenderness thus it should be optimized for minimal muscle contraction and maximal proteolysis, which can be achieved by controlling the pH/temperature decline in the muscle (Farouk, Wiklund, & Rosenvold, 2009). The commercial chilling procedure applied in Chinese cattle abattoirs is transferring the carcasses immediately after slaughter to a chilling chamber (air temperature, 0–4 °C; relative humidity, about 90%; air velocity, 0.5 m/s) until 24–48 h postmortem. Rapid/blast chilling of cattle carcasses was considered to be an alternative chilling practice to minimize evaporative loss and reduce microbial proliferation but electrical stimulation should be applied at the same time to avoid cold shortening (Li et al., 2006; Zhu, Gao, & Luo, 2011). However, currently beef processing industry in China has a low rate of technology incorporation, with limited commercial application of electrical stimulation. The critical time during postmortem chilling is the pre-rigor period (Troy, 1999), when the relationship between pH and temperature is a decisive factor affecting meat tenderness (Farouk & Lovatt, 2000; Hannula & Puolanne, 2004). Many studies on muscle excised pre-rigor have been undertaken and identified that the highest degree of tenderness was obtained at pre-rigor (pH > 6.0) temperature of 12–18 °C (Hildrum, Nilsen, & Wahlgren, 2002; Locker & Hagyard, 1963; Thompson, 2002; Tornberg, 1996). It is necessary to confirm whether this result obtained from excised muscles could be applied into carcasses in commercial slaughter plants to improve beef tenderness.

The present study focuses on the temperature control, a stepwise chilling (SC) treatment of Chinese yellow cattle carcasses that ensure that *Musculuslongissimus lumborum* (LL) reach a rigor center temperature window of 12–18 °C: a fast chilling (air temperature, −11 ± 1 °C; air velocity, 0.5 m/s) for 2 h, then the refrigeration was stopped (air velocity, 0 m/s) until 10 h postmortem, followed by a 1 ± 1 °C chilling (air velocity, 0.5 m/s) to 48 h postmortem. The aim was to

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investigate the effects of this temperature control on the tenderness of Chinese yellow cattle LL muscle during aging.

2. Materials and methods

2.1. Animals, experimental design and treatments

Eighteen Chinese crossbred yellow cattle [(Luxi × Simmental, 24 months of age and live weight of 493.8 ± 60.3 kg) (mean ± SD)] were selected on the slaughter line from a commercial feedlot (Sishui Xinlv Food Co., Ltd., China) where animals were fed with a similar diet. The experiment was replicated three times on separate slaughter days, with six cattle slaughtered each day. After sides were washed and weighed in preparation for chilling, the left side of each carcass was stored in a conventional chilling room (air temperature, 1 ± 1 °C; air velocity, 0.5 m/s) for 48 h postmortem as the control chilling (CC) treatment. The right side went through a stepwise chilling (SC) treatment in another chilling room (air temperature, − 11 ± 1 °C; air velocity, 0.5 m/s) for 2 h, then the refrigeration was stopped (air velocity, 0 m/s) to hold *M. longissimus lumborum* (LL) center temperature at 12–18 °C until 10 h postmortem, thereafter the SC-treated sides were railed into the conventional chilling room (air temperature, 1 ± 1 °C; air velocity, 0.5 m/s) for the remainder time of chilling (to 48 h postmortem). Each of the LL muscles was cut into 3 segments, vacuum packaged and continually stored in incubators at 3 ± 1 °C aging for 1, 7 and 14 d.

The experiment was approved by the State Scientific and Technological Commission (China, 19881114) and the animals were treated in accordance with the guidelines outlined by the Animal Ethics Committee in Shandong Agricultural University.

2.2. Sampling and measurements

2.2.1. Carcass temperature and pH measurements

Carcass temperature and pH were measured at 1, 3, 10, 24 and 48 h after slaughter using a digital thermometer (DM6801A, Shenzhen Victor Hi-Tech Co. Ltd., China) and a portable pH meter (SenvenGo, Mettler-Toledo, Switzerland) which was calibrated in buffers with pH 4.00 and 7.00. The probes were inserted into the center (about 3 cm) of the LL muscles between the 12th and 13th ribs.

2.2.2. Warner–Bratzler shear force (WBSF)

Muscle samples (approximately 3 cm thick) were removed from the muscle aged 1, 7 and 14 d. The WBSF was measured by the modification of the method of Luo, Zhu, and Zhou (2008). Samples were packaged in polyethylene bags respectively and then cooked in 80 °C water bath until a core temperature reached 70 °C. During cooking, the digital thermometer was inserted into the samples to track the internal temperature. Then, the cooked samples were stored into an incubator (air temperature 3 ± 1 °C) before evaluation the next day. Six or more columnar cores were removed parallel to muscle fiber orientation from each steak sample and were cleaved perpendicular to the fiber orientation using a texture analysis machine (model TA-XT2i Stable Micro Systems, England) with a HDP/BSW blade. The average of at least 6 shear measurements of columnar cores from each steak sample was the value of WBSF.

2.2.3. Myofibril fragmentation index (MFI)

MFI was determined according to Culler, Parrish, Smith, and Cross (1978). Small samples were taken from muscles after aging for 1, 7 and 14 d, then frozen in liquid nitrogen immediately and stored at −80 °C until testing. Meat samples were minced with all visible fat and connective tissue removed. In triplicate, 4 g minced meat was homogenized for 30 s at 4 ± 2 °C in 40 mL MFI buffer (pH 7.0, 4 ± 2 °C, mixed liquor of 100 mM KCl, 1 mM EGTA, 1 mM $MgCl_2$ and 1 mM NaN_3). The homogenate was centrifuged (1000 ×*g*, 15 min) and the supernatant was discarded. The sediment was re-suspended in 40 mL MFI buffer, shaken, centrifuged and the supernatant was discarded again as above. The sediment was re-suspended in 10 mL MFI buffer, mixed by shaking, and filtered through a polyethylene strainer to remove fat and connective tissue. Then, another 10 mL MFI buffer was added to facilitate the passage of myofibrils through the strainer. Then the protein concentration of filter liquor was measured by the Biuret method (Gornall, Bardawill, & David, 1949). After that, the suspension was adjusted to a protein concentration of 0.5 ± 0.05 mg/mL with MFI buffer. Finally, absorbance of the suspension was measured at 540 nm. The value of MFI was the A_{540} value multiplied by 200.

2.2.4. Sarcomere length

Sarcomere length of the samples was measured at 1, 7 and 14 d postmortem respectively by the modification of the method of Cross, West, and Dutson (1981) and Hou et al. (2014). Samples (3 g) were removed from the same inner LL muscle position and homogenized at low speed in 18 mL of 2.5 M sucrose solution for 30 s in a homogenizer (T18, IKA, Germany). Immediately after that, a drop of homogenate was transferred onto a microscope slide and covered with a cover slip. The slide was examined with the oil-immersion objective of a phase-contrast microscope (BX41, Olympus, Japan). Single myofibrils (30) were photographed with an Olympus camera. Five measurements of sarcomere length were performed at different points on each image using the software Image-Pro Plus (6.0, Media Cybernetics, USA). The mean of 150 measurements was the sarcomere length of each sample.

2.2.5. Water holding capacity (WHC)

2.2.5.1. Purge loss. At 48 h postmortem (aging for 1 d after the development of rigor), the meat samples were weighed and vacuum packaged. After aging for 7 and 14 d, purge loss during vacuum storage was measured by weighing samples. Before weighing, the samples were patted dry with filter paper. Purge loss was calculated as the percentage weight loss.

2.2.5.2. Cooking loss. After aging for 1, 7 and 14 d, the samples were cooked individually in plastic bags in a water bath at 80 °C until the internal temperature reached 70 °C. During cooking, the core temperature of each sample was tracked by a digital thermometer (DM6801A, Shenzhen Victor Hi-Tech Co. Ltd., China). Then, the cooked meat samples were stored in an incubator overnight with an air temperature of 3 ± 1 °C. Cooking loss was expressed as the percentage of weight loss before cooking and after cooking and storage in the incubator.

2.2.6. Meat color

Meat color of the samples aging for 1, 7 and 14 d was measured by a colorimeter (SP62, X-rite Incorporated, Grand Rapids, USA) with an 8 mm diameter measuring aperture, illuminant D65, and CIE L* a* b* color scale. Before measurement, samples were exposed in the air for 30 min. Then each sample was measured on 8 sites, and the average of the 8 measurements was reported.

2.3. Statistical analysis

The trends in pH against temperature were modeled according to the approach of Hopkins, Ponnampalam, van de Ven, and Warner (2014) and van de Ven, Pearce, and Hopkins (2014). The average pH trends with temperature within two chilling treatments (CC and SC) were modeled as separated spline models. The model was fitted using the lmer function in the package lme4 under R (R Development Core Team, 2010) (Bates, Maechler, & Bolker, 2011). The fitted model was used to predict mean temperature at pH 6 (Temp@pH6) and mean pH at a temperature of 12 °C (pH@Temp12), and the standard errors of these estimates were estimated by bootstrap methods (Efron &