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# Feasibility assessment of vacuum cooling followed by immersion vacuum cooling on water-cooked pork

Xiaoguang Dong, Hui Chen, Yi Liu, Ruitong Dai, Xingmin Li *

*College of Food Science and Nutritional Engineering, China Agricultural University, No. 17 Qinghua East Road, Beijing 10083, China*

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Vacuum cooling followed by immersion vacuum cooling was designed to cool water-cooked pork (1.5 ± 0.05 kg) compared with air blast cooling (4 ± 0.5 °C, 2 m/s), vacuum cooling (10 mbar) and immersion vacuum cooling. This combined cooling method was: vacuum cooling to an intermediate temperature of 25 °C and then immersion vacuum cooling with water of 10 °C to the final temperature of 10 °C. It was found that the cooling loss of this combined cooling method was significantly lower ($P<0.05$) than those of air blast cooling and vacuum cooling. This combined cooling was faster ($P<0.05$) than air blast cooling and immersion vacuum cooling in terms of cooling rate. Moreover, the pork cooled by combined cooling method had significant differences ($P<0.05$) in water content, color and shear force.

## 1. Introduction

Cooked meats are a significant segment of the meat industry to be used in ready-meals or as an ingredient in meat-based food products. Although there are many commercial cooling methods being extensively used, such as air blast cooling, water immersion cooling and slow chilling, techniques for obtaining a fast cooling method to satisfy safety requirements have been of great importance to the meat industry. Thus, some new cooling methods like vacuum cooling and immersion vacuum cooling have been studied.

Vacuum cooling (Huber & Laurindo, 2006; McDonald & Sun, 2000; Wang & Sun, 2001, 2002) has been studied. The principle of vacuum cooling process was based on the evaporation of water contained in cooked products under vacuum condition. This process enables cooked food products such as meat products to be chilled in an extremely short period of time (Sun & Zheng, 2006; Zheng & Sun, 2004). However, the water evaporating from cooked food represents the undesired mass loss. Moreover, since most products are sold by weight, it means less profit for manufacturers. For large meat products, high moisture loss during vacuum cooling would lead to a decrease in tenderness and juiciness (Desmond, Kenny, Ward, & Sun, 2000; McDonald, Sun, & Kenny, 2000). Various methods have been reported to reduce or compensate the moisture loss, such as adjusting injection level (Desmond, Kenny, & Ward, 2002; McDonald, Sun, & Kenny, 2001; McDonald & Sun, 2001b), adjusting the evacuation rate (Huber & Laurindo, 2005; McDonald & Sun, 2001a) and cooling the meat in soup (Houska, Sun, Landfeld, & Zhang, 2003). Among these methods, cooling beef in soup obtained the best result with no weight loss. Instead, it was found that the mass of meat cooled in soup increased by 7.7% due to water penetration at the end of the vacuum cooling. And immersion vacuum cooling was studied and the results showed that immersion vacuum cooling can substantially reduce the weight loss and improve the quality of the cooled products (Cheng & Sun, 2006a, 2006b; Schmidt, Aragão, & Laurindo, 2010). Houska, Landfeld, and Sun (2005) found pork and beef ripened in the brine and cooled by immersion vacuum cooling would have a better quality. To prevent the solution from boiling over during immersion vacuum cooling, the rate of pressure decrease was adjusted following the curve of saturated steam and according to the temperature of the cooking solution. Therefore, a bleed valve was needed to regulate the pressure during immersion vacuum cooling (Cheng & Sun, 2006a). During immersion vacuum cooling, the thermal conduction played a more important role than water evaporation for most of the time. Because the thermal conductivity of meat was low, the cooling rate of immersion vacuum cooling was smaller compared to that of vacuum cooling. As Drummond, Sun, Vila, and Scannell (2009) showed in his experiment, the cooling time of immersion vacuum cooling was longer than that of vacuum cooling. And as the way of heat release, the size of the meat cooled by immersion vacuum cooling had a great influence on the cooling time. Drummond and Sun (2008) illustrated that the size of the meat significantly affected the cooling rate and meat product larger than the sample (4 kg) in their study would take more time to cool down which may no longer comply with safety guidelines. Moreover, as the remaining hot solution after cooking was placed together with cooked meat into the vacuum chamber, the cooling load was increased (Cheng & Sun, 2006a).

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* Corresponding author. Tel.: +86 010 62737547.
*E-mail address:* meatlxm@gmail.com (X. Li).

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The study conducted by Cheng, Sun, and Scannell (2005) showed that water cooking compared with dry air cooking and wet air cooking would process pork ham with high yield and compatible nutritional and textural qualities. Drummond and Sun (2006) also illustrated beef samples cooked in water were significantly tender and had higher water holding capacity values than dry heat oven cooked samples. So water cooking could be an advantageous method combined with cooling to render safety and high quality meat products.

Based on the above, it was proposed that it would be possible to design a combined cooling method of vacuum cooling followed by immersion vacuum cooling for the water-cooked pork. This combined cooling method involved the extremely rapid temperature drop in the beginning of vacuum cooling to an intermediate temperature and then immersion vacuum cooling to compensate the cooling loss of vacuum cooling until the final temperature. This study was to assess the feasibility of the vacuum cooling followed by immersion vacuum cooling (VC–IVC), compared to air blast cooling (AB), vacuum cooling (VC) and immersion vacuum cooling (IVC).

## 2. Materials and methods

### 2.1. Sample preparation

The ellipsoid-shaped pork samples were cut from hindquarters (*M.* semimembranosus group) which were purchased from a local butcher (Fifth meat factory, Beijing, China). The pork samples were free of skin, visible fat and connective tissue. The pH of the meat was measured at three different points using a pH probe (pH211, HANNA instruments Inc., USA). Only muscles with pH between 5.70 and 6.10 and with weights of 1.5 ± 0.05 kg were used. Finally the pork samples were vacuum packed and stored at 4 ± 1 °C for aging before cooking (duration time was about 2 days).

### 2.2. Sample cooking

Before cooking, the vacuum bags were removed from the samples. All pork samples were cooked in 2% salt solution bath (Model DK-8B, Jing Hong Laboratory Instrument, China) to core temperature of 72 °C. Additionally, the weights of the pork samples before and after cooking were recorded.

### 2.3. Sample cooling

For air blast cooling (AB), immediately after the cooked sample was weighed, it was placed in a laboratory scale air-blast cooler (model PRx-350, Ningbo Haishu Safe Experimental Instrument Factory, China) with 0.35 $m^3$ chamber capacity at an air temperature of 4 ± 0.5 °C and air velocity 2 m/s. Then the sample was cooled with air blast cooling till core temperature reached 10 °C.

For vacuum cooling (VC), the cooked pork sample was placed on a perforated stainless steel table in the vacuum chamber. After the equipment door was closed, the pressure of the chamber was allowed to drop to the working pressure of 10 mbar.

For the immersion vacuum cooling (IVC), samples were transferred into a container, together with the hot salt solution from cooking enough to cover the sample. Samples cooled with the solution from 72 °C to 10 °C of core temperature under the controlled pressure in the vacuum chamber. To avoid spilling of the water from the container during cooling, the chamber pressure was controlled precisely, according to saturated steam pressure (Cheng & Sun, 2006a), to reach the final working pressure of 10 mbar.

For vacuum cooling followed by immersion vacuum cooling (VC–IVC), immediately after the cooked sample was weighed, it was transferred into the container of vacuum chamber. The pork sample was vacuum cooled until the thermocouples read the target intermediate temperature of 25 °C, in the meantime, the hot salt solution from cooking was cooled with ice water bath to 10 °C. After vacuum cooling to 25 °C, the cooking solution (10 °C) was injected into the container and sufficiently covered the sample. Then the sample was cooled with immersion vacuum cooling till core temperature reached 10 °C.

The vacuum cooler (model WBN-5, Beinuo Machinery Co., Ltd., Wenzhou, China) used was specially designed for research. It consists of a cylindrical metal chamber with door (free volume of chamber was about 0.12 $m^3$). The equipment is completed with a condenser and a vacuum pump (model 2ZX(S), China) with a pumping rate of 14.4 $m^3/h$. The vacuum cooler was run to cool the vacuum chamber before cooking was completed. During all the cooling process, pork temperature and weight of the pork samples after cooling were recorded. The core temperature was recorded using 3 K-type thermocouples (model DM6801B, Tondaj Instruments and Meters Co., China) inserted into an appropriate position around the geometric center of the samples to record the temperature of the samples during cooking and cooling process.

### 2.4. Cooking and cooling process parameters

The parameters determined for each process were cooking loss, cooling loss, cooling rate and the mean temperature reduction per unit of percentage weight loss ($\eta_T$). The cooking loss was considered to be the percentage weight loss between the uncooked and the cooked sample. The cooling loss was the percentage weight loss between the cooked and the cooked–cooled sample. The yield (%) was calculated as the weight after cooling divided by the weight of raw sample. The $\eta_T$ was calculated as the quotient between the core temperature reduction during the cooling stage ($\Delta T$) and the cooling loss. The cooling rate was the core temperature reduction during the cooling stage ($\Delta T$) divided by the cooling time.

### 2.5. Water content

The water content of the cooled pork was measured in triplicate by oven drying at 104 °C, 24 h (AOAC, 1980).

### 2.6. Warner Bratzler shear (WBS)

Strips (10 mm × 10 mm × 30 mm) were cut parallel to the muscle fiber orientation from the cooled pork samples. Strips were sheared at room temperature using the Warner-Bratzler shear device (Model WARNER-BRATZLER, G-R Manufacturing Co., USA) at the shear head speed of 4 mm/s.

### 2.7. Texture profile analysis (TPA)

Samples were cut parallel to the longitudinal orientation of the muscle fibers into 20 mm × 20 mm × 20 mm size and examined by textural instrument (Model TMS-Pro, Food Technology Corporation, USA). Two cycles of 6 mm target distance were applied to the samples using a 60 mm circular flat disk attached to the textural instrument at cross-head speed 30 mm/min. The outputs from TPA included hardness, gumminess, springiness, chewiness, and adhesiveness.

### 2.8. Color

The color of cooled pork was measured by the CIE L*a*b* (L*—lightness, a*—red/green and b*—yellow/blue) system using a reflectance colorimeter (WSC-S, Shanghai Precision & Scientific Instrument Co., Ltd., China).

### 2.9. Statistical analysis

All experiments were performed three times in triplicates. All data was analyzed by one-way analysis of variance (ANOVA) using SPSS