Meat Science 95 (2013) 425–432

Contents lists available at SciVerse ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Effects of processing parameters on immersion vacuum cooling time and physico-chemical properties of pork hams

Chao-Hui Feng, Liana Drummond, Zhi-Hang Zhang, Da-Wen Sun *

FRCFT, School of Biosystems Engineering, University College Dublin, National University of Ireland, Belfield, Dublin 4, Ireland

ARTICLE INFO

Article history:
Received 2 February 2013
Received in revised form 16 April 2013
Accepted 17 April 2013

Keywords:
Immersion vacuum cooling
Pork ham
Pressure reduction rate
Water initial temperature

ABSTRACT

The effects of agitation (1002 rpm), different pressure reduction rates (60 and 100 mbar/min), as well as employing cold water with different initial temperatures (IWT: 7 and 20 °C) on immersion vacuum cooling (IVC) of cooked pork hams were experimentally investigated. Final pork ham core temperature, cooling time, cooling loss, texture properties, colour and chemical composition were evaluated. The application for the first time of agitation during IVC substantially reduced the cooling time (47.39%) to 4.6 °C, compared to IVC without agitation. For the different pressure drop rates, there was a trend that shorter IVC cooling times were achieved with lower cooling rate, although results were not statistically significant ($P > 0.05$). For both IWTs tested, the same trend was observed: shorter cooling time and lower cooling loss were obtained under lower linear pressure drop rate of 60 mbar/min (not statistically significant, $P > 0.05$). Compared to the reference cooling method (air blast cooling), IVC achieved higher cooling rates and better meat quality.

1. Introduction

Ready meals and convenience products are increasingly favoured by consumers who have limited time or opportunity for conventional meal preparations. Pork ham, as one of the ready-to-eat meals, plays an essential part in people's daily life (Ferrentino, Balzan, & Spilimbergo, 2013; Zell, Lyng, Morgan, & Cronin, 2012). Irrespective of how the meat is prepared or cooked, meat should be rapidly chilled to avoid multiplying pathogens that survived from cooking (Drummond & Sun, 2010; Drummond, Sun, Vila, & Scannell, 2009; Mor-Mur & Yuste, 2010; Norton & Sun, 2008). It is well known that the optimal temperature for microorganism growth is 63 to 5 °C, quickly spanning this temperature range during cooling is thus extremely critical. According to the updated guidelines for chilling processes published by the Food Safety Authority of Ireland (2006), the cooling time for large non-reformed or non-restructured meat joints (thickness or height: 100 mm; weight > 2.5 kg) from a core temperature of 50 to 12 °C should be less than 4 h, and a final core temperature below 3 °C should be achieved within additional 2 h (Anon, 2006). In other European countries, similar recommendations apply: cooked food should achieve cooling from core temperature of 80 to 15 °C in at most 2 h in Germany, 2 h in France (from 70 to 10 °C) and 3 h in Denmark (from 65 to 1 °C) (Cheng & Sun, 2006a). It is thus a big challenge for traditional cooling methods such as air blast cooling (AB) and immersion cooling (IC) systems to meet these strict cooling time requirements. Therefore, besides the development of novel refrigeration processes (Sun, 1996, 1997a, 1997b, 1999; Sun & Eames, 1996; Sun, Eames, & Aphornratana, 1996), development of innovative freezing (Li & Sun, 2002; Sun & Li, 2003) and cooling (Sun & Zheng, 2006) methods is also important. For cooling a large meat joint of 6 kg from 70 to 4 °C, it took about 9.4 h and 14.3 h for AB and IC, respectively (Sun & Wang, 2000). The long cooling time is because these cooling methods mainly rely on heat conduction to cool the inside of the large pieces of meat and its thermal conductivity was notably low. The thermal conductivity of ham has been reported to vary between 0.339 ± 0.037 and 0.437 ± 0.058 W m^{-1} K^{-1} from 22 to 79 °C (Marcotte, Taherian, & Karimi, 2008), compared with that of glass (0.8–1.4 W m^{-1} K^{-1} at 20 °C) and pure aluminium (204.3–214.6 W m^{-1} K^{-1} from 20 to 93 °C) (Young & Sears, 1992).

Being an innovative modification of vacuum cooling (VC) (Hu & Sun, 2001; Sun & Brosnan, 1999; Sun & Hu, 2003; Sun & Zheng, 2006; Wang & Sun, 2002), immersion vacuum cooling (IVC) – which involves vacuum cooling of a hot food product while immersed in a surrounding liquid – showed a potential to meet the high cooling rate requirements mentioned above (Feng, Drummond, Zhang, Sun, & Wang, 2012). During IVC processing, it is not only based on water evaporation where the latent heat would be absorbed and chilling thus is to be completed, but also conduction and convection, especially in the later stage of IVC. Research previously undertaken employed IVC to cool meat products such as chicken fillets (Schmidt, Aragão, & Laurindo, 2010), beef (Drummond et al., 2009; Houska, Sun, Landfeld, & Zhang, 2003), and pork hams (Cheng & Sun, 2006a; Cheng & Sun, 2006b; Cheng & Sun,

* Corresponding author. Tel.: +353 1 7167342; fax: +353 1 7167493.
E-mail address: dawen.sun@ucd.ie (D.-W. Sun).
URL's: http://www.ucd.ie/refrig, http://www.ucd.ie/sun (D.-W. Sun).

0309-1740/$ – see front matter
http://dx.doi.org/10.1016/j.meatsci.2013.04.057

2007; Dong, Chen, Liu, Dai, & Li, 2012). Results revealed that compared to conventional cooling methods, IVC achieved higher cooling rates, while compared to VC, IVC accomplished much lower cooling losses. However, the longer cooling time compared to VC, and particularly the relationship between cooling time and product size, still drive researchers to further develop this technology. Employing agitation in the surrounding cooling liquid during IVC has been recommended as one of the necessary improvements to reduce IVC cooling time (Cheng & Sun, 2006a; Drummond & Sun, 2008a; Drummond & Sun, 2008b; Feng et al., 2012), as in IVC conduction and convection became the controlling heat transfer mechanisms at the later stage of IVC, thus limiting the cooling rate. Although it is logical to suppose that agitation during IVC would improve convection between meat surface and surrounding chilling water, leading to a reduction in cooling time, the extent of this reduction had not yet been investigated.

In prior research works, IVC pressure drop rate was manually controlled according to the degree of water boiling (to avoid violent water evaporation), and as a consequence, experimental repeatability was very poor. The use of different vacuum cooling pressure reduction rates has been comprehensively investigated for lettuce and cooked beef products (He, Feng, Yang, Wu, & Li, 2004; Rennie, Vigneault, Raghavan, & DeEll, 2001; Wang & Sun, 2002). However, knowledge on the effects of different pressure reduction rates during IVC, especially under accurate pressure drop control, is still lacking. It is thus worth to study the effect of different pressure reduction rates on immersion vacuum cooling parameters and on the final quality of the meat product.

Previous works have employed hot water (usually the same solution used during the cooking step) as the surrounding liquid during IVC. However, water cooking of large meat products such as hams is not commonly used in the industry. Instead, oven cooking (steam or dry air), and air blast cooling, are the most employed cooking and cooling methods currently in use respectively. In some factories, a cold shower is also employed immediately after hams come out of the oven, before transferring them into the air blast chamber. As cold (tap) water of good microbiological quality is generally available in food factories, the use of cold water as the surrounding liquid during IVC of hams merited investigation. Additionally, the use of water at a lower temperature will significantly reduce the amount of water evaporated, thus reducing the system (condenser and pumps) cooling load. Tap water temperature may vary according to the area and season. Generally, the average tap water temperature in Ireland can be as low as 7 °C in winter and as high as 20 °C in summer. Therefore, two pressure drop rates combined with these two different IWTs were investigated for their potential commercial utilization.

The objectives of this work were firstly to verify the extent of cooling parameter improvement after application of liquid agitation on IVC of large cooked hams; and then to evaluate the effect of different water initial temperatures and different pressure drop rates with agitation. Results from hams cooled by the different IVC conditions were compared to those obtained using air blast cooling (as a reference).

2. Materials and methods

2.1. Sample preparation

Raw pork hams were supplied by a local meat processor (McCarren, Co. Cavan, Ireland). Cylindrical hams (logs) were individually packaged in perforated fibrous bags, fastened at two ends with metal clips. The average weight, diameter (cross-section) and length of logs were 3.8 ± 0.2 kg, 13 ± 0.5 cm, 30 ± 1.0 cm, respectively. Since the samples packed in required packages were prepared by the supplier, weight variation occurred as indicated by the standard error above. In order to reduce the effect of sample weight variability on results, 18 samples were divided based on their weights into six groups (treatments), namely: 20/L 60, 20/LA 60, 20/LA 100, 7/LA 60, 7/LA 100 and air blast cooling. Three samples with similar weights were employed for each treatment. All samples were kept frozen (−18 °C) until use, and then defrosted in a fridge (3 °C) for three days before each experimental run. In order to reduce cooking loss, each log was vacuum packaged in cooking bags, heat shrunk in hot water (90 °C for 10 s) and finally wrapped with an elastic net before cooking.

2.2. Cooking and cooling procedures

A convective steam oven set at 83 °C (FCV6, Zanussi, Italy) was used to cook hams until the core temperature reached 72 °C for 2 min.

Cooked samples were cooled by either immersion vacuum cooling (IVC) or air blast cooling (AB) until final core temperature fell below 4 °C. For IVC, samples were transferred into a container (36 × 40 × 36.5 cm) and approximately 28 l of water was added to cover the ham (4 cm above meat surface). A specially designed lid was used to reduce water splashing while allowing generated vapour to escape from the container easily. The pressure reduction rate in the vacuum chamber was automatically regulated using an electronic valve connected to a PC. When vacuum broke, the valve was totally open and connected to atmosphere. Labview software (v4.1, National Instruments) was used to develop the control programme. Three different stages of experimental comparison were carried out: 1) comparison between LA 60 and L 60; 2) comparison of effects of different pressure drop rates (60 mbar/min; 100 mbar/min) at different IWTs (7 °C, 20 °C); and 3) comparisons among LA 60 with 7 and 20 °C, L 60 and air blast cooling.

Stage 1: based on the preliminary optimal and economic results of IVC, similar operating conditions were applied to samples during comparison trials between IVC with or without agitation: initial water temperature of 20 °C using linear pressure reduction rate of 60 mbar/min. Liquid agitation was provided by a magnetic stirrer bar placed at the bottom of the container and separated from the sample by a mesh shelf. Agitation was applied from the very beginning of cooling at a constant speed of 1002 rpm, experiments were carried out in triplicates. The data obtained in stage 1 were also used for the following stage comparisons.

For the comparison of different cooling treatments (7/LA 60, 7/LA 100, 20/LA 60, 20/LA 100) in stage 2, another three complementary experiments: 7/LA 60, 7/LA 100, 20/LA 100 were conducted. Results of 20/LA 60 were obtained from stage 1. Linear pressure drop rates were applied between a starting (320 mbar) and final (5.0 mbar) chamber pressure values, chosen based on preliminary tests (320 mbar is the approximate flash point for water at 72 °C). After chamber pressure reading reached the final pressure value (5.0 mbar), the programme controlled the electronic valve to maintain chamber pressure at this value until ham temperature reached 4 °C (end of cooling). For all IVC experiments, the condenser in the system was connected to a refrigerated circulator (FP50, Julabo, Germany), which was set at −12 °C.

As far as the comparisons of different cooling methods in stage 3 are concerned, experimental data of 7/LA 60, 20/LA 60, L 60 were from stages 1 and 2. A supplementary experiment (AB, triplicates) was conducted by a laboratory scale blast cooler (CBF 20, Foster Refrigerator, UK) with an air velocity of 1.4 m/s and an air temperature of −2.9 °C were employed.

2.3. Cooling loss and total mass loss

Cooling loss and total mass loss are calculated by using the following equations; three samples were used to evaluate the losses for each cooling condition.

$$\text{Coolingloss}(\%) = \frac{W_1 - W_2}{W_1} \times 100\% \quad (1)$$

$$\text{Totalmassloss}(\%) = \frac{W_3 - W_2}{W_3} \times 100\% \quad (2)$$