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Impact of Pressure Reduction Rate on the Quality of Steamed Stuffed Bun

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ABSTRACT

Effects of three pressure reduction rates (PRR) of 103 Pa s^{-1}, 197 Pa s^{-1}, and 347 Pa s^{-1} on temperature distribution and variation, moisture content, and sensory quality of steamed stuffed buns were investigated after vacuum cooling. The distributions and variations of surface temperatures were determined by the thermal infrared imaging method. The temperature profiles presented significant differences in the average cooling rates of the different parts, depending on the PRR. Results showed that the greatest mass loss of 8.1% and the shortest cooling time of 288 seconds were found with the quickest PRR of 347 Pa s^{-1}, while the least mass loss of 5.96% and the longest cooling time of 955 seconds were observed in the case of the slowest PRR of 103 Pa s^{-1}. The pressure reduction rates had little influence on the changes of moisture contents in the crumb and stuffing. The sensory quality scores of vacuum-cooled buns at 103 and 197 Pa s^{-1} were higher than those at 347 Pa s^{-1}.

Keywords: Moisture content, Sensory quality, Steamed stuffed bun, Thermal infrared imaging, Vacuum cooling.

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INTRODUCTION

Steamed stuffed bun is a very common food in China and is formulated with wheat flour, water, yeast and stuffing (Pan and Zhu, 2006). The commercial production of the steamed stuffed bun in China has made it more convenient for consumers and has further enhanced its popularity. After cooking by water vapor at temperatures of 95-106ºC, the steamed stuffed bun may be directly consumed or be cooled for storage, transportation, and marketing. Usually, the conventional cooling methods such as air blast need more than 1h to cool the steamed stuffed bun to room temperature and take longer time for reaching below 10ºC (Liu, 2008). In order to retard starch retro gradation (Yu et al., 2009), inhibit growth of heat resistant microorganisms (Ma et al., 2004), and reduce water loss (McDonald and Sun, 2000) of the cooked food , it is imperative to rapidly cool the steamed filled bun to proper temperatures lower than the cooking temperature .

Vacuum cooling is an established technique for rapid cooling processing and is extensively used for pre-cooling some agricultural and food products that have a high surface area to volume ratio and a porous structure (He et al., 2004; Sun and Zheng, 2006). In bakery industry, vacuum cooling is generally used to reduce post bake processing time and to extend product shelf life (Bradshaw, 1976; Gray, 1992; McDonald and Sun, 2000; Sun and Zheng, 2006). Moreover, Primo-Martin et al. (2008) found that both fracture property and sound emission by bread

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crust were affected by vacuum cooling. These studies on vacuum cooling of bakery products were mostly carried out for one set of pressure and, therefore, it is difficult to compare the effects of the PRR's on the product quality and cooling time. Although Chinese steamed stuffed bun is distinctly different from baking bread in the formulation components, processing factors, and etc, its large surface to mass ratio and porous structure can offer feasibility of vacuum pre-cooling. The application of vacuum cooling in the steamed stuffed bun pre-cooling has not been previously reported in the literature. Therefore, this work should identify the feasibility and possible benefits of vacuum cooling for cooling the steamed buns .

Generally, a sample of steamed stuffed bun after cooking is divided into crust, crumb, and inner stuffing part, which exhibit different heat and mass transfer properties during the cooling period. Thus, the method of measuring and monitoring the variations and distributions of the temperatures in different regions of the stuffed bun during cooling is also very important. Passive thermal infrared imaging has been widely used in industrial test procedures as a non-destructive method for the detection of surface temperature distributions and changes (Bajons and Sun, 2005; Kaukoranta et al., 2005; Kitaya and Hirai, 2008; Primo-Martin et al., 2008; Wang et al., 2007). However, up to now, there are no published studies on the application of thermal infrared imaging in vacuum cooling system. In this study, thermal infrared imaging was applied to monitor the real-time thermal temporal variation and distribution of the bun surface during vacuum cooling.

The aims of this study are: (1) to comprehensively investigate the temperature variations and distributions of crust, crumb and stuffing at different pressure reduction rates (PRR's), and (2) to reveal the effects of PRR's on cooling time, weight loss, moisture content, and sensory quality of the steamed stuffed buns.

MATERIALS AND METHODS

Steamed Stuffed Bun Preparation

Steamed stuffed buns were prepared according to the modified Pan and Zhu (2006), including four main procedures: flour mixing and softening, stuffing, wrapping and steaming .

Flour Mixing and Softening

A basic formula consisting of wheat flour (100 g) (American roses brand, Shekou Nanshun flour Co. Ltd., Shenzhen), sugar(5 g), dry yeast (2 g) (Harbin Mauri Yeast Co., Ltd), baking powder (1 g) (Guangzhou Valumaster Food Co. Ltd., Guangzhou) and water (60 mL, 30ºC) were mixed into dough in a flour mixer. The dough was then fermented for 50 minutes at 30ºC and 85% relative humidity and was allowed to double the original size .

Stuffing Making

The pork stuffing was made by mixing thoroughly minced bacon belly (100 g), soy-bean sauce (3 mL), sugar (3 g), salt (1 g), monosodium glutamate (1 g), chopped green onion (20 g), chopped ginger (20 g) cooking wine (3 mL), shrimp (10 g) with water (35 mL.(

Wrapping

The softening dough (about 25 g) was rolled into round wrappers, and then the stuffing (about 6 g) was placed on the wrappers, finally, they were formed into

Figure 1. The photos of steamed stuffed bun before and after vacuum cooling: (A) Steamed stuffed buns after steaming before cooling; (B) Steamed stuffed buns after cooling at 103 Pa s^{-1}; (C) Steamed stuffed buns after cooling at 197 Pa s^{-1}, (D) Steamed stuffed buns after cooling at 347 Pa s^{-1}.

buns of about 6.0 cm diameter and 3.5 cm height (Figure 1).

Steaming

After bringing a pot of water to boil, the buns were placed on stainless steel grate in the pot, and steamed for 10 minutes .

Vacuum Cooling System

The system used in this study was a commercial set-up for vacuum cooling (Danyang Dacheng Freshness Keeping Engineering Co., Ltd. VC-2, Jiangsu, China), mainly consisting of a vacuum pump (F-26501, Sogevac, France), vapour condenser, and vacuum chamber (with a volume of approximately 2 m3), instrumentation and control valves.

Temperature Measurement

The temperature of the steamed stuffed bun crust after cooking was measured during cooling by using an infrared workstation (Figure2) covering a thermal infrared imager (Research-N1) and a remote dynamic control system (Song et al., 2010). The main work specifications includes spectral range of 8-14 μm, viewing angle of 24°×18°, spatial resolution of 1.3mrad, temperature resolution of 0.08℃, frame frequency of 50 Hz, an un-cooled focal plane array, auto correction for set-in blackbody, atmospheric transmissivity, and radiance. The model of blackbody is LS2000-100 (Electro Optical Industries, INC., Santa Barbara, California, USA). The remote dynamic control system includes a wide area network, local area network, network server and wireless router. The temperatures of the crumb and stuffing parts were monitored using calibrated T-type welded tip copper-constant thermocouples with an accuracy of 10^{-2}°C. All of the experimental data were recorded automatically using a data collecting system that was controlled by a computer.

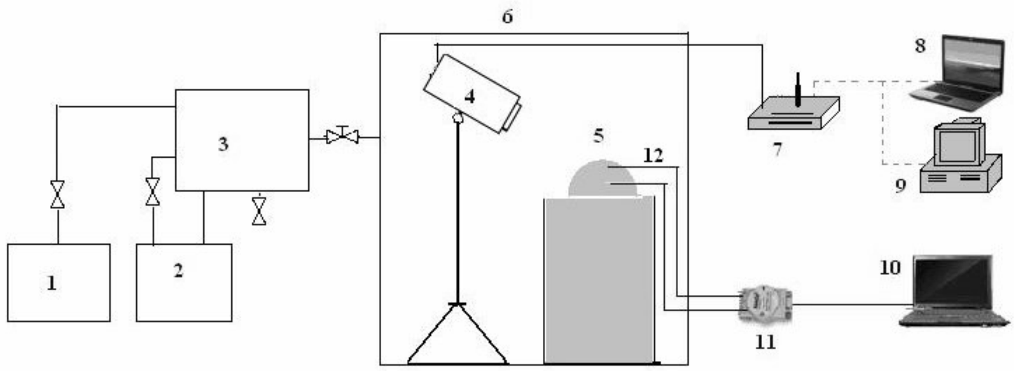

Figure 2. Experimental set-up of the steamed stuffed bun vacuum cooling system: 1. Vacuum pump; 2. Refrigerator; 3. Stem condenser; 4. Thermal infrared imager; 5. Steamed stuffed bun; 6. Vacuum chamber; 7. Wireless router; 8. Local area network; 9. Network server (100 M); 10. Personal computer; 11. Data acquisition modules, 12. copper-constantan thermocouples.

Moisture Content

Before and after vacuum cooling of the products, samples of the steamed stuffed bun crust (about 2 mm thickness), the crumb, and the inner stuffing were taken from each bun. Samples were weighted (±0.0001 g) into aluminum dishes, and dried in an oven at 105℃ for 24 hours. The moisture content was calculated from the weight determined before and after oven drying (Primo-Martin et al., 2008). Triplicates were used per sample.

Sensory Evaluation

Sensory evaluation of the steamed bun with stuffing was performed for the three cooling conditions by a panel including 6 students of our lab and 4 staff members who were familiar with the product. The participants were 6 men and 4 women aged between 22 and 55. The quality scoring system was based on sensory standard of Yangzhou Baozi (Zhu et al., 2006) (Table 1). Briefly, steamed stuffed buns were scored for quality parameters including color, appearance, elasticity, interior structure, mouth-feel and taste. Each parameter was evaluated and scored based on its percentage in the total score of 100.

Statistical Analysis

The data were analyzed using ANOVA ($P< 0.05$). Mean differences were established by the Duncan's multiple range tests. The data were analyzed using SAS 8.0 statistical data analytical software.

Table 1. Quality evaluation system for steamed bun with stuffing.

Sensory attributes	Full score	Criterion
Color	10	High score given to milk-white skin
Appearance	20	High score given to round shape, clear strips, smoothness, free of collapse, wrinkle and crackle
Elasticity	20	High score given to elastic bun
Interior structure	20	High score given to evenly open crumb
Mouth feel	20	High score given to soft and cohesive crumb and to not stick to teeth when chewing
Taste	10	High score given to bun's special flavor, without off-flavor
Total score	100	

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RESULTS AND DISCUSSION

Temperature Variations and Distributions in Steamed Stuffed Buns

During vacuum cooling, the temperature variations and distributions of the crust, crumb, and the stuffing were measured by three different rates of pressure reduction rates (PRR) i.e. 103 Pa s^{-1}, 197 Pa s^{-1}, and 347 Pa s^{-1}. It is evident from Figures 3-5 that the initial temperatures in the crust, crumb and the stuffing were different due to different heat losses caused by adjusting thermal infrared camera and arranging the thermocouples. Figures 3-5 also show that there were temperature declination rate differences among the three parts. During the vacuum cooling, heat was removed from the products through water evaporation and, therefore, evaporation and cooling of the sample started from the crust surface, followed by the crumb and the stuffing part. As such, cooling time was the shortest for the crust, moderate for the crumb, and the longest for the stuffing regardless of the PRR.

Effects of the PRR on the temperature changes were reflected clearly in Figures 3-5. It can be seen from Figure.1 that the crust surface temperature variations were not the same at different PRR's. At the rate of 103 Pa s^{-1}, a fast initial rate of cooling within the first 49s was followed by a progressive decrease in the rate for the following 906 seconds (Figure 3-A1). During the rapid cooling stage, adequate free water evaporated from the crust surface leading to a fast cooling rate. The free water decreased gradually over time, resulting in a slight decrease. For the "red line" and the "blue rectangle" regions on the crust in Figure 3-A2, the average cooling rates were 2.10 and 1.44 ℃ min^{-1}, respectively, and the temperature deviations between the two regions decreased with cooling time (Figure 3-A1). In the case of 197 Pa s^{-1}, the temperature variation trends were similar for the "red line" and the "blue rectangle" regions and, basically, included five stages: rapid cooling, constant level, slight decrease, slight rise and light decrease (Figure 3-B1). Starting 32 seconds after initiation, the crust surface temperature kept constant during the following 92 seconds for the "red line" region and 263 seconds for the "blue rectangle" region. The average cooling rates were 5.34 ℃ min^{-1} for the former and 3.30 ℃ min^{-1} for the latter region. The temperature rose slightly at 403 seconds due to the hot vapor evaporating from the sample interior. The deviation between the "red line" and the "blue rectangle" regions decreased gradually within 263 seconds and was almost zero thereafter (Figure 3-B1). This cooling rate cessation or reduction can be accounted for as there was no more free water available for evaporation (McDonald and Sun, 2000). The cooling curve of the crust at 347 Pa s^{-1} could be divided into three periods: rapid cooling within 26 seconds, slight rise in the following 62 seconds, and a slight decrease thereafter (Figure 3-C1). For the first 88 seconds of the cooling time, the cooling rate divergence of the "red line" and "blue rectangle" regions were almost equal and no obvious changes occurred during the following 62 seconds; however, the divergence increased for the latter cooling period (Figure 3-C1). The average cooling rates were 11.46 ℃ min^{-1} for the "red line" region and 7.14 ℃ min^{-1} for the "blue rectangle" region. As shown in Figure 3 (A2, B2 and C2), the isothermal images taken at random cooling times were good for visual observation of the temperature variations and distributions over the crust surface. Therefore, when making non-destructive surface temperature measurements, thermal infrared imaging is an attractive alternative to the thermocouple .method

From Figure's 4 and 5, it can be seen that the cooling curves were obviously different at the three pressure reduction rates (PRR) during vacuum cooling. The cooling curve of the crumb was similar to that of the stuffing at the same PRR. For the slowest evacuation rate i.e.103 Pa s^{-1}, the temperature dropped gradually over time.

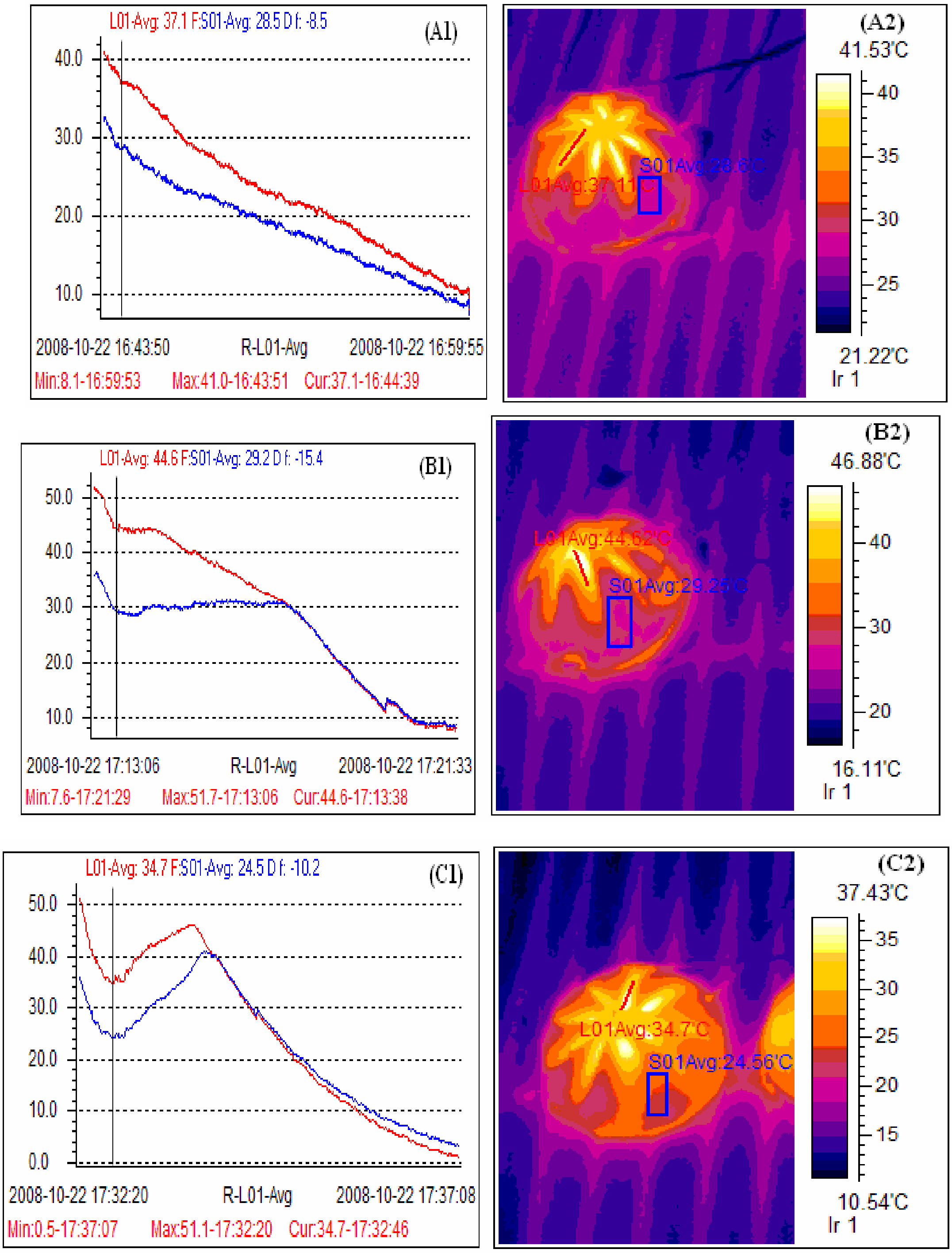

Figure 3. Typical surface temperature profiles and isothermal images of the crust at different pressure reduction rates: (A1-C1) Typical temperature profiles of the "red line" and the "blue rectangle" positions at the rates of, respectively, 103 Pa s^{-1}, 197 Pa s^{-1}, and 347 Pa s^{-1}, (A2-C2) Thermal infrared image of "red line" and "blue rectangle" positions at, respectively, 49s and 103 Pa s^{-1}; 32s and 197 Pa s^{-1}, and at 288 s and 347 Pa s^{-1}. L01 and S01 represent the average temperatures of different positions on the crust.

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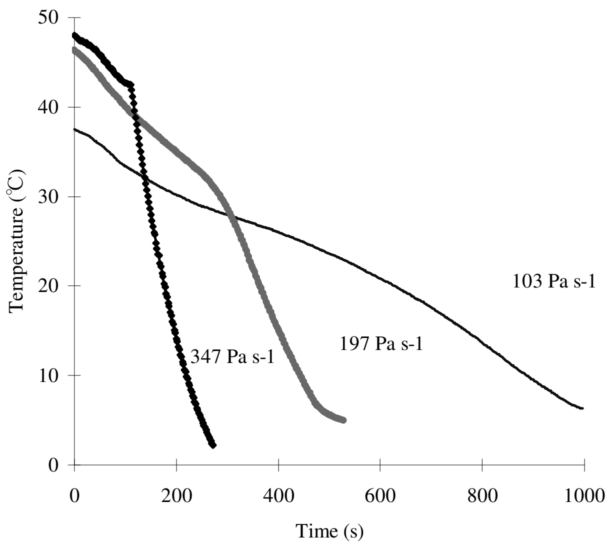

Figure 4. Changes in temperatures of the crumb at different pressure reduction rates.

However, cooling curves of the crumb and the stuffing part at the other two PRR's could be divided into two periods: a decelerating decreasing rate period and an accelerating decreasing rate period, with the transition occurring about 106 and 40 seconds for, respectively, the crumb and stuffing part (347 Pa s^{-1}) and 258 and 210 seconds after the beginning for, respectively, the crumb and the stuffing part (197 Pa s^{-1}). In this study, the temperature of the bun decreased from initial temperature down to about 7ºC. During the whole vacuum cooling process, evaporation and cooling occurred through the bun over time. At PRR's of 103 Pa s^{-1}, 197 Pa s^{-1}, and 347 Pa s^{-1}, the average cooling rates were 1.87 ºC min^{-1}, 4.70 ºC min^{-1} and 10.11 ºC min^{-1} for the crumb and 3.13 ºC min^{-1}, 6.95 ºC min^{-1} and 14.95 ºC min^{-1} for the stuffing. This showed that the cooling rates increased with increasing the PRR (Figures 4 and 5). Furthermore, rapid cooling rate decrease the moisture content of

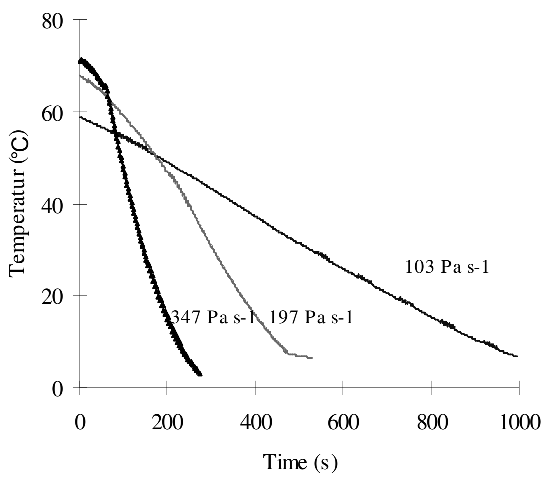

Figure 5. Changes in temperatures of the stuffing at different pressure reduction rates.

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the steamed stuffed buns (Table 2). As the surface area of all the samples was similar, this confirms that the cooling rate was influenced by such factors as the water activity, moisture permeability, and moisture transfer rate to the surface of the sample. Generally, the total cooling time depends on the specimen material and shape of the product, porosity, pore size, the pore distribution within the samples, availability of free water in the pores, and the set pressure (Ozturk and Ozturk, 2008). Comparison of Figure 3 with Figures 4 and 5 shows that the cooling time at 347 Pa s^{-1} was the shortest (288, 236 and 242 seconds for, respectively, the crust, crumb and the stuffing), moderate at 197 Pa s^{-1} (507, 520 and 530 seconds), and the longest at 103 Pa s^{-1} (965, 968 and 988 seconds), respectively. As expected, the slower the evacuation rate the longer the cooling period required.

Changes in Weight and Moisture Content

Weight loss took place during vacuum cooling because the cooling process was a direct consequence of water evaporation from the steamed stuffed bun (Primo-Martin et al., 2008). The percentage weight loss was closely related to the final set pressure. The results showed that the rate of pressure reduction had a significant effect on the weight loss for the steamed stuffed bun (Table 2). There appeared to be a positive relationship between levels of weight loss and the level of PRR. After the samples cooled down to about 7ºC, the greatest loss in weight (8.1%) was observed for PRR of 347 Pa s^{-1} due to a lower vacuum for the entire cooling period. The smallest weight loss (5.96%) was recorded for PRR of 103 Pa s^{-1}, giving a deviation of 2.14% from the former. This can be attributed to the fact that there was more release of the moisture at lower PRR, even though most of the cooling occurred in a short period at high PRR (Figures 3-5). This finding was consistent with previous reports on beef joint (McDonald and Sun, 2001), cut flowers (Brosnan and Sun, 2003), and iceberg lettuce (Ozturk and Ozturk, 2008) on mass loss reduction during modulated vacuum cooling, confirming that the weight loss of the product can be controlled by modulating the vacuum level.

The moisture contents of the steamed stuffed bun crust, crumb, and stuffing were also measured after vacuum cooling (Table 2). Compared with the initial sample, the moisture contents of the three parts in the bun were reduced markedly due to evaporation ($P< 0.05$). The reduction in moisture content was the greatest for the crust, moderate for the crumb, and the lowest for the stuffing. This may be due to the fact that the vapor that was generated in the crumb and stuffing could not easily escape outward. The crust had a moisture content of about 26-27% after vacuum application at PRR's of 103 Pa s^{-1} and 197 Pa s^{-1} and was somewhat higher for the 347 Pa s^{-1} rate. It was found that the PRR selected had no statistically-significant influence on the moisture content in the crumb or the stuffing during cooling.

The main differences in the steamed stuffed bun quality attributes among the three PRR's are shown in Table 3. Obviously, the steamed filled bun vacuum-cooled at 103 Pa s^{-1} and 197 Pa s^{-1} achieved higher scores in appearance, elasticity, interior structure, and taste compared to the rate of 347 Pa s^{-1} ($P< 0.05$). From Figure 1 (A-D), it can be seen that the steamed stuffed buns did not present an obvious change in visual appearance before and after vacuum cooling at the rates of 103 Pa s^{-1} and 197 Pa s^{-1}, while the rate of 347 Pa s^{-1} led to visibly local collapse, wrinkle, and crackle of the surface after cooling, as shown by arrows in Figure 1-D. However, there were no significant differences in color and mouth feel among the three rates. Moreover, no significant deviations in all quality parameters were observed between the rates of 103 Pa s^{-1} and 197 Pa s^{-1}. The total scores of buns pre-cooled at 347 Pa s^{-1} were lower than that of the samples at the other two PRR's .

CONCLUSIONS

The results of the present study show that thermal infrared imaging is an attractive alternative when making non-destructive surface temperature real-time detection. Using this method, we found that the average cooling rates of different positions of the crust were different. Vacuum cooling resulted in rapid evaporative cooling of the products and low pressure reduction rate led to less weight loss. There were significant differences in the crust moisture contents among the three PRR's, but not in the crumb or the stuffing. The cooling curves, cooling time, distributions and variations of temperatures were dependent on the rates of pressure reduction. Overall, higher PRR had a negative effect on the quality scores of the steamed stuffed buns, although it could shorten the cooling time. Therefore, a full investigating of the influences of vacuum cooling parameters on the quality attributes of the steamed stuffed buns should help food scientists to further design and optimize cooling processes as well as vacuum cooling system suitable for the steamed stuffed buns

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اثر تغییر سرعت کاهش فشار بر کیفیت نوعی نان میان پر بخار داده شده

ی. دنگ، ژ. سونگ، و ی. لی

چکیده

اثر تغییرسه سرعت کاهش فشار (۱۰۳،۱۹۷ و ۳۴۷ پاسکال بر ثانیه) بر توزیع و اختلاف دما، مقدار رطوبت و کیفیت حسی نان میان‌پر بعد از سرد کردن با روش استفاده از خلاء بررسی شد. توزیع و تفاوت دمای سطح نان با استفاده از روش تصویری اشعه مادون قرمز اندازه گیری شد. پروفیل دمای سطح نان نشان داد که اختلاف معنی‌داری در معدل سرعت سرد شدن قسمتهای مختلف نان وجود دارد. این اختلاف بستگی به سرعت کاهش فشار دارد. نتایج نشان داد که بیشترین کاهش جرم نان که برابر ۸/۱ درصد و کمترین زمان سرد شدن که برابر ۲۸۸ ثانیه بود در سریعترین حالت کاهش فشار ۳۴۷ پاسکال بر ثانیه اتفاق افتاده است. کمترین کاهش جرم که برابر ۵/۹۶ درصد و بیشترین زمان سرد شدن که ۹۵۵ ثانیه بود در حالت کاهش فشار با کمترین سرعت یعنی ۱۰۳ پاسکال بر ثانیه به وجود آمد. تغییر سرعت کاهش فشار، اثر خیلی کمی بر رطوبت مغز نان و مواد پر شده داخل نان داشت. امتیاز ارزیابی حسی نان خنک شده با روش خلاء برای سرعت کاهش فشار ۱۰۳و ۱۹۷ پاسکال بر ثانیه بیشتر از حالت سرعت ۳۴۷ پاسکال بر ثانیه بود.

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