Alternative processing strategies to reduce the weight loss of cooked chicken breast fillets subjected to vacuum cooling

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A R T I C L E   I N F O

Article history:
Received 29 August 2013
Received in revised form 28 November 2013
Accepted 6 December 2013
Available online 12 December 2013

Keywords:
Cooling
Chicken breast
Immersion vacuum cooling
Vacuum impregnation

A B S T R A C T

In this paper, two processing strategies were evaluated aiming to reduce/compensate the weight loss of chicken breast fillets subjected to cooking and vacuum cooling: immersion cooling followed by pulsed immersed vacuum cooling (ICk-PIVC); and a new approach that incorporates a vacuum impregnation stage to the immersion cooking followed by vacuum cooling (ICk-VC-VI). Both strategies were compared to processes of cooking followed by vacuum cooling (ICk-VC), and cooking followed by cold-chamber cooling (ICk-CC). The ICk-PIVC led to smaller global weight loss and cooling time (22.9%, 61 min) as compared with the ICk-CC (25.3%, 82 min) and to a cooling weight loss 76% lower than that observed to ICk-VC at the cost of a cooling time 54% larger. In contrast, the ICk-VC-VI permitted to obtain products with global weight loss (25.4%) and mechanical properties that are similar to those of fillets subjected to ICk-CC, while avoiding the larger cooling times of the ICk-PIVC.

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1. Introduction

The growing demand for convenience foods that require minimal preparation efforts have been pushing the development of a wide range of products with high added value, such as ready-to-eat meals. Many of these products have cooked chicken breast cuts as the main ingredient. Such kind of ingredient requires a proper handling and a fast cooling after cooking, aiming to ensure its microbiological quality. As a consequence, increasingly strict guidelines have been adopted in different countries regarding the cooling time of meat cuts after a cooking process (McDonald and Sun, 2000; Zheng and Sun, 2004; Drummond et al., 2009). For instance, the Food Safety and Inspection Service (FSIS) of the United States Department of Agriculture (USDA) recommends that the time for cooling non-cured meat products from 54.4 to 26.6 °C (internal temperature) must be at most 1.5 h, whereas such products must reach 4 °C in 5 additional hours (USDA, 1999). Moreover, the Irish government guidelines recommend that pieces of meat should be cooled from 74 to 10 °C within 2.5 h after the cooking process (Sun and Wang, 2000). In this context, the development of new operational strategies aiming to reduce both the cooling time and the handling of meat products are of great importance for the meat industry.

A technique that has been considered successfully for the cooling of different meat products is the vacuum cooling (VC). As shown by several authors (Desmond et al., 2000; McDonald et al., 2000; Zhang et al., 2013), such a technique can be used to obtain faster cooling rates than those obtained using conventional cooling methods such as slow air cooling, air blast cooling, and water immersion cooling. Moreover, as shown by Schmidt et al. (2010), the vacuum cooling can be integrated with the cooking process in a single equipment, allowing to reduce the product manipulation and thus the risk of microbiological contamination. On the other hand, since the vacuum cooling is based on evaporating the water from the product under low pressure levels, an excessive weight loss (water loss) is often obtained, which represents a significant problem for the application of this type of technique in the industry. To cope with such a problem, a considerable research effort has been carried out aiming to reduce the weight loss obtained during the vacuum cooling and thus avoid compromising the sensorial quality of the product. Some studies have shown that a reduction on the pressure drop rate during the vacuum cooling may produce a slight diminution of the product weight loss (McDonald and Sun 2001b; Huber and Laurindo, 2005). However, a direct relationship between the pressure drop rate and the weight loss is not well described in the literature and was also not verified in the studies conducted by Sun and Wang (2003). In the last decade, many studies have shown that the vacuum cooling of cooked meat cuts and cooked meat products immersed in soups or in the cooking solution (immersion vacuum cooling – IVC) may significantly reduce the weight loss and thus avoid both yield losses and the other undesirable effects on the product quality (Houska et al., 2003; Cheng and Sun 2006a,

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2. Materials and methods

2.1. Sample preparation

Fillets of chicken breast (from a single company) purchased in a local supermarket (Florianópolis, Brazil) were used in the experiments. The pH of the fillets was measured at three different points using a pH probe and only fillets with pH between 5.80 and 6.10 and with weights ranging from 240 to 270 g were used. The initial moisture of the samples was determined by the gravimetric method (AOAC, 2000). In each experiment, 4 fillets (halves of chicken breasts) were used with total mass of approximately 1 kg.

2.2. Experimental device for cooking, vacuum cooling and vacuum impregnation

The experimental device used in the experiments consists of an adapted autoclave connected to a vacuum pumping system with a vapor condenser, as presented by Schmidt et al. (2010). This experimental device, illustrated in Fig. 1, allows the integration of the cooking, vacuum cooling and vacuum impregnation processes, avoiding an excessive product manipulation. For evacuating the air in the cooking–cooling vessel from atmospheric pressure to the given vacuum pressure, a vacuum pump with pumping rate of 350 m³ h⁻¹ was used (DVP, model LC305, Italy). The lowest vacuum pressure achieved in the chamber was approximately 9 mbar. The temperature was monitored using T-type thermocouples (IOPE, model TX-TF-TF-R-30AWG, Brazil) connected to a data acquisition system (Agilent, model 34970A, Malaysia). The vapor condenser consists of a hermetically closed vessel which contains a serpentine fed by cold water (at 1 °C) from a thermostatic bath (Microquímica, model MQBMP-01, Brazil). The pressure acquisition in the cooking–cooling vessel was performed using a pressure sensor (Freescale, model MPX2102, USA).

2.3. Cooking, cooling and vacuum impregnation procedures

As mentioned in Section 1, this work was dedicated to the evaluation of two alternative processes (ICK-PIVC and ICK-VC-VI) for reducing or compensating the cooling weight loss of cooked chicken breast fillets. Such processes are compared with three other processes, namely ICK-IVC, ICK-VC, and ICK-CC. All the considered processes were evaluated in triplicate.

For monitoring the temperature of the samples, thermocouples were inserted in the middle of two different sections of the chicken breast fillets (sections with greatest and smallest thickness). The temperatures of the cooking water, the air-vapor mixture in the vacuum chamber, and the air in the cold chamber used for the conventional cooling were also monitored. Temperature measurements were recorded at intervals of 1 s.

The cooking stage was performed in the device illustrated in Fig. 1 for all the evaluated processes. The samples were put over a grille suspended using rubber supports inside a stainless-steel perforated basket. In a first step, the basket along with the samples were weighted and then immersed in the cooking water (preheated to 100 °C) inside the chamber. The cooking was performed in atmospheric pressure until the temperature of the samples in the middle of the section with greater thickness (Tc) reached a value of 80 °C ± 2 °C.

For the immersion vacuum cooling stages (PIVC and IVC), before closing the chamber and starting up the vacuum pump, the basket with cooked samples was quickly weighted outside the chamber. During the immersion vacuum cooling, the samples remained submerged in a volume of liquid that was sufficient to cover them (approximately 1 L). In the PIVC stage, three cycles of pressure...
variation were applied after the moment in which the immersion liquid reached a temperature of 15 °C, with an interval of 10 min between each of the cycles (each cycle corresponds to reestablishing atmospheric pressure followed by other vacuum pulse).

For the standard vacuum cooling stages involved in the ICk-VC and ICk-VC-VI processes, before starting the vacuum pump (to begin the cooling stage), the water used for the cooking was drained and the basket with samples were quickly weighted outside the chamber.

For the ICk-CC process, after the cooking stage, the basket containing the samples were quickly weighted and transferred to the cold chamber (350 L). The chamber was equipped with two fans positioned in order to promote a uniform temperature distribution. The operating conditions during the CC stage were: temperature of 4 °C ± 1 °C; mean air speed of 2 ± 0.2 m s⁻¹ near the fans and of 0.5 ± 0.2 m s⁻¹ near the samples; and relative air humidity superior to 85%. The air speed was determined using an anemometer (Testo, model 425, Germany) and the relative moisture, using a hygrometer (Testo, model 610, Germany).

The cooling was performed until the temperature of all the samples reached a value of approximately 10 °C in the middle of the thickest section for all the evaluated processes – T1 (which corresponds to the saturation temperature of the water on the minimal pressure attained in the chamber during the vacuum cooling (9 mbar), determined by Antoine's Equation). After the cooling, the samples were weighted and subjected to the analyses described in Section 2.4.

For the vacuum impregnation (VI) stage of the ICk-VC-VI process, after the cooling stage, the basket containing the samples was quickly weighted and transferred to the cold chamber. Cooling weight loss (Ck), impregnation weight gain (Dc), and impregnation weight loss (AIC) were determined according to Eqs. (1)–(4), respectively.

\[
\Delta m_{c_1} = \frac{m_o - m_{c_1}}{m_o} \times 100
\]

\[
\Delta m_{c} = \frac{m_{c} - m_c}{m_c} \times 100
\]

\[
\Delta m_{t} = \frac{m_t - m_c}{m_c} \times 100
\]

\[
\Delta m_{c_{ir}} = \frac{m_o - m_{c_{ir}}}{m_o} \times 100
\]

where \(m_o\) is the initial mass of the samples, \(m_{c_1}\) is the mass of the sample after the cooling stage, \(m_c\) is the mass of the samples after the cooling stages, and \(m_t\) is the mass of the samples after the impregnation. All parameters are expressed as means of the values obtained for three repetitions of each process.

Aiming to visualize and qualitatively evaluate the impregnation in the pores of the cooked and vacuum cooled chicken breast fillets, a methylene blue solution (0.1% w/w) was used as impregnating fluid in the previously described VI and AI experiments. Then, the samples were sectioned and photographed to observe the solution infiltration.

2.4. Process parameters and analytical determinations

The cooking weight loss (\(\Delta m_{c_1}\)), cooling weight loss (\(\Delta m_c\)), impregnation weight gain (\(\Delta m_c\), for the VI an AI stages), and global weight loss (\(\Delta m_{c_{ir}}\)) were determined according to Eqs. (1)–(4), respectively.

\[
\Delta m_{c_1} = \frac{m_o - m_{c_1}}{m_o} \times 100
\]

\[
\Delta m_{c} = \frac{m_{c} - m_c}{m_c} \times 100
\]

\[
\Delta m_{t} = \frac{m_t - m_c}{m_c} \times 100
\]

\[
\Delta m_{c_{ir}} = \frac{m_o - m_{c_{ir}}}{m_o} \times 100
\]
in 50 mL polypropylene tubes (containing absorbent cotton wool) at 5697 g for 10 min at 20 °C (Sigma Centrifuge, model 4k15, Germany). The samples were weighted before and after the centrifugation and the WHC was calculated according to Eq. (5) (ratio between the water mass retained by the sample after the centrifugation and the mass of the dried sample). The mean of eight values measured for each process was considered for statistical analysis.

\[
\text{WHC} = \frac{(m_b - x_w)}{m_b - (1 - x_w)}
\]

where \(m_b\) and \(x_w\) are the mass of the samples before and after the centrifugation, respectively, and \(x_w\) is the moisture content.

2.5. Mechanical properties

The force required to cut a piece of the cooked–cooled sample or of the cooked–cooled–impregnated sample was determined using a Warner–Bratzler shear (WB) attachment on a texture analyzer (Stable Micro Systems, model TAXT2, UK). Strips of 13 mm × 15 mm × 30 mm were obtained from the center of each sample and maintained at 5 °C until testing. The WB shear force was measured perpendicularly to the orientation of the muscle fibers and using a shear speed of 5 mm s\(^{-1}\). The texture profile analysis (TPA) of the samples was also performed using the texture analyzer. Cubes of 25 mm × 20 mm, obtained from the center of each chicken breast fillet (thicker section), were compressed twice with a 50% compression ratio using a 50 mm circular flat probe with a crosshead speed of 1 mm s\(^{-1}\). From the analysis of the curves of force versus time provided by the equipment, it was possible to determine the following parameters: hardness (H), cohesiveness (C), springiness (S), gumminess (G), and chewiness (Ch). For the WB and TPA analyses, the mean of eight measured values was considered for each evaluated process.

2.6. Statistical analysis

The results were evaluated by one-way ANOVA at the 95% probability level. In the case of significant effects (\(p < 0.05\)), the means were compared using the Tukey’s test.

3. Results and discussion

3.1. Temperature profiles of cooked chicken breast fillets subjected to different cooling methods

The temperature profiles measured in the middle of the thicker section of the samples during the cooling stage of the ICK-PIVC, ICK-VC-VI, ICK-IVC, ICK-VC and ICK-CC processes as well as the pressure profile in the vacuum chamber are presented in Fig. 2. Such a stage begins with the start of the vacuum pump and the consequent reduction of the chamber pressure in the case of the PIVC, VC, and IVC. On the other hand, the CC stage begins in the moment in which the samples are put inside the cold chamber.

From the results shown in Fig. 2a, a significant difference was observed between the cooling rates of the samples subjected to VC and those observed for the samples subjected to CC. In the considered experimental conditions, the time for cooling 1 kg of chicken breast fillets from 80 °C to 10 °C (in the middle of the thicker section of the samples) was approximately 3 times smaller using the VC method (28 min) as compared to the CC (82 min). Such a difference is, in essence, caused by the different mechanisms of heat transfer involved in each method. In the case of the CC, the cooling is obtained basically due to the heat transfer by convection between the sample surface and the cold air, and then by conduction between the sample core and its surface. On the other hand, the vacuum cooling occurs due to the evaporation of the free water of the product, leading to the removal of a great amount of latent heat instantaneously (Sun and Wang, 2000). Since the pressure is homogeneous throughout the chamber and the evaporation takes place in both, surface and pores of the samples, a uniform cooling is obtained. This characteristic was attested through the similarity between the temperature profiles in two different sections of the samples (in the middle of both the thicker and thinner sections) (results not shown). Similar results were reported by Schmidt et al. (2010).

Regarding the immersion vacuum cooling methods (PIVC and IVC), the cooling rates of the samples subjected to these methods were similar (Fig. 2a). Moreover, one can note that the time for cooling the samples using either the PIVC or the IVC methods (about 61 min) was smaller than that obtained using the conventional cold chamber cooling (CC, 82 min). This attests the effectiveness of the evaporative cooling under low pressures as compared with the conductive and convective heat transfer involved in the CC.
One can also note that the time for cooling the samples until 10 °C using the PIVC and IVVC methods was approximately 2 times larger than the cooling time obtained using the VC. The smaller cooling rate of the PIVC and IVVC is due to a lower evacuation rate in the chamber (see Fig. 2b), which is a consequence of the larger amount of vapor to be withdrawn. Schmidt et al. (2010) observed a cooling time 3.5 times larger for the IVVC in comparison with the VC by using an experimental setup with a larger relationship between the amount of cooking water and amount of product VC by using an experimental setup with a larger relationship between the amount of cooking water and amount of product.

With respect to the cooling weight loss, the samples subjected to the immersion vacuum cooling with pressure variation cycles (PIVC stage) presented significantly smaller values (2.8%, p < 0.05) as compared with the values observed for the immersion vacuum cooling (IVVC, 4.8%). The abrupt pressure changes during the PIVC (from 9 mbar to 1013 mbar, and then back to 9 mbar in a few seconds – Fig. 2b) may have generated an additional increase in the spaces between the muscle fibers and between the fiber bundles due to the expansion of the gas inside the sample pores during the reduction of pressure in each cycle (Fito et al., 1996; Laurindo et al., 2007). Consequently, it became possible to impregnate a larger amount of cooking solution in the porous structure of the muscular tissue throughout the process. Similar results were observed by Cheng and Sun (2006b) in the study of the vacuum cooling of pork ham immersed in the cooking solution. For the ham samples subjected to the pulsed immersion vacuum cooling with 3–7 cycles of pressure variation, the authors observed values of cooling weight loss that are statistically similar (between 4.9% and 5.3%, with p > 0.05), whereas the weight loss were significantly larger (p < 0.05) for the samples subjected to the immersion vacuum cooling (7.0%). Moreover, the authors also concluded that there is a limit to the reduction of weight loss with the increase of the number of pressure variation cycles, which is due to the limitation of the volume expansion of the samples. In addition, one can note, from Table 1, that the samples subjected to the methods of vacuum cooling with the product immersed in the cooking water (PIVC and IVVC) also presented significantly smaller values of weight loss (p < 0.05) than the samples subjected to the conventional method of cold chamber cooling (6.8%).

Regarding the final moisture content of the samples, a significant difference was not observed between the values obtained using the ICK-PIVC and ICK-IVVC processes, despite the smaller cooling weight loss observed during the PIVC stage (see Table 1). This can be related to the variability of the weight loss during the cooking (due to factors that are inherent to the raw material and experimental factors as, for instance, the position of the thermocouple in the sample). In fact, the mean value of cooking weight loss for the ICK-PIVC process was larger than that for the ICK-IVVC process, despite the fact that this difference was not statistically significant (p > 0.05). On the other hand, the final moisture content for the samples subjected to the ICK-PIVC and ICK-IVVC were significantly larger (between 70.3 and 70.6 g of water/100 g of sample) than those observed in the samples subjected to the ICK-VC (67.7 g/100 g) and the ICK-CC (68.5 g/100 g) processes.

Regarding the ICK-VC-VI integrated process, the weight gains for the samples subjected to the VI were statistically similar (p > 0.05) to all the sub-atmospheric pressures considered (weight gain between 5.1% and 5.4% with respect to the weight of the cooked and vacuum cooled samples). In contrast, the values of weight gain for the samples submersed under atmospheric pressure (AI) were approximately 60% smaller than the values observed for the VI stage. In the case of the impregnation under atmospheric pressure, the solution uptake by the samples is mainly due to the relative contributions of the capillarity and attraction forces (water–protein interaction, for instance). In the vacuum impregnation process, additionally to the aforementioned contributions, the weight gain of the samples is intensified by the liquid infiltration in the pores of the muscular tissue due to the macroscopic pressure gradients imposed to the system (application of vacuum followed by reestablishing the atmospheric pressure). Thus, the vacuum

![Fig. 3. Samples of cooked–cooled chicken breast fillets subjected to impregnation with methylene blue solution using: (a) vacuum impregnation (VI); and (b) impregnation at atmospheric pressure (AI).](Image 344x73 to 483x219)
application during the impregnation along with the increased porosity of meat cuts previously subjected to vacuum cooling (McDonald and Sun, 2001a) may improve the impregnation of either a solute dispersed in water (NaCl or liquid smoke, for instance) or a soup on the porous structure of the product. The impregnation phenomenon is illustrated by Fig. 3, in which pictures of samples subjected to the ICK-VC-VI and ICK-VC-AI processes using a methylene blue solution as the impregnating fluid are presented. From this figure, one can clearly notice the greater solution infiltration (evidenced by the dyed solution) in the sample subjected to the VI stage in comparison with that subjected to the AI. As a consequence, in addition to the greater global mass transfer provided by the VI due to the hydrodynamic mechanism, the diffusive mechanism that takes place afterwards has a much larger surface for the mass transfer (since it actuates on both the internal surface of the impregnated pores and the external surface of the product). Moreover, one can observe, in Table 1, that the values of global weight loss for the samples subjected to the ICK-VC-VI process (between 25.2% and 25.5%) were similar to those observed for the samples subjected to the conventional ICK-CC process (25.3%) and approximately 12% smaller than the values observed for samples subjected to the ICK-VC process (due to the solution impregnation observed at the end of the IV stage of the ICK-VC-VI process). On the other hand, the samples subjected to the process with an additional stage of vacuum impregnation presented values of global weight loss that are greater than those of the samples subjected to the ICK-PIVC process (22.9%) and to the ICK-VC one (22.6%). However, it is important to highlight that (i) the time for cooling chicken breast fillets from 80 to 10 °C in the vacuum cooling stage of the ICK-VC-VI process was 2 times smaller than the cooling time obtained using the immersion vacuum cooling, and also that (ii) the total processing time was 25% smaller.

Regarding the WHC, important differences were not observed between the processes evaluated in this study.

3.3. Influence of the different processes considered on the mechanical properties and physical–chemical properties of chicken breast fillets

The values of the mechanical properties of the chicken breast fillets subjected to the different processes evaluated in this work are shown in Table 2. With respect to the effect of the PIVC stage on the mechanical properties of the chicken breast fillets, significant differences were not observed (p > 0.05) between the samples subject to such a method and those subject to the IVC method (without vacuum pulses). On the other hand, the samples subjected to the ICK-PIVC and ICK-VC presented significantly smaller values (p < 0.05) of hardness, cohesiveness, gumminess, chewiness, and WB shear force in comparison with the samples subjected to the ICK-V. Moreover, with the exception of the cohesiveness and springiness parameters, all other mechanical parameters were significantly smaller (p < 0.05) for the samples subjected to both the ICK-PIVC and ICK-VC as compared to the conventional process (ICK-CC). In general, the smaller values of hardness and WB shear force obtained by the ICK-PIVC and ICK-VC in comparison with the ICK-VC and ICK-CC may be attributed to the greater moisture content (see Table 1). In addition, the modifications in the structure of the samples during the vacuum cooling, caused by the expansion of the gas and the vapor generated in the vacuum stage as well as by the compression of the gas and the liquid penetration when restoring the atmospheric pressure, may have contributed positively to the tenderization of the meat.

Regarding the effect of the vacuum impregnation stage on the mechanical properties of the chicken breast fillets previously subjected to cooking and vacuum cooling (ICK-VC-VI), one can note, from Table 2, that the samples presented smaller values of hardness, cohesiveness, gumminess, chewiness, and WB shear force as compared with the samples subjected to the ICK-VC. As previously mentioned, this is related with the higher moisture content of the samples subjected to the impregnation stage (see Table 1). Moreover, the mechanical properties of the fillets subjected to the ICK-VC-VI were similar to those observed in the samples subjected to the conventional ICK-CC, except for the hardness property, which was statistically smaller for the samples subjected to the ICK-VC-VI. This difference may be associated with a tenderization effect occurring in the samples subject to repetitive pressure variations.

4. Concluding remarks

In this paper, two processing strategies were evaluated aiming to reduce or compensate the weight loss of cooked chicken breast cuts subjected to vacuum cooling. The first one is based on the use pulsed immersion vacuum cooling (PIVC). As shown by the experimental results, the PIVC can significantly reduce the cooling weight loss as compared to the standard vacuum cooling or immersion vacuum cooling (without pulses). Moreover, the PIVC stage also allows to obtain cooling rates that are superior to those obtained using the conventional cold chamber cooling along with smaller water losses. The second processing strategy proposed in this paper, the ICK-VC-VI one, is based on the use of the vacuum impregnation technique integrated with the cooking and vacuum cooling. Such a strategy is also very interesting, since it permits to reduce the global weight loss during the processing of chicken breast cuts without presenting the extended cooling time of the immersion vacuum cooling. In addition, through the vacuum impregnation of aqueous solutions, it becomes possible to obtain cooked and vacuum cooled chicken breast fillets with moisture content and mechanical properties that are similar to those of fillets subjected to the conventional processes of immersion cooling followed by cold chamber cooling. In this context, one observes that, in applications where the processing time is critical, the use of the ICK-VC-VI is advised. In contrast, when smaller weight losses

### Table 2

Influence of the ICK-PIVC, ICK-VC, ICK-VC, and ICK-VC-VI integrated processes as well as of the conventional ICK-CC process on the mechanical properties of chicken breast fillets.

<table>
<thead>
<tr>
<th>Process</th>
<th>H (N) (n = 8)</th>
<th>Co (n = 8)</th>
<th>S (n = 8)</th>
<th>G (N) (n = 8)</th>
<th>Ch (N) (n = 8)</th>
<th>WB shear force (N) (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICK-PIVC</td>
<td>87.4 ± 4.3</td>
<td>0.34 ± 0.01</td>
<td>0.63 ± 0.03</td>
<td>29.7 ± 1.7</td>
<td>18.8 ± 0.8</td>
<td>26.5 ± 5.2</td>
</tr>
<tr>
<td>ICK-VC</td>
<td>89.9 ± 4.7</td>
<td>0.34 ± 0.02</td>
<td>0.63 ± 0.05</td>
<td>30.3 ± 2.5</td>
<td>18.9 ± 1.4</td>
<td>29.5 ± 4.5</td>
</tr>
<tr>
<td>ICK-CC</td>
<td>102 ± 5</td>
<td>0.34 ± 0.01</td>
<td>0.63 ± 0.04</td>
<td>34.4 ± 2.3</td>
<td>21.6 ± 1.3</td>
<td>32.4 ± 2.3</td>
</tr>
<tr>
<td>ICK-VC-VI (9 mbar)</td>
<td>94.5 ± 1.9</td>
<td>0.37 ± 0.02</td>
<td>0.63 ± 0.01</td>
<td>34.9 ± 2.0</td>
<td>21.8 ± 0.9</td>
<td>31.7 ± 3.1</td>
</tr>
<tr>
<td>ICK-VC-VI (130 mbar)</td>
<td>94.1 ± 2.2</td>
<td>0.37 ± 0.02</td>
<td>0.63 ± 0.02</td>
<td>34.8 ± 1.8</td>
<td>21.6 ± 1.9</td>
<td>32.2 ± 2.9</td>
</tr>
<tr>
<td>ICK-VC-VI (270 mbar)</td>
<td>93.1 ± 3.5</td>
<td>0.36 ± 0.02</td>
<td>0.63 ± 0.04</td>
<td>33.7 ± 1.5</td>
<td>21.4 ± 1.9</td>
<td>31.5 ± 2.6</td>
</tr>
</tbody>
</table>

n = Number of repetitions.

a-d Mean values in the same column with different letters indicate significant difference (p < 0.05). (H) Hardness, (Co) cohesiveness, (S) springiness, (G) gumminess, (Ch) chewiness, (WB shear force) Warner–Bratzler shear force.
are required, the PVC technique should be used. Moreover, it is worth mentioning that the study of vacuum impregnation using solutions with different viscosities (such as sauces) and also of its impact on the microbiological quality of products subjected to a preliminary thermal treatment must be appropriately evaluated aiming to obtain an improved ICk-VC-VI processing strategy.

Acknowledgments

The authors thank to CAPES/Brazil and CNPq/Brazil for financial support.

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