LWT - Food Science and Technology 163 (2022) 113527

Contents lists available at ScienceDirect

LWT

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

Comprehensive analysis of vacuum application in desalting lean white fish to develop a highly acceptable ready-to-use product

Marion Daniela Marchetti [a,b,*], Alejandra Tomac [a,b], María Isabel Yeannes [a,b], Analía Belén Garcia Loredo [a,b]

[a] *Food Quality and Preservation, INCITAA, Faculty of Engineering, National University of Mar del Plata, Mar del Plata, Buenos Aires, Argentina*
[b] *National Scientific and Technical Research Council (CONICET), Argentina*

ARTICLE INFO

Keywords:
Merluccius hubbsi
Desalting
Vacuum pulses
Mass transfer kinetics
Sensory acceptance

ABSTRACT

Changes in consumers' lifestyle, coupled with a trend towards healthier low-sodium food, have led to a decline in salted fish consumption. Today, ready-to-use, high-quality food products are what the consumer demands. We evaluated the use of vacuum during the desalting of heavily salted hake, to develop a ready-to-use product. A partial vacuum pressure of 10,000 Pa was applied for 15 min (DV), and for 5 min followed by 5 min at atmospheric pressure in three pulses (DVP). Both were compared with the treatment at atmospheric pressure (DC). The application of vacuum during desalting hake fillets had significant effects on product yield and salt transfer kinetics. DV was more effective when considering the product yield, while DVP samples reached the lowest NaCl values. Vacuum pulses reduced the desalting time by at least 66%, resulting in lower a_w values that would influence the product's microbiological stability. Vacuum did not modify the product texture significantly, though the effect of DVP was greater compared to DC. The developed desalted product had high sensory acceptability scores when evaluated by the consumer panel. The use of vacuum pulses would be a feasible and economical alternative to reduce desalting processing times of this ready-to-use fish product.

1. Introduction

The Southwestern Atlantic Ocean is an important source of seafood for South American countries, where *Merluccius hubbsi* (argentine hake) is the most important commercial fish species. Seafood contains functional components that are not present in other animal sources. These nutrients are polyunsaturated fatty acids and proteins, vitamins, and minerals with a significant role in the maintenance and promotion of health (Hosomi, Yoshida, & Fukunaga, 2012; Pigott & Tucker, 1990, pp. 176–204).

Salting is a technique for preserving food that causes important sensory changes, leading to a product that is highly appreciated by consumers. Highly salted fish products, such as salted cod *(Gadus morhua)*, present NaCl concentrations as high as 20% w/w, which can affect the product palatability. This is the reason why such products are desalted before consumption. The desalting process is usually carried out in the consumer's kitchen and takes between 24 and 48 h. Changes in consumer's lifestyle have been the main reason for the decreasing consumption of salted fish. Nowadays, ready-to-use, high-quality safe food products are what the consumer demands, and the food industry should meet this need.

Salt concentration in the muscle tissue plays an important role in the solubility of fish proteins. During strong salting, the myofibrillar structure weakens causing effects of aggregation, precipitation and decrease of water holding capacity. In turn, these changes are believed to be accompanied by muscle contraction (i.e. the cross-sectional area of muscle cells is smaller and the inter-cellular space larger than the observed in raw muscle) (Barat, Rodríguez-Barona, Andrés, & Fito, 2003; Marchetti, Gomez, Yeannes, & García Loredo, 2022; Offer, 1988; Stefansson & Hultin, 1994). During rehydration (or desalting), the absorption of water causes the solubility of proteins to increase again and the tissue to expand. However, the alterations in the inter- and intra-cellular matrix and the modification of structural components caused by salting (such as connective tissue collagen), appear to be irreversible (Thorarinsdóttir et al., 2011). Protein rehydration implies loss of firmness (Barat, Rodríguez-Barona, Andrés, & Ibanez, 2004) and

* Corresponding author. Food Quality and Preservation, INCITAA, Faculty of Engineering, National University of Mar del Plata, Juan B. Justo 4302 (7600), Mar del Plata, Buenos Aires. Argentina.
E-mail address: mmarchetti@fi.mdp.edu.ar (M.D. Marchetti).

https://doi.org/10.1016/j.lwt.2022.113527
Received 11 February 2022; Received in revised form 6 April 2022; Accepted 1 May 2022
Available online 7 May 2022

improvement of water holding capacity, contributing to total weight gain (Oliveira, Pedro, Nunes, Costa, & Vaz-Pires, 2012).

On an industrial scale, the desalting process includes some undesirable conditions, such as extended processing times, which can affect the quality of the final product. For this reason, some research has concentrated on new fish desalting methods in order to improve the mass transfer process, like tumbling technology (Bjørkevoll, Olsen, & Olsen, 2004), high pressures (Salvador, Saraiva, Fidalgo, & Delgadillo, 2013) or vacuum pulses (Andrés, Rodríguez-Barona, & Barat, 2005). Desalting under vacuum is hydrodynamic mechanism based on the porosity of food (Fito & Pastor, 1994). Vacuum pulses consist in the application of a partial vacuum pressure that allows the removal of liquid and gases trapped in tissues (Radziejewska-Kubzdela, Biegańska-Marecik, & Kidoń, 2014). During a first stage, vacuum pressure is applied to the matrix immersed in a solution (or water), during a period of time. Gases are released to the exterior of the matrix while pores remain opened and in contact with the solution provoking a deformation-relaxation phenomenon. In a second stage, atmospheric pressure is restored during a certain time period, occurring a pressure gradient that favors the rehydration and filling of the intra-cellular spaces. As it was previously mentioned, these spaces would be enlarged by strong salting.

Vacuum pulses have been applied during osmotic dehydration or vacuum impregnation of fish, such as salmon and cod (Chiralt et al., 2001; Halsebakke, 1996), pirarucu (Galvão Martins, Nunes Chada, & da Silva Pena, 2019), and hake (Tomac, Rodríguez Mallo, Perez, Garcia Loredo, & Yeannes, 2020). In these works, the authors reported that the weight yield of salted fish was higher using the vacuum method. The effect of vacuum on water content was not clear and the mechanism did not influence the color and texture of muscle compared to the traditional method. Yet, studies on desalting combined with vacuum of fish products are still scarce in the international scientific literature. Andrés, Rodríguez-Barona, Barat, and Fito (2001) and Andrés et al. (2005) studied the desalting of cod with vacuum application. They found that the vacuum affected the kinetics and performance of the process during the first hours (Andrés et al., 2005).

Considering the aforementioned, the aim of this work was to evaluate the feasibility of using vacuum pulses during desalting of strongly salted hake, analyzing the mass transfer kinetics and texture evolution, and comparing them with the traditional treatment at atmospheric pressure. Also, we aimed to analyze the sensory acceptability of the desalted ready-to-use product.

2. Materials and methods

2.1. Salting of hake samples

Hake (*M. hubbsi*) specimens were harvested in February 2018, in the Southwestern Atlantic Ocean (41–50° S). Forty-two whole specimens (approximately 70 kg) were obtained from a local market (Mar del Plata, Buenos Aires, Argentina) and stored at 4 ± 1 °C for 1–2 h until the filleting operations. After washing, scaling and gutting, two skinless fillets (pieces 10 cm length and 5 cm width) from each specimen were prepared to perform the salting treatment. The thickness was obtained in the range of 1.0 ± 0.1 cm using a micrometer (Teclock dial, model SM-124, Japan). First, the fresh hake fillets were biochemically characterized according to the methods of The Association of Official Analytical Chemists (AOAC, 1993) (g/g): 0.803 ± 0.005 for water, 0.163 ± 0.008 for protein, 0.022 ± 0.002 for fat, and 0.0105 ± 0.0008 for ashes (Marchetti, Gomez, Yeannes, & García Loredo, 2020).

Hake pieces (72 pieces) were salted at 4 ± 1 °C by immersion into a 26% w/w NaCl saturated solution (coarse salt, CELUSAL, Buenos Aires, Argentina) for 48 h and then these were randomly distributed between three groups for desalting procedures (Marchetti et al., 2020). Additional samples of hake were removed at different salting times (0, 2, 4, 6, 8, 24 and 48 h), superficially dried with absorbent paper and preserved at 4 ± 1 °C for water content and water activity analysis.

2.2. Desalting and rehydration process

The salted hake parallelepipeds (48 h) were used in the desalting process. Three desalting treatments were evaluated: desalting without application of vacuum (DC), desalting with vacuum (DV) and desalting with vacuum pulses (DVP). For the vacuum system, a closed container with a vacuometer was used, connected to a water vapor trap and a vacuum pump with pressure regulator (Model N35-A, Silfab, Argentina) (Tomac et al., 2020). All desalting procedures were carried out by immersing the samples into tap water at 4 ± 1 °C using a 1:10 fish-to-solution ratio (Marchetti, Ameztoy, Yeannes, & García Loredo, 2021). For DV, a partial vacuum pressure of 10,000 Pa was applied during 15 min and then atmospheric pressure was restored for 24 h; for DVP, three pulses with a partial vacuum pressure of 10,000 Pa during 5 min followed by 5 min at atmospheric pressure were applied, then atmospheric pressure was restored for 24 h. The same experimental conditions were used to perform the desalting process at atmospheric pressure (DC) (Andrés et al., 2005; Tomac et al., 2020). Desalted samples were removed at different times (0, 0.5, 2, 6, 10 and 24 h), superficially dried with absorbent paper and preserved at 4 ± 1 °C for further analysis. The whole experience was replicated once.

2.3. Experimental determinations

The weight of samples before (M_0) and at sampling times (Mt) during the desalting process was determined using a balance (Adventurer, Ohaus Corp., USA) with a precision of ±0.0001 g. The total mass change was calculated according to Equation (1):

$$\Delta M_T = \frac{(M_t - M_0)}{M_0} * 100 \quad (1)$$

Water content (x_w) was performed using the AOAC technique (AOAC, 1993). The sodium content was determined using an ion-selective electrode (FC300B model, Hanna instruments Inc., Italy) according to Kindstedt, Mattick, and Kosikowski (1983) procedure. The NaCl content (x_{NaCl}) was estimated using the conversion tables provided by the manufacturer. Water activity (a_w) was measured with an Aqua-Lab CX-2 water activity meter at 20 °C (Decagon Devices Inc., Pullman, WA). Analyses were conducted in triplicate.

From the values of x_w and a_w determined in the aforementioned desalting times, the sorption isotherms (4 ± 1 °C) of salted hake were constructed for the different desalting conditions.

2.4. Texture profile analysis

The Texture Profile Analysis was done with a TMS-Pro texturometer (Food Technology Corporation, Virginia, USA) equipped with a 500 N load cell. A double compression test was performed on hake cylinders (9 mm thick and 16.5 mm diameter) using a cylindrical probe (25 mm) at 70% deformation with a crosshead speed of 0.001 m/s (Marchetti, Gomez, Yeannes, & García Loredo, 2021). Hardness (H), Springiness (S), Cohesiveness (C), Adhesiveness (A), Gumminess (G) and Chewiness (Ch) were obtained from the force vs. time curves, according to the definitions of Bourne (2002, pp. 175-253). The measurements were replicated at least 8 times for each sample and mean values for each parameter were calculated.

2.5. Mathematical modeling

Sorption isotherms of salted hake were fitted with the following two-term model proposed by Peleg (1993) for high water activities (Equation (2)):

$$x_w = A.a_w / (B + a_w) + C.a_w / (D - a_w) \quad (2)$$

where A, B, C and D are constants, x_w is the water content (dry basis, g g_{db}^{-1}) and a_w is the equilibrium water activity. The first term represents sorption with a decreasing rate and the second term with an ever increasing rate.

In addition, in order to study the mass transfer phenomena that take place during the desalting process, the NaCl and water content vs. time curves were fitted using different mathematical models.

Peleg (1988) proposed the following two-parameter equation (Eq. (3)) to describe the mass transfer kinetics that approaches to equilibrium asymptotically:

$$x_t = x_0 \pm t/(k_1 + k_2.t) \quad (3)$$

$$\frac{\partial x_t}{\partial t} = \pm \frac{1}{k_1} \quad (4)$$

$$x_{eq} = x_0 \pm \frac{1}{k_2} \quad (5)$$

where x_t is the NaCl or water content (dry basis, g g_{db}^{-1}) at desalting time t (h) and x_0 is the initial NaCl or water content. The Peleg rate constant k_1 $(h(g/g_{db})^{-1})$ is related to mass transfer rate at the beginning of the process (Eq. (4)) and the capacity constant k_2 $((g/g_{db})^{-1})$ is related to NaCl or water content at $t \rightarrow \infty$ (Eq. (5)).

Zugarramurdi and Lupin (1980) (Z&L) proposed the following mathematical model, with an exponential approach to the equilibrium value of NaCl or water concentrations:

$$x_t = x_0.\left(e^{-k.t}\right) + x_{eq}.\left(1 - e^{-k.t}\right) \quad (6)$$

where x_t, x_0 and x_{eq} are the NaCl or water content (dry basis, g g_{db}^{-1}) at desalting time t (h), t = 0 and at equilibrium, respectively. k $(h(g/g_{db})^{-1})$ is the corresponding specific rate constant.

2.6. Sensory analyses

The product sensory acceptability was determined using a hedonic test. Samples served to consumers consisted of *sous-vide* cooked hake fillets, previously desalted to a final concentration of 5 g NaCl/100 g wet basis. The fillets were placed in low-density polyethylene (LDPE) and polyamide (PA) heat-sealable bags (Cryovac Sealed Air Corporation, Omaha, NE, USA) and were vacuum packed using a packaging machine (Servivac DZ 400, Buenos Aires, Argentina). Afterwards, samples were cooked for 102 min in water at 65 °C (Baldwin, 2012). The raw desalted hake samples had a moisture content of 0.826 ± 0.004 w/w with a salt content of 0.0505 ± 0.0004 w/w; while in the cooked samples these contents were 0.744 ± 0.003 w/w and 0.0624 ± 0.0002 w/w for water and NaCl, respectively.

Sixty unpaid volunteers from Mar del Plata National University, fish consumers, aged between 20 and 65 years old, participated in the sensory acceptability test. The samples were presented at room temperature on a plastic plate, with two cubes of boiled potato as support, per piece of cooked desalted fish. Also, additional samples were placed in closed plastic containers in order to retain the aroma for the specific evaluation of this sensory attribute. Cooked desalted hake was judged for its smell, general appearance, texture (in mouth), taste, and global acceptability. These attributes were selected as the most representative and important for the food industry and consumers (Rodrigues, Ho, López-Caballero, Bandarra, & Nunes, 2005). The score sheet consisted of linear hedonic scales (8 cm) with three anchor points: 0: very unpleasant, 4: neutral and 8: very pleasant. The acceptability limit was set at 4.0. Data obtained from the position in the scales were assigned scores between 0 and 8.

2.7. Statistical analysis

Two-way analysis of variance (ANOVA) was used to test differences in ΔM_T and salt content of hake fillets, according to the factors "desalting treatment" and "time" ($p < 0.05$). If the interaction between factors was significant, individual effects were examined and multiple comparisons were performed using the Tukey test. Two-way multivariate analysis of variance (MANOVA) was used to detect significant differences in mechanical parameters, according to the factors "desalting treatment" and "time" ($p < 0.05$). Hotelling corrected for Bonferroni test was performed when significant differences were found. The fitting of the models was performed by non-linear regression analyses using the software Origin Pro 9.1 (OriginLab, Northampton, MA). The model fit and the performance were evaluated using the adjusted determination coefficient (R^2_{adj}) and the root mean square error (RMSE), respectively (Alzamora, Guerrero, Viollaz, & Welti-Chanes, 2005). An agglomerative hierarchical cluster analysis was carried out using weighted average linkage and Euclidean distance to find whether there was segmentation in the global acceptability of consumers for desalted hake sample without vacuum application (DC) (Vásquez-Mazo, García Loredo, Ferrario, & Guerrero, 2019). Principal component analysis (PCA) was applied to illustrate the association between the clusters obtained for the global acceptability with the scores corresponding to the different evaluated attributes. The cophenetic correlation coefficient (CCC) was used to measure the general goodness of fit. An adequate fit for the cluster is described by a CCC value close to 1 (Vásquez-Mazo et al., 2019).

The analyses were carried out using the software InfoStat 2019 (Universidad Nacional de Córdoba, Argentina InfoStat Group, FCA-UNC, Córdoba, Argentina).

3. Results and discussion

3.1. Total mass changes during desalting

Fig. 1 shows ΔM_T values at different desalting times for all samples. DV samples showed the highest increase in total mass variation for all desalting times, while DC and DVP samples did not show positive mass variations until 2 h of rehydration. The analysis of variance presented significant interaction between "time" and "desalting treatment" ($p < 0.05$). When analyzing the desalting effect, ΔM_T values for DV samples were significantly higher (and positive) than the ones for DC and DVP samples. During the first 2 h, DV samples were significantly different compared to DC and DVP samples. At 4 h of desalting, vacuum treatments (DV and DVP) presented significantly higher mass changes than the control samples; this trend was maintained until 6 h. At longer times (>8 h), significant differences were observed among the samples treated with vacuum. DV significantly exceeded the ΔM_T reached by DVP. When

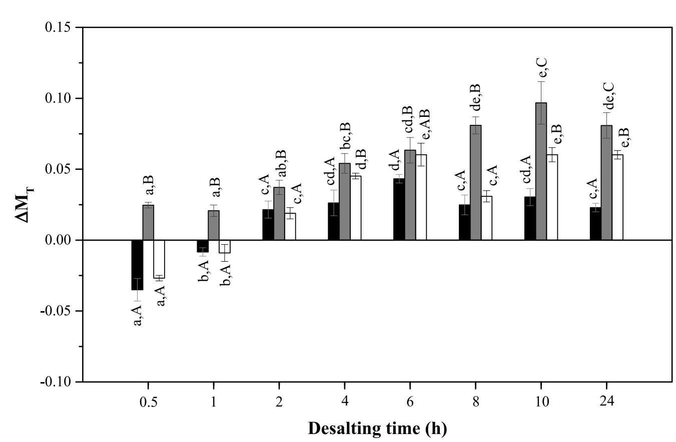

Fig. 1. Total mass change during hake fillet desalting. DC (■), DV (■), and DVP (□). Different capital letters (A, B, C) indicate significant differences in ΔM_T between desalting treatments for a same time. Different letters (a, b, c, d, e) indicate significant differences in ΔM_T for a specific treatment due to desalting time ($p < 0.05$).

analyzing the effect of time on the treatments (desalting), for DC samples, significant differences were found in ΔM_T for 0.5, 1 and 2 h; the highest increase in total mass variation was observed at 6 h. For DV samples, there were no significant variations in ΔM_T during 2 h, and the maximum value was observed at 10 h. The treatment with vacuum pulses presented a similar tendency to the control, with significant variations until 6 h, where ΔM_T was maximum. The final values of ΔM_T (24 h) were 0.023 ± 0.003, 0.081 ± 0.009 and 0.060 ± 0.003 for DC, DV and DVP, respectively.

Desalting under vacuum conditions had a significant positive effect on total mass gain. This would imply a higher yield in desalted hake production comparing with the traditional treatment. The application of a constant vacuum pulse was more advantageous than the application of intermittent vacuum pulses. Similar results to the ones of this work were observed on the desalting kinetics of salted cod using vacuum (15 min at 5,000 Pa) (Andrés et al., 2005). The effect of vacuum depends on extrinsic factors, such as the working pressure and the solution (Betoret et al., 2003; Chiralt et al., 2001; Gomez-Galindo & Yusof, 2015), and intrinsic factors (i.e. tissue characteristics) (Tornberg, 2005). Osmotic vacuum dehydration has been informed to be a more efficient method for treating particularly porous foods, such as fruits and vegetables, than for fish tissue, because of its more compact muscle structure. Due to the size of myofibril capillaries (1–100 nm), the capillary forces are very high and so, high pressures are required to remove water from muscle region (intra-cellular spaces). Inter-cellular space porosity of the muscle is greater (10–100 μm) and the capillary forces are lower, so that the fluid is more easily eliminated (Tornberg, 2005). Therefore, food matrix porosity would also influence the vacuum processing efficiency during the rehydration process.

3.2. Moisture sorption isotherms

The isotherms of salted-desalted hake, with and without the application of vacuum pulses, are shown in Fig. 2. The curves presented the typical shape of food sorption isotherms with high water activity (Peleg, 1993). The working region for salted/desalted fish products is $0.75<a_w<1$, where the control phase is assumed to be the liquid phase constituted by the aqueous solution of soluble solids (Fito, Fito, Betoret, Argüelles, & Chenoll, 2011). During salting and rehydration, a less pronounced slope was observed for the lowest moisture contents and a_w (until $a_w \approx 0.93$), while it was steeper for $0.93<a_w<0.99$, a range at which foods are more susceptible to spoilage reactions. This behavior is in agreement with Rockland (1969) findings. He reported that foods that are rich in fats and proteins present isotherms with soft slopes at low a_w values and abrupt slopes at high a_w values.

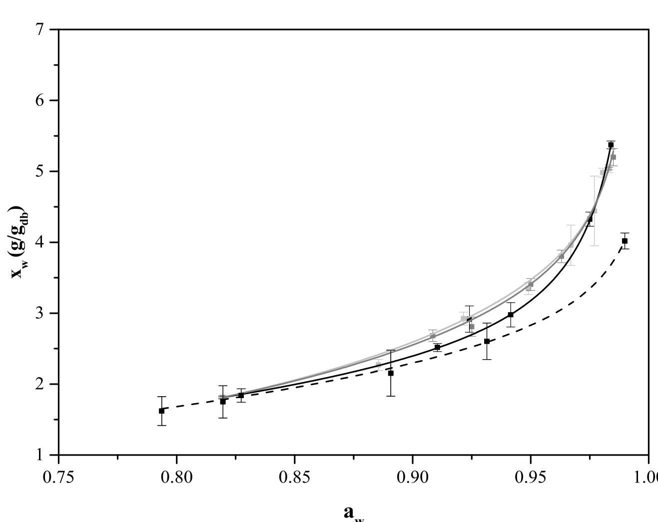

Fig. 2. Isotherms during the salting and desalting processes of hake fillets with different vacuum treatments at 4 ± 1 °C. DC (■), DV (■), and DVP (■). – Peleg (Eq. (2)) fit to experimental results of absorption/desalting and — Peleg fit to experimental results of desorption/salting.

In this work, the isotherms presented hysteresis phenomenon, that is, the dehydration and rehydration of fish muscle did not occur in the same way, even for the curve of samples that were not treated with vacuum (DC). The moisture content during desalting was significantly higher than the one during salting, indicating that the rehydration speed was higher than the dehydration speed (Andrés et al., 2005; Barat et al., 2004). Trying to explain the hysteresis phenomena in multicomponent products, such as salted-desalted fish is extremely difficult (Al-Muhtaseb, McMinn, & Magee, 2004). The different components can adsorb water and also interact between them. The hysteresis in this case could be a consequence of the modifications caused by the diffusion of salt into the muscle, like changes in the protein structure (Marchetti et al., 2022). Analysis of vacuum effect during rehydration showed more pronounced hysteresis in DV and DVP isotherms. DV and DVP showed higher moisture contents than DC samples for a constant a_w value, almost exclusively in the range of 0.85–0.97. Table 1 exhibits the estimated parameters of Peleg model (Eq. (2)) and the adjusted determination coefficient (R^2_{adj}). The proposed model fitted well to the experimental data with high R^2_{adj} values. It is observed that the application of vacuum pulses had no significant effect on the parameters of the first term of the equation (decreasing rate), while the constants of the second term (increasing rate) were mainly affected by the DVP treatment ($p < 0.05$). So, this four-parameter model could be useful to estimate the sorption curves of desalted fish, and also to establish the operational processing conditions taking into account the product a_w.

3.3. Mass transfer kinetics analysis during salted hake desalting process

Fig. 3 shows salt content at different desalting times for all samples. For all desalting times, the lowest and the highest salt contents were found in DVP and DC samples, respectively. The two-ways ANOVA showed significant interaction between the "desalting treatment" and "time" factors ($p < 0.05$). For 0.5 h of desalting, samples DC and DVP were significantly different; DV samples presented intermediate x_{NaCl} values (0.355–0.481 g/g_{db}). For t = 2 h, DV and DVP samples presented similar salt contents (≈0.289 g/g_{db}), which were significantly lower than those of DC samples (0.424 g/g_{db}). For t = 10 h, all samples showed significant differences between them. Analyzing the effect of time on desalting process, DC samples required 2 h of desalting to obtain a significant decrease in the chloride content. Between 6 h and 10 h of desalting, the salt content did not significantly vary; after 24 h, x_{NaCl} was significantly lower. Samples treated with vacuum (DV and DVP) showed a similar behavior in the desalting time. Between 0.5 and 10 h, there were significant differences in salt content. The final values of x_{NaCl} (g/g_{db}) (24 h) were 0.132 ± 0.005, 0.115 ± 0.004 and 0.0727 ± 0.0007 for samples DC, DV and DVP samples, respectively. Significant differences were found in these values between the three applied desalting procedures ($p < 0.05$), where DC yielded the highest values and DVP the lowest.

Table 1
Equilibrium moisture sorption isotherm constants and adjusted determination coefficient values obtained adjusting Eq. (2) to Control (DC) and Vacuum experimental results (DV, DVP) during hake fillets desalting.

	A	B	C	D	R^2_{adj}
DC	−0.056 ± 0.017[a]	−1.002 ± 0.003[a]	1.55 ± 0.48[a]	1.63 ± 0.29[a]	0.999
DV	−0.036 ± 0.014[a]	−1.002 ± 0.003[a]	0.86 ± 0.05[ab]	1.24 ± 0.04[ab]	0.999
DVP	−0.021 ± 0.018[a]	−0.998 ± 0.005[a]	0.78 ± 0.05[b]	1.19 ± 0.04[b]	0.999

Different letters in the same column indicate that there were significant differences ($p < 0.05$).

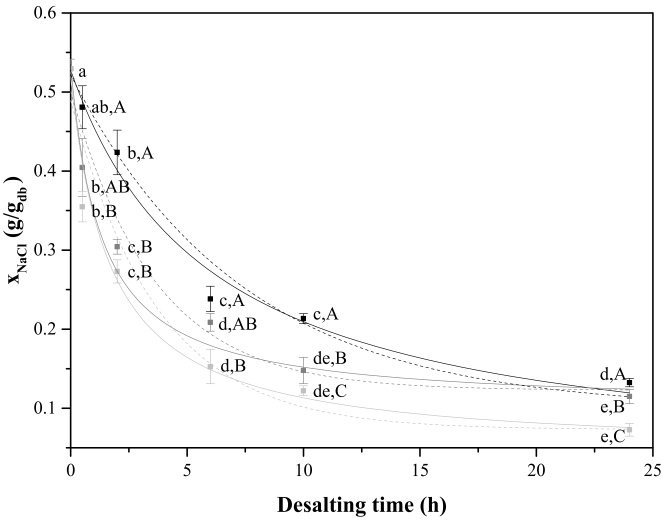

Fig. 3. Sodium chloride weight fraction (dry basis) during hake fillets desalting at 4 °C. DC (■), DV (■), and DVP (■). Different capital letters (A, B, C) indicate significant differences in x_{NaCl} between desalting treatments for a same time. Different letters (a, b, c, d, e) indicate significant differences in x_{NaCl} for a specific treatment due to desalting time ($p < 0.05$). – Peleg (Eq. (3)) fit to experimental results and — Z&L (Eq. (6)) fit to experimental results.

Fig. 3 shows the fitting of the experimental salt content values to the Peleg (Eq. (3)) and Z&L (Eq. (6)) models (water content behavior during desalting is not shown). Table 2 exhibits the estimated parameters of the models for NaCl and water content, the adjusted determination coefficient (R^2_{adj}) and the RMSE. Both models were appropriate for representing the experimental data (i.e. high R^2_{adj} values showed that between 86.3% and 98.1% of the variation could be explained by the selected models). The parameters obtained with the Peleg model for NaCl content showed significant differences for the DC samples compared to the vacuum treatments (DV and DVP), where k_1 and k_2 were similar. The same trend was found for k parameter of the Z&L model, while x_{eq} was significantly different for the three desalting treatments. Meanwhile, there was no significant effect of vacuum pulses on water transfer kinetics (Table 2). Desalted samples using vacuum showed higher mass transfer rates than those reported for control samples. Analyzing the parameters related to the mass transfer rate at the beginning of the process, for vacuum treatments, the Peleg rate constant (k_1) values were the lowest and the Z&L specific rate constant (k) values were the highest. Although these parameters were very similar between DV and DVP samples ($p > 0.05$), DV had the highest initial speed of salt transfer. The higher value of k_1 is related to a lower NaCl initial mass transfer rate (Peleg, 1988), as it was observed in control samples. The equilibrium salt content values predicted by both models were not comparable. Equilibrium values predicted by the Z&L model were similar to the experimental equilibrium values. Several authors reported that the Peleg model tends to overestimate the equilibrium values during osmotic dehydration of fish tissues (Casales & Yeannes, 2016; Czerner & Yeannes, 2010; Marchetti et al., 2020). Vacuum treatments showed considerable effects on mass transfer kinetics during salted hake desalting process. The observed differences when making comparisons using control samples could be explained by the hydrodynamic mechanism promoted by vacuum pulses that favors the diffusion of components into the protein matrix (Fito, 1994). In this particular case, mass transfer fluxes were those of salt from muscle towards the impregnation solution (water) and of water in the opposite way, towards fish tissue.

Considering the theoretical kinetic parameters predicted by Peleg model (this model showed better fit and performance, see Table 2), DC samples would reach 5 g NaCl/100 g (wet basis) in hake muscle (0.26 g/g_{db}) at 6.64 h of rehydration, while DV and DVP samples would reach the same salt content at 2.27 h and 2.02 h, respectively. This would indicate a significant reduction of the desalting time of 66% and 70% with DV and DVP, respectively. This could allow the design of more efficient desalting processes for the industrialization of ready-to-use desalted fish products that contain the nutritional benefits of fish such as high biological value proteins, polyunsaturated fatty acids, minerals and vitamins. In this sense, previous studies on *Merluccius hubbsi* showed that wet salting in a NaCl saturated solution decreased the protein content (0.140 g/g) and increased the fat content (0.051 g/g) compared with fresh hake (values in Section 2.1) (Marchetti, Gomez, Yeannes, & García Loredo, 2021). In addition, the fatty acid profile was modified in the salted product, showing increases in the polyunsaturated fatty acid (PUFA) fraction (43.6%). The fatty acids proportion reported in fresh hake was: 42.7% saturated (SFA), 33.4% monounsaturated (MUFA) and 24.6% PUFA (Marchetti, Yeannes, & García Loredo, 2021). In the desalted product, it was found that the protein and lipid contents slightly decreased (0.116 g/g and 0.0062 g/g, respectively). However, the proportion of PUFA was the highest (48.5%) in relation to salted and fresh hake (Marchetti, Yeannes, & García Loredo, 2021). Therefore, the desalted hake product is a good source of protein and its lipid composition revealed a higher proportion of PUFAs with multiple health benefits. The use of vacuum pulses would contribute to reducing the loss of soluble in salt and water proteins and certain groups of lipids (mainly triacylglycerols) (Juárez et al., 2009; Szymczak, 2011).

For the aforementioned desalting times, the water contents achieved according to the Peleg model (Table 2) were 4.34 g/g_{db}, 3.32 g/g_{db} and 3.44 g/g_{db} for DC, DV and DVP, respectively. These values correspond to a_w values of 0.975, 0.946 and 0.949, respectively (Fig. 3). The application of vacuum pulses made it possible to obtain a product with the same salt content but with a slightly lower water activity, which favors the microbiological stability of the product. It is important to note that a

Table 2
Peleg and Z&L models constants, adjusted determination coefficient and RMSE values obtained for Control (DC) and Vacuum experimental results (DV, DVP) of NaCl and water contents during hake fillets desalting.

	Peleg				Zugarramurdi & Lupín			
				NaCl				
	k_1^{NaCl} ($h(g_{NaCl}/g_{db})^{-1}$)	k_2^{NaCl} ($(g_{NaCl}/g_{db})^{-1}$)	R^2_{adj}	RMSE	x_{eq}^{NaCl} (g_{NaCl}/g_{db})	k^{NaCl} (h^{-1})	R^2_{adj}	RMSE
DC	11.87 ± 2.72[a]	1.95 ± 0.11[a]	0.981	0.018	0.098 ± 0.009[a]	0.136 ± 0.020[a]	0.974	0.023
DV	3.02 ± 0.71[b]	2.31 ± 0.17[b]	0.973	0.021	0.123 ± 0.003[b]	0.278 ± 0.023[b]	0.975	0.037
DVP	3.58 ± 1.06[b]	2.11 ± 0.12a[b]	0.981	0.028	0.073 ± 0.003[c]	0.268 ± 0.069[b]	0.955	0.056
				Water				
	k_1^{w} ($h(g_{water}/g_{db})^{-1}$)	k_2^{w} ($(g_{water}/g_{db})^{-1}$)	R^2_{adj}	RMSE	x_{eq}^{w} (g_{waterl}/g_{db})	k^{w} (h^{-1})	R^2_{adj}	RMSE
DC	1.33 ± 0.39[a]	0.224 ± 0.019[a]	0,950	0.326	5.66 ± 0.20[a]	0.155 ± 0.028[a]	0.957	0.355
DV	1.14 ± 0.55[a]	0.278 ± 0.035[a]	0,876	0.350	5.17 ± 0.28[a]	0.178 ± 0.059[a]	0.863	0.382
DVP	0.68 ± 0.19[a]	0.257 ± 0.018[a]	0,957	0.298	5.22 ± 0.14[a]	0.268 ± 0.048[a]	0.958	0.327

Different letters in the same column indicate that there were significant differences ($p < 0.05$).

5% w/w salt concentration and $a_w \leq 0.96$, along with refrigeration, minimize the growth risk of *Clostridium botulinum* type E, guaranteeing the safety of this product (Fernández-Segovia, Escriche, Fuentes, & Serra, 2007). Marchetti, Yeannes, and García Loredo (2021) reported the absence of pathogenic microorganisms (including Sulphite-reducing *Clostridium*) in the desalted hake product with an a_w value of 0.95. Although these conditions would allow the growth of *Listeria monocytogenes*, the desalted hake developed in this study is a ready-to-use product, so it must be cooked before consumption and consumers would not be directly exposed to the risk of this microorganism.

3.4. Texture profile analysis

Fig. 4 shows the typical double compression curves of desalted hake fillets for the applied rehydration procedures. Regardless of the applied desalting treatment, texture profiles decreased with increasing desalting time, as it was expected. Curves showed a decrease in force and area under the curve of both compressions. The slope of the first seconds of the first compression gradually decreased with the desalting time, consistent with the combined effect of water gain and salt loss salt in the protein matrix (Hatae, Yoshimatsu, & Matsumoto, 1990). Analyzing the effect of the desalting treatment over time, for $t = 0.5$ h, slight differences were observed between DVP profile and DC and DV profiles (Fig. 4a). In general, for $t = 2$, 10 and 24 h, no differences were observed in the texture profiles with and without vacuum. After 24 h of processing, DVP texture profile showed a similar behavior to that reported for fresh hake muscle (Fig. 4d).

The MANOVA analysis of mechanical parameters indicated no significant interaction between “desalting treatment” and “time” ($p > 0.05$). When the factors were independently evaluated, “desalting treatment” did not present significant differences ($p = 0.9752$), while the factor “time” did ($p < 0.0001$). Therefore, variations in the textural parameters were due to desalting time (i.e. water gain and salt loss) and not to the vacuum pulses application. In general, all samples showed a decrease in hardness, springiness, cohesiveness, gumminess and chewiness with increasing rehydration time (Fig. 5). Meanwhile, the adhesiveness increased for $t = 0.5$ and 2 h, and then remained constant until the end of the rehydration process (24 h) (data not shown). These results coincide with Tomac et al. (2020), who reported that the use of vacuum did not influence the brined hake muscle texture in comparison with the traditional method. Also, the observed behavior was mainly related to the variations in salt content rather than to vacuum processing.

3.5. Sensory evaluation of the ready-to-use product

In Table 3 are shown the mean scores for each sensory attribute evaluated by consumers in cooked desalted hake without vacuum application. When applying the cluster analysis to obtain the segmentation of consumer group preferences, three clusters emerged: Cluster 1 (C1), with 75.6% of consumers, encompassing scores of 5.3–8, Cluster 2

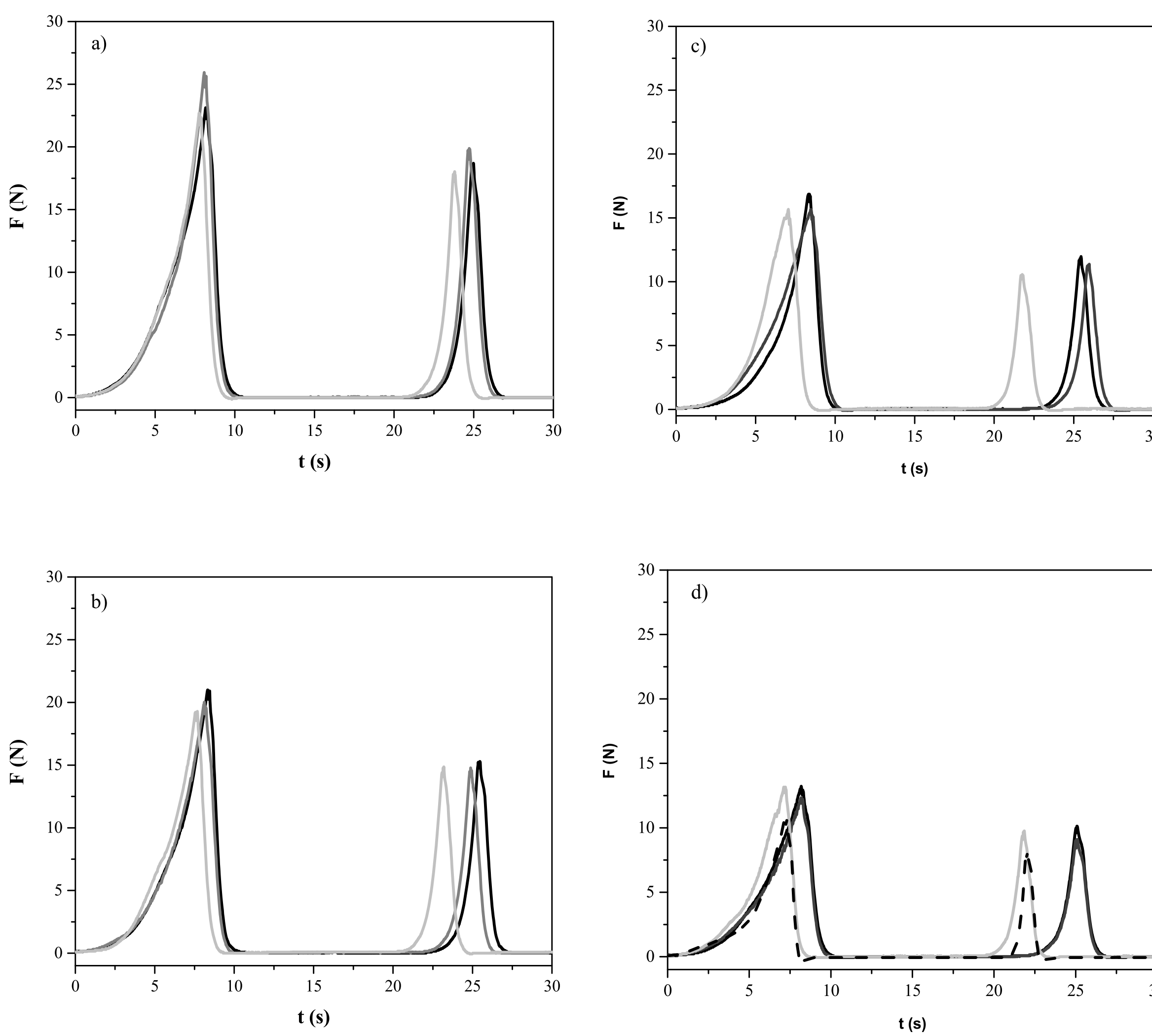

Fig. 4. Typical double compression curves during hake fillet desalting. DC (▬), DV (▬), DVP (▬), and fresh hake (– –), only showed in Fig. d), at 24 h). a) 0.5 h, b) 2 h, c) 10 h, and d) 24 h.

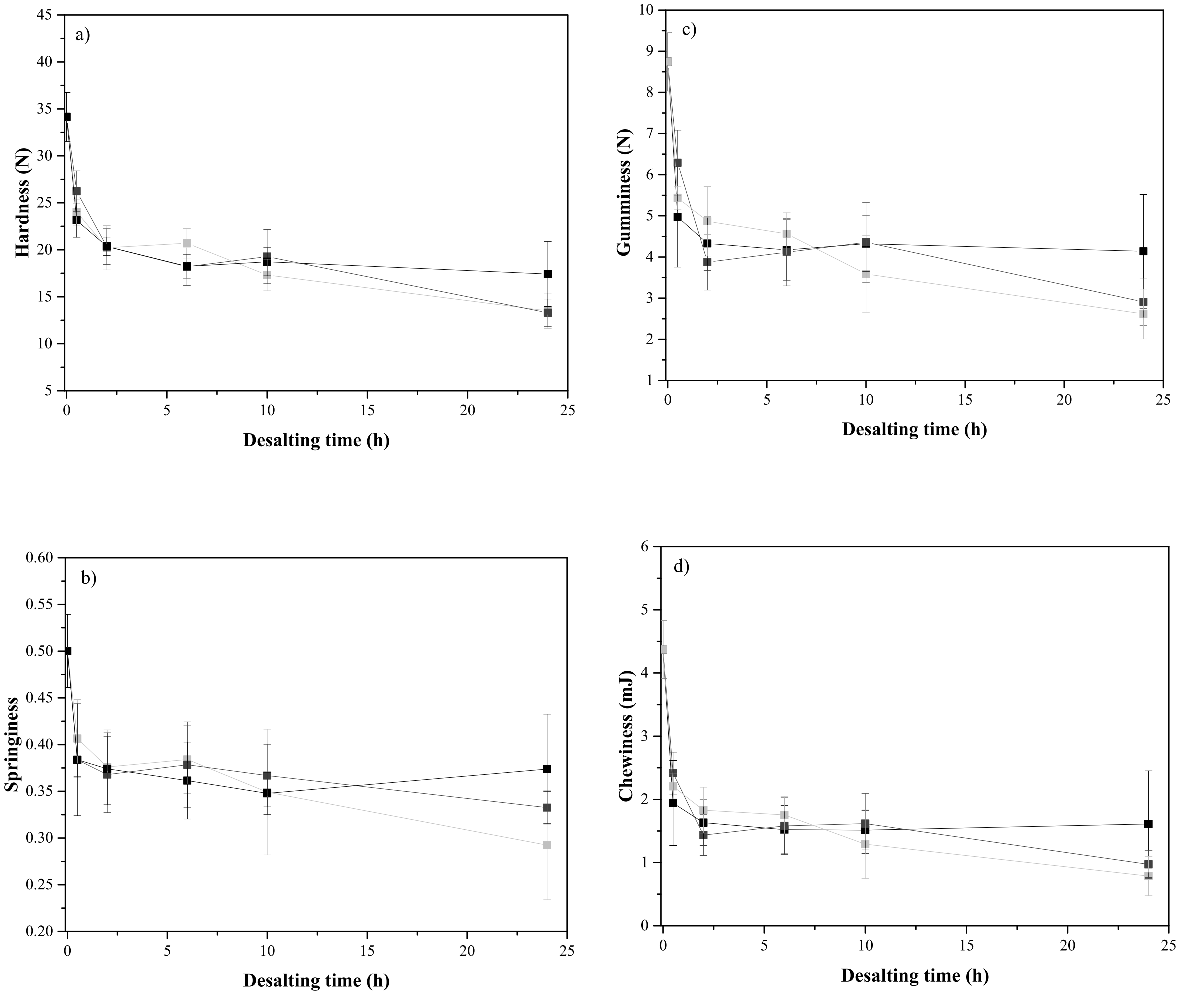

Fig. 5. Mechanical parameters evolution during hake fillet desalting. DC (■), DV (■), and DVP (■). a) Hardness (N), b) Springiness (–), c) Gumminess (N), and d) Chewiness (mJ).

Table 3
Score average and standard deviation for the different attributes evaluated in cooked desalted hake. C1: Cluster 1, C2: Cluster 2, C3: Cluster 3.

Cluster	Smell	General appearance	Texture mouth	Taste	Global acceptability
C1	5.9 ± 2.0^{a}	6.6 ± 1.1^{a}	7.0 ± 1.0^{a}	6.6 ± 1.5^{a}	6.9 ± 0.8^{a}
C2	5.2 ± 1.5^{a}	5.2 ± 1.0^{a}	5.4 ± 1.7^{b}	3.4 ± 2.0^{b}	4.6 ± 0.1^{b}
C3	4.2 ± 2.4^{a}	5.6 ± 1.0^{a}	5.8 ± 1.3^{ab}	1.9 ± 1.3^{b}	3.0 ± 0.3^{c}

Different letters in the same column indicate that there were significant differences ($p < 0.05$).

(C2), with 12.2% of consumers, including scores from 4.5 to 4.8, and Cluster 3 (C3), with 12.2% of consumers, including scores from 2.5 to 3.3. These clusters would correspond to the "pleasant", "neutral" and "unpleasant" categories, respectively. The CCC value obtained was 0.806, indicating that a good fit was achieved by this analysis.

C1 showed a marked interest in the product by consumers, exhibiting an average global acceptability of 6.9 ± 0.8 on the 0 to 8 hedonic scale. They also significantly perceived taste as more pleasant (6.6 ± 1.5) than C2 (3.4 ± 2.0) and C3 (1.9 ± 1.3) ($p < 0.05$) (Table 3). Therefore, the proposed ready-to-use product exhibited a maximal appeal to a group of consumers, in agreement with the segmentation approach, which manufacturers have largely embraced in recent years. This approach takes into account that developing different products for consumer groups showing different tastes will exhibit more acceptability than developing a single product for all users (Lawless, 2013). The two-dimensional representation (PCA bi-plot) is presented in Fig. 6. The first two principal components explained the total of the variance. The PC1 was principally associated to taste and texture (positively). On the other hand, PC2 showed positive association to smell and negative association to general appearance. This analysis showed that C1 (scores from 5.3 to 8) was associated with higher intensity values of pleasant taste and texture than C2 (scores from 4.5 to 4.8) and C3 (scores from 2.5 to 3.3).

Aliño, Fuentes, Fernández-Segovia, and Barat (2011) reported similar results during the sensory analysis of cooked desalted-cod when using the same attributes proposed by Rodrigues et al. (2005). These authors obtained scores higher than 3 on a scale from 1 to 5, for which the samples were considered acceptable. The sensory characteristics of desalted lean white fish were generally described as cured, sweet, marine, buttery and earthy odors and tastes, quite soft, juicy and tender, with a somewhat rubbery and foamy texture (Jónsdóttir et al., 2011). However, it is important to note that this type of product is consumed together with other foods, introducing other flavors, and thus reducing the intensity of the perceived salty taste (Aliño et al., 2011).

4. Conclusions

The application of vacuum pulses during desalting of hake fillets had

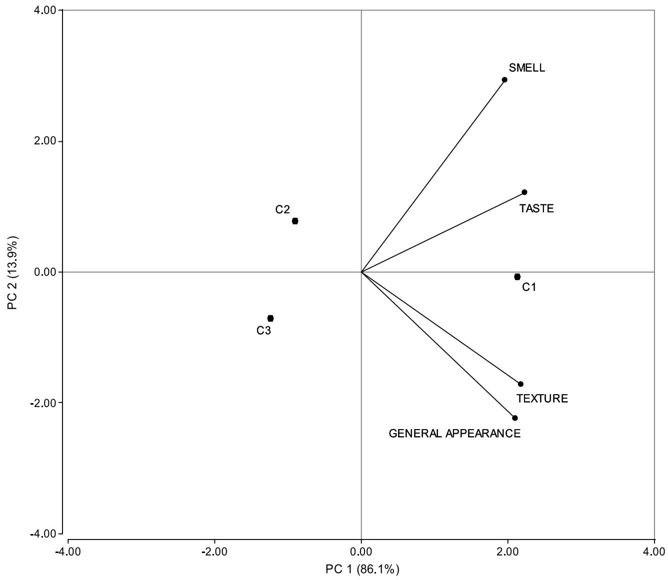

Fig. 6. Principal component analysis (PCA) bi-plot of scores assigned by panelists for global acceptability, and the scores assigned for the others attributes evaluated in the sensory acceptability analysis. C1, C2, and C3, corresponding to Cluster 1, Cluster 2 and Cluster 3, respectively.

significant effects on the product yield, and also on the kinetics of salt transfer. Salt loss was improved by the use of DV and DVP treatments, which resulted in shorter times to reach the desired salt concentration in the final product. The total mass change in the desalting stage was positive and significantly higher in hake fillets treated with vacuum pulses. Moisture sorption isotherms and salt and water contents during desalting were adequately modeled using Peleg and Zugarramurdi & Lupin equations. Vacuum treatments had a significant effect on the constants related to the second term (increasing rate) of isotherms and on the initial mass transfer rate of NaCl. The use of vacuum pulses reduced desalting time by at least 66%, which resulted in lower a_w values in the final product. This could also contribute to reducing the loss of salt- and water-soluble proteins and certain groups of lipids. On the other hand, the use of vacuum pulses did not greatly influence the texture profile of the hake fillets compared to the traditional treatment. The application of vacuum pulses yielded a desalted product with the typical characteristics, such as a softer texture than the salted fish, and comparable to that of fresh hake. Finally, the desalted hake developed in this study had high global acceptability. The Clusters analysis revealed that 75.6% of consumers were very interested in the product, with average global acceptability scores of 6.9 on the 0 to 8 hedonic scale. So, the application of vacuum pulses in the rehydration stage at industrial scale would be a feasible and economical alternative to reduce desalting times of ready-to-use products-to meet increasing consumer demand.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Marion Daniela Marchetti: Methodology, Investigation, Formal analysis, Writing – original draft, Visualization. **Alejandra Tomac:** Methodology, Formal analysis, Writing – original draft. **María Isabel Yeannes:** Conceptualization, Resources, Writing – review & editing. **Analía Belén Garcia Loredo:** Conceptualization, Supervision, Resources, Project administration, Writing – review & editing.

Acknowledgements

This work was supported by grants from the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET-PIP 0437) and the Universidad Nacional de Mar del Plata (ING550/19), Argentina.

References

Al-Muhtaseb, A. H., McMinn, W., & Magee, T. (2004). Water sorption isotherms of starch powders. Part 2: Thermodynamic characteristics. *Journal of Food Engineering, 62*, 135–142. https://doi.org/10.1016/S0260-8774(03)00202-4

Aliño, M., Fuentes, A., Fernández-Segovia, I., & Barat, J. M. (2011). Development of a low-sodium ready-to-eat desalted cod. *Journal of Food Engineering, 107*, 304–310. https://doi.org/10.1016/j.jfoodeng.2011.07.012

Alzamora, S. M., Guerrero, S., Viollaz, P., & Welti-Chanes, J. (2005). Experimental protocols for modeling the response of microbial populations exposed to emerging technologies: Some points of concern. In G. Barbosa-Cánovas (Ed.), *Novel food processing* (pp. 591–607). Marcel Dekker Inc.

Andrés, A., Rodríguez-Barona, S., & Barat, J. M. (2005). Analysis of some cod desalting process variables. *Journal of Food Engineering, 70*, 67–72. https://doi.org/10.1016/j.jfoodeng.2004.09.014

Andrés, A., Rodríguez-Barona, S., Barat, J. M., & Fito, P. (2001). Application of vacuum impregnation technology to salting and desalting of cod (*Gadus morhua*). *Food Preservation Technology Series. Osmotic Dehydration & Vacuum Impregnation, 49*, 185–192 (Lancaster, Pennsylvania: Technomic Publishing Company, Inc).

AOAC. (1993). *Official methods of analysis* (16th ed.). Washington, DC, USA: Association of Official Analytical Chemists.

Baldwin, D. (2012). Sous vide cooking: A review. *International Journal of Gastronomy and Food Sciences, 1*, 15–30. https://doi.org/10.1016/j.ijgfs.2011.11.002

Barat, J. M., Rodríguez-Barona, S., Andrés, A., & Fito, P. (2003). Cod salting manufacturing analysis. *Food Research International, 36*(5), 447–453. https://doi.org/10.1016/S0963-9969(02)00178-3

Barat, J. M., Rodríguez-Barona, S., Andrés, A., & Ibanez, J. B. (2004). Modeling of the cod desalting operation. *Journal of Food Science, 69*(4), 183–189. https://doi.org/10.1111/J.1365-2621.2004.TB06345.X

Betoret, N., Puente, L., Díaz, M., Pagán, M., García, M., & Gras, M. (2003). Development of probiotic-enriched dried fruits by vacuum impregnation. *Journal of Food Engineering, 56*, 273–277. https://doi.org/10.1016/S0260-8774(02)00268-6

Bjørkevoll, I., Olsen, J., & Olsen, R. L. (2004). Rehydration of salt-cured cod using injection and tumbling technologies. *Food Research International, 37*, 925–931. https://doi.org/10.1016/j.foodres.2004.06.002

Bourne, M. C. (2002). *Food texture and viscosity concept and measurement*. New York: Academic Press, An Elsevier Science Imprint.

Casales, M. R., & Yeannes, M. I. (2016). Mass transfer modeling during marination of anchovy fillets in ternary and multicomponent solutions. *Journal of Aquatic Food Product Technology, 25*, 760–769. https://doi.org/10.1080/10498850.2014.924168

Chiralt, A., Fito, P., Barat, J. M., Andrés, A., González-Martínez, C., & Escriche, I. (2001). Use of vacuum impregnation in food salting process. *Journal of Food Engineering, 49* (2–3), 141–151. https://doi.org/10.1016/S0260-8774(00)00219-3

Czerner, M., & Yeannes, M. I. (2010). Brining kinetics of different cuts of anchovy (*Engraulis anchoita*). *International Journal of Food Science and Technology, 45*(10), 2001–2007. https://doi.org/10.1111/j.1365-2621.2010.02361.x

Fernández-Segovia, I., Escriche, I., Fuentes, A., & Serra, J. A. (2007). Microbial and sensory changes during refrigerated storage of desalted cod (*Gadus morhua*) preserved by combined methods. *International Journal of Food Microbiology, 116*(1), 64–72. https://doi.org/10.1016/j.ijfoodmicro.2006.12.026

Fito, P., Fito, P. J., Betoret, N., Argüelles, A., & Chenoll, C. (2011). Thermodynamic approach to equilibrium isotherms in salted structured food. *Journal of Food Process Engineering, 34*, 623–638. https://doi.org/10.1111/j.1745-4530.2009.00406.x

Fito, P., & Pastor, R. (1994). Non diffusional mechanism occurring during vacuum osmotic dehydration. *Journal of Food Engineering, 21*, 513–519. https://doi.org/10.1016/0260-8774(94)90070-1

Galvão Martins, M., Nunes Chada, P. S., & da Silva Pena, R. (2019). Application of pulsed-vacuum on the salt impregnation process of pirarucu fillet. *Food Research International, 120*, 407–414. https://doi.org/10.1016/j.foodres.2019.03.016

Gomez-Galindo, F., & Yusof, N. L. (2015). New insights into the dynamics of vacuum impregnation of plant tissues and its metabolic consequences. *Journal of the Science of Food and Agriculture, 95*, 1127–1130. https://doi.org/10.1002/jsfa.6777

Halsebakke, H. T. (1996). *Vakuumsalting av torsk*. N: M. Science Thesis at the Norwegian College of Fishery Science, University of Tromsø.

Hatae, K., Yoshimatsu, F., & Matsumoto, J. J. (1990). Role of muscle fibers in contributing firmness of cooked fish. *Journal of Food Science, 55*, 693–696. https://doi.org/10.1111/j.1365-2621.1990.tb05208.x

Hosomi, R., Yoshida, M., & Fukunaga, K. (2012). Seafood consumption and components for health. *Global Journal of Health Science, 28*, 72–86. https://doi.org/10.5539/gjhs.v4n3p72

Jónsdóttir, R., Sveinsdottir, K., Magnusson, H., Arason, S., Lauritzsen, K., & Torarinsdottir, K. (2011). Flavor and quality characteristics of salted and desalted cod (*Gadus morhua*) produced by different salting methods. *Journal of Agricultural and Food Chemistry, 59*(8), 3893e3904. https://doi.org/10.1021/jf104203p

Juárez, M., Marco, A., Brunton, N., Lynch, B., Troy, D. J., & Mullen, A. M. (2009). Cooking effect on fatty acid profile of pork breakfast sausages enriched in conjugated linoleic acid by dietary supplementation or direct addition. *Food Chemistry, 117*, 393–397. https://doi.org/10.1016/j.foodchem.2009.04.023

Kindstedt, P. S., Mattick, L. R., & Kosikowski, F. V. (1983). Simple selective sodium ion electrode measure of sodium in cheese. *Journal of Dairy Science, 66*, 988–993. https://doi.org/10.3168/jds.S0022-0302(83)81892-X

Lawless, H. (2013). Segmentation. In H. Lawless (Ed.), *Quantitative sensory analysis. Psychophysics, models and intelligent design*. New York: Oxford: Wiley Blackwell.

Marchetti, M. D., Ameztoy, I., Yeannes, M. I., & García Loredo, A. B. (2021). Physicochemical, microbiological and sensory changes during refrigerated storage of desalted hake (*Merluccius hubbsi*): Shelf life evaluation. In *Proceedings of the IX food congress XXI century: Food, nutrition and health*. Argentina: Chubut.

Marchetti, M. D., Gomez, P. L., Yeannes, M. I., & García Loredo, A. B. (2020). Mathematical modelling of the mass transfer kinetics during salting procedures of hake fillets. *Journal of Food Processing and Preservation, 45*, Article e15002. https://doi.org/10.1111/jfpp.15002

Marchetti, M. D., Gomez, P. L., Yeannes, M. I., & García Loredo, A. B. (2021). Effect of salting procedures on quality of hake (*Merluccius hubbsi*) fillets. *Heliyon, 7*, Article e07703. https://doi.org/10.1016/j.heliyon.2021.e07703

Marchetti, M. D., Gomez, P. L., Yeannes, M. I., & García Loredo, A. B. (2022). Structure of fish proteins as modified by salting procedures: A rheological and ultrastructural analysis of hake (*Merluccius hubbsi*) fillets. *Journal of Food Science*, 1–14. https://doi.org/10.1111/1750-3841.16056, 00.

Marchetti, M. D., Yeannes, M. I., & García Loredo, A. B. (2021). Impact of salting and rehydration on the stability and nutritional quality of hake fillets (*Merluccius hubbsi*). In *Proceedings of the IX food congress XXI century: Food, nutrition and health*. Argentina: Chubut.

Offer, G. K. P. (1988). The structural basis of water-holding in meat. Part 1: General principles and water uptake in meat processing. In R. Lawrie (Ed.), *Developments in meat science ± 4* (pp. 63–171). London: Elsevier Applied Science.

Oliveira, H., Pedro, S., Nunes, M. L., Costa, R., & Vaz-Pires, P. (2012). Processing of salted cod (*Gadus* spp.): A review. *Comprehensive Reviews in Food Science and Food Safety, 11*, 546–564. https://doi.org/10.1111/j.1541-4337.2012.00202.x

Peleg, M. (1988). An empirical model for the description of moisture sorption curves. *Journal of Food Science, 53*, 1216–1219.

Peleg, M. (1993). Assesment of a semi-empirical four parameter general model for sigmoid moisture sorption isotherms. *Journal of Food Process Engineering, 16*, 21–39. https://doi.org/10.1111/j.1745-4530.1993.tb00160.x

Pigott, G. M., & Tucker, B. W. (1990). *Seafood. Effects of technology on nutrition*. New York: Marcel Dekker, Inc.

Radziejewska-Kubzdela, E., Biegańska-Marecik, R., & Kidoń, M. (2014). Applicability of vacuum impregnation to modify physico-chemical, sensory and nutritive characteristics of plant Origin products-A review. *International Journal of Molecular Sciences, 15*, 16577–16610. https://doi.org/10.3390/ijms150916577

Rockland, L. B. (1969). Water activity and storage stability. *Food Technology, 23*, 1241–1251.

Rodrigues, M. J., Ho, P., López-Caballero, M. E., Bandarra, M. N., & Nunes, M. L. (2005). Chemical, microbiological, and sensory quality of cod products salted in different brines. *Journal of Food Science, 70*(1), M1–M6. https://doi.org/10.1111/j.1365-2621.2005.tb09039.x

Salvador, A. C., Saraiva, J. A., Fidalgo, L. G., & Delgadillo, I. (2013). Effect of high pressure on cod (*Gadus morhua*) desalting. *High Pressure Research, 33*, 432–439. https://doi.org/10.1080/08957959.2013.787070

Stefansson, G., & Hultin, H. O. (1994). On the solubility of cod muscle proteins in water. *Journal of Agricultural and Food Chemistry, 42*(12), 2656–2664. https://doi.org/10.1021/JF00048A002

Szymczak, M. (2011). Comparison of physicochemical and sensory changes in fresh and frozen herring (Clupea harrengus L.) during marinating. *Journal of the Science of Food and Agriculture, 91*, 68–74. https://doi.org/10.1002/jsfa.4149

Thorarinsdóttir, K. A., Arason, S., Sigurgisladottir, S., Gunnlaugsson, V. N., Johannsdottir, J., & Tornberg, E. (2011). The effects of salt-curing and salting procedures on the microstructure of cod (*Gadus morhua*) muscle. *Food Chemistry, 126*, 109–115. https://doi.org/10.1016/j.foodchem.2010.10.085

Tomac, A., Rodríguez Mallo, S., Perez, S., Garcia Loredo, A. B., & Yeannes, M. I. (2020). Vacuum impregnation in *Merluccius hubbsi* hake fillets brining. Effect on mass transfer kinetics, texture and color. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 119*, 108892. https://doi.org/10.1016/j.lwt.2019.108892

Tornberg, E. (2005). Effects of heat on meat proteins - implications on structure and quality of meat products. *Meat Science, 70*, 493–508. https://doi.org/10.1016/j.meatsci.2004.11.021

Vásquez-Mazo, P., García Loredo, A., Ferrario, M., & Guerrero, S. (2019). Development of a novel milk processing to produce Yogurt with improved quality. *Food and Bioprocess Technology, 12*, 964–975. https://doi.org/10.1007/s11947-019-02269-z

Zugarramurdi, A., & Lupin, H. (1980). A model to explain observed behavior of fish salting. *Journal of Food Science, 45*. https://doi.org/10.1111/j.1365-2621.1980.tb06543.x, 1305–131.