Food Chemistry 112 (2009) 599–603

Contents lists available at ScienceDirect

Food Chemistry

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

Citric acid as pretreatment in drying of Pacific Lion's Paw Scallop (*Nodipecten subnodosus*) meats

E. Marquez-Rios [a], V.M. Ocaño-Higuera [b], A.N. Maeda-Martínez [c], M.E. Lugo-Sánchez [a], M.G. Carvallo-Ruiz [a], R. Pacheco-Aguilar [a,*]

[a] *Centro de Investigación en Alimentación y Desarrollo, A.C. P.O. Box 1735. Hermosillo, Sonora 83000, Mexico*
[b] *Departamento de Ciencias Químico Biológicas, Universidad de Sonora, Encinas y Rosales s/n, Hermosillo, Sonora 83000, Mexico*
[c] *Centro de Investigaciones Biológicas del Noroeste, Mar Bermejo 195, La Paz, BCS 23090, Mexico*

ARTICLE INFO

Article history:
Received 15 October 2007
Received in revised form 9 June 2008
Accepted 11 June 2008

Keywords:
Scallop
Isoelectric point
Maillard reactions
Acid immersion

ABSTRACT

Pacific Lion's Paw Scallop meats were dried at 50, 60, and 70 °C after pretreatment in citric acid at pH 3 during zero (control), one, and three hours. Immersion in the acid solution reduced the scallop pH from 6.20 to 5.99 (1 h) and 5.88 (3 h) and directly affected the drying times. At 50 °C drying times were 22, 10 and 8.5 h, at 60 °C they were 15, 9.5 and 8 h, and at 70 °C they were 13, 8 and 6 h for control, 1 h, and 3 h of acid treatment. Drying times were considerably reduced as acid immersion time increased. The drying temperature had no significant effect ($p \geqslant 0.05$) on colour and texture, whereas the acid treatment had a significant effect ($p < 0.05$), with the control scallops having greater hardness and a more intense dark colouration than those treated with acid ($p < 0.05$). The citric acid treatment in drying meats of scallops is a good option to decrease the drying times and therefore the process cost. Moreover, the final product has a better colour because the acid treatment reduces Maillard reaction.

1. Introduction

Pacific Lion's Paw Scallop (*Nodipecten subnodosus*) is a bivalve mollusk harvest along the Pacific coast of the Baja California Peninsula, Mexico, where it is an important marine resource (Massó-Rojas, Morales-Bojórquez, Talavera-Mayer, Fajardo-León, & Hernández-Valenzuela, 2001). The only commercial fishery is in the Laguna Ojo de Liebre in Baja California Sur (Barrios-Ruiz, Chavez-Villalba, & Cáceres-Martínez, 2003) where the scallop is harvested by Hooka divers. The yearly production of adductor muscle increased from 5 tonnes in 1991 to a peak of 216 tonnes in 2005 (Flores, 2008). This scallop fishery is still underdeveloped and it is a good candidate for production through aquaculture. The product has a highly economic value and the scallop rapidly grows (Koch, Mazón-Suástegui, Sinsel, Robles-Mungaray, & Dunn, 2005). From 2001 to 2002, several Mexican enterprises cultivated and produced $\sim 3.2 \times 10^6$ specimens in the Laguna Manuela. The scallop can reach commercial size in culture (7 cm) in 8 months.

Scallops production and culture are increasing worldwide promoting the diversification of product lines of these organisms by means of the development of a wide variety of fresh ready-to-eat and fresh-frozen products. This phenomenon has been a consequence of a major increase in the consumption of scallops (Ocaño-Higuera, Maeda-Martínez, Lugo-Sanchez, & Pacheco-Aguilar, 2006).

The most common forms of processed scallops are the traditional tinned, and semidried (Cheng, Shing, & Joo-Shin, 2001; Pacheco-Aguilar, Ocaño-Higuera, & Maeda-Martínez, 2001). There has been a great acceptance of the product, though there is little information about conditions of drying and pretreatments of the sample (Tanikawa, 1985). The quality of the dried product depends on the drying time (Cohen & Yang, 1995; Strumillo & Adamiec, 1996). This has renewed the interest of food technologists looking for a reduction of energy used by decreasing the drying period. Variables such as temperature, air flow, and relative humidity have been used but they have had little effect on the speed of the water elimination. The use of certain pretreatments has given good results. One example is the osmotic dehydration of a great variety of vegetables, which allows the starting of the drying process with less moisture, this because of the immersion in highly concentrated sugar solutions causing the elimination of moisture by osmosis.

For dried scallop meats a common pretreatment is precooking (Tanikawa, 1985), which decreases the drying time and gives the product a better appearance. In this study we have investigated the immersion in citric acid solution and the drying temperature to see the effect of these variables on both process efficiency and product quality.

* Corresponding author. Tel./fax: +52 662 2800421.
E-mail address: rpacheco@ciad.mx (R. Pacheco-Aguilar).

0308-8146/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2008.06.015

2. Materials and methods

2.1. Samples

For this study we used the abductor muscle of the Pacific Lion's Paw Scallop (*N. subnodosus*), which was commercially acquired from Guerrero Negro, Baja California Sur, Mexico. The average weight was 70 g. The frozen abductor muscle was sent by air to the laboratories of the CIAD AC in Hermosillo, Sonora, Mexico. Once the scallop was received, it was stored at −20 °C until its use.

2.2. Immersion in acid solution

The pretreatment and the whole experiment were done three times. The frozen meat was perpendicularly sliced to the orientation of the muscle fib to a thickness of 1.2 cm and then it was allowed to come to 4 °C during 12 h. The slices were immersed in 0.1 M citric acid solution, at pH 3, for 1 and 3 h at 4 °C (1 kg scallop/2 L acid solution) with the control being scallop meat without immersion. Scallop slices were left to drain for 5 min at 4 °C.

2.3. Cooking

After immersion and draining the slices were cooked for 5 min in a solution of 5% salt and 3% sugar. Then, they were drained for 10 min at room temperature.

2.4. Drying

Scallop meat slices were placed in an oven, Enviro-Pack (Micro-Pack series MP500, E.U.), in an air stream of 3 m/s. Three drying temperatures were used (50, 60, and 70 °C). The drying time for each temperature was ended when the product reached a moisture content of 20%.

2.5. Proximate analysis

Moisture, protein, fat and ash analyses were carried out according to methods of the AOAC (1990).

2.6. Drying kinetics

Drying kinetics were realised by determining the initial moisture in scallop and weighing them over drying time thus calculating the moisture decrease according to the gravimetric method (Kemp et al., 2001). The results were expressed by plotting percentage of moisture vs. drying time.

2.7. Texture

To evaluate the product texture it was used a puncture test with a 1.2-mm diameter device and a penetration of 0.3 mm for each scallop. The determination was made with a texture analyzer TA.XT2 (Texture Technologies, Scarsdale, NY) using a compression cell of 5 kg and a rate of 10 cm/min.

2.8. Colour

The colour evaluation was made colorimetrically using a Minolta instrument CR 300 (Minolta Corporation, NJ). The parameters *L*, *a*, b were measured, and the hue angle and chromaticity were calculated.

3. Experimental design

In this experiment a 2^3 factorial arranged with two main effects was used. The main effect A, drying temperature, had three levels (50, 60, and 70 °C) and the main effect B, time of immersion in acid solution, also with three levels (0, 1 and 3 h). Multiple comparisons were made according to the Tukey method when it was necessary using a significant level of 5%. The data was analyzed using the NCSS program version 5.1.

4. Results and discussion

4.1. Proximate analysis

Table 1 shows the results of the proximate analysis of the fresh-frozen Pacific Lion's Paw Scallop meats. The scallops had a 78% content of moisture and about 15% crude protein. These results are similar to those obtained in scallops (*Argopecten* sp.) by Web, Thomas, Busta, and Monroe (1969). These authors studied the proximate variations of *Argopecten irradians*, *A. gibbus*, and *Placopecten magellanicus* in different seasons and different regions of North Carolina. They found wide variations between regions and seasons with moisture between 74% and 83%, protein of 13–21%, fat of 0.23–0.91% and ash of 1.2–1.85%.

4.2. Yield

The acid treatment before drying (Table 2) caused a partial decrease in moisture content of scallop meats, both for the precooked and acid treated. In the control scallops the moisture reduction was due to thermal processing (5 min at boiling). During this process the heat caused protein denaturation with a loss of water-holding capacity as a result of structural changes in myofibrillar proteins, the principal proteins responsible for this property (Huidobro & Tejeda, 1993). The use of acid solutions as a pretreatment caused a more pronounced elimination of moisture. This occurs because when the acid solution penetrates the abductor muscle, the pH of the muscle becomes acidic tending to be closer to the isoelectric point of the myofibrillar proteins. This in turn causes physical changes in the protein, resulting in a smaller water-holding capacity (Fennema, 1996). At constant pH, the pH decline in the muscle depends only on the immersion time in the acid solution and

Table 1
Proximal analysis of Pacific Lion's Paw Scallop fresh-frozen

Component	Percentage
Moisture	78.0 ± 1.20
Protein	14.6 ± 0.81
Carbohydrates	5.8 ± 0.53*
Fat	0.3 ± 0.03
Ash	1.3 ± 0.01

Values are the mean ± standard deviation of three replicates.
* Carbohydrates calculated by difference.

Table 2
Effect of dying treatments on yields of Pacific Lion's Paw Scallop adductor muscle

Stage	Yield (%)
Frozen scallop	100.00
Thawed scallop	77.1 ± 3.1
Cooked scallop control	68.2 ± 1.3
Cooked scallop immersed for 1 h in citric acid (pH 3)	50.4 ± 2.5
Cooked scallop immersed for 3 h in citric acid (pH 3)	46.2 ± 1.6

Values are the mean ± standard deviation of three replicates.

therefore a greater moisture elimination in the scallop with decreasing pH. However, there is little information about the pH decrease in muscle when it is immersed in acid solution.

4.3. Drying kinetics

Fig. 1 shows the effect of drying temperature and acid immersion on drying kinetics. The drying time decreased when the drying temperature and the immersion in acid solution time increased. At 50 °C the drying times were 22.0, 10.0, and 8.5 h for 0, 1, and 3 h of acid immersion (0.1 M citric acid, 1 kg scallop/2 L acid solution). At 60 °C the drying times were 15.0, 9.5, and 8.0 h for 0, 1, and 3 h of acid immersion. At 70 °C they were 13.0, 8.0, and 6.0 for 0, 1, and 3 h of acid immersion. This is an important decrease in the process cost due to the reduction of drying time. At 50 °C the drying time decreases were 55% and 61% at 1 h and 3 h of acid immersion; at 60 °C the reductions were 37% and 47% for 1 and 3 h; and at 70 °C the reduction in drying times were 38% and 53% for 1 and 3 h. The decrease in drying times was caused by an increase in drying temperature because air at higher temperature has a greater ability to remove moisture (May, Sinclair, Hughes, Halmos, & Tran, 2000). In turn, the acid immersion has an evident effect on drying, with the drying time less for acid-treated scallops compared to the control.

The pH of the abductor muscle was different in each of the treatments, being 6.2, 5.9, and 5.8 for control; 1 and 3 h of acid immersion. As the pH decreased the drying time notably decreased for each of the temperatures used. This can be due to a reduction in the water-holding capacity brought about by the decrease of the muscle pH (Huidobro & Tejeda, 1993). The elimination of moisture by heat is facilitated in the acid-treated meats. This will have a strong impact on the production cost of drying scallops.

Berberien (1971a, 1971b) improved the process of dehydration and obtained a better sensory quality in the final product using a brine containing lactic acid at levels of 1% and 4% as pretreatment for charqui production. By working with meat in another study Bifani, Paredes, and de la Vega (1984) reported that the immersion in solutions of pH 2.5 and 6.5 for 16 h had no effect on the drying efficiency. The lower content of stroma protein in scallop meat might be positively affected by the immersion in the acid solution (Sikorski, 1990). In contrast, the greater proportion of these proteins in other muscles like red meat might make more difficult the penetration of the acid solution.

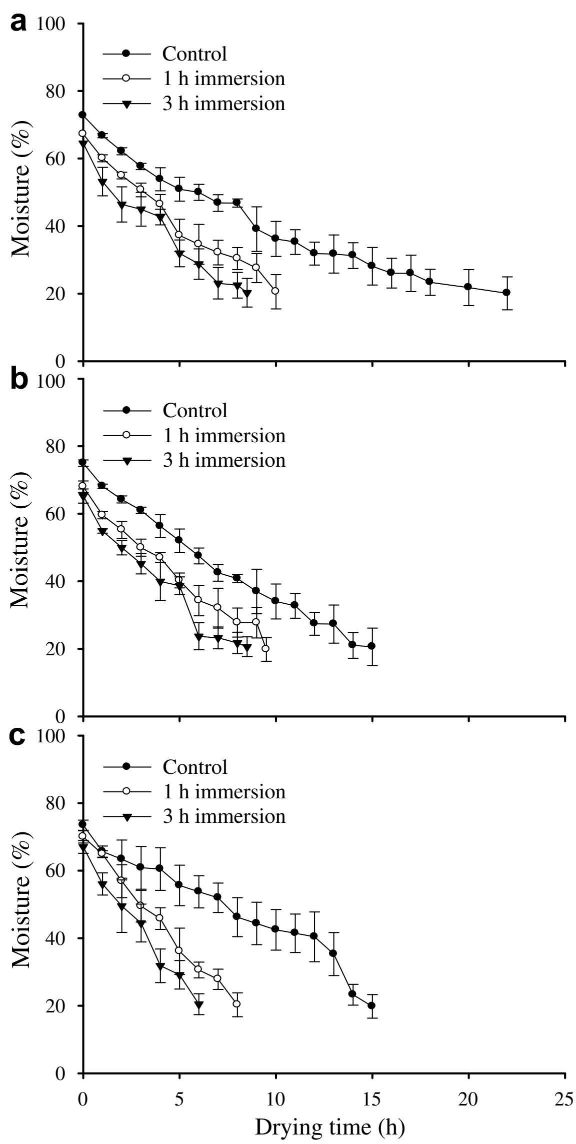

Fig. 1. (a) Drying kinetics of Pacific Lion's Paw Scallop at 50 °C. (b) Drying kinetics at 60 °C. (c) Drying kinetics at 70 °C. Scallop was immersed during different times in citric acid at pH 3. Values are the mean ± s of six scallops.

4.4. Texture

The texture of the dried products is an important factor in the acceptance of this food. The drying temperature has a significant effect (Strumillo & Adamiec, 1996). Although no significant differences were found for a temperature effect ($p \geqslant 0.05$) used under experimental conditions, there was a significant effect caused by the pretreatment ($p < 0.05$).

Fig. 2 shows the product texture obtained by each treatment. The control scallop meat (no acid immersion) was much harder and statistically different from the acid-treated scallop meat ($p < 0.05$), even though at 70 °C there were no significant differences ($p \geqslant 0.05$). This it might have been caused by the formation of a physical barrier during drying process, which yielded a harder product. The surface dries and hardens because the evaporation rate to the surface is greater than to the interior. The texture of the acid-treated scallop had lower values of hardness, presenting no significant difference for the different times of immersion in the acid solution ($p \geqslant 0.05$). It is possible that the acid-treated scallop did not form any physical barrier because as the pH in

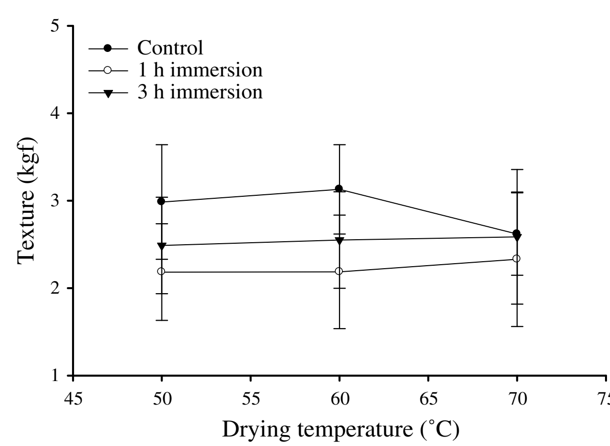

Fig. 2. Combined effect of temperature and acid immersion times at pH 3 on texture of dried Pacific Lion's Paw Scallop. Values are the mean ± s of six scallops.

the scallop muscle resulting of the acid immersion decreased the water-holding capacity. It is possible that the acid-treated scallop did no form any physical barrier due to pH reduction on scallop surface, which, at the same time, could cause a decrease in the water-holding capacity of the proteins on scallop surface. This as a result of the conformational changes in myofibrillar proteins that as a consequence widely facilitates the removal of water vapour in scallop by drying effect. As can be clearly observed in the drying kinetics obtained, the reduction in the water-holding capacity and the thermal effect facilitate the moisture rapid elimination from the product. To be in balance with the speed of evaporation at the surface, the easy removal of moisture caused the diffusion of water out of the cent of the product towards its surface, therefore the formation of a physical barrier was not possible.

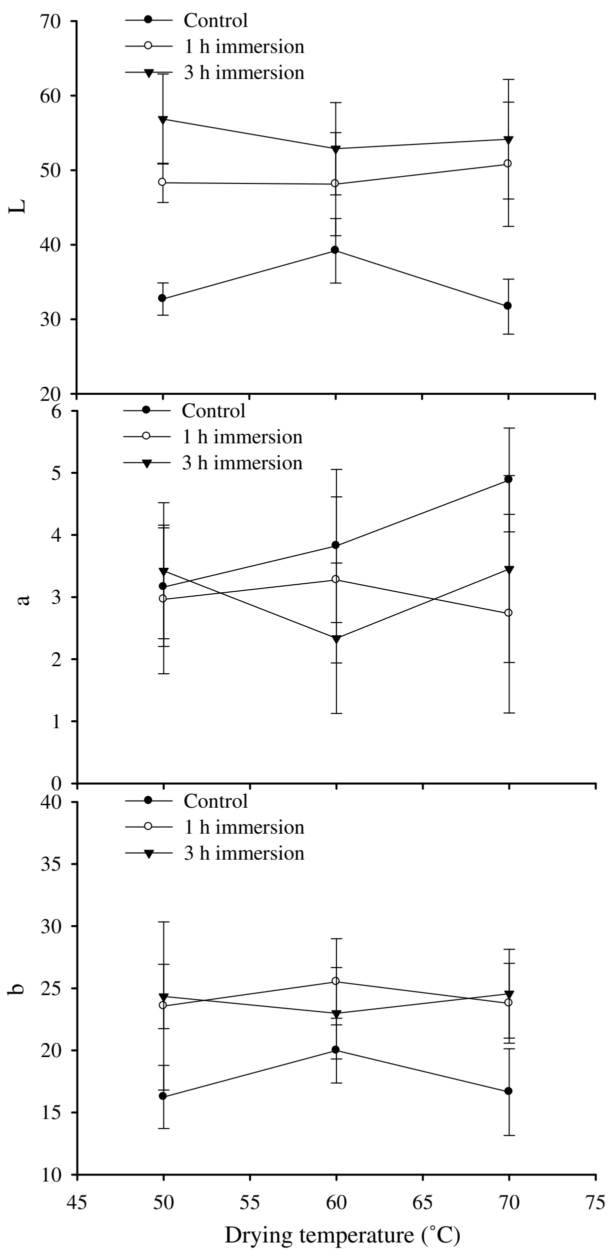

Fig. 3. Combined effect of temperature and acid immersion times at pH 3 on parameters *L*, *a*, and *b* in dried Pacific Lion's Paw Scallop. Values are the mean ± *s* of six scallops.

4.5. Colour: L, a, and b parameters, Hue angle, and chromaticity

Mollusks have a large quantity of free amino acids and sugar (Chung-Hong, Bonnie, & Ming-Sheng, 1991), which under appropriate conditions of concentration, pH, and temperature can initiate Maillard reactions and form dark pigments. The colour parameter "*L*" seems to be a good indicator to observe these changes (Fig. 3). The results obtained for drying temperature and the effect of pretreatment showed a significant interaction ($p < 0.05$) between these two principal effects. The control scallop had lower values than the acid-treated scallop. The former one had a darker colour caused by the formation of dark pigments during drying. Such dark colour was less intense in the acid-treated scallops with higher "*L*" values. It is assumed to be the effect of the pH on Maillard reactions, in which the first step in the reaction is pH dependent and is favoured by alkaline pH (Lee, 1983; Rizzi, 1997). An acid pH or pH less than the pK of the amine groups decreases the reaction because the amine groups are mostly protonated and are thus unavailable for the reaction. A greater decrease of the pH in the scallop caused a larger value of "*L*" ($p < 0.05$).

The parameters "*a*" and "*b*" (Fig. 3) also showed a significant interaction between both principal effects ($p < 0.05$). The small "*a*" values obtained because of the treatment placed the product in a gray region of the colour sphere. The "*b*" values indicated lower red and a higher yellow colour for the acid-treated scallop. Greater values of "*b*" were obtained from scallops immersed in the acid solution than from control scallop. It was noted that there were no significant differences between scallop immersed for 1 and 3 h, respectively ($p \geqslant 0.05$). The "*a*" and "*b*" values are more illustrative with the Hue angle (Fig. 4) placing the dried product

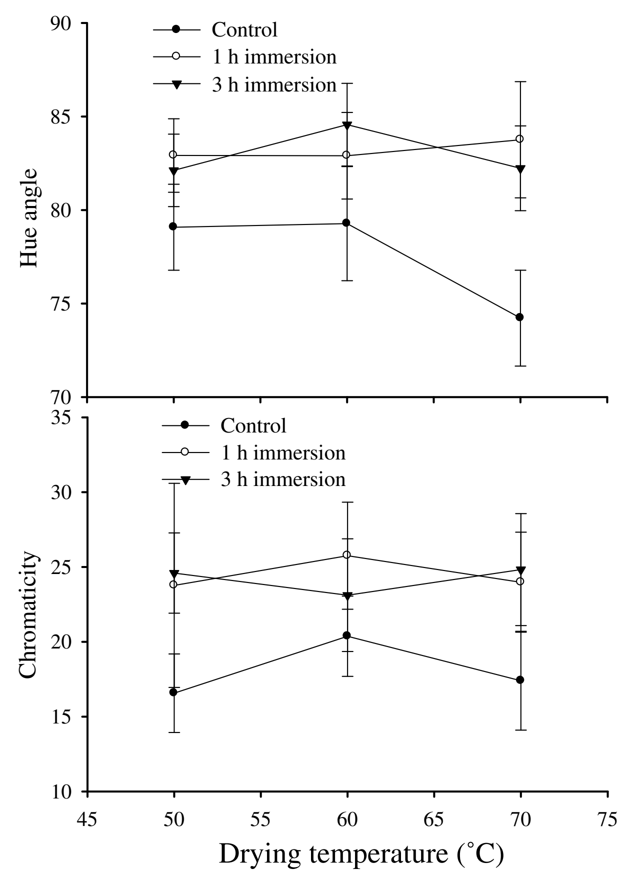

Fig. 4. Combined effect of temperature and acid immersion times at pH 3 on hue angle and chromaticity in dried Pacific Lion's Paw Scallop. Values are the mean ± *s* of six scallops.

as brownish (control) or yellowish (acid-treated). The Hue angle did not show any significant interaction between the main effect (temperature and acid immersion) nor from any main effect separately ($p \geqslant 0.05$). However, it is important to highlight that at 70 °C the Hue angle of the control product was lower than the other product dried at the same temperature. The chromaticity results (Fig. 4) showed no significant interaction between the main effect ($p > 0.05$) but a significant difference for acid immersion ($p \leqslant 0.05$), with chromaticity values greater for acid-treated scallops than for the control ($p \leqslant 0.05$). This occurs because the values of "*b*" in the acid-treated scallops are greater than the control ones and are located in the gray region.

5. Conclusions

The acid pretreatment offers a better drying speed in the range of temperatures used and represents a good option for reducing the drying time, and thus a decrease in the process cost. The acid immersion is also helpful in the control of Maillard reactions developed in dried products.

References

AOAC. (1990). Association of official analytical chemists official methods of analysis of association of official analytical chemist (Vol. II 15th). Arlington Virginia, USA.

Barrios-Ruiz, D., Chavez-Villalba, J., & Cáceres-Martínez, C. (2003). Growth of *Nodipecten subnodosus* (Bivalvia: Pectinidae) in La Paz Bay, Mexico. *Aquaculture Research, 34*, 633–639.

Berberien, A. (1971a). Influência da adição do ácido láctico no prepare da carne curada em salmoura. *Boletim do ITAL do Brasil, 25*, 69–80.

Berberien, A. (1971b). O efeito do ácido láctico no charque. *Boletim do ITAL do Brasil, 26*, 17–35.

Bifani, C. V., Paredes, R. C., & de la Vega, M. J. A. (1984). Deshidratación de carne. Condiciones de pretratamiento y secado. *Revista de Agroquímica y Tecnología de Alimentos, 24*, 239–249.

Cheng, H. Y., Shing, I. K., & Joo-Shin, K. (2001). Comparison of volatile components in dried scallop (*Chlamys farreri* and *Patinopecten yessoensis*) prepared by boiling and steaming methods. *Journal of Agricultural and Food Chemistry, 49*, 192–202.

Chung-Hong, T., Bonnie, S. P., & Ming-Sheng, K. (1991). Browning behavior of taurine and proline in model and dried squid systems. *Journal of Food Biochemistry, 15*, 67–77.

Cohen, J. S., & Yang, C. S. (1995). Progress in food dehydration. *Trends in Food Science and Technology, 6*, 20–24.

Fennema, O. R. (1996). *Food Chemistry*. New York: Marcel Dekker Inc.

Flores, O. M. A. (2008). Pesquería de mano de león en Guerrero Negro, B.C.S. Presente, pasado y futuro. Comité pesquero social y privado de Guerrero Negro, B.C.S. <www.pescadorapescador.net>.

Huidobro, A., & Tejeda, M. (1993). Revisión: Propiedades de hidratación del músculo de pescado. Revista Española en Ciencia y Tecnología. *Alimentaria, 33*, 365–381.

Kemp, I. C., Christran, F. B., Stephane, L., Roques, M. A., Groenewold, G. E., Tsotsas, E., et al. (2001). Methods for processing experimental drying kinetics data. *Drying Technology, 19*, 15–34.

Koch, V., Mazón-Suástegui, J. M., Sinsel, F., Robles-Mungaray, M., & Dunn, D. (2005). Lion's paw scallop (*Nodipecten subnodosus*, Sowerby 1835) aquaculture in Bahía Magdalena, Mexico: Effects of population density and season on juvenile growth and morality. *Aquatic Research, 36*, 505–512.

Lee, F. A. (1983). *Browning reactions. Basic Food Chemistry*. Westport, Connecticut: The Avi Publishing Company, Inc.

Massó-Rojas, J. A. , Morales-Bojórquez, E., Talavera-Mayer, J., Fajardo-León, M., & Hernández-Valenzuela, R. (2001). Almeja mano de león. In *Sustentabilidad y pesca responsable en México. Evaluación y manejo* (pp. 349–366). México: Editorial Instituto Nacional de la Pesca.

May, B. K., Sinclair, A. J., Hughes, J. G., Halmos, A. L., & Tran, V. N. (2000). A study of temperature and sample dimension in the drying of potatoes. *Drying Technology, 18*, 2291–2306.

Ocaño-Higuera, V. M., Maeda-Martínez, A. N., Lugo-Sanchez, M. E., & Pacheco-Aguilar, R. (2006). Postmortem biochemical and textural changes in the adductor muscle of catarina scallop stored at 0 °C. *Journal of Food Biochemistry, 30*, 373–389.

Pacheco-Aguilar, R., Ocaño-Higuera, V. M., & Maeda-Martínez, A. N. (2001). Manejo y procesamiento de pectínidos. In A. N. Maeda-Martínez (Ed.), *Los Moluscos Pectínidos de Iberoamérica: Ciencia y Acuicultura* (pp. 431–450). México: Editorial Limusa.

Rizzi, G. P. (1997). Chemical structure of colored Maillard reaction products. *Food Reviews International, 13*, 1–28.

Sikorski, Z. E. (1990). *Seafood: Resources, nutritional composition and preservation*. Boca Raton, FL: CRC Press Inc.

Strumillo, C., & Adamiec, J. (1996). Energy and quality aspects of food drying. *Drying Technology, 14*, 423–448.

Tanikawa, E. (1985). *Marine products in Japan*. Tokyo: Koseish Koseikaku Co. Ltd.

Web, N. B., Thomas, F. B., Busta, F. F., & Monroe, R. J. (1969). Variations in proximate composition of North Carolina scallop meats. *Journal of Food Science, 34*, 471–474.