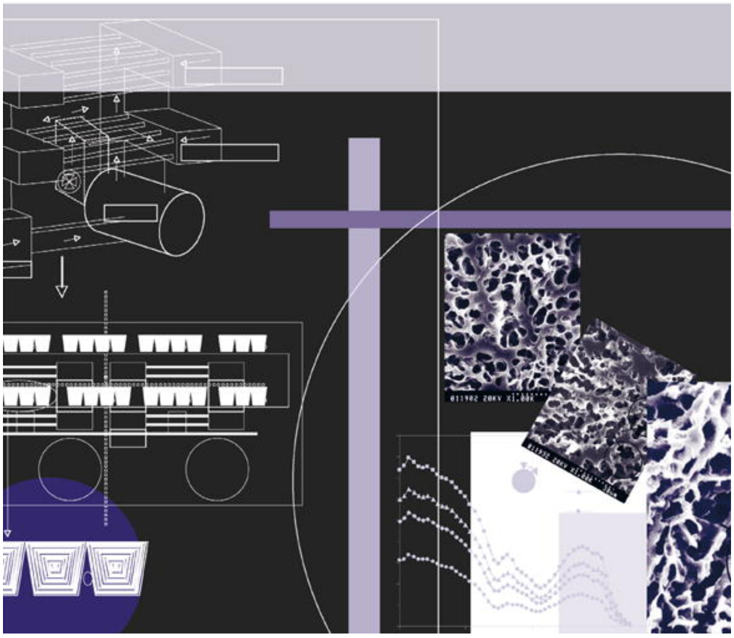
ELSEVIER

Volume 81, Issue 2

ISSN 0260-8774

journal of
food engineering



Available online at www.sciencedirect.com
ScienceDirect
Journal of Food Engineering 81 (2007) 336–340
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Evaluation of texture parameters of *Rohu* fish (*Labeo rohita*) during iced storage

Dilip Jain *, Pankaj B. Pathare, M.R. Manikantan

Central Institute of Post Harvest Engineering and Technology, PAU Campus, Ludhiana 141 004, India

Received 17 May 2006; received in revised form 4 November 2006; accepted 7 November 2006
Available online 22 December 2006

Abstract

The textural parameters of Indian major carp *Rohu* fish (*Labeo rohita*) during iced storage have been studied during iced storage for the duration of eight days. Textural parameters, viz. skin hardness, toughness and stiffness has been evaluated on a texture analyzer for the different day of iced fish. The abruptly reduction in skin hardness (bio-yield point) and toughness was observed after fifth day of storage. The skin hardness ranged between 86.911 and 95.656 N within five days of storage and thereafter reduced within the range from 48.714 to 65.920 N. The stiffness ranged between 3.1474 and 4.6340 N mm^{-1} and toughness, 588.9–713.2 N mm for five days. After five days of storage, the stiffness and toughness reduced in the range of 2.0030–2.8111 N mm^{-1} and 415.0–526.3 N mm, respectively. During this storage period the pH of fish flesh was also determined with pH meter. The pH increased from 6.10 to 6.90 during the period of storage. Exponential regression presents the relationship between fish flesh stiffness F_s and pH with coefficient of determination 0.9695 and standard error 0.167. The results of skin hardness curve were fitted to modified Maxwell model. The modified Maxwell model could satisfactorily described relationship between skin hardness and compression time for iced fish with the coefficient of determination ranged from 0.9910 to 0.9967 and standard error ranged from 1.184 to 2.014. The coefficients of Maxwell model were further fitted in exponential expression to relate with the days of storage. Thus, the developed Maxwell model could predict the skin hardness for fish with an error of 0.06%, which was within the limit of experimental uncertainty of 5.54%.

Keywords: Fish storage; Texture analysis; Modified maxwell model; Skin hardness; pH

1. Introduction

India ranks second in global freshwater fish production with annual production of 3.5 Mt during 2004–2005 (Anonymous, 2006). Preservation is necessary to prolong shelf life and reduce the spoilage of fish. Preservation aims to alter factors that aid spoilage without changing taste, texture and the physical appearance of the fish. Icing is widely accepted for chilling the fish, which is the economical and readily available method. Ice keeps the fish moist and glossy and also prevents from the dehydration (Graham, Johnston, & Nicholson, 1992). Jain, Ilyas, Pathare, Prasad, and Singh (2005) developed the exponential and asymptotic models to represent the cooling of *Rohu* fish *(Labeo rohita*) in ice.

Texture is an important variable of quality of the fish flesh and is increasing concern to aquaculture industries (Bjornevik, Karlsen, Johnston, & Kiessling, 2003). Some of the most important sensory attributes of flesh are appearance, juiciness, flavor and texture (Barton-Gade, Cross, Jones, & Winger, 1988). Texture in flesh foods is usually referred to as tenderness, which is most important quality factor in meat, poultry and fish products (Crystall, 1994). Texture includes the most common characteristics like hardness, springiness and chewiness of food. Some authors also recognized the juiciness (Szczesniak, 1963) and greasiness (Brandt, Skinner, & Coleman, 1963) of food as the attributes of texture. Firm flesh is a valued sensory

* Corresponding author. Tel.: +91 161 2808155; fax: +91 161 2808670.
E-mail addresses: jaindilip25@rediffmail.com, jaindilip25@sify.com (D. Jain).

0260-8774/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2006.11.006

characteristic for consumer and also an important attribute for the mechanical processing of fillets by the fish food industries (Dunajski, 1979; Haard, 1992). Among textural attributes, hardness is the most important to the consumer, as it decides the commercial value of the meat (Chambers & Bowers, 1993). Texture is defined as a sensory parameter that only a human being can perceive, describe and quantify (Hyldig & Nielsen, 2001). In some cases, the flesh foods become too soft or mushy, which refers as lack of texture. The pH is also an important parameter to show depletion in tissue and quality of flesh during storage. Process technology is influenced by rigor development, postmortem temperature and pH (Greaser & Pearson, 1999).

Unlike terrestrial animal, fish muscle has higher levels of indigenous proteases, which immediately start to break down the proteins after the harvesting, during processing, improper handling storage, and cooking (Aksnes, 1989; Toyohara, Sakata, Yamashita, Kimoshita, & Shimizu, 1990). Texture analysis for fish and fish products are important in research, quality control and product development in the seafood industry (Coppes, Pavlisko, & De Vecchi, 2002). Therefore, the study of textural attributes, development of mathematical model for fish skin hardness and determination of the relationship between stiffness and pH of fish stored in ice has been carried out.

2. Theoretical consideration

To explain the viscoelastic behavior of fish, the force–time relationship can be fitted into the modified Maxwell model and expressed as (Mohsenin, 1970; Herrero & Careche, 2005)

$$F_t = C_0 + \sum_{i=1}^{n} C_i \exp(t/T_{\mathrm{rel},i}) \tag{1}$$

where F_t is the force at any time t, C_0 is the force at equilibrium, C_i are decay force, $T_{\mathrm{rel},i}$ are relaxation time and n is the number of exponential terms. A non-linear regression model (Eq. (1)) is used with two and three exponential terms. The single exponential term ($n = 1$) may be used for linear exponential regression model and the expression can be written as

$$F_t = C_0 + C \exp(t/T_{\mathrm{rel}}) \tag{2}$$

The peak force attained by the probe during the experiment is referred as the skin hardness or bio-yield point. Bio-yield point is the first break in the force–deformation curve (Mohsenin, 1970). Toughness is defined as an area under the force–deformation curve till the bio-yield point. It is a measure of the total energy required to penetrate through sample (Sajeev, Manikanthan, Kingsly, Moorthy, & Sreekumar, 2004). Stiffness is the resistance of a visco-elastic body from the deflection, when the force is applied. The stiffness F_s of a body that deflects a distance under an applied force F_t. Stiffness of fish skin in N mm^{-1} is determined from the gradient of the force–displacement curve based on the secant modulus given by Mohsenin (1970).

3. Materials and methods

Freshwater *Rohu* fish were brought live from nearby fish farm of Ludhiana. Where the cultural practices were same. The fish sample weighed around 400 ± 20 g was taken for the present study. The thickness of fish was 60 ± 5 mm at the experimental area. Fish were kept free from stress before stunned death. The fish were killed by stunning the head for sudden death on zero day (Abbas, Mokhtar, Sapuan, & Mawlood, 2005). The fish were stored in the ice-box by arranging in the alternate layers of ice and fish. The fish were totally covered with ice during storage. Observations were taken at 11 h for every day of storage. A single fish sample was used for measuring textural attributes and pH as one replication. The reported value in this study is the mean of three replications.

Textural properties of sample were measured by using texture analyzer TA-Hdi (Stable micro systems, England) with 50 kg load cell and computer software of texture expert exceed. A flat-ended cylindrical probe of stainless steel having 5 mm diameter was used for compression/penetration study. Due to non-homogeneity in the fish flesh the sampling area was selected from the upper portion with respect to the lateral line of the fish body (Fig. 1). The sample was placed (Fig. 1b) under the probe that moved downwards till the distance of 35 mm at a constant speed of 1.0 mm s^{-1}. During the test run, the resistance of the sample was recorded for every 0.02 s and plotted in a force (N)–time (s) graph (Fig. 2). The observation of force till the bio-yield point of skin hardness with an interval of one second were recorded on texture analyzer were used for fitting the force and time relationship in modified Maxwell model. The experimental error has been determined in terms of percent internal uncertainty for force (Jain & Pathare, 2004).

Fish muscle just below the skin was taken for the determination of pH. A solution of one part of fish muscle and five parts of distilled water was prepared for measurement

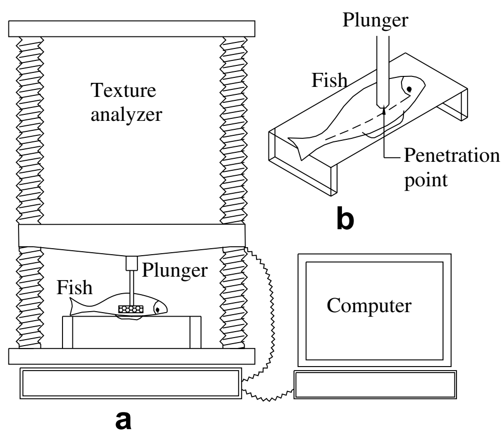


Fig. 1. (a) Experimental set up of texture study of iced storage of fish; (b) showing the selected sampling area.

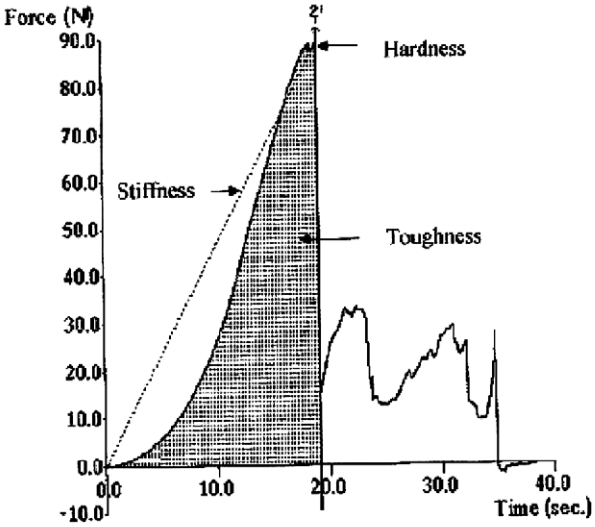


Fig. 2. Typical force–time deformation curves during compression/penetration for *Rohu* fish.

of pH (Abbas et al., 2005). A digital pH-meter (Max Electronics, Chandigarh, India, model 962-P) with the least count of 0.05 was used for measuring the pH.

4. Results and discussion

4.1. Variation of textural parameters and pH with storage duration

The variation in the textural parameters of iced fish sample for eight days of storage is presented in Table 1. The skin hardness (bio-yield point) of the fish was having small variation for the first five days, which ranged between 95.656 and 86.911 N. It decreased drastically from fifth day onwards within the range of 65.920–48.714 N. Toughness of fish skin ranged between 713.2 and 588.9 N mm for initial five days of iced storage and reduced to 526.3–415.0 N mm for next three days. The stiffness of fish skin decreased from 4.634 N mm^{-1} to 2.00 N mm^{-1} during the eight days of storage of iced fish. This variation may be due to rigor mortis, described the stiffness in muscle tissue after death. For all the textural parameters, there was decrease in their values after five days of storage. Greaser and Pearson (1999) reported that course of completion of rigor mortis requires 5–24 h in fish. The fish is considered as fresh and fit for human consumption during rigor mortis. After rigor mortis stage, the decomposition of fish starts rapidly. Hence, extending the rigor mortis may be considered as extension of shelf life (Khanna, 1996). Thus, it can be revealed from this study that shelf life of fresh water fish could be extended for six days, while stored in ice.

The initial pH of the fresh sample was 6.1. The pH of iced fish sample were increased from 6.2 to 6.9 during first to eighth day of storage. The stiffness of iced fish were decreased consecutively with the storage period. This confers the earlier work reported by Gould and Peters (1971) and Abbas et al. (2005) that the increase in pH during fish storage is due to depletion of the tissues. On sixth day of storage, the pH of iced fish was increased to 6.6, together with skin hardness was reduced from 86.911 to 65.920 N. Which indicated the loss of texture from sixth day onwards due to depletion in tissue of iced fish. It was also in concurrence with the work reported by Love (1983) and Rhee et al. (1984) that enzyme catalyze oxidation reaction in fish muscle tissue was optimum at 6.5 pH.

The fish skin stiffness exponentially decreased with increase in pH during ice storage. The following expression was obtained by fitting with linear exponential regression between fish skin stiffness F_s and pH

$$F_s = 4603 \exp(-1.129\ \mathrm{pH}) \quad (r^2 = 0.9695, e_s = 0.167) \tag{3}$$

The increase in pH during the storage, which resulted due to the depletion of tissues, may cause decrease in stiffness.

4.2. Force and time relationship

The regression analysis was done relating the compression time (t) and skin hardness (F_t) with the experimental data of individual fish for every day of storage in the modified version of Maxwell model (Eq. (2)). The model coefficients and correlation parameters are presented in Table 2. The adequacy of the modified Maxwell model is presented with the value of the coefficient of determination r^2, which

Table 1
Variation in texture parameters and pH during storage of fish with ice

Days	Skin hardness (N)	Uncertainty (%)	Toughness (N mm)	Stiffness (N mm^{-1})	pH
0	89.445	4.2188	649.2	4.6340	6.10
1	92.778	3.1392	713.2	4.4130	6.20
2	95.656	2.9169	588.9	4.3772	6.30
3	87.563	2.5809	625.3	3.3139	6.35
4	87.867	4.3072	655.8	3.1474	6.40
5	86.911	3.9911	679.1	3.1436	6.50
6	65.920	3.1882	526.3	2.8111	6.60
7	51.021	3.0288	479.2	2.2907	6.70
8	48.714	2.2976	415.0	2.0030	6.90

Table 2
Coefficients for force–time model [$F_t = C_0 + C \exp(t/T_{\mathrm{rel}})$] and their correlation parameters for different days of ice storage of fish

Days (d)	C_0	C	T_{rel} (s)	r^2	e_s
1	−77.15	73.09	26.8312	0.9926	2.014
2	−41.93	39.78	22.0167	0.9967	1.184
3	−17.57	16.37	12.5754	0.9944	1.545
4	−14.67	13.23	12.1138	0.9964	1.583
5	−7.582	8.159	10.9202	0.9925	1.924
6	−25.59	22.53	17.1350	0.9916	2.005
7	−24.31	21.32	17.5902	0.9936	1.672
8	−18.04	15.99	17.1821	0.9910	1.485

should be close to one, and low value of standard error e_s. It can be observed (Table 2) that the force–time model fitted well with the range of coefficient of determination from 0.9910 to 0.9967 and standard error from 1.184 to 2.014. These results are also graphically presented in Fig. 3 for four different days of iced fish, which are the evidences of appropriateness of a Maxwell model. Therefore, further analysis was carried out to establish the relationship between the coefficients of Maxwell model and number of storage days of iced fish. Exponential regressions were performed between the number of storage days (d) and coefficients of the modified Maxwell model. The suitable expressions of model coefficients were as follows:

$$-C_0 = 173.8\exp(-0.884d) + 5.311\exp(0.182d) \quad (r^2 = 0.9341; e_s = 7.521) \tag{4}$$

$$C = 163.9\exp(-0.8773d) + 4.951\exp(0.1759d) \quad (r^2 = 0.9479; e_s = 6.367) \tag{5}$$

$$T_{Rel} = 39.83\exp(-0.5868d) + 4.714\exp(0.1683d) \quad (r^2 = 0.8418; e_s = 2.823) \tag{6}$$

These expressions can be used to estimate the fish skin hardness at any time with respect to the storage days with the greater accuracy. The established model was validated with observed values of skin hardness for all the tests of experiment. The performance of the model is shown in Fig. 4. The predicted data banded over the straight line of 1:1 ratio, with a value for the coefficient of correlation of 1.0. The linear regression of these results gave the following expression as

$$F_{t,pre} = 0.9871F_{t,exp} + 0.6315 \quad (r = 1.0; e_p = 0.06\%) \tag{7}$$

where $F_{t,pre}$ and $F_{t,exp}$ are the predicted and measured skin hardness of fish, respectively.

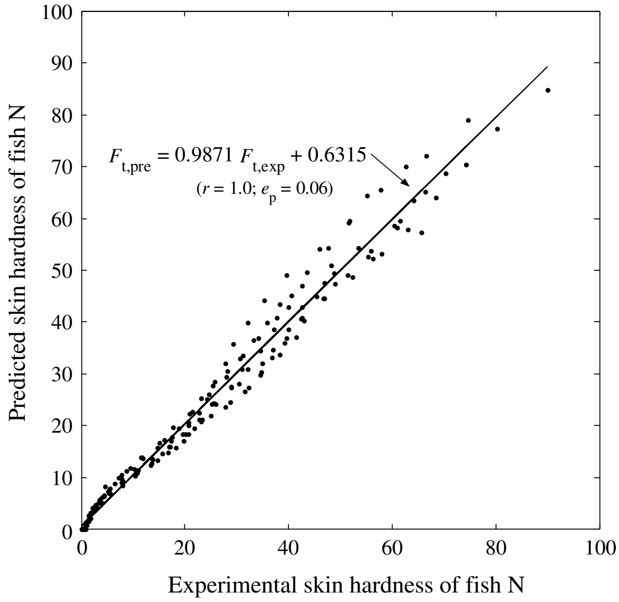


Fig. 4. Correlation between predicted and experimental skin hardness.

4.3. Prediction of accurate skin hardness of fish

The skin hardness of fish for the specific day of iced fish can be predicted with the help of Eqs. (2) and (4)–(6). The coefficients C_0, C and T_{res} of Maxwell model (Eq. (2)) for specific day of iced fish can be computed from Eqs. (4)–(6), respectively. Once the coefficients of model are known than the skin hardness can be evaluated for the period of 25 s of time with the help of Eq. (2). The value of skin hardness of fish thus computed would be $F_{t,pre}$ of Eq. (7). The $F_{t,exp}$ can be calculated from Eq. (7) would be much closer to the measured value of skin hardness of fish. This was the actual prediction of skin hardness of fish

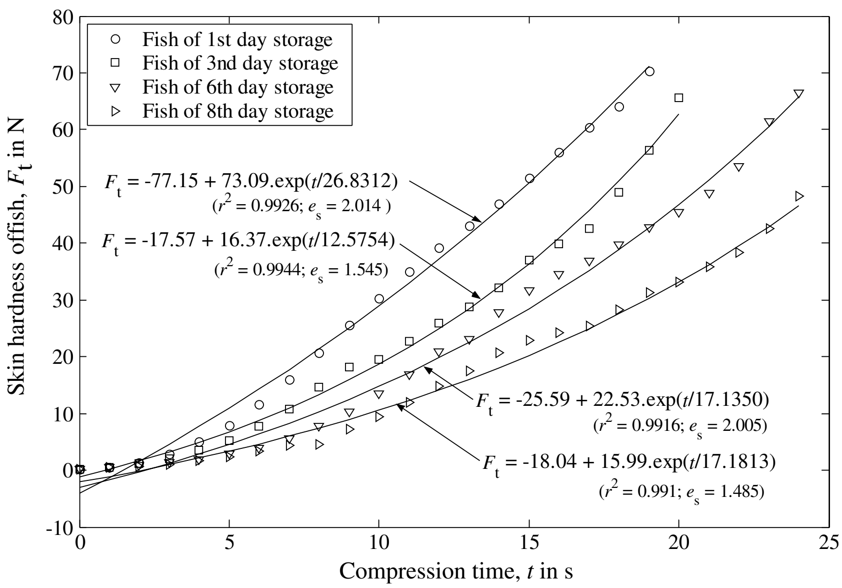


Fig. 3. Representation of modified Maxwell model for force–time relationship for fish skin hardness stored in ice.

from the above model. The maximum value of $F_{t,\exp}$ can be considered as the bio-yield point. Once the force and time curve are plotted then the toughness and stiffness can also be predicted by the method mentioned in Section 3. The error of prediction (e_p) of force by this method was 0.06%, which was within the limit of experimental uncertainty of 5.54%. Therefore, the above results proved the suitability of the modified Maxwell model in describing skin hardness of iced fish during the period of storage.

5. Conclusion

Studies on the textural properties of Indian major carp *Rohu* fish during ice storage indicated considerable changes. The skin hardness ranged from 95.778 N to 48.714 N during the eight days of iced fish. A small variation in skin hardness was observed for first five days of iced fish. Skin hardness and toughness decreased visibly after fifth day of iced storage of fish. The stiffness of iced fish also decreased from 4.6340 to 2.0030 N mm^{-1} during storage. The pH of the fish during storage period has been observed in increasing trend from 6.1 to 6.9. Exponential regression presents the relationship between fish stiffness F_s and pH of iced storage with coefficient of determination 0.9695 and standard error 0.167. Modified Maxwell model adequately described the force–time relationship of iced fish during storage. The developed modified Maxwell model can predict the skin hardness for fish with an error of 0.06%, which would be within the limit of experimental uncertainty of 5.54%.

Acknowledgements

The authors gratefully acknowledge the financial support of Indian Council of Agricultural Research, New Delhi for the ad hoc Project No. 0668002. The special thanks to Dr. O.D. Wanjari, Principal Scientist and Dr. R.T. Patil Director, Central Institute of Post Harvest Engineering and Technology, Ludhiana and Dr. S. Ayyappan, Deputy Director General (Fisheries) ICAR for their guidance and encouragements. Help in conducting experiment given by Mr. Suday Prasad is thankfully acknowledged.

References

Abbas, K. A., Mokhtar, A. S., Sapuan, S. M., & Mawlood, M. K. (2005). Quality deterioration of Malaysian patin fish during cold storage. *Journal of Food Agriculture and Environment, 3*(2), 88–91.

Aksnes, A. (1989). Effects of proteinase inhibitors from potato on the quality of stored herring. *Journal of the Science of Food and Agriculture, 49*, 225–234.

Anonymous. (2006). Ministry of Agriculture, Government of India. http://dahd.nic.in.

Barton-Gade, P. A., Cross, H. R., Jones, J. M., & Winger, R. J. (1988). In H. R. Cross & A. J. Overby (Eds.), *Meat science milk science and technology* (pp. 141–171). Amsterdam: Elsevier Science Science Publishers B.V.

Bjornevik, M., Karlsen, O., Johnston, I. A., & Kiessling, A. (2003). Effect of sustained exercise on white muscle structure and flesh quality in farmed cod (*Gadus morhua* L.). *Aquaculture Research, 34*, 55–64.

Brandt, M. A., Skinner, E. Z., & Coleman, J. A. (1963). Texture profile method. *Journal of Food Science, 29*, 404–409.

Chambers, E. N., & Bowers, J. R. (1993). Consumer perception of sensory quality in muscle foods. *Food Technology, 47*(11), 116–120.

Coppes, Z., Pavlisko, A., & De Vecchi, S. (2002). Texture measurements in fish and fish products. *Journal of Aquatic Food Product Technology, 11*(1), 89–105.

Crystall, B. B. (1994). Meat texture measurement. *Advances in Meat Research, 9*, 316–336.

Dunajski, E. (1979). Texture of fish muscle. *Journal of Texture Studies, 10*, 301–318.

Gould, E., & Peters, A. J. (1971). *On letting the freshness of frozen fish*. London: Fishing News Book.

Graham, J., Johnston, W.A., & Nicholson, F.J. (1992). Ice in fisheries. FAO fisheries technical Paper No. 331 (p. 75). Rome: FAO.

Greaser, M. L., & Pearson, A. M. (1999). Flesh foods and their analogues. In A. J. Rosenthal (Ed.), *Food texture measurement and perception* (pp. 236–246). Maryland: Aspen Publication.

Haard, N. F. (1992). Control of chemical composition and food quality attributes of cultured fish. *Food Research International, 25*, 289–307.

Herrero, A. M., & Careche, M. (2005). Stress–relaxation test to evaluate textural quality of frozen stored Cap hak (*M. capensis* and *M. paradoxus*). *Food Research International, 38*, 69–76.

Hyldig, G., & Nielsen, D. (2001). A review of sensory and instrumental methods used to evaluate the texture of fish muscle. *Journal of Texture Studies, 32*, 219–242.

Jain, D., Ilyas, S. M., Pathare, P., Prasad, S., & Singh, H. (2005). Development of mathematical model for cooling the fish with ice. *Journal of Food Engineering, 71*(3), 324–329.

Jain, D., & Pathare, P. B. (2004). Selection and evaluation of thin layer drying models for infrared radiative and convective drying of onion slices. *Biosystems Engineering, 89*(3), 289–296.

Khanna, S. S. (1996). In *An introduction to fishes* (pp. 516–525). Allahabad: Central Book Depot.

Love, J. D. (1983). The role of hemi iron in the oxidation of lipids in red meat. *Journal of Food Technology, 37*, 117–123.

Mohsenin, N. N. (1970). *Some basic concepts of rheology*. *Physical properties of plant and animal materials*. New York: Gordon and Breach.

Rhee, K. S., Dutson, T. R., & Sminth, G. C. (1984). Enzymic lipid peroxidation in microsomal fraction from beef skeletal muscle. *Journal of Food Science, 49*, 675–689.

Sajeev, M. S., Manikanthan, M. R., Kingsly, A. R. P., Moorthy, S. N., & Sreekumar, J. (2004). Texture analysis of taro (*Colocasia esculenta* L. Schott) cormels during storage and cooking. *Journal of Food Science, 69*(7), 315–321.

Szczesniak, A. (1963). Classification of textural characteristics. *Journal of Food Science, 28*, 385–389.

Toyohara, H. T., Sakata, K., Yamashita, M., Kimoshita & Shimizu, Y. (1990). Degradation of oval-filefish meat gel caused by myofibrillar proteinases. *Journal of Food Science, 55*, 364–368.