Development of *Pangasius* steaks by improved *sous-vide* technology and its process optimization

Namita Kumari¹ · Chongtham Baru Singh¹ · Raushan Kumar¹ · K. A. Martin Xavier¹ ·
Manjusha Lekshmi¹ · Gudipati Venkateshwarlu² · Amjad K. Balange¹

Revised: 18 June 2016 / Accepted: 4 November 2016 / Published online: 23 November 2016
© Association of Food Scientists & Technologists (India) 2016

Abstract The present study embarked on the objective of optimizing improved *sous-vide* processing condition for development of ready-to-cook *Pangasius* steaks with extended shelf-life using response surface methodology. For the development of improved *sous-vide* cooked product, *Pangasius* steaks were treated with additional hurdles in various combinations for optimization. Based on the study, suitable combination of chitosan and spices was selected which enhanced antimicrobial and oxidative stability of the product. The Box–Behnken experimental design with 15 trials per model was adopted for designing the experiment to know the effect of independent variables, namely chitosan concentration (X_1), cooking time (X_2) and cooking temperature (X_3) on dependent variable i.e. TBARS value (Y_1). From RSM generated model, the optimum condition for *sous-vide* processing of *Pangasius* steaks were 1.08% chitosan concentration, 70.93 °C of cooking temperature and 16.48 min for cooking time and predicted minimum value of multiple response optimal condition was $Y = 0.855$ mg MDA/Kg of fish. The high correlation coefficient ($R^2 = 0.975$) between the model and the experimental data showed that the model was able to efficiently predict processing condition for development of *sous-vide* processed *Pangasius* steaks. This research may help the processing industries and *Pangasius* fish

farmer as it provides an alternative low cost technology for the proper utilization of *Pangasius*.

Keywords *Sous-vide* · Ready-to-cook · Response surface methodology · Box–Behnken design · *Pangasius* · Chitosan

Introduction

Ready-meals are major players in the market place (Redmond et al. 2004) and there is a strong emphasis on innovation leading to higher quality products. Consumers have been demanding fresh, high quality, low salt, and preservative free convenience meals that require minimal preparation time. This demand by consumers has resulted in increased production of minimally processed, ready-to-cook (RTC) or ready-to-eat (RTE), extended shelf-life refrigerated foods, which include *sous-vide* (i.e. under vacuum processed) food products. However, *sous-vide* is increasingly used to process convenience foods including ready-meals (Creed 2001) as it is reputed to give superior quality because of the mild process and the absence of oxygen in the pack. *Sous-vide* processing involves vacuum packing of the food in plastic bags followed by a mild pasteurization treatment and storage at 2–4 °C. This results in a shelf-life of up to 30 days (Tansey et al. 2005). Being minimally processed with the inclusion of fewer additives, *sous-vide* foods have improved nutritional and sensory attributes (Creed 2001). *Sous-vide* cooking reduces heat damage to proteins and lipids, reduces the loss of aromatic compounds and heat sensitive nutrients. It also improves the texture compared with conventionally cooked products due to the mild temperature used in cooking (Garcia-Linares et al. 2004). *Sous-vide* processed foods also have

✉ Amjad K. Balange
amjadbalance@cife.edu.in

¹ Department of Post-Harvest Technology, ICAR-Central Institute of Fisheries Education, Versova, Mumbai, Maharashtra 400061, India

² Education Division, Indian Council of Agricultural Research, New Delhi 110001, India

the advantage of lower storage costs incurred since freezing is not required.

Pangasius is the riverine catfish belonging to the family Pangasidae. *Pangasius* has achieved impressive success as a commercial aquaculture species. Its production levels and distribution in global markets are now similar to that of other established top-tier aquaculture species such as tilapia, shrimp and salmon. While global markets for the latter species matured over the past 20 years, *Pangasius* aquaculture has developed impressively within the last decade. In India *Pangasius* is widely cultured in the inland sector mainly in states of Andhra Pradesh and West Bengal and some parts of Maharashtra. The annual production is presently around 700,000 tonnes, which is produced from 32,000 ha of culture area (Singh and Lakra 2012).

The rapidly developing *Pangasius* farming in India is facing major challenges including a severe crisis of steep decline in market price owing to yellow discoloration of its fillets (Orban et al. 2008). Consecutive rejection from export market is another major constrain. The alternative marketing solutions should be brought out to help the industry to curtail price fluctuation and to cope up with the pressure of a mounting loss to the farmers. In Indian context, more emphasis was given to the production of fish and less importance was given to processing and marketing aspects. So, there is need to increase the market acceptability of unutilized resources by developing ready-to cook product by improved *sous-vide* method.

Till date, there is no standardized time-temperature combination for *sous-vide* cooking of *Pangasius*. Hence the present study was aimed at development of *sous-vide* processed *Pangasius* steaks and its process optimization and also quality evaluation during storage. In order to optimize the levels of various hurdles, multivariate statistical techniques such as Response Surface Methodology (RSM) have been suggested. When many factors and interaction affect desired response, RSM is an effective tool for optimization of process (Baskaran et al. 2007). RSM is a collection of mathematical and statistical techniques for modeling and analysis of problems in which a response of interest is influenced by several variables (Montgomery 2001). The main objective of RSM is to determine the optimum operational conditions for the system or to determine a region that satisfies the operating specifications (Montgomery 2001). A standard RSM design called Box–Behnken Design (BBD) was applied in this work for three variables; each with three levels (the minimum and maximum and central value) was used as experimental design model. The main goal of this research was to obtain an optimum combination of chitosan concentration, temperature and time which gives a minimum TBARS value in order to develop ready-to-cook steaks from *Pangasius* by *sous-vide* process with extended shelf-

life. The development of such a convenient and nutritious product is expected to enhance the utilization of *Pangasius* by increasing its market acceptability.

Materials and methods

Materials

Sample

Fresh *Pangasius* were procured from Deshai dam, Karjat, Raigad and immediately brought to the laboratory in iced condition by keeping in insulated boxes filled with crushed ice in the ratio of 1:1 for further processing. The *Pangasius* fish used for study had a total length range from 40.0 to 44.5 cm and total weight range from 750 to 900 g.

Chemicals and glassware

Potassium carbonate, hydrochloric acid and concentrated sulphuric acid were procured from Qualigens, India. Trichloroacetic acid and sodium hydroxide were procured from Merck specialities Pvt. Ltd., Mumbai. Copper sulphate was brought from HIMEDIA Lab. Pvt. Ltd. All other reagents were of analytical grade. The glassware used in this study were from Borosil, India and Merck, India and plasticware were from Tarsons, India.

Equipments

Electronic Digital Thermometer (Fisher Scientific, India), Centrifuge (Remi Industries, India), Tissue Homogenizer (Poly System PT 2100, Kinematica, AG), Waterbath (Modern Industrial Corporation, Mumbai), Weighing balance (GR-200, A and D Ltd., India), Digital pH meter (Eutech tutor pH/°C meter, Eutech Instruments, Singapore), Texture analyzer (Stable Micro Systems, Surrey U.K.), Spectrophotometer (UV1 Thermo Spectronic, U.K.) and vacuum packing machine (ACE PAC, Vacupack, India).

Methods

Preparation of *sous-vide* products

Fish samples were beheaded, eviscerated and cut into uniform steaks having about 100 grams weight and then washed properly using potable water. Brining of washed steaks was done with 15% salt concentration for 10 min based on result of preliminary experiment. After that dip treatment of chitosan solution with three different concentrations (0.5, 1 and 1.5%) was given for 5 min and the steaks were coated with

chilli powder and turmeric powder at the rate of 3.13 and 0.63 g/steak respectively. Then the fish steaks were vacuum packaged in a food grade plastic pouch (12 μ PET/80 μ PE, Dimension: 220 mm $\times$ 330 mm) by using a vacuum packing machine (ACE PAC, Vacupack, India). The packaged samples were cooked in a water bath (Modern Industrial Corporation, Mumbai) at different time-temperature conditions as per the experimental design. After cooking, samples were cooled rapidly in iced water and then were stored at chilled condition (0–2 °C). During the storage process, thermocouple was placed into the centre of the sample and the temperature was monitored regularly. The samples were analyzed at 10 days interval during storage.

Proximate composition

Proximate composition was analyzed in accordance with AOAC (2005). Moisture content of fish muscle was determined by direct heating method using hot air oven at temperature 100 $\pm$ 5 °C for 16–18 h. Ash was analysed in a muffle furnace held at a temperature of 550 $\pm$ 50 °C and incinerated until white ash was obtained (about 6–7 h). The crude protein content of the sample was determined by using Micro-Kjeldahl apparatus with digestion and distillation method. Fat was analysed with Soxhlet apparatus using petroleum ether as solvent for extraction of fat.

Preliminary experiment for selection of hurdles

For selection of the best combination of hurdles and to observe the effect of them, six samples of *sous-vide* processed *Pangasius* steaks were prepared having different combination of spices, chitosan solution and acetic acid. In this process amount of spices (chilli and turmeric powder) were incorporated in the ratio of 5:1 based on result of preliminary experiment where as concentration of acetic acid and chitosan were 0.5 and 1% respectively. After that quality analyses including Total Volatile Base Nitrogen (TVBN), Thio-barbituric acid reactive substances (TBARS) and Total plate count (TPC) were done for all six samples to know the best combination of hurdles. On the basis of these results, variables are selected for the optimisation study.

Table 1 Independent variables and their coded levels used in RSM for optimization

Independent variables	Symbol	Coded levels		
		−1	0	1
Chitosan conc. (%)	X ₁	0.5	1	1.5
Temperature (°C)	X ₂	70	80	90
Time (min.)	X ₃	10	15	20

Design of experiment

Software (Unscrambler9.7, CAMO, OSLO, Norway) was used for experimental design, data analysis, and model building followed by Response Surface Methodology (RSM). The Box–Behnken design with three variables was employed in this study. The three independent variables used in this work were chitosan solution concentration (X₁), cooking temperature (X₂) and cooking time (X₃) with 3 levels of each variable, while the dependent variable was TBARS value. The 3 levels of independent variables are presented in Table 1. The values were selected based on the results of preliminary experiments. The Box–Behnken experimental design consists of fifteen runs with three central points (Table 2). Experimental runs were randomized to minimize the effects of unexpected variability in the observed response. The Box–Behnken design was used to identify the relationship between the response function and the process variable as well as to determine the conditions that optimize the cooking process.

Analysis of quality indices

pH value of fish homogenate was measured by a digital pH meter (Eutech tutor pH/°C meter, Eutech Instruments, Singapore) standardized by buffer at pH 4 and 9. Determination of TBARS according to Tarladgis et al. (1960), TVBN as per Conway and Byrne (1933) and TPC by the method of Maturin and Peeler (2001) using spread plate technique were carried out.

Table 2 Design matrix for the optimization of the *sous-vide* process parameters and TBARS values for all experiments on 40th day

Runs	X ₁	X ₂	X ₃	TBARS (mg MDA /kg)
1	0.5	70	15	1.62
2	1.5	70	15	1.14
3	0.5	90	15	2.22
4	1.5	90	15	2.34
5	0.5	80	10	1.98
6	1.5	80	10	2.46
7	0.5	80	20	2.14
8	1.5	80	20	2.11
9	1	70	10	2.01
10	1	90	10	2.12
11	1	70	20	1.20
12	1	90	20	2.57
13	1	80	15	1.08
14	1	80	15	1.03
15	1	80	15	1.04

X₁—concentration of chitosan (%), X₂—cooking temperature (°C), X₃—cooking time (minutes)

Statistical analysis

A surface regression model given below was derived for each response except sensory responses.

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3 + B_1^2X_1^2 + B_2^2X_2^2 + B_3^2X_3^2 + e$$

In this equation, Y represents the response variable and X_i ($i = 1-3$) represents the design variables. The coefficients of the polynomial equation were represented by B_0 (constant term), B_1 , B_2 and B_3 (linear coefficients), B_1^2 , B_2^2 , and B_3^2 (quadratic coefficients) B_{12} , B_{13} , and B_{23} (interactive coefficients). The random error is represented as e .

For the storage study, the data obtained from sampling were analyzed by Statistical Package for Social science (SPSS) software version 16. This was performed to examine whether there were significant differences in the parameters analyzed with storage time.

Results and discussion

Proximate composition of *Pangasius* fish

Proximate composition of *Pangasius* was carried out for moisture, protein, fat and ash (Table 3). Moisture content was estimated to be $78.79 \pm 0.05\%$ and the protein content was $18.05 \pm 0.06\%$. The total fat content of *Pangasius* was found as $4.34 \pm 1.46\%$ and ash content was around $0.28 \pm 0.19\%$. pH of the homogenized fish muscle was found to be 6.23. The proximate analysis showed that *Pangasius* muscle has lower moisture and higher protein and medium amount of lipid content. Lower moisture and higher lipid content in *Pangasius* muscles was reported by Hossain et al. (2004). Orban et al. (2008) found that protein content in *Pangasius* fillet was 12.6–15.6% and lipid content was 1.3–3.0%. Where as in another study by Majumdar et al. (2015), biochemical constituents of *Pangasius* (*Pangasianodon hypophthalmus*) were moisture ($740.4 \pm 2.5 \text{ g kg}^{-1}$), protein ($163.9 \pm 3.4 \text{ g kg}^{-1}$), fat ($75.7 \pm 1.4 \text{ g kg}^{-1}$) and ash ($10.9 \pm 0.2 \text{ g kg}^{-1}$).

Preliminary experiment for selection of hurdles

A preliminary experiment for selection of hurdles in *sous-vide* processing of *Pangasius* steaks was done and the comparison of shelf life on 40th day of storage is shown in Table 4. The TVBN, TBARS and TPC value of 6th sample (sample with spices and chitosan) were 12.80 mg-N%, 1.09 mg MDA/kg and $1.2 \times 10^1 \text{ cfu/g}$ respectively.

Table 3 Proximate composition of *Pangasius* fish

Parameters	Composition (%)
Moisture	78.79 ± 0.05
Crude protein	18.05 ± 0.06
Crude fat	4.34 ± 1.46
Ash	0.28 ± 0.19

Results are mean $\pm$ standard deviation on wet weight basis

Those values were less than other 5 samples which clearly indicated that the spices i.e. turmeric and chilli powder have antioxidant properties that helped in reduction of TBARS value and chitosan has alone showed excellent antimicrobial properties. The cooking of meat makes it more sensitive to lipid oxidation than raw meat, due to protein denaturation and structural damages in membranes caused by heat (Gray et al. 1996). Addition of antioxidants before cooking process therefore minimizes oxidative rancidity in meat. The TPC count was also very less than maximum permissible limit (7 log cfu/g) of microbiological load, recommended by ICMSF (1986) for fresh fish. Cakli et al. (2008) also reported that the psychrophilic bacterial count of culture species (*Diplodus puntazzo*) increased from 3.34 to 7.11 log cfu/g in 10 days of refrigerated storage. However preliminary experiment clearly demonstrated the efficacy of chitosan and spices as a potent antimicrobial and antioxidant agent that are used for preservation and shelf life extension of fish products. Therefore, the potential of chitosan and spices, as additional hurdles for *sous-vide* fish products was investigated.

Optimization of *sous-vide* process conditions for improved shelf life

Chitosan concentration (%), temperature ($^{\circ}\text{C}$), and time (min.) were considered as the independent variables for the optimization of *sous-vide* cook-chill conditions. TBARS value was identified as dependent variable on the basis of preliminary work because TBARS is a measure of malonaldehyde (MDA) content, one of the degradation products of lipid hydroperoxides formed during the oxidation process of polyunsaturated fatty acids (Gomes et al. 2003), which is widely used as spoilage index. The experiment was optimized using Box–Behnken Design of Response Surface Methodology by employing quadratic model to study the individual, interactive and square effects of the independent variables on the dependent variable. The model has the advantage that it permits the use of relatively few combinations of variables for determining the complex response function (Muthukumar et al. 2003). For that samples were developed according to the

Table 4 Effect of different hurdles on *sous-vide* cooked *Pangasius* steaks quality on 40th day

Sample	TVB-N (mg-N %)	TBARS (mg MDA/kg)	TPC (cfu/g)
1	16.86	2.50	4.24×10^2
2	16.40	1.41	6.5×10^1
3	15.28	1.80	1.4×10^1
4	14.34	1.20	2.5×10^1
5	15.46	2.11	1.5×10^1
6	12.80	1.09	1.2×10^1

Sample1 = control, sample 2 = steaks with spices, sample 3 = steaks with acetic acid (0.5%), sample 4 = steaks with spices and acetic acid (0.5%), sample 5 = steaks with chitosan solution (1%) and sample 6 = steaks with spices and chitosan solution (1%)

design given in Table 2 and kept in chilled condition (1–2 °C). Then the TBARS value was measured up to 40th day of storage. Optimization was done based on TBARS value on 40th day of storage. The measured values for the response along with code values are given in Table 2. Table 5 shows the experimentally measured response of TBARS values.

Development of response surface model and equations

The experimental data from different treatments as previously mentioned was analyzed using multiple regression analysis using the Unscrambler 9.7, CAMO, OSLO, Norway, to fit a full response surface model for the response TBARS value including all linear (X_1 , X_2 , X_3), interaction (X_1X_2 , X_1X_3 , X_2X_3), and quadratic terms (X_1^2 , X_2^2 , X_3^2) and the model was developed. The predicted values calculated by these models along with the measured values are presented in graph in Fig. 1. The ANOVA of the response was studied for finding the significance of variables and its interaction (Table 5).

To develop the fitted response surface model equation, all the insignificant terms ($p > 0.05$) were ignored. The ANOVA of the response was studied for finding the significance of variables and its interaction and square effects. The significance of all terms in the polynomial functions were assessed statistically using F-value at a probability (p) 0.05. R^2 values were used to judge the adequacy of the models.

The Response surface model equations for response, TBARS value is given below:

Table 5 ANOVA for quadratic model of TBARS

	SS	DF	MS	F-ratio	<i>p</i> value	B coefficients	Std error	Min point
Summary								
Model	4.304	9	0.478	23.953	0.001			
Error	0.1	5	0.02					
Adjusted total	4.404	14	0.315					
Variable								
Intercept	0.111	1	0.111	5.545	0.065	1.05	0.446	
Chitosan conc. (X_1)	0.001	1	0.001	0.051	0.831	0.023	0.1	1.083
Temperature (X_2)	1.345	1	1.345	67.358	0.0004	0.041	0.005	70.93
Time (X_3)	0.038	1	0.038	1.894	0.227	−0.014	0.01	16.48
X_1X_2	0.09	1	0.09	4.508	0.087	0.086	0.04	
X_1X_3	0.065	1	0.065	3.257	0.131	−0.073	0.04	
X_2X_3	0.397	1	0.397	19.88	0.007	0.18	0.04	
X_1X_1	0.882	1	0.882	44.178	0.001	0.279	0.042	
X_2X_2	0.313	1	0.313	15.688	0.011	0.166	0.042	
X_3X_3	1.483	1	1.483	74.279	0.0003	0.362	0.042	
Model check								
Main	1.384	3	0.461	23.101	0.002			
Int	0.552	3	0.184	9.215	0.018			
Squ	2.368	3	0.789	39.542	0.001			
Error	0.1	5	0.02					
Lack of fit	0.098	3	0.033	46.869	0.021			
Pure error	0.001	2	0.001					
Total error	0.1	5	0.02					

Multiple correlation = 0.989 (cal), R^2 = 0.977 (cal) and predicted minimum value = 0.85

Fig. 1 Response surface plot showing the effect of time and chitosan concentration on TBARS value

$$Y = 1.05 + 0.041X_2 + 0.18X_2X_3 + 0.279X_1^2 + 0.166X_2^2 + 0.362X_3^2$$

The optimum conditions of the design variables obtained by using Unscrambler Software were found to be chitosan concentration 1.08%, temperature 70.93 °C and cooking time 16.48 min and the predicted minimum response value for TBARS was found to be 0.855 mg MDA/kg of fish. The regression analysis of the response model developed was carried out. Table 5 shows the analysis of variance (ANOVA) for the model that explains the response of the dependent variable TBARS. The resulting model was found to be significant at p value 0.05 (0.0032). The ANOVA table shows the variables X_2 , X_2X_3 , X_1^2 , X_2^2 and X_3^2 are significant ($p < 0.05$). By analysis of variance, the R^2 value of this model was determined to be 0.975 (cal) which proved that that the regression model defined the true behavior of the system. From the response surface plots (Figs. 1, 2, 3), we can see that with the increase in the dependent (input) variables there was decrease in TBARS value but when the input variables increased further, the TBARS value started increasing. From the result it can be possible to standardize time-temperature combination with chitosan concentration for *sous-vide* cooking of *Pangasius* steaks.

Response surface plots for the response i.e. TBARS value was generated as a function of two independent variables, while keeping other independent variable at their centre point.

Figures 1, 2 and 3 showed the estimated response function and the effects of the independent variables (X_1 , X_2 , and X_3) on the dependent variable (TBARS value). A decrease in TBARS value was observed when the cooking time and chitosan concentration increased but when cooking time and chitosan concentration were further increased an increased in TBARS value was noticed (Fig. 1). This may be due to potent antioxidant or reducing capacity of chitosan as described by Pushkala et al. (2012) and Rajalakshmi et al. (2013).

Fig. 2 Response surface plot showing the effect of temperature and chitosan concentration on TBARS value

Fig. 3 Response surface plot showing the effect of time and temperature concentration on TBARS value

A linear positive effect of temperature and linear negative effect of chitosan concentration on TBARS value was observed in response surface plot (Fig. 2) generated in the present study. Low status of lipid oxidation was noticed when the chitosan concentration approached 1% and cooking temperature remained low.

The effect of cooking temperature and time were visible in the response surface plot (Fig. 3) in which the low TBARS values were observed when cooking was done at low temperature (70 °C) for prolonged time (20 min). Interestingly, the lipid oxidation was found maximum when cooking temperature and chitosan concentration reached the highest levels of experiment range (Fig. 2) and cooking time and temperature attained extreme levels of the range (Fig. 3). This may be due to the effect of temperature which accelerated the rate of oxidation and this has suppressed the antioxidant effect of chitosan as described by Vaidya and Eun (2013) that when oxidation time and temperature increased, p -anisidine value of walnut and grape seed oils increased due to formation of secondary oxidation products, mainly aldehydes in the oil, by decomposition of hydroperoxides. Lu et al. (2014) found

that generation of lipid oxidation product in krill oil is enhanced during storage after an increase in incubation temperature. Hamm et al. (1968) found that peroxide and TBA value of milk fat increased significantly at higher temperature where as no increase in peroxide and TBA value was observed at lower temperature.

Conclusion

The study optimized the conditions for *sous-vide* processing of *Pangasius* steaks using RSM. Accordingly, a chitosan concentration of 1.08%, temperature of 70.93 °C and cooking time of 16.48 min were found to be suitable. *Sous-vide* processing of *Pangasius* steaks under these conditions resulted in enhanced quality and oxidative stability of the product. This study presents a promising methodology of processing which can be effectively used by the processors for developing ready-to-cook convenient products from *Pangasius*.

Acknowledgements The authors are thankful to the Director of ICAR-Central institute of fisheries education for providing necessary facilities and funding.

References

- AOAC (2005) Official methods of analysis of AOAC international, 18th edn. AOAC International, Rockville
- Baskaran R, Devi AU, Nayak CA, Kudachikar VB, Prakash MK, Prakash M, Ramana KVR, Rastogi NK (2007) Effect of low-dose γ -irradiation on the shelf life and quality characteristics of minimally processed potato cubes under modified atmosphere packaging. *Radiat Phys Chem* 76(6):1042–1049. doi:10.1016/j.radphyschem.2006.10.004
- Cakli S, Kilinc B, Dincer T, Tolasa S (2008) Shelf life of new culture species (*Diplodus puntazzo*) in refrigerator. *J Muscle Foods* 19:315–332. doi:10.1111/j.1745-4573.2008.00121.x
- Conway EJ, Byrne A (1933) An absorption apparatus for the micro-determination of certain volatile substances: the micro-determination of ammonia. *Biochem J* 27(2):419
- Creed P (2001) Chilling and freezing of prepared consumer foods. *Advances in food refrigeration*. Leatherhead Publishing, Leatherhead, pp 438–471
- Garcia-Linares MC, Gonzalez-Fandos E, Garcia-Fernandez MC, Garcia-Arias MT (2004) Microbiological and nutritional quality of sous-vide or traditionally processed fish: influence of fat content. *J Food Qual* 27:371–387
- Gomes HdA, Silva ENd, Nascimento MRLd, Fukuma HT (2003) Evaluation of the 2-thiobarbituric acid method for the measurement of lipid oxidation in mechanically deboned gamma irradiated chicken meat. *Food Chem* 80:433–437. doi:10.1016/S0308-8146(02)00499-5
- Gray J, Gomaa E, Buckley D (1996) Oxidative quality and shelf life of meats. *Meat Sci* 43:111–123. doi:10.1016/0309-1740(96)00059-9
- Hamm D, Hammond E, Hotchkiss D (1968) Effect of temperature on rate of autooxidation of milk fat. *J Dairy Sci* 51:483–491. doi:10.3168/jds.S0022-0302(68)87016-X
- Hossain M, Kamal M, Shikha FH, Hoque M (2004) Effect of washing and salt concentration on the gel forming ability of two tropical fish species. *Int J Agri Biol* 6:762–766
- ICMSF (1986) International commission on microbiological specifications for foods. Sampling plans for fish and shellfish, vol 2. ICMSF, microorganisms in foods. Sampling for microbiological analysis: principles and scientific applications, 2edn. University of Toronto Press, Toronto, Canada
- Lu F, Bruheim I, Haugsgjerd B, Jacobsen C (2014) Effect of temperature towards lipid oxidation and non-enzymatic browning reactions in krill oil upon storage. *Food Chem* 157:398–407. doi:10.1016/j.foodchem.2014.02.059
- Majumdar RK, Saha A, Dhar B, Maurya PK, Roy D, Shitole S, Balange AK (2015) Effect of garlic extract on physical, oxidative and microbial changes during refrigerated storage of restructured product from Thai pangas (*Pangasianodon hypophthalmus*) surimi. *J Food Sci Tech* 52(12):7994–8003. doi:10.1007/s13197-015-1952-7
- Maturin L, Peeler JT (2001) BAM: aerobic plate count. U.S. Food and Drug Administration. <http://www.fda.gov/Food/FoodScienceResearch/LaboratoryMethods/ucm063346.htm>. Accessed 05 Aug 2013
- Montgomery D (2001) Design and analysis of experiments, 5th edn. Wiley, New York
- Muthukumar M, Mohan D, Rajendran M (2003) Optimization of mix proportions of mineral aggregates using Box Behnken design of experiments. *Cem Concrete Comp* 25:751–758. doi:10.1016/S0958-9465(02)00116-6
- Orban E, Nevigato T, Di Lena G, Masci M, Casini I, Gambelli L, Caproni R (2008) New trends in the seafood market. Sutchi catfish (*Pangasius hypophthalmus*) fillets from Vietnam: nutritional quality and safety aspects. *Food Chem* 110:383–389. doi:10.1016/j.foodchem.2008.02.014
- Pushkala R, Parvathy K, Srividya N (2012) Chitosan powder coating, a novel simple technique for enhancement of shelf life quality of carrot shreds stored in macro perforated LDPE packs. *Innov Food Sci Emerg Technol* 16:11–20. doi:10.1016/j.ifset.2012.03.003
- Rajalakshmi A, Krithiga N, Jayachitra A (2013) Antioxidant activity of the chitosan extracted from shrimp exoskeleton. *Middle-East J Sci Res* 16:1446–1451. doi:10.5829/idosi.mejrs.2013.16.10.12033
- Redmond G, Gormley RT, Butler F, Dempsey A, Oxley E, Gerety A (2004) Freeze-chilling of ready-to-eat meal components. The National Food Centre Research report no. 66. Teagasc, Teagasc 19 Sandymount Avenue Ballsbridge Dublin 4
- Singh A, Lakra W (2012) Culture of *Pangasianodon hypophthalmus* into India: impacts and present scenario. *Pak J Biol Sci* 15:19. doi:10.3923/PJBS.2012.19.26
- Tansey F, Gormley RT, Carbonell S, Oliviera J, Bourke P, O’Beirne D (2005) Developing sous vide/freezing systems for ready-meal components. Teagasc Oakpark Carlow Co. Carlow, Ashtown, Dublin 15, Ireland
- Tarladgis BG, Watts BM, Younathan MT, Dugan L Jr (1960) A distillation method for the quantitative determination of malonaldehyde in rancid foods. *J Am Oil Chem Soc* 37:44–48
- Vaidya B, Eun J-B (2013) Effect of temperature on oxidation kinetics of walnut and grape seed oil. *Food Sci Biotech* 22:273–279. doi:10.1007/s10068-013-0077-x