Development of shelf-stable, ready-to-eat (RTE) shrimps (*Litopenaeus vannamei*) using water activity lowering agent by response surface methodology

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Abstract Three water-activity-lowering agents (composite phosphate, sorbitol and glycerol) were used to develop a kind of shelf-stable, ready-to-eat (RTE) shrimp. Formula of water-activity-lowering agents was optimized by response surface methodology (RSM) using a central composite design. Model equation was proposed with regard to the contents of composite phosphate (X_1), sorbitol (X_2) and glycerol (X_3): $Y = 1.0004 - 0.5851X_1 - 0.0322X_2 - 0.0243X_3 + 0.0167X_1X_2 + 0.0156X_1X_3 + 1.0000 \times 10^{-3}X_2X_3 + 1.0844X_1^2 + 3.3500 \times 10^{-3}X_2^2 + 2.6000 \times 10^{-3}X_3^2$. The model with a very low probability value ($P < 0.0003$) was highly significant and the value of lack-of-fit was 0.4028, indicating that the model could predict water activity of shrimps using different agents. Composite phosphate of 0.22%, sorbitol of 3.12% and glycerol of 2.51% were found to be the optimal condition to obtain the lowest water activity of 0.884. Compared to the control shrimps, RTE shrimps treated with water-activity-lowering agents had a longer shelflife and higher sensorial acceptability. During storage at temperature of 35 °C, the quality of RTE shrimps in term of appearance, flavor and texture was found to be superior to the untreated ones. Texture profile, TBARS value, contents of astaxanthin and free amino acid of treated samples were found to be decreased slower from origin value compared to that of untreated samples. These RTE shrimps were biologically safe and sensorially acceptable after 30 days of storage at temperature of 35 °C. Briefly, the application of water-activity-lowering agents extent the

shelflife of RTE shrimps obviously and would be beneficial for the exploitation of white shrimp.

Keywords Ready-to-eat shrimp · Water-activity-lowering agent · Response surface methodology · Storage

Introduction

Fresh shrimps are highly perishable, thus they predominantly appear in the form of frozen raw or cooked products in markets. A ready-to-eat (RTE) product would be more convenient for the consumer. RTE shrimp is a novel type of important domestic products in China. The shrimp is apt to be microbially contaminated as result of the ways of post-harvest and process by manpower, affecting the storage characteristic.

Investigations have been carried out to prepare shelf-stable and microbiologically safe RTE shrimps using combination of various hurdles such as reducing water activity (a_w), packaging pickling and sterilization. Reduction of a_w is an effective preservation method of perishable materials and growth of the spoilage bacteria is will be partially restrained when the water activity is less than 0.90 (Ledward 1981). There are a number of reports on the development of intermediate moisture (IM) products having reduced a_w (Wang and Leistner 1993, 1994; Kanatt et al. 2002). RTE shrimps are also reported to be processed by decreasing water activity (Kanatt et al. 2006; Thomas et al. 2007). The most effective way to reduce water activity is dehydration. But such products are however susceptible to spoilage by mold and are inferior in quality due to loss of color, texture and flavor (Singh et al., 2006; Sagar and Suresh Kumar 2010). Water-activity-lowering agents could maintain high water content and low a_w , maintaining the

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quality of food in high level. Composite phosphate, sorbitol and glycerol are found to be valid water-activity-lowering agents (Stella et al. 1994; Galmarini 2008; Lilia et al. 2010). But their composite utilization in the process of RTE shrimps is limited, while common method to optimize formula is response surface methodology (RSM) Alok et al. (2011); Subir et al. 2011; Baljeet et al. 2011).

When developing new products that promote shrimp as the primary ingredient, the product developer has two main concerns: quality and shelflife. On the account of the influence of microbe and enzyme, texture and color deteriorate during storage. Protein breakdown induces the deterioration of texture index. TPA experiment is usually carried out to determine the texture of food (Niamnuy et al. 2007a; Hatae et al. 1989; Kanatt et al. 2006; Thomas et al. 2007). Sensorial score indicates acceptability of shrimp products to consumers and could be used to determine the shelflife. Sensory analysis of shrimp products has been conducted by several researchers (Morita et al. 2001; Farmer et al. 2000; Papadopoulos and Finne 1986; Bak et al. 1999; Lin et al. 1999; Xiong et al. 2002; Erickson et al. 2007). At present, the research about development of RTE shrimps with water-activity-lowering agents is still limited. In this paper, composition of water-activity-lowering agents in RTE shrimps was optimized by using RSM and quality change during storage was evaluated.

Material and methods

Preparation of instant shrimps

White shrimps (*Penaeus vannamei*) were purchased from local aquatic products market. The average mass of headless white shrimp was 7.35 ± 0.20 g and the average equivalent diameter was 1.63 ± 0.07 cm. All the shrimps were procured from the same marineland and decapitated less than 24 h post-mortem. The headless and beheaded shrimps were soaked in different water-activity-lowering agents for 1 h. The pickled shrimps were steamed for 5 min in a perforated steel container and then cooled. After being drained, shrimps were seasoned using mixed quelite (1.5% salt, 1% sugar, 1% aginomoto and 0.1% I & G). Shrimps were dehydrated in the hot pump for 2 h. Then shrimps were vacuumized in polyethylene bag and packed products were autoclaved at the temperature of 115 °C for 5 min. Then shrimps were stored at the condition of constant temperature (35 °C).

Response surface methodology

In order to describe the nature of the response surface in the experimental region, a Box–Behnken design was

applied (Box and Behnken 1960). RSM was explored in designing this experiment to optimize the formula of water-activity-lowering agents. As presented in Table 1, the experimental design involved three parameters (X_1 , X_2 and X_3), each at three levels, coded -1, 0, and +1 for low, middle and high concentrations, respectively. Contents of composite phosphate (0.1–0.25%), glycerol (1–3%) and sorbitol (1–4%) were adopted. Table 2 represents the design matrix of a 17 trials experiment. For predicting the optimal point, a second order polynomial function was fitted to correlate the relationship between independent variables and response. For the three factors, the equation was as follow:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \quad (1)$$

The coefficients of the polynomial were represented by b_0 (constant term), b_1 , b_2 and b_3 (linear coefficient), b_{11} , b_{22} and b_{33} (quadratic coefficient), and b_{12} , b_{13} and b_{23} (interactive coefficient). Y was response (a_w). X_1 , X_2 and X_3 were contents of composite phosphate, glycerol and sorbitol, respectively.

The software Design Expert (Version 7.0.1, Stat-Ease, Inc., Minneapolis, USA) was used for experimental design, data analysis and quadratic model building. The optimal conditions for water- activity-lowering agents were obtained by solving the regression equation and also by analyzing the response surface contour plots using the same software.

Measurement of water activity and content

A_w of shrimps was measured using Novasina ms1 set-aw water activity analyzer (Novasina, Novasina Ltd, Switzerland). Water content of RTE was analyzed using oven drying method.

Microbiological analysis

Samples, about 3 to 4 pieces, were randomly taken to estimate total viable counts (TVC) according to standard AOAC methods (2002). Firstly, 10.0 g of shrimp meat were

Table 1 Design of experiment-levels of various process parameters

Parameter	Level		
	-1	0	+1
X_1 : composite phosphate	0.10	0.17	0.25
X_2 : glycerol	1	2	3
X_3 : sorbitol	1.0	2.5	4.0

Table 2 The actual design of experiments and response of lowering water activity

Experiment No.	X ₁	X ₂	X ₃	a _w ^a
1	0.10	3	2.5	0.885
2	0.250	2	1.0	0.892
3	0.250	3	2.5	0.870
4	0.175	3	1.0	0.882
5	0.175	2	2.5	0.879
6	0.175	2	2.5	0.879
7	0.100	1	2.5	0.913
8	0.175	2	2.5	0.888
9	0.175	2	2.5	0.879
10	0.175	1	1.0	0.913
11	0.175	2	2.5	0.879
12	0.175	1	4.0	0.895
13	0.250	1	2.5	0.893
14	0.250	2	4.0	0.871
15	0.100	2	4.0	0.890
16	0.100	2	1.0	0.918
17	0.175	3	4.0	0.870

^a The values given in the table are the average of three dependent experiments

blended with 90 ml of 0.85% sterile saline solution and then stomached for 3 min. Serial decimal dilutions of 10⁻¹, 10⁻² and 10⁻³ were prepared with 0.85% sterile saline solution diluent. And then 0.1 ml of each dilution was pipetted onto the surface of plate count agar (Oxoid) plates. They were then incubated for 2 days at 35 °C.

TBA analysis

The thiobarbituric acid (TBA) reactive substances assay was performed as described by Karin and Daren (2010). Briefly, duplicate 0.2000 g shrimp meat was mixed with 3.0 ml of stock solution containing 0.375% thiobarbituric acid, 15% trichloroacetic acid, and 0.25 N HCl. The mixture was heated for 10 min in a boiling water bath to develop a pink color, cooled in tap water and then centrifuged (4,300×g for 10 min). The absorbance of the supernatant was measured by spectrophotometer at 532 nm. TBA values (mg malondialdehyde/kg of shrimp meat) were calculated using an extinction coefficient of 156,000 M⁻¹·cm⁻¹ (Sinhuber and Yu 1958) as follows:

$$\text{TBA(mg/kg)} = A_{532} \times \frac{1\text{Mchromagen}}{156,000} \times \frac{1\text{mol/L}}{\text{M}} \times \frac{0.0003\text{L}}{1.0\text{gmeat}} \times \frac{72.07\text{gMDA}}{\text{mole}} \times \frac{1000\text{g}}{\text{kg}} \quad (2)$$

Texture profile analysis

A texture analyzer (TMS texture analyzer, FTC corporation, USA) was used to evaluate the texture of shrimp, such as hardness, springiness, cohesiveness and chewiness. Texture profile analysis was conducted in the 2nd (thickest) segment of shrimp. The shrimp was placed on a planar base in the direction of variable thickness and the force was then applied to the sample with the barprobe of P/1.0 at a constant speed of 60 mm/min to a depth of 70% deformation.

The maximum compressive stresses (maximum compressive forces during compression divided by the contact area between shrimp and probe) were indicated as the hardness values (Niamnuy et al. 2007b). Specific values between the first and second compressive stress were indicated as springiness. Cohesiveness is the extent to which a material can be deformed before it ruptures. It was calculated as the ratio (dimensionless) of the positive force area during the second compression portion to the positive area during the first compression. Chewiness was calculated as the product of hardness, cohesiveness and springiness. The measurements were performed on 20 shrimp samples and the average values were reported.

Determination of astaxanthin

Astaxanthin content was determined according to the modified method of Chalida et al. (2008). Shrimp meat (2.0000 g) was extracted for three times, each with 40 ml of acetone using an Ultra-Turrax homogenizer (IKA T18 basic, Staufen, Germany) at speed of 6,000 g for 2 min. After extraction, the samples were centrifuged (Jouan, MR23i, France) at 4,000×g at 4 °C for 5 min. To separate the water insoluble compounds, the acetone extracts of the samples were transferred to 40 ml of petroleum ether in a 250 ml separating funnel. Then, 100 ml of distilled water containing 0.5% (w/v) sodium chloride was added to the mixture. After continuous shaking by hands, approximately 1 h later, the petroleum ether layer was separated and transferred into a 50 ml volumetric flask. The absorption spectrum of the water insoluble compounds was recorded at 472 nm using a visible spectrophotometer (Unico 2000, Shanghai Scientific Instruments, Shanghai, China). Calculation of the astaxanthin concentration was done using the standard curve of astaxanthin of Tolasa et al. (2005). Analyses of the samples were done in triplicate.

Sensory analysis

Acceptability of products at different storage points was determined as described in Kanatt et al. (2002). Briefly, convenient shrimp product was presented to a panel of 12

trained panelists for sensory evaluation. The panelists were familiar with the characteristics of RTE shrimps. Panelists were asked to rate samples as ‘acceptable’ or ‘non-acceptable’ on the basis of appearance, odor, flavor and taste using a 10-point scale, where 10 corresponds to a product of highest quality and 0 corresponds to a poor quality of product. Scores of 6 and above were considered acceptable.

Statistical analysis

All the measurements in this study were made in three replications, except texture analysis. Statistical analysis of the results was conducted by using Statistical Analysis System (SAS 8.2, SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) was employed to determine the significance of main effects. Significant differences ($P < 0.05$) between means were identified by using Duncan’s multiple range test.

Results and discussion

Optimization of water-activity-lowering agents’ formula

White shrimps contained $75 \pm 1.5\%$ moisture, $90 \pm 1.2\%$ protein (dry basis). After dehydration, the shrimp product contained $58 \pm 1.8\%$ moisture. The experimental results on the effect of parameter namely, contents of composite phosphate, glycerol and sorbitol on the response function (water activity), are shown in Table 2. When the water-activity-lowering agents were added to shrimps, water activity decreased obviously. The lowest a_w (0.870) was observed in experiment 14, which contained 0.175% composite phosphate, 3% glycerol and 4% sorbitol. The highest a_w (0.918) was found in experiment 16, which contained 0.1% composite phosphate, 2% glycerol and 1% sorbitol.

Data obtained from the experiments (Table 2) was analyzed by linear multiple regression using software Design Expert version 7.0.1. The center point in the design was repeated five times for estimation of errors (Tables 2 and 3). The following equation was obtained:

$$Y = 1.0004 - 0.5851X_1 - 0.0322X_2 - 0.0243X_3 + 0.0167X_1X_2 + 0.0156X_1X_3 + 1.0000 \times 10^{-3}X_2X_3 + 1.0844X_1^2 + 3.3500 \times 10^{-3}X_2^2 + 2.6000 \times 10^{-3}X_3^2 \quad (3)$$

Where Y was the predicted response variable, viz., a_w ; X_1 , X_2 and X_3 were the coded values of the independent variables, viz., contents of composite phosphate, glycerol and sorbitol, respectively.

Table 3 Analysis of variance (ANOVA) for response surface quadratic model demineralization

	Degree of freedom	Sum of squares	Mean squares	p-Value
Model	9	3.424×10^{-3}	3.805×10^{-4}	0.0003
Residual	7	1.256×10^{-4}	1.794×10^{-5}	
Lack of fit	3	6.075×10^{-5}	2.025×10^{-5}	0.4028
Pure Error	4	6.480×10^{-5}	1.620×10^{-5}	
Corrected Total	16	3.550×10^{-3}		

$$R^2 = 0.9646, \text{ Adjusted } R^2 = 0.9192, R = 0.9813$$

The statistical significance of Eq. 3 was checked by an F-test, and the analysis of variance (ANOVA) for response surface quadratic model is summarized in Table 4. It is evident from Table 4 that the model was highly significant, as was evident from the model F-value and a very low probability value ($P < 0.0003$). The quadratic regression was significant at the level of 0.9813. The goodness of the model could be checked by the determination coefficient R^2 and the multiple correlation coefficient, R . The value of adjusted R^2 which was 0.9646 for Eq. 2 suggested that the total variation of 96.46% for demineralization was attributed to the independent variables and only less than 4% of the total variation could not be explained by the model. The value of lack-of-fit was non-significant ($P = 0.4028$). In brief, the model could be used to predict a_w of shrimps with different agents.

Verification of model

To confirm the validity of the statistical experimental strategies, six additional confirmation experiments were conducted. A_w of RTE shrimp under the optimal content are listed in Table 4. The measured water activities were close to the predicted values for a_w using RSM. These results confirmed the predictability of the model for shrimp with water-activity-lowering agents in the experimental condition used. The optimal formula of water-activity-lowering agents was as following: composite phosphate of 0.22%, sorbitol of 3.12% and glycerol of 2.51%.

The purpose of this study was to reduce the water activity of shrimps and extend the shelflife. After optimization, a_w of RTE shrimps was reduced to less than 0.90. Under this condition, water content of shrimps was about $58 \pm 0.50\%$, and the mouth feel of shrimp was good. Comparably, a_w of untreated shrimps was 0.94 and products was adapt to deteriorate. Most bacteria fail to grow at a_w of less than 0.90 (Ledward 1981). IM products in which a_w are reduced to inhibit growth of micro organisms (bacteria and fungi) can be stored for extended duration under ambient conditions (Ledward 1981). The effect of water-activity-lowering agents on the quality change during storage was discussed then.

Table 4 Six groups of parameters from regression model and verification results

	Parameters			a_w		Relative error/%
	composite phosphate/%	Glycerol/%	Sorbitol/%	Observed A_w	Predicted A_w	
1	0.22	2.51	3.12	0.885	0.869	1.84
2	0.22	2.51	3.12	0.889	0.869	2.30
3	0.22	2.51	3.12	0.878	0.869	1.04
4	0.22	2.51	3.12	0.885	0.869	1.84
5	0.22	2.51	3.12	0.875	0.869	0.69
6	0.22	2.51	3.12	0.890	0.869	2.42

Texture profile analysis

Most of the water in muscle is held within the myofibrils, in the space between the thick filaments (myosin) and thin filaments (actin) (Offer et al. 1989). The system of food and

water affects the texture. During storage, breakage of macromolecules in food occurs which in turn influences its texture properties. According to the Fig. 1a and b, the indexes of TPA, such as hardness, chewiness, elasticity and coherency, decreased obviously. And deterioration of

Fig. 1 Textural and chemical changes in untreated and treated ready-to-eat shrimps during storage at 35°C ($n=20$ for textural changes; $n=3$ for chemical changes). **a** hardness and chewiness; **b** elasticity and coherency; **c** TBA value; **d** free amino acid and astaxanthin content

treated shrimps with water-activity-lowering agents was slower as compared to that of untreated samples. The breakage of macromolecules related to a_w . Reduction of a_w restrained the deterioration of texture. It was thus clear that reduction of a_w restrains deterioration of texture on account that chemical reaction was correlated with a_w of food. According to Fig. 1d, free amino acid of shrimp products increased. Breakage of macromolecules, such as protein, produces micromolecule. Amino acid is by-product of protein splitting. In initial period of storage, lowering of a_w restrained the increase of free amino acid. The decrease of amino acid relates to creation of the amino, such as biogenic amino. Zhao et al. (2007) reported that content of biogenic amino in shrimps increased during storage. In brief, during storage, the texture of RTE shrimps was maintained due to the addition of water-activity-lowering agents.

Change of TBARS and astaxanthin

The TBARS content is an important quality index, indicating lipid oxidation in food product. The results of TBARS change in RTE shrimps during storage are shown in Fig. 1c. During storage, a gradual increase in TBARS was noted. Astaxanthin is one of the carotenoid which is fat-soluble and apt to be oxidated when exposed to the sunlight or oxygen (MIKI et al. 1982). During the storage, oxidation and decomposition caused by air and beam lead to the loss of astaxanthin and fading of shrimp meat. According to Fig. 1d, the continued decrease of astaxanthin in RTE shrimps occurred during storage. However, slower changes of TBARS and astaxanthin were observed during storage of treated shrimps with water-activity-lowering agents. Development of lipid peroxidation in meat is influenced by several factors such as packaging, storage and other processing conditions. Processing conditions such as cooking and heating are known to accelerate lipid

peroxidation (Kanner 1994). According to the previous research (kanner 1994), peroxidation of lipids had been getting quickly with increase of a_w . Especially in the later period of storage, TBARS of treated shrimps with low a_w was lower than that of untreated ones obviously. It was thus clear that the addition of water-actiity-lowering agents obviously restrained the oxidation of astaxanthin so that color of RTE shrimps was preserved better.

Sensory evaluation and microbiological analysis

The sensory scores and counts of bacterial population in RTE shrimps are shown in Table 5. Different changes in appearance, odor and taste of treated and untreated shrimps were detectable by sensory evaluation panelists. After 20 days storage, quality of untreated shrimps was unacceptable. But treated shrimps could be accepted after 30 days according to sensory index. Hence, addition of water-activity- lowering agents increased the sensorial acceptability of RTE shrimps during storage. The total viable bacterial count results were identical with sensory experiment.

Thus, shrimps that were treated with water-activity-lowering agents, such as composite phosphate, glycerol and sorbitol, obviously increased storability. Deterioration of texture, content of astaxanthin and sensory score was slower compared to the untreated shrimps. Therefore, shelflife of RTE shrimps was extended due to use of water-activity-lowering agents.

Conclusion

The present study showed the development of shelf-stable convenience RTE shrimps with water-activity-lowering agents and formula was optimized using response surface methodology. A_w of products was reduced, but moisture

Table 5 Sensorial score and TVC results of untreated and treated shrimps

Storage time	Untreated shrimps					Treated shrimps				
	Appearance	Flavor	Texture	Sensory score	TVC (cfu/g)	Appearance	Flavor	Texture	Sensory score	TVC (cfu/g)
0	8.9	8.5	9.1	8.8	ND	9	8.2	9.0	8.7	ND
5	8.6	8.3	8.9	8.6	ND	8.7	7.6	8.7	8.3	ND
10	8.1	7.5	8.4	8.0	10	8.2	7.5	8.2	8.0	ND
15	7.7	7.1	7.8	7.5	10	7.9	7.1	7.9	7.6	ND
20	6.4	6.2	5.4	6.0	10-10 ³	7.2	6.8	7.1	7.0	10
30	5.2	4.7	3.1	4.3	NCO	6.5	6.2	6.2	6.3	10
40	3.9	3.1	3.0	3.3	NCO	5.3	5.9	5.8	5.7	10

The values given in the table are the average of three dependent experiments

TVC total viable counts, ND not detected by method used, NCO analysis not carried out as visual fungal growth was observed

content kept at high level, maintaining sensorial acceptability of RTE shrimps at a high level. Deteriorations of shrimps during storage were restrained so that shelflife was extended. Therefore, one RTE with good mouthfeel and long shelflife was obtained and such product is of a great economic significance by expanding the exploitation of white shrimps.

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References

- Alok J et al (2011) Process optimization for manufacture of pearl millet-based dairy dessert by using response surface methodology (RSM). J Food Sci Technol. doi:10.1007/s13197-011-0347-7
- AOAC (2002) Official methods of analysis. Standard methods for the examination, 17th edn. Association of Official Analytical Chemists, Washington, DC
- Bak LS, Andersen AB, Andersen EM, Bertelsen G (1999) Effect of modified atmosphere packaging on oxidative changes in frozen stored cold water shrimp (*Pandalus borealis*). Food Chem 64:169–175
- Baljeet SY et al (2011) Optimization of osmotic dehydration conditions of peach slices in sucrose solution using response surface methodology. J Food Sci Technol. doi:10.1007/s13197-011-0298-z
- Box GEP, Behnken DW (1960) Some new three level designs for the study of quantitative variables. Technometrics 2:455–475
- Chalida N, Sakamon D, Somchart S (2008) Kinetics of astaxanthin degradation and color changes of dried shrimp during storage. J Food Eng 87:591–600
- Erickson MC, Bulgarelli MA, Resurreccion AVA, Vendetti RA, Gates KA (2007) Sensory differentiation of shrimp using a trained descriptive analysis panel. LWT—Food Sci Technol 40:1774–1783
- Farmer LJ, McConnell JM, Kilpatrick DJ (2000) Sensory characteristics of farmed and wild Atlantic salmon. Aquaculture 187:105–125
- Galmarini MV, Chirife J, Zamora MC, Pérez A (2008) Determination and correlation of the water activity of unsaturated, supersaturated and saturated trehalose solutions. LWT—Food Sci Technol 41(4):628–631
- Hatae K, Lee KH, Tsuchiya T, Shimada A (1989) Textural properties of cultured and wild fishmeat. Nippon Suisan Gakkaishi 55:363–368
- Kanatt SR, Chawla SP, Chander R, Bongirwar DR (2002) Shelf-stable and safe intermediate moisture (IM) meat products using hurdle technology. J Food Protect 65:1628–1631
- Kanatt SR, Chawla SP, Chander R, Sharma A (2006) Development of shelf-stable, ready-to-eat (RTE) shrimps (*Penaeus indicus*) using γ -radiation as one of the hurdles. LWT—Food Sci Technol 39:621–626
- Kanner J (1994) Oxidative processes in meat and meat products: quality implications. Meat Sci 36:169–189
- Karin A, Daren C (2010) Comparison of spice-derived antioxidants and metal chelators on fresh beef color stability. Meat Sci 85:613–619
- Ledward DA (1981) Intermediate moisture meats. Lawrie developments in meat science. Applied Science Publisher, London, pp 159–194
- Lilia N, Paola P, Gianni B, Danila T, Giampiero S (2010) Influence of water activity and molecular mobility on peroxidase activity in salt and sorbitol–maltodextrin systems. J Food Eng 101(3):289–295
- Lin T, Durance TD, Scaman CH (1999) Physical and sensory properties of vacuum microwave dehydrated shrimp. J Aquat Food Prod Technol 8(4):41–53
- Miki W, Yamaguchi K, Konosu S (1982) Comparison of carotenoids in the ovaries of marine fish and shellfish. Comp Biochem Physiol B 71(1):7–11
- Morita K, Kubota K, Aishima T (2001) Sensory characteristics and volatile components in a romas of boiled prawns prepared according to experimental designs. Food Res Int 34:473–481
- Niamnuy C, Devahastin S, Soponronnarit S (2007a) Quality changes of shrimp during boiling in salt solution. J Food Sci 72:289–297
- Niamnuy C, Devahastin S, Soponronnarit S (2007b) Effects of process parameters on quality changes of shrimp during drying in a jet spouted bed dryer. J Food Sci 72(9):553–563
- Offer G, Knight P, Jeacocke R, Almond R, Cousins T, Elsej J (1989) The structural basis of the water-holding, appearance and toughness of meat and meat product. Food Microstruct 8(1):151–170
- Papadopoulos LS, Finne G (1986) Effect of environmental salinity on sensory characteristics of penaeid shrimp. J Food Sci 51:812–814
- Sagar VR, Suresh Kumar P (2010) Recent advances in drying and dehydration of fruits and vegetables: a review. J Food Sci Technol 47(1):15–26
- Singh U, Sagar VR, Behera TK, Kumar PS (2006) Effect of drying conditions on the quality of dehydrated selected vegetables. J Food Sci Technol 43:579–582
- Sinhuber RO, Yu TC (1958) 2-Thiobabutaric acid method for the measurement of rancidity in fisher products: II. The quantitative determination of malonaldehyde. Food Technol 12(1):9–12
- Stella MA, Jorge C, Lía NG (1994) Determination and correlation of the water activity of propylene glycol solutions. Food Res Int 27(1):65–67
- Subir KC et al (2011) Influence of processing parameters on textural characteristics and overall acceptability of millet enriched biscuits using response surface methodology. J Food Sci Technol 48(2):167–174
- Tolasa S, Cakli S, Ostermeyer U (2005) Determination of astaxanthin and canthaxanthin in salmonid. Eur Food Res Technol 221:787–791
- Thomas JR, Douglas LM, Linda SA, Patti CC (2007) Combined effect of packaging atmosphere and storage temperature on growth of *Listeria monocytogenes* on ready-to-eat shrimp. Food Microbiol 24:703–710
- Wang W, Leistner L (1993) Shafu: a novel dried meat product of China based on hurdle technology. Fleischwirtschaft 73:854–856
- Wang W, Leistner L (1994) Traditional Chinese meat products and their optimization by hurdle technology. Fleischwirtschaft 74:1135–1145
- Xiong S, Xiong YL, Blanchard SP, Wang B, Tidwell JH (2002) Evaluation of tenderness in prawns (*Macrobrachium rosenbergii*) marinated in various salt and acid solutions. Int Journal of Food Sci Technol 37:291–296
- Zhao QX, Xu J, Xue CH (2007) Determination of biogenic amines in squid and white prawn by high-performance liquid chromatography with postcolumn derivatization. J Agric Food Chem 55:3083–3088