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Research Article

Marinating yield optimization of phosphate soaking process to enhance water uptake in white shrimp (*Penaeus vannamei*)

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Abstract: This paper aims to demonstrate the application of different marinating conditions (i.e., phosphate concentration, partial pressure and shrimp to marinating solution ratio) to maximize water uptake and minimize processing time during soaking. The water uptake profiles of single and interacting effects of each treatment were studied to provide a comprehensive knowledge of the shrimp marinating process. A laboratory-scale hermetic reactor was constructed to accommodate the change of inside pressure from positive to negative and equipped with temperature sensors to monitor the core temperatures of shrimp and marinating solution during soaking. The marinating pressures were varied using a vacuum pressure (approximately 5 kPa), an atmospheric pressure (100 kPa) and three positive pressures (200, 400, and 600 kPa). Three levels of phosphate concentration (i.e., 1, 3, and 5 %, w/v) and three ratios of shrimp to marinating solution (i.e., 1:20, 1:10, and 1:2) were included in the experiments. The marinating temperature was held constant at 4°C. At each sampling interval, triplicate samples were taken to observe the change of soaking yield over one hour of marination. Higher phosphate concentration resulted in higher amount of water absorbed into the shrimp meat. As high as 110.63 ±0.3 % soaking yield can be achieved after an hour of marination in the 1:20 ratio and vacuum treatment. Vacuum marination noticeably returned better soaking yield comparing to the other treatments. At low phosphate concentration in marinade solution, the difference of soaking yield between treatments was minimal.

Keywords: seafood, partial pressure, sodium tripolyphosphate (STPP), shrimp to marinating ratio, soaking yield, vacuum treatment, Thailand

Introduction

Frozen shrimp export plays a critical role in buffering domestic shrimp surpluses and generating export revenue for the Thai economy. For a number of years, shrimp farms and related industry have multiplied in many regions, especially the east and the south of Thailand. Not only are shrimp economically important species but are also sources of nutrition for the human diet, containing many amino acids, peptides, proteins and other useful nutrients [1]. Among several aquaculture industries, Penaeid shrimp, in particular white shrimp (*Penaeus vannamei*), are of paramount interest for food processors, exporters and aquaculture scientists alike. This species has become one of the dominant economically-important shrimp products of Thailand [1, 2].

Processing of frozen shrimp products encompasses a wide array of pre-and post-treatments to create higher value addition. Many desirable attributes can be modified during these steps, for example, texture and yield improvement during the marinating process. In order to retain as much water uptake as possible, proper water-binding compounds must be effectively selected to increase water holding capacity such as sodium chloride, sodium phosphates, etc. [3]. The polyphosphates have been widely accepted as additives in seafood and sodium tripolyphosphates (STPP) are the most popular choice of polyphosphates to improve functional properties during marinating [4, 5].

The science of the physicochemical interaction between STPP and shrimp protein has been well-established. The film of STPP and protein on the surface of the shrimp flesh is formed to enhance water binding of the shrimp and promote diffusion of phosphate molecules through the surface [5]. Parts of these phosphate molecules interact to positively charged groups of shrimp protein, while the rest of the molecules are available to bind with water molecules [6]. However, to date, little has been known about applying positive pressure and/or vacuum pressure to facilitate water absorption of shrimp. Application of moderate pressure has been demonstrated to accelerate the salt diffusion of components into pork meat [7]. In addition, vacuum has been shown to effectively incorporate external solutes into porous structures of animal tissues and increase marinating efficiency [8, 9]. According to the literature, the use of a combination of STPP and partial pressures (e.g., positive and negative pressures) has not yet been explored to optimize shrimp marination. In this paper, several marinating parameters (i.e., partial pressures, shrimp to marinating solution ratios and STPP concentrations) are investigated with the aim to shorten processing time and provide an effective guideline for shrimp marination.

Methodology

Experimental setup

Small size raw white shrimp (135 shrimp/pound) were obtained from a local seafood wholesaler. After de-heading, peeling, de-veining and washing with tap water, the fresh shrimp were ready for marinating experiments. At the ratio of 1:20 of shrimp to marinating liquid, each batch of marination contains 5 shrimp (approximately 15 grams) in 300 mL of marinate solution, or as otherwise stated. Different mass ratios of shrimp to the soaking solution (i.e., 1:20, 1:10 and 1:2) were applied. The marinating solution contains 1% (w/v) of sodium salt and different concentrations of STPP. The concentrations of phosphate in the soaking solution were varied from 1%, 3% and 5% (w/v). The soaking interval was limited to 1 hour.

The prototype of the marinating system is shown in Fig 1. A 300 mL hermetic reactor was used to perform marination under vacuum and pressurized conditions. One temperature probe was inserted into shrimp meat to measure the core temperature and the other was placed in the chamber to monitor soaking solution temperature. The soaking temperature was fixed at 4°C. A compound pressure gauge was installed to keep track of the change of pressure inside the reactor. The vacuum pump and air compressor were utilized to manipulate marinating pressure from 5-600 kPa.

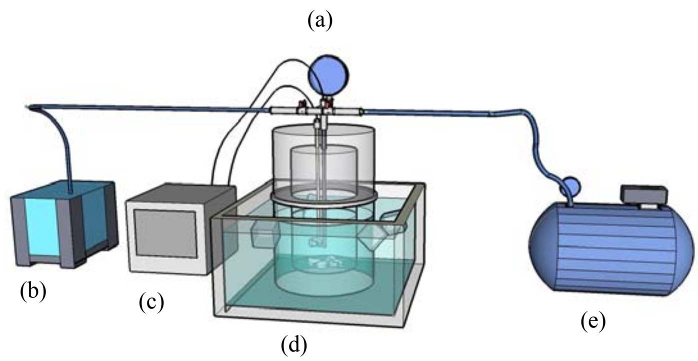

Figure 1. Prototype of the marinating system.
(a) hermetic pressure reactor equipped with 2 thermocouples and a compound pressure gauge.
(b) vacuum pump (Busch Model 0522-P335-G5090AX, USA).
(c) digital temperature recorder (Yogogawa 2455, Japan).
(d) temperature-controlled ice bath (GFL D3006, Germany).
(e) air compressor (ABAC Model 6P00060, Italy).

Soaking yield measurement
Soaking yield is of paramount interest to many shrimp processors and a critical parameter to determine the effectiveness of the marinating process. Yield was generally calculated from the differences in mass of shrimp before and after soaking Eq. (1) [3].

$$\%\ \text{Soaking yield} = \frac{\text{Mass after soaking}}{\text{Mass before soaking}} \times 100 \qquad (1)$$

Statistical analysis
A full-factorial experimental design was applied to the experiments. All data were subjected to statistical analysis. Differences between mean values were established using the Tukey’s multiple range tests at a confidence level of 95%.

Results and Discussion

Effect of sodium tripolyphosphate (STPP) concentration

When the fresh shrimp were submerged in the STPP solution, the phosphate and water molecules started diffusing into the shrimp meat. The role of phosphates was to enhance protein-water interaction. Part of the phosphate molecule anchored to positively charged groups of proteins, while the rest scavenged for free water molecules and presumably created a concentration gradient to allow more water to propagate into shrimp meat [5, 6].

In this experiment, the same principle applies in describing water molecule binding to the protein-STPP film. Without phosphates in the marinating solution, shrimp meat slowly gained additional weight as the marinating time proceeds (Fig. 2). The final soaking yield reached 103.42% by the end of the hour. The phosphate effect considerably improved the water uptake and accelerated the marinating process. The asymptotic soaking yield was shifted from 103.42% up to 108.38% in the 5% phosphate treatment. The increase of phosphate concentrations also helped heighten the protein-water interaction and significantly promoted soaking yield. For industry, the soaking time can be substantially reduced by increasing phosphate concentration.

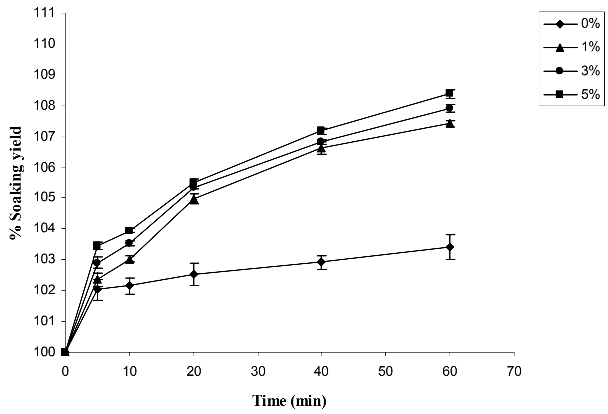

Figure 2. Soaking yield profile of white shrimp dipped in different STPP solutions under atmospheric pressure.

Effect of shrimp to marinating solution ratio

In order to apply these experimental results in industrial production, the issue of sufficient phosphate concentration during marination is worthwhile exploring in more detail. The previous experiment was carried out using 1:20 mass ratios of shrimp to soaking solution. When the shrimp density was increased, it had a subtle effect on the soaking yield (Fig. 3). At the initial period of marination, the differences between treatments were not apparent although the average values of soaking yield in the 1:20 treatment were always higher than the 1:10 and 1:2 treatments. However, toward the end of the hour the gap of the average values between treatments seemed to be widened. At

60 minutes, the soaking yield of the 1:20 treatment was significantly different to that obtained in the other treatments.

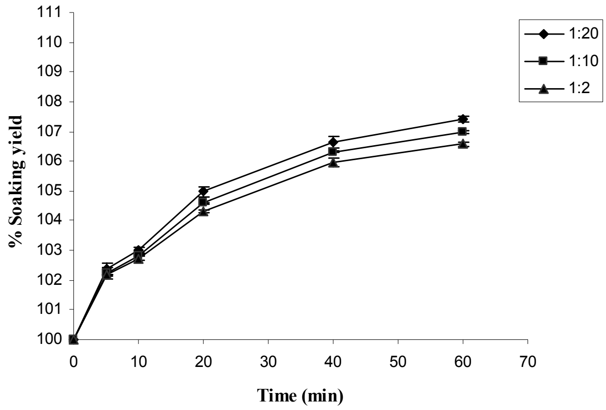

Figure 3. Soaking yield profile of white shrimp at different shrimp to STPP marinating solution ratios under atmospheric pressure.

Complementary to the study of shrimp surface-to-volume ratio by Erdogdu et al., [11], this experiment suggested that there should be an optimal ratio of shrimp to the soaking solution to maintain adequate concentration of phosphate ions in the marinating solution and ensure the maximum phosphate diffusion into shrimp meat. This result also implied that there was a need to adjust the shrimp and solution to an appropriate ratio when the size (or the surface-to-volume ratio) was altered.

To accommodate larger shrimp density during soaking, an increase of STPP concentration is an economical choice to help mitigate the fast saturation of soaking yield at higher shrimp densities and improve the soaking capacity (Table 1).

Table 1. Change of % soaking yield in white shrimp at different STPP concentrations and shrimp to marinating solution ratios under atmospheric pressure.

STPP concentration (%)	Shrimp to marinating solution ratio	Soaking time (min)				
		5	10	20	40	60
1	1:20	102.36^{aA}	103.02^{aB}	104.97^{aC}	106.62^{aD}	107.42^{aE}
	1:10	102.25^{aA}	102.83^{bB}	104.58^{aC}	106.32^{abD}	106.98^{bE}
	1:2	102.18^{bA}	102.74^{cB}	104.31^{bC}	105.97^{bD}	106.58^{bE}
3	1:20	102.90^{cA}	103.54^{dB}	105.34^{cC}	106.89^{cD}	107.90^{cE}
	1:10	102.80^{cA}	103.34^{eB}	105.26^{cC}	106.62^{cdD}	107.45^{dE}
	1:2	102.57^{dA}	103.19^{fB}	104.49^{dC}	106.47^{dD}	107.33^{dE}
5	1:20	103.46^{eA}	103.95^{gB}	105.51^{eC}	107.17^{eD}	108.38^{eE}
	1:10	103.40^{eA}	103.86^{hB}	105.44^{eC}	107.13^{efD}	108.23^{fE}
	1:2	102.96^{fA}	103.64^{iB}	104.96^{fC}	106.97^{fD}	108.08^{fE}

Note: Values in the same column with different superscripts means that the values are significantly different ($p<0.05$). Values in the same column with different capital superscripts means that the values aresignificantly different ($p<0.05$).

When the STPP concentrations were increased from 1 to 3%, not only were the differences between different ratio treatments minimized, but also the average soaking yields were improved. This statement also held true when the STPP concentration was extended to 5%. However, a practical level of the STPP used is subject to further optimization because the level of STPP absorbed into shrimp is likely to be limited by regulations of importing countries. Also the costs associated with the soaking process is of great concern to shrimp factories.

Effect of marinating method

Alternatively, vacuum soaking can be applied to minimize the fast saturation of soaking yield when the shrimp density was high. Fig. 4 demonstrates the soaking yield profile of the same experiment as in Fig. 3, except for the application of vacuum during soaking. It was evident that vacuum helped eliminate the differences of the average soaking yields for all treatments during the course of marination, especially toward the final period. Vacuum condition provided a marinating environment such that the entrapped internal gas inside the shrimp matrix was allowed to expand and escape due to pressure difference. Once the atmospheric condition was restored at the end of marination, the following compression from outside pressure created a second influx of marinating solution due to further reduction of residual gas inside shrimp [9, 12].

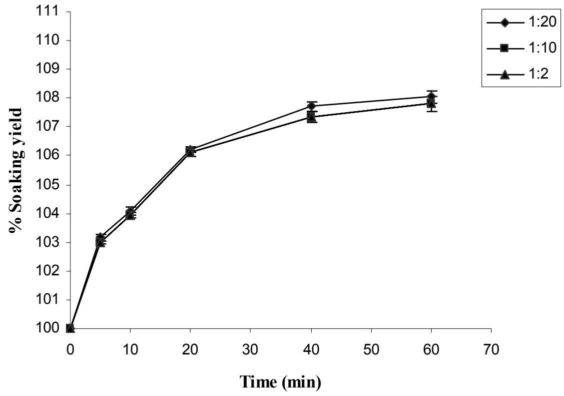

Figure 4. Soaking yield profile of white shrimp at different ratios of shrimp to marinating solution under vacuum pressure.

To integrate vacuum and STPP addition in the soaking scheme, the soaking yield can be stretched to 110.63%, exceeding the asymptotic values of the separate treatment either vacuum or STPP addition alone at 108.04% and 108.38%, respectively (Fig. 5). The reason for the significant gain of approximately 2% addition involved two complementary mechanisms. One was the higher concentration and deeper penetration of phosphate and water molecules as a result of the replacement of the internal gas**.** This scheme provided larger concentration of phosphate sites and larger availability of free water molecules to occupy those sites. This situation enhanced water absorption and demonstrated the synergistic effect by combining the two effective yet economical strategies to improve soaking yield.

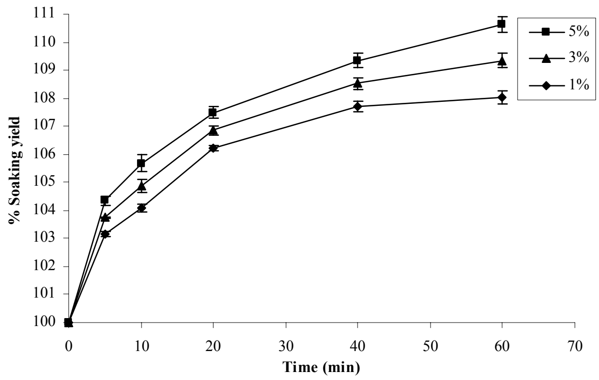

Figure 5. Soaking yield profile of white shrimp dipped in different STPP solutions under vacuum pressure.

Application of positive pressure as opposed to negative pressure (vacuum soaking) proved to be of no avail. The blockage of gas inside shrimp pores cannot be overcome by applying a moderate positive pressure (100-600 kPa). The asymptotic values of the

soaking yield were not significantly different compared to conventional soaking (or soaking under the atmospheric condition). Additionally, if the additional cost of reactor fabrication is taken into consideration, the pressurized soaking reactor method discourages the implementation of positive pressure soaking.

Conclusion

A synergic strategy of shrimp soaking by combining vacuum and optimal STPP concentration was explored to improve soaking yield and time. A wealth of useful shrimp soaking knowledge was accumulated to investigate a wide array of soaking conditions used in the shrimp industry. The best soaking yield of 110.63% was obtained by applying 5 kPa vacuum pressure using 5% (w/v) STPP concentration. The use of either vacuum or STPP concentration separately can only achieve moderate soaking yields, not in excess of 108.38%. The implementation of positive pressure was not able to significantly improve the soaking yield any better than atmospheric soaking. The constructed prototype of laboratory hermetic soaking reactor performed well in carrying out different sets of experiments and greatly facilitated many findings in this study.

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References

1. Sriket, P., Benjakul, S., Visessanguan, W. and Kijroongrojana K. (2007). Comparative studies on chemical composition and thermal properties of black tiger shrimp (*Penaeus monodon*) and white shrimp (*Penaeus vannamei*) meats. **Food Chemistry**, 103, pp. 1199–1207.

2. Leung, P. and Engle, C. (2006). *Shrimp culture: economics, market, and trade.* Baton Rouge, USA. World Aquaculture Society.

3. Xiong, Y. L. (2005). Role of myofibrillar proteins in water-binding in brine-enhanced meats, **Food Research International**, 38, pp. 281–287.

4. Chang, C. C. and Regenstein, J. M. (1997). Water Uptake, Protein Solubility, and Protein Changes of Cod Mince Stored on Ice as Affected by Polyphosphates. **Journal of Food Science**, 62, pp. 309.

5. Ünal, B. S., Erdogdu, F. and Ekiz, H. I. (2006). Effect of temperature on phosphate diffusion in meats. **Journal of Food Engineering**, 76, pp. 119–127.

6. Shahidi, F. and Synowiecki, J. (1997) Protein hydrolyzates from seal meat as phosphate alternatives in food processing applications, **Food Chemistry**, 60, pp. 29-32.

7. Villacis, M. F., Rastogi, N.K. and Balasubramaniam, W.M. (2008). Effect of high pressure on moisture and NaCl diffusion into turkey breast. **LWT Food Technology**, 41, pp. 836–844.

8. Guillemin, A., Degraeve, P., Noel, C. and Saurel, R. (2008). Influence of impregnation solution viscosity and osmolarity on solute uptake during vacuum impregnation of apple cubes. **Journal of Food Engineering**, 86, pp. 475–483.

9. Zhao, Y. and Xie, J. (2004). Practical applications of vacuum impregnation in fruit and vegetable processing. **Trends in Food Science & Technology**, 15, pp. 434–451.

10. Faithong, J. (2005). *Effect of phosphate types, salt and pH on yield and quality of frozen cooked cultured white shrimp (Penaeus vannamei)*. Master of Science (Fishery Products) Thesis, Kasetsart University.

11. Erdogdu, F., Balaban, M. O., Otwell, W. S. and Garrido, L. (2004). Cook-related yield loss for pacific white (*Penaeus vannamei*) shrimp previously treated with phosphates: effects of shrimp size and internal temperature distribution. **Journal of Food Engineering**, 64, pp. 297–300.

12. Fito, P., Chiralt, A., Betoret, N., Gras, M., Chafer, M., Martinez-Monzo, J., Andres, A. and Vidal, D. (2001). Vacuum impregnation and osmotic dehydration in matrix engineering application in functional fresh food development. **Journal of Food Engineering**, 49, pp. 175–183.