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Effect of foaming agents and dilution ratio on the foaming properties of *Artemia franciscana* biomass puree

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ABSTRACT

This study was carried out to optimize foaming preparation conditions for Artemia biomass using the three-level Box–Behnken experimental design of Response Surface Methodology. Three independent variables, namely, water/Artemia ratio (WAR) (2/1, 4/1 and 6/1), egg albumin (EA) (9.2, 12.2 and 15.2%), and xanthan gum (XG) concentration (0.1, 0.24 and 0.38%), together with three dependent variables characterizing the foam stability, including foam expansion volume (EV), foam density (FD), and drainage volume (DV) were optimized. Multiple regression analyses were applied to analyze the relationship between dependent variables (EV, FS, and DV) and three independent variables (WAR, EA, and XG) as indicators of foaming capacity and foam stability. In addition, simultaneous optimization of multiple responses has also been applied. The optimal combination of WAR was 4.6 (v/w), EA = 13.5%, and XG = 0.25% which gave the maximum foam expansion 293.4%, minimum FD 0.27 g/mL, and volume drainage of at least 0.7 mL. The validated values were found to be very close to the experimental values.

ARTICLE HIGHLIGHTS

This study aims to use dried Artemia biomass with high nutritional value (high protein and lipid content with essential amino acids and unsaturated fatty acids) in the development of new food products for humans. The recent method of foam drying has been noticed as an effective new technique, overcoming disadvantages related to traditional methods. The influence of additives on foaming and stabilizing foam has been evaluated in this study. Optimizing the parameters of the foaming process was also done to create the best conditions for the next foam mat drying process. The foam-mat dried Artemia biomass powder obtained from this method can be applied in spice/seasoning processing.

1. INTRODUCTION

Artemia (*Artemia franciscana,* family: Artemiidae) is a small crustacean that lives in salt water areas. In Vietnam, this species has been raised and grown for more than 30 years in Vinh Chau, in the Mekong Delta of Vietnam. Artemia has a short life cycle; they can mature into adults within 10 to 15 days and start to reproduce [1], such a short reproductive cycle the amount of Artemia biomass can be very large. Many studies have shown that Artemia biomass contains high levels of nutrients [2-5]. Research by Hoa *et al*. [6] announced that frozen Artemia biomass (raised in Vinh Chau, Vietnam) possesses high protein content (44.0–52.7%), lipid (6.0–13.2%), and total fatty acids (84.6–99.6 mg/g DW). The protein composition of Artemia biomass contains about 16 of 20 amino acids, especially seven of eight essential amino acids. Artemia biomass is also rich in high-chain polyunsaturated fatty acids, accounting for 52.31% of the total fatty acids, and PUFA accounting for 7.43% of the total fatty acids [7]. For a long time, Artemia biomass has predominantly been used as feed for aquatic animals. With such a high nutritional value, Artemia biomass can be evaluated as a potential raw material for use as feed for domestic animals as well as for humans [7,8]. This study aims to use the dried Artemia biomass for further seasoning powder processing, in addition to the market for seasoning powder, which is diversified from rich sources of nutrients such as pork bones, chicken, and mushrooms, and others.

One of the potential uses of A is to convert them into a dry, highly nutritious, and easy to use form. Foam mat drying has recently gained attention as a new efficient technique because it does not pose the major problems associated with traditional dehydration methods. With this method, the dispersion of air bubbles in a continuous matrix (liquid or solid) is stabilized by surfactants. Foam mat drying involves incorporating foaming agents into liquid or semi-liquid foods followed by whipping to form a stable foam [9]. The more porous the foam structure, the larger the liquid surface area which enhances the heat transfer and drying rate, resulting in higher nutritional and sensory

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quality of the dried foam product [10]. Foam-mat dried Artemia powder can be used to produce soup seasoning powder, diversifying this product group alongside other types of chicken, meat, and mushroom seasonings currently on the market. In addition, foaming of Artemia puree could be optimized by response surface methodology (RSM) to give optimum conditions such as the highest expansion volume (EV) and the lowest foam density (FD) and drainage. RSM has been extensively utilized to optimize several parameters in the extraction process [10,11]. It provides the interactive effects between variables and reduces the required numbers of experimental runs which are used to evaluate multiple parameters and their interactions. The effects of water/shrimp ratio and xanthan gum (XG) concentration on characteristics of shrimp foam were investigated by Azizpour *et al*. [12]. Study on the utilization of Artemia biomass in combination with dried vegetables to produce rice-seasoning or furikake product was conducted by Thuy *et al*. [13]. The development of a variety of new products from Artemia for humans is also a matter of concern, both to help diversify food sources for people and increase income for farmers. The objective of this study was to determine and optimize the parameters for the foaming process. Optimal parameters of the WAR, EA, and XG concentration were selected to maximize EV while minimizing FD and DV from the foam mass, preparing the best foam characteristics for the next foam-mat drying study.

2. MATERIALS AND METHODS

2.1. Materials

Fresh Artemia biomass was reared at the Vinh Chau experimental farm of Can Tho University, Vietnam. From 18 to 20 days after stocking, Artemia biomass was harvested. Egg albumin (EA) (India) and XG (Bob's Red Mill, USA) were used.

2.2. Preparation of the Artemia Puree and Foam

The Artemia biomass were cleaned and then frozen at −10°C. Before starting each experiment, the samples were thawed at 3–5°C for 12 h. Thawed samples were steamed for 5 min to destroy microorganisms or enzymes. Next, the samples were cooled at ambient temperature about 10 min and was used for our experiments. To prepare the foam samples, the concentrations of EA (9.2–15.2%), XG (0.1–0.38%), and the WAR (2/1–6/1) were transferred to a 250 mL beaker, the mixture was mechanically whipped (Philips HR3705 300 W) at the highest speed for 6 min, fixing the batch volume at 100 mL. During whipping, the foam was developed by incorporating air in it to increase the surface area, which expanded in volume (according to the optimization conditions obtained in the previous study by Thuy *et al*. [10]). At the end of each treatment, the mixture was evaluated on the foam properties, including foam EV, FD, and volume drainage.

2.3. Optimization Process

The ranges and levels of variables investigated in the research are tabulated in Table 1. Three independent variables were studied namely EA (X_1), XG (X_2), and WAR (X_3). RSM was utilized to determine the numbers of experimental runs required for the Box–Behnken experimental design that produces reliable measurement of the response. The optimization was conducted for multiple responses of extraction yield (EV = Y_1, FD = Y_2, and volume drainage Y_3). Table 2 exhibits that the total of 18 were required for three variables employed in this experiment. The experimental plan based on Box–Behnken design consisting of six center points.

RSM (using Statgraphics Centurion XV software) was applied to determine the optimal conditions for the foaming process from Artemia puree. A full second order reaction model (equation 1) was established.

Table 1: Independent variables with range and factor level.

Symbol	Factors	Unit	Range and levels		
			-1	0	1
X_1	EA	%	9.2	12.2	15.2
X_2	XG	%	0.1	0.24	0.38
X_3	WAR	v/w	2/1	4/1	6/1

EA: Egg albumin, XG: Xanthan gum, WAR: Water/Artemia ratio.

Table 2: Design of experiment of three variables.

No.	EA (%)	XG (%)	WAR (v/w)	No.	EA (%)	XG (%)	WAR (v/w)
1.	12.2	0.24	4	9	12.2	0.38	6
2.	15.2	0.24	6	10	9.2	0.1	4
3.	15.2	0.24	2	11	15.2	0.38	4
4.	12.2	0.24	4	12	9.2	0.38	4
5.	12.2	0.24	4	13	9.2	0.24	2
6.	12.2	0.24	4	14	12.2	0.24	4
7.	12.2	0.24	4	15	9.2	0.24	6
8.	12.2	0.1	6	16	12.2	0.1	2

EA: Egg albumin, XG: Xanthan gum, WAR: Water/Artemia ratio.

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_{11} + \beta_{22} X_{22} + \beta_{33} X_{33} \quad (1)$$

Where: Y: Predicted responses (EV, FD, and volume drainage); β_o: Intercept coefficient; β_1, β_2, β_3: Linear terms; β_{11}, β_{22}, β_{33}: Quadratic terms; β_{12}, β_{13}, and β_{23}: Interaction terms and X_1, X_2, and X_3: Uncoded independent variables.

2.4. Analysis of Foam Properties

FD was determined by the method described by Abd Karim and Wai [14] (equation 2).

$$\text{FD} = \frac{\text{Foam weight (g)}}{\text{Volume (mL)}} \times 100 \quad (2)$$

EV was analyzed to represent the amount of air introduced into the water during foaming and measured as a percentage increase in water volume, calculated using equation 3 [15].

$$EV\,(\%) = \frac{V_1 - V_o}{V_o} \times 100 \quad (3)$$

Where V_o the initial volume (mL) and V_1 is final volume (mL).

Drainage volume (DV) was measured based on a method defined by Narender Raju and Pal [16]. 100 g of foam was poured into a Buchner filter (diameter 80 mm) and placed in a 100 mL cylinder. Volume of liquid released from the foam in 120 min, then uses a 5 mL pipette or a 100 mL measuring cylinder to determine the drain volume.

3. RESULTS AND DISCUSSIONS

3.1. Effect of EA, XG, and Water/Artemia Ratio (WAR) on FD

One of the most difficult problems in foaming in preparation for drying is the stability of the foam during foaming and drying. If the foam is not stable, the porous structure will collapse, resulting in a deterioration in product quality after drying. Foaming ability can be assessed by the FD index, lower FD also means that more air is trapped in the foam [11,17]. The lower the FD, the more the foam expands and helps to transfer heat better for the subsequent drying process. All variables (EA, XG, and WAR) had a significant effect on FD. The values obtained ranged from 0.263 to 0.415 g/mL. Multiple range tests for FD by EA, XG, and WAR were performed. FD values were significantly reduced using EA from 9.2% (0.38 g/mL) to 12.2% (0.30 g/mL) and were not significantly different when increasing this concentration to 15.2% (0.31 g/mL). The low concentration of EA makes the bubble unstable because it cannot form the critical thickness required for the foam film. However, when the concentration of EA increases too much, it also reduces the overall foaming ability, possibly because the viscosity of the solution increases as the protein content increases, so it does not create favorable conditions for large gas escapes. Large amounts of gas are incorporated at the interface [18]. An increase in XG (0.1–0.38%) led to an increase in FD (values ranged from 0.31 to 0.34 g/mL). Azizpour *et al*. [12] reported that FD increased significantly with increasing concentration of XG, probably due to an increase in the thickness of the mixture. The high viscosity liquid phase will prevent air trapping during whipping or mechanical mixing. Salahi *et al.* [19] reported that when albumin and XG were added to cantaloupe pulp for foaming, an increase in albumin concentration from 1% to 3% resulted in a significant decrease in FD, while FD increased with increasing XG content from 0.05% to 0.2%. The increase in the ratio of water/Artemia caused the FD to decrease significantly, when the WAR changed from 2/1 to 4/1, the FD value decreased from 0.36 to 0.30 g/mL and could not be showed a significant difference between the 4/1 and 6/1 ratios. That may be because increasing dilution during foaming reduces the viscosity of the Artemia mixture and thus the FD decreased. The ANOVA table [Table 3] partitions the variability in FD into separate pieces for each of the effects, it then tests the statistical significance of each effect by comparing the mean square against an estimate of the experimental error. The results show that most of the independent variables, their first and second order interactions have a significant effect on FD. Specifically in this case, eight effects have $P < 0.05$, showing that they are statistical significance at the 95.0% confidence level, only the X_1X_3 interaction has no significant effect on FD.

The equation of the fitted model is presented in equation 4, where the values of variables are specified in their original units. Since *P*-value for lack-of-fit is >0.05 ($P = 0.65$), the model appears to be adequate for the observed data at the 95.0% confidence level.

$$Y_1 = 1.468 - 0.133X_1 - 1.045X_2 - 0.085X_3 + 0.005X_1^2 + 0.037X_1X_2 + 0.794X_2^2 + 0.063X_2X_3 + 0.0078X_3^2 \quad (4)$$

Where Y_1 is FD (mg/L), X_1 is EA concentration (%), X_2 is XG (%), and X_3 is WAR (v/w) ($R^2 = 92.6\%$; R^2 adj. = 91.28%; SEE = 0.013)

3.2. Effect of EA, XG, and WAR on EV

The amount of air integrated into the Artemia puree during foaming was measured using the foam EV. The analysis of variance (ANOVA) results showed that eight effects have $P < 0.05$ (data are not fully presented here), indicating that they are significant different from zero at the 95.0% confidence level. It was observed that double interaction (X_1 X_3) did not affect the foam EV. This pane shows the regression equation that has been matched to the data, where the values of the variables are specified in their original units. The equation 5 of the fitted model is:

Table 3: Analysis of variance for FD.

Source	Sum of squares	Df	Mean square	F-ratio	*P*-value
X_1	0.0298	1	0.0298	182.92	0.0000
X_2	0.0009	1	0.0009	5.65	0.0222
X_3	0.0058	1	0.0058	35.68	0.0000
X_1X_1	0.022	1	0.022	137.69	0.0000
X_1X_2	0.003	1	0.003	18.23	0.0001
X_1X_3	0.00002	1	0.00002	0.13	0.7252
X_2X_2	0.0032	1	0.0032	19.47	0.0001
X_2X_3	0.0037	1	0.0037	22.90	0.0000
X_3X_3	0.0126	1	0.0126	77.56	0.0000
Lack-of-fit	0.0004	3	0.0004	0.79	0.5079
Pure error	0.0067	41	0.0067		

R^2=91.62%; R^2_{adj}=91.11%; Standard Error of Est. = 0.0128, X_1: Egg albumin; X_2: Xanthan gum; X_3: WAR: Water/Artemia ratio. FD: Foam density.

Table 4: Predicted and experimented value of responses from optimal conditions.

Response variables	Predicted values	Experimental values
FD (g/mL)	0.27	0.28±0.01*
Foam EV (%)	293.4	284.5±7.1
DV (mL)	0.7	0.7±0.01

*Mean±STD. EA: Egg albumin, XG: Xanthan gum, WAR: Water/Artemia ratio.

$$Y_2 = -755.52 + 110.62X_1 + 966.28X_2 + 71.82X_3 - 3.63X_1^2 - 31.91X_1X_2 - 804.44X_2^2 - 57.70X_2X_3 - 6.15X_3^2 \quad (5)$$

Where Y_2 is EV (%), X_1 is EA concentration (%), X_2 is XG (%), X_3 is WAR (v/w) ($R^2 = 92.99\%$; Adjusted $R^2 = 91.74\%$, SEE = 12.05)

Similar to FD, all three variables had a significant influence on foam EV. The minimum and maximum analyzed EV values are 156.63 and 310.03%, respectively, at different levels of EA, XG, and WAR. The EV values were significantly increased from 183.12% to 262.8% in increasing of EA concentration from 9.2% to 12.2% and were not significantly different (269.27%) when increasing this concentration to 15.2% (269.03%). Foaming ability and foam stability are important functions of EA. Foam is a colloidal system consisting of small air bubbles that propagate in a continuous aqueous phase. The protein in EA acts as an amphoteric emulsifier between the air and water phases, resulting in good foam stability [20]. The XG content was raised from 0.1% to 0.24%. The EV values increased from 240.14% to 258.34%. However, when increasing XG up to 0.38%, the EV value decreased (228.94%). Increasing the XG concentration affects the increase in the viscosity of the continuous phase. In addition, XG aids in the formation of durable films and stabilizes the interfacial films. However, when it is increased too much, the EV decreases. This is probably because when the viscosity of the mixture increases, the incorporation of air decreases, leading to a decrease in foam expansion and an increase in FD [21]. High viscosity liquids prevent air from being trapped during whipping or mechanical mixing. Similar trends were also reported for bael fruit pulp [22]. Increasing the ratio of water to raw material significantly increased the EV, when the WAR changed from 2/1 to 4/1, the EV value increased from 212.57% to 247.68% and showed no significant difference between the ratio 4/1 and 6/1 (59.57%). As explained above, it is possible that increasing dilution during foaming

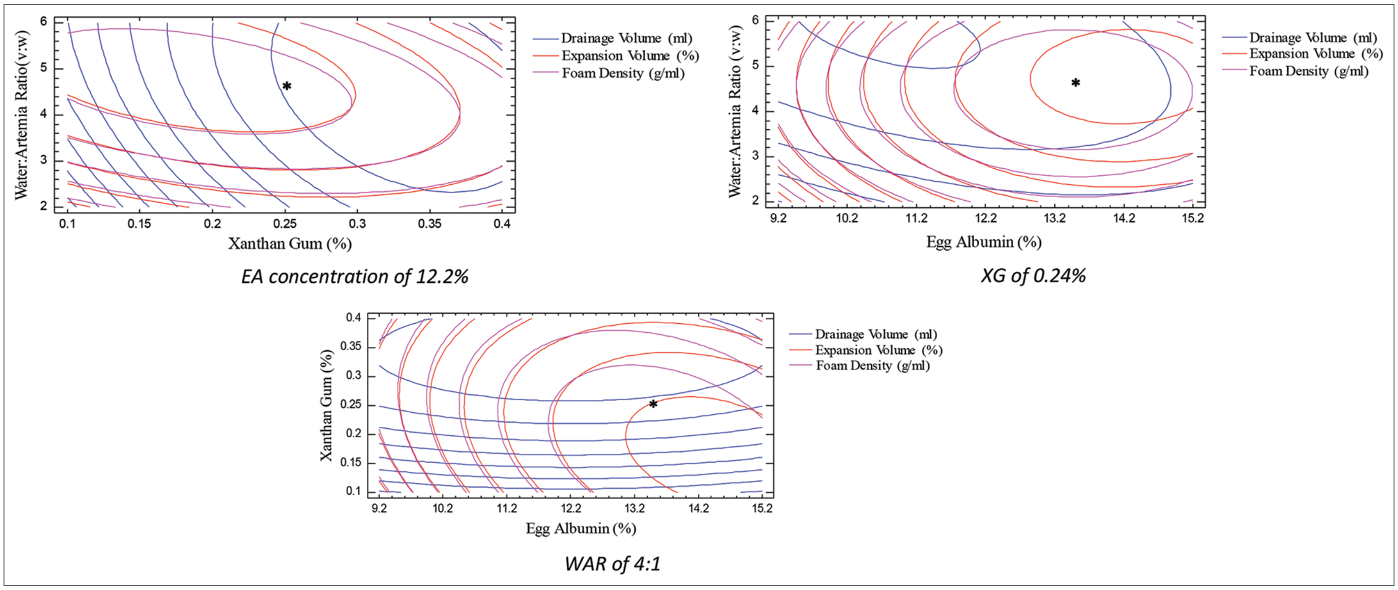

Figure 1: Overlay plot of foam density, foam expansion volume, and drainage volume at different levels of input variables.

reduces the viscosity of the Artemia mixture and hence FD decreases and EV increases.

3.3. Effect of EA, XG, and WAR on DV

Drainage or liquid phase from the foam is measured as the factor that destabilizes the foam. Therefore, measuring DV is also one of the better methods to determine its stability. The measured DV values ranged from 0.2 to 7 mL. WAR and XG had significant effect on the DV (at 5% level of significance). It was observed that with higher ratios of WAR exhibited greater drainage. This is due to the increase of dilution rate and decrease of solid content of the mixture. In addition, increasing the XG concentration reduced the DV of Artemia foams (increased the stability). Pasban *et al*. [23] determined that XG at 0.3% gave good foam stability. Muthukumaran [24] also reported a strong effect of XG as a stabilizer. Some previous studies have also reported similar results [9,20,25,26]. In this study, XG and WARs affect DV clearly than EA, ANOVA for DV was performed. In this case, seven effects have $P < 0.05$ (data are not fully presented here), indicating that they are significantly different at the 95.0% confidence level. The interaction of X_1 and X_1X_2 is not significant ($P > 0.05$), so these interactions are omitted from the equation, the equation 6 of the fitted model is:

$$Y_3 = 26.33 - 1.64X_1 - 59.78X_2 - 2.9X_3 + 0.05X_1^2 + 0.08X_1X_3 + 74.76X_2^2 + 2.2X_2X_3 + 0.13X_3^2 \quad (6)$$

Where Y_3 is DV (%), X_1 is EA concentration (%), X_2 is XG (%), and X_3 is WAR (v/w) (R^2 = 88.96%; Adjusted R^2 = 87.29%, SEE = 0.68).

Since *P*-value for lack-of-fit in the ANOVA table is >0.05 (*P*-value of Lack-of-fit = 0.64), the model appears to be adequate for the observed data at the 95.0% confidence level.

3.4. Multiple Response Optimization

Optimizing multiple responses is more useful when it is necessary to evaluate the impact of multiple variables on responses. The numerical optimization results show that the desired maximum (0.91) can be achieved using the optimal concentrations of EA, XG, and WAR of 13.5%, 0.5%, and 4.6:1. At these maximum levels, the predictive values of responses such as FD, EV and DV are 0.7 g/mL, 293.4%, and 0.27 mL, respectively, shown in asterisk (*) on Figure 1.

The validity of the model has also been confirmed through the experimental performance at the optimal level of the independent variables. The validation results gave the experimental values almost good agreement with the response values predicted from the selected models [Table 4]. In addition, the test data on the responses obtained at the optimum level have also shown that the foam has good properties and is ready for the next stage of drying.

4. CONCLUSIONS

In this work, the influence of foaming and stabilizing agents was examined. It was found that were affected by all three independent variables (EA, XG, and WAR); however, DV was influenced mainly by XG and WAR. The optimum values of EA, XG, and WAR were found for the optimal foaming process to achieve the maximum value of EV, minimum of FD, and DV. Foamed Artemia biomass can be dried and effective seasoning substitute in food products such as soup or snacks with a beneficial increase in protein content and nutritional value.

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6. AUTHORS' CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agreed to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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8. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

9. ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

10. DATA AVAILABILITY

All data generated and analyzed are included within this research article.

11. PUBLISHER'S NOTE

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