Improving Mixing Process Quality for Sweet Soybean Sauce Using Full Factorial Design of Experiment

Noorilyana Abu Bakar
Department of Mechanical Engineering
Politeknik Ibrahim Sultan
Km 10, Jalan Kong Kong, 81700 Pasir Gudang, Johor, Malaysia.
med_liya@hotmail.com, noorilyana@pis.edu.my

Adnan Hassan
Department of Materials, Manufacturing & Industrial Engineering
School of Mechanical Engineering
Universiti Teknologi Malaysia
Skudai, Johor 81310, Malaysia
adnan@utm.my, adnanhassann@yahoo.com

Abstract

Soybean sauce is a common condiment in Asian cooking. It is made from fermented soybeans combined with other ingredients. The manufacturing of soybean sauce involves fermentation, extraction, sterilization, homogenization, bottling, labeling, and packaging. Several researchers have reported investigations related to soybean production. Our review reveals that there has been limited literature on the optimization of mixing parameters for soybean sauce using fractional factorial experimental design. There are variations of soybean sauces available in the market where the quality is dependent on the method and duration of fermentation, and the ratios of fermented soy, water, sugar, caramel, salt, and other addition to the ingredients. The mixing ratios among the ingredients are critical to ensure that the resulted Brix value conforms to specification. This study was conducted on a Malaysian case study company in Johor where it experienced high variability in the Brix value in sweet soybean source production. Prior to this investigation, a trial-and-error approach was used to balance among the ingredients. The quantity of sugar was increased if it was too salty, and additional soy water was added if it was too sweet until the standard specification was achieved. The objective of this study is to reduce the mixing process variability by investigating its optimum parameter setting. To simplify the experiments, two stages of 2^k full factorial design of experiments were conducted. The first stage involved mixing ingredients of sugar, caramel, and monosodium glutamate (MSG), and the second stage involved mixing ingredients of sugar, salt, water, and acetic acid. The responses (Brix readings) were statistically analyzed using ANOVA and the factors and interaction effects. The mathematical regression models were formulated to predict the Brix readings. The optimum parameter setting proposed in this paper should be used to replace the traditional trial-and-error approach in the mixing process.

Keywords
Design of experiment, Soybean sauce, Process optimization, Quality.

1. Introduction
Soybean sauce is one of the world's oldest condiments made from fermented soybeans combined with other ingredients. It was originated from China and has become a common condiment in Asian cooking as a flavour enhancer and seasoning ingredient. Soybean source is made by boiling soybeans and fermenting them for several weeks. After fermentation, the paste is pressed to produce liquid, which is the soybean sauce, and a solid by product, which is often used as animal feed. Generally, the manufacturing of soybean sauce involves fermentation, extraction, sterilization, homogenization, bottling, labelling, and packaging. Several researchers have reported studies related to soybean production. Syifaa et al. (2016) investigated the chemical characteristics in various types of soy sauce. They reported that the sauce characteristics namely, color, caramel odor, viscosity, and sweetness taste may increase the overall

acceptance of the soy sauce. Lynn et al. (2013) investigated the quality improvement of fermented soybean sauce by using Aspergillus flavus and Aspergillus oryzae.

There are variations of soy sauces available in the market. Their variation is basically depended on method and duration of fermentation and the ratios of fermented soy, water, sugar, caramel, salt, and other addition to the ingredients. The mixing ratios among the ingredients are critical to ensure that the resulted brix value conforms to specification. In this paper, the case study company was facing high variability in the brix value where trial and error approach was used to balance among the ingredients. Quantity of sugar was increased if it was too salty, and additional soy water was added if it was too sweet until the standard specification achieved. The current approach was not systematic, time consuming and resulted in inconsistency in the Brix value.

A systematic approach such as factorial design or fractional factorial design have been used for factor screening and for product and process designs (Hassan et al., 2006). Researchers such as Eladl et al. (2018), Yizong et al. (2017), and Toh and Hassan (2021) have used designed of experiment (DoE) to evaluate the effect of process parameters in injection moulding processes on different responses. Our review reveals that there have been limited literature on the optimization of soybean sauce mixing parameters using DoE.

The objective of this study is to reduce the mixing process variability by applying design of experiments to search the optimum parameter setting. Other parameters, such as the temperature setting to avoid soybean source from contaminated by fungi or poisonous microbes such as E-coli and pH level were not investigated in this paper. The study was limited to the ingredients of mixing process for sweet soybean source. Sweet soybean sauce was selected since it had higher demand compared to the salty soybean sauce. The investigation started with the characterization of existing process and followed by experiments to search for optimum mixing ingredients. This study was based on a case study company as described in Abu Bakar (2015). This paper is organized into five sections where Section 2 highlights the methodology, Section 3 explains the existing process capability and selection of process parameters, Section 4 discusses the optimization of mixing process settings, and Section 5 concludes the paper.

2. Methodology

The study began with investigation of the current process where process capability was evaluated. Then process parameters for mixing processes were identified and selected. Details on these are explained in Section 3. Optimization of the mixing process parameters was divided into two stages, namely the optimization of Ingredient II and the optimization of ingredients III. The Ingredient I was made of only soybean sauce and no mixing process was involved. The experimental run was conducted based on full factorial 2^3 and 2^4 design matrices for Ingredient II and Ingredient III, respectively. The results were analyzed using effect plots and ANOVA. Confirmation run was conducted for both Ingredients II and III. The predicted performance based on mathematical model then compared with the actual performance. Details discussion on the design of experiments methodology can be found in Taguchi (1986), Antony (1998) and Montgomery (2012).

3. Existing Process Capability and Selection of Process Parameters

3.1 Existing Process Capability

Mixing process is one of the most important stages in a production of soybean sauce. The company monitored specifications for Brix, pH, temperature, and specific gravity. The specification for sweet soybean sauce should be between 63 and 65 ^{o}Brix. The company had to pay higher production cost if excess ingredients were used besides its negative effect to consumers' health. As such, focus of the study was to search the optimum mixing process parameters that influence the Brix level. Figure 1 shows the current mixing process capability with respect to the Brix reading.

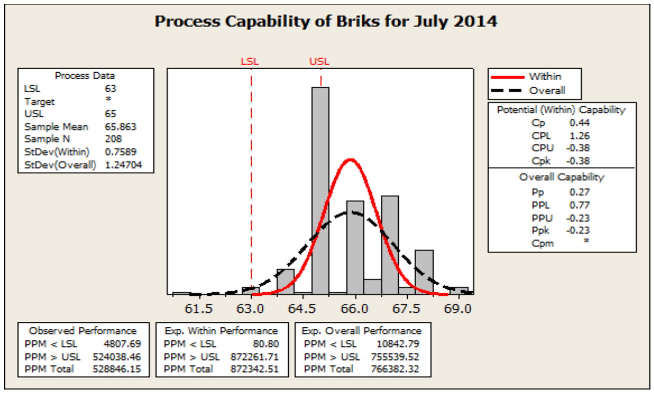

Figure 1. Histogram for the current process capability based on Brix reading

The plot shows that the process capability Cp = 0.44 and Cpk = −0.38. This suggest that the process was not capable to produce the sauce according to the specification limits (Besterfield, 2009). Furthermore, the process mean had shifted to be outside the control limits. This plot suggests that there was a need for improvement, by reducing the variability in the mixing process and adjusting the process setting to be closer to the target.

3.2 Parameter Selection

In soybean sauce mixing process, there were three main ingredients, labelled as Ingredient I (Soybean water), Ingredient II (sugar, monosodium glutamate (MSG) and caramel) and Ingredient III (sugar, salt, acetic acid and water). The correct mixing ratio among the ingredients was crucial to ensure the Brix reading met the specifications. In the existing practice, the workers did not measure the quantity of ingredients before proceeding with the mixing process. It was assumed that the weights stated on the packaging were reliable and accurate. For liquid ingredients, the flow meter was used to control the volume poured. The production department was required to ensure the Brix reading was within the specification limit. That optimum composition for Ingredients II and III were investigated through two stages of the experimental design. The 2^k factorial design was implemented. The values at each level were selected based on recommendation from the company. Since it was not possible to run the 2^k factorial design under homogeneous conditions, blocking was used for eliminating the unwanted variation (Woodall, 2000). In this study, there were 56 experimental runs where each run took about one hour.

4. Optimization of Mixing Process Parameters

4.1 Optimization of Ingredient II

A two stages full factorial experiment was conducted. First, the mixing experiments for Ingredient II were conducted. Then the best setting for Ingredient II was adopted in proceeding to the second stage experiment where the mixing of Ingredient III (sugar, salt, water, and acetic acid) was controlled. The best setting from this experiment was expected to give the optimum Brix reading. A laboratory scale experiment was conducted under the supervision of company's Quality Control (QC) Supervisor. Table 1 provides the level settings for each factor as suggested by the company.

Table 1: Range and level of factors for Ingredient II

Factor	Level	
	Low (-1)	High (+1)
Sugar (gram)	450g	650g
MSG (gram)	68g	80g
Caramel (gram)	225g	325g

Table 2 shows the full factorial design matrix for mixing Ingredient II. The three replicates and three blocks design resulted in 24 runs. The Brix values were recorded as response of the experiments.

Table 2: Full factorial 2^3 design matrix for Ingredient II

StdOrder	RunOrder	Blocks	Factors			^oBrix
			A(sugar)	B(MSG)	C(caramel)	
16	1	2	1	1	1	65.2
10	2	2	1	-1	-1	66.0
13	3	2	-1	-1	1	64.2
14	4	2	1	-1	1	66.2
12	5	2	1	1	-1	65.0
9	6	2	-1	-1	-1	64.0
15	7	2	-1	1	1	64.3
11	8	2	-1	1	-1	64.5
1	9	1	-1	-1	-1	64.1
6	10	1	1	-1	1	66.5
2	11	1	1	-1	-1	66.2
4	12	1	1	1	-1	65.1
5	13	1	-1	-1	1	64.3
7	14	1	-1	1	1	64.3
8	15	1	1	1	1	65.2
3	16	1	-1	1	-1	64.5
18	17	3	1	-1	-1	66.2
19	18	3	-1	1	-1	64.6
20	19	3	1	1	-1	65.0
24	20	3	1	1	1	65.2
17	21	3	-1	-1	-1	64.0
23	22	3	-1	1	1	64.3
21	23	3	-1	-1	1	64.3
22	24	3	1	-1	1	66.3

Figure 2 shows the main effect based on Brix value plots for the Ingredient II (Sugar, MSG and Caramel). From the plots, the slope for sugar was the biggest. It suggests that sugar was the most sensitive main effect for the Brix value. MSG and caramel did not show any significant difference between low- and high-level settings. However, these plots by themselves were not conclusive without analyzing the interaction plots.

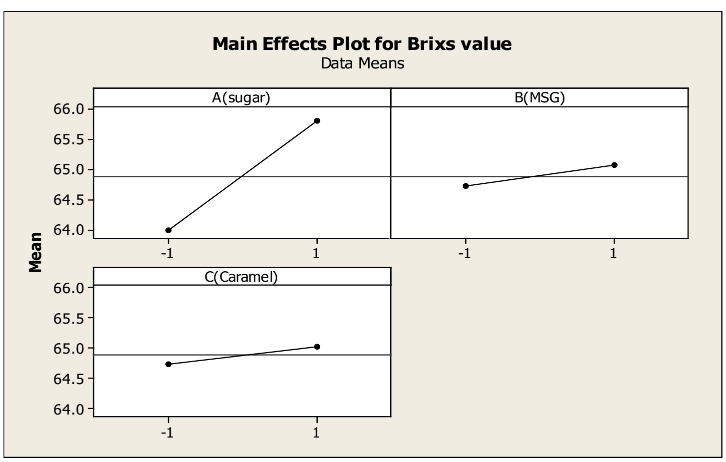

Figure 2.Main effect plots for experiments on Ingredient II

Tables 3 and 4 show the estimated effects and the analysis of variance for Ingredient II. The results suggest that all the materials (Sugar, MSG and Caramel) were significant as they were significant interactions existed between these materials especially for the two-way interactions between Sugar (A) × Caramel (C), and MSG (B) × Caramel (C). The R-Square value for all interactions suggest that the model is highly fitted. The corresponding regression model is shown in Equation 1.

Table 3: Estimated Effects and Coefficients for Ingredient II

Term	Effect	Coef	SE Coef	T	P
Constant		64.8833	0.02505	2590.20	0.000
Block 1		0.0667	0.03543	1.88	0.081
Block 2		-0.0708	0.03543	-2.00	0.065
A(sugar)	1.8167	0.9083	0.02505	36.26	0.000
B(MSG)	0.3500	0.1750	0.02505	6.99	0.000
C(Caramel)	0.3000	0.1500	0.02505	5.99	0.000
A(sugar)*B(MSG)	0.1333	0.0667	0.02505	2.66	0.019
A(sugar)*C(Caramel)	0.1833	0.0917	0.02505	3.66	0.003
B(MSG)*C(Caramel)	-0.4500	-0.2250	0.02505	-8.98	0.000
A(sugar)*B(MSG)*C(Caramel)	-0.1667	-0.0833	0.02505	-3.33	0.005

S = 0.122717 PRESS = 0.619592 R-Sq = 99.09% R-Sq(pred) = 97.31% R-Sq(adj) = 98.50%

Table 4: Analysis of Variance for Ingredient II

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Blocks	2	0.0758	0.0758	0.0379	2.52	0.116
Main Effects	3	21.0767	21.0767	7.0256	466.52	0.000
A(sugar)	1	19.8017	19.8017	19.8017	1314.89	0.000
B(MSG)	1	0.7350	0.7350	0.7350	48.81	0.000
C(Caramel)	1	0.5400	0.5400	0.5400	35.86	0.000
2-Way Interactions	3	1.5233	1.5233	0.5078	33.72	0.000
A(sugar)*B(MSG)	1	0.1067	0.1067	0.1067	7.08	0.019
A(sugar)*C(Caramel)	1	0.2017	0.2017	0.2017	13.39	0.003
B(MSG)*C(Caramel)	1	1.2150	1.2150	1.2150	80.68	0.000
3-Way Interactions	1	0.1667	0.1667	0.1667	11.07	0.005
A(sugar)*B(MSG)*C(Caramel)	1	0.1667	0.1667	0.1667	11.07	0.005

$$^{o}Brix = 64.8833 + 0.9083A + 0.1750B + 0.1500C + 0.0667\,(A\times B) + 0.0917\,(A\times C) - 0.2250\,(B\times C) - 0.0833\,(A\times B\times C) \quad (1)$$

The coded setting (+1 or -1) can be represented into the model by replacing the main effect and the interaction factor settings. The best setting is low level (-1) for all factors that are sugar, MSG and caramel with the predicted value = 64.57 $^{o}Brix$. This value falls within the company's specification limits.

4.2 Optimization of Ingredient III

For the optimization of Ingredients III, four materials (factors) namely sugar, salt, acetic acid and water investigated. Table 5 summarizes the factors and the corresponding levels for each factor as recommended by the company. The investigation was implemented according to full factorial design with 2 replications that resulted in 32 random runs in 4 blocks. The response was the Brix value.

Table 5: Factors and levels for Ingredient III

Factors	level	
	Low (-1)	High (+1)
Sugar (g)	1400	1600
Salt (g)	50	150
Water (ml)	750	850
Acetic acid (ml)	0.4	0.6

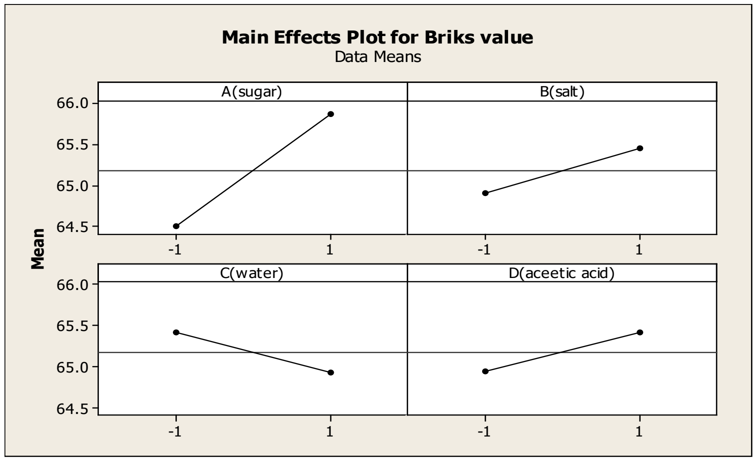

Figure 3: Main Effect Plot for Optimization of Ingredient III

Figure 3 shows the main effect plots for optimization of Ingredient III. The plot suggests that sugar was the most important effect for the Brix value. The plots suggest that to produce a low Brix soybean sauce, the mixture among sugar, salt and acetic acid should be at low level but water should be set at high level. However, these findings are not conclusive without consideration of interaction plots. Table 6 summarizes the estimated effects and coefficients for Ingredient III.

Table 6: Summary of Estimated Effects and Coefficients for Ingredient III

Term	Effect	Coef	SE Coef	T	P
Constant		65.1750	0.02409	2705.41	0.000
Block 1		0.0125	0.04173	0.30	0.769
Block 2		-0.0375	0.04173	-0.90	0.384
Block 3		0.0125	0.04173	0.30	0.769
A(sugar)	1.3625	0.6813	0.02409	28.28	0.000
B(salt)	0.5500	0.2750	0.02409	11.42	0.000
C(water)	-0.4875	-0.2437	0.02409	-10.12	0.000
D(acetic acid)	0.4750	0.2375	0.02409	9.86	0.000
A(sugar)*B(salt)	-0.1625	-0.0812	0.02409	-3.37	0.005
A(sugar)*C(water)	-0.0500	-0.0250	0.02409	-1.04	0.317
A(sugar)*D(acetic acid)	-0.3375	-0.1688	0.02409	-7.00	0.000
B(salt)*C(water)	0.0375	0.0188	0.02409	0.78	0.449
B(salt)*D(acetic acid)	-0.1250	-0.0625	0.02409	-2.59	0.021
C(water)*D(acetic acid)	-0.2875	-0.1438	0.02409	-5.97	0.000
A(sugar)*B(salt)*C(water)	0.3500	0.1750	0.02409	7.26	0.000
A(sugar)*B(salt)*D(acetic acid)	-0.0625	-0.0313	0.02409	-1.30	0.216
A(sugar)*C(water)*D(acetic acid)	0.3750	0.1875	0.02409	7.78	0.000
B(salt)*C(water)*D(acetic acid)	0.0375	0.0188			

S = 0.136277 PRESS = 1.35837 R-Sq = 98.97% R-Sq(pred) = 94.64% R-Sq(adj) = 97.73%

The results in Table 6 suggest that significant factors are sugar, salt, water and acetic acid, sugar and salt. The significant two-way interactions are sugar × acetic acid, salt × acetic acid, water × acetic acid. The significant three-way interaction are among sugar × salt × water and the three-way interaction of sugar × water × acetic acid. The mathematical regression model to represents the above response is given in Equation 2.

$$\text{Brix value} = 65.1750 + 0.6813A + 0.2750B - 0.2437C + 0.2375D - 0.0812\ (A\times B)\ -0.1688\ (A\times D)\ 0.0625(B\times D) - 0.1438\ (C\times D) + 0.1750\ (A\times B\times C) + 0.1875(A\times C\times D) \qquad (2)$$

The +1 or -1 coded setting can be inserted into main effects and interaction plots. The best setting is -1 for sugar, salt and acetic acid and +1 for water. This setting results in the predicted Brix value 63.93 which falls within the specification.

4.3 Confirmation Run

Conformation experiments were done for both Ingredients II and III. The conformation runs for Ingredients III are summarized in Table 7. Three confirmation runs were conducted using low level (-1) for sugar, salt and acetic acid and high level (+1) for water. Table 8 provides comparison between the predicted and actual results for Brix readings. The difference between the predicted and actual values is less than 5% error margin and this suggest that the prediction model is acceptable.

Table 7: Confirmation run for Ingredient III

Confirmation Experiment	Ingredients				
	Sugar	Salt	water	Acetic Acid	Brix reading
No. 1	-1	-1	+1	-1	64.0
No. 2	-1	-1	+1	-1	64.3
No. 3	-1	-1	+1	-1	63.8

Table 8: Comparison between predicted and actual Brix values for Ingredient III

Confirmation run	Predicted Brix	Actual Brix	Error
1	63.93	64.0	0.1%
2	63.93	64.3	0.57%
3	63.93	63.8	0.2%

5. Conclusion

The problem of poor process capability in sweet soybean sauce production was investigated. Two major ingredients in the mixing process were analyzed in two stages 2^k full factorial design of experimental. The results suggest that sugar was the most significant material influencing the Brix value. The recommended settings for the sweet soybean mixing Stage 1 (Ingredient II) are sugar (450~500 ×1000kg), MSG (64~68 ×1000kg), and caramel (200~225×1000kg). For mixing Stage 2 (Ingredient III), the recommended settings are sugar (1350~1450 ×1000kg), salt (45~55 ×1000kg), water (800 ~ 900 ×1000litres) and acetic acid (0.35~0.45 ×1000litres). This finding should benefit the case study company to replace the trial-and-error mixing approach. This study can be extended to explore the application of response surface methodology for refining the prediction model (Toh and Hassan, 2021).

References

Abu Bakar, N., *An optimization of mixing process parameters for soy sauce production*, Unpublished M.Sc. Project Report, Universiti Teknologi Malaysia, 2015.

Antony, J., Some key things industrial engineers should know about experimental design, *Logistics Information Management*, vol. 11, no.6, pp. 386-392.1998.

Besterfield, D. H., *Quality Control*, 8th ed. Pearson. 2009.

Eladl A, Mostafa R, Islam A, Loaldi D, Soltan H, Hansen H and Tosello G., Effect of-process parameters on flow length and flash formation in injection moulding of high aspect-ratio polymeric micro features, *Micromachines*, vol. 9, no. 2, 58, 2018.

Hassan, A., Nabi Baksh, M. S., Shaharoun, A. M. and Jamaluddin, H., Feature selection for SPC chart pattern recognition using fractional factorial experimental design, in *Intelligent Production Machines and Systems*, D.T. Pham, E.E. Eldukhri and A.J. Soroka (eds), pp. 442 – 447, 2006.

Lynn, T. M., Aye, K. N and Khaing, K. M (2013), Study on the production of fermented soybean sauce by using aspergillus oryzae and aspergillus flavus, *Journal of Scientific & Innovative Research*, vol. 2, no. 2, pp. 1 – 10.

Montgomery, D.C., *Design and Analysis of Experiments*, Wiley, 2012.

Syifaa, A. S., Jinap, S., Sanny, M and Khatib, A., Chemical profiling of different types of soy sauce and the relationship with its sensory attributes, *Journal of Food Quality*, vol. 39, no.6., pp. 714–725, 2016.

Taguchi, G., *Introduction to Quality Engineering*, Asian Productivity Organization, Tokyo, 1986.

Toh, H.T. and Hassan, A. Quality improvement in a multi-cavity injection moulding process using response surface methodology. in Akhyar (ed), *Lecture Notes in Mechanical Engineering*, Springer Nature, chapter 28, pp. 277-288, 2021.

Woodall, W.H., Controversies and contradiction in SPC, *Journal of Quality Technology*, vol. 32, no. 4, 2000.

Yizong T, Ariff Z, Muhammad Khalil A., Influence of processing parameters on injection molded polystyrene using Taguchi Method as design of experiment. *Procedia Engineering,* vol. 184: pp. 350–359, 2017.

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Biographies

Noorilyana Abu Bakar earned the B.Eng (Mechanical - Industrial) from Universiti Teknologi Malaysia, the M.Sc degree in Industrial Engineering from Universiti Teknologi Malaysia. Currently she is a lecturer at Politeknik Ibrahim Sultan, Pasir Gudang, Johor, Malaysia.

Adnan Hassan earned the B.Sc (Hons: Cum Laude) in Industrial Engineering from the University of Miami, FL, USA, the M.Sc. degree in Industrial Measurement Systems from Brunel University London, U.K. and the Ph.D degree from Universiti Teknologi Malaysia (UTM), Malaysia. He was a former Head of Manufacturing and Industrial Engineering Department at UTM and a former Chairman of Industrial Engineering Department, King Abdulaziz University, Rabigh, Saudi Arabia. Currently, he is an Associate Professor at the School of Mechanical Engineering, UTM. His research interests include quality engineering, pattern recognition for process monitoring, supply chain, and performance measure. He is a professional member of the IEOM Society International.