한국유가공기술과학회지
Korean J. Dairy Sci. Technol
Vol. 26. No. 2, pp. 51~56 (2008)

반응표면분석법에 의한 가공버터 제조의 최적화 및 Rheology 분석

서문회* · 윤 경 · 백승천
서울우유 중앙연구소

Optimization of the Manufacturing of Process Butter by Response Surface Methodology and Its Texture and Rheological Properties

Mun-Hui Suh*, Kyeong Yoon and Seung-Chun Baick
Institute of Dairy Food Research, Seoul Dairy Co-operative, Ansan 425-838, Korea

ABSTRACT

Using central composite design, we have designed optimization of the manufacturing of processed butter. And response surface analysis by least-square regression was used Statistical Analysis System(SAS). Central composite design can be achieved by response surface techniques that allow flexibility in modeling and analysis. Response surface methodology(RSM) was used to optimize hardness(%) using as independent variables; the content of butter(X_1), ranging from 50 to 90(%), the content of soybean oil(X_2), from 0 to 20(%), and the hydrogenated soybean oil(X_3) from 0 to 4(%). The results on the regression coefficients calculated for overrun by response surface by least-square regression(RSREG) were followed. It was considered that the linear regression was significant($p<0.01$). As for the processed butter, the regression model equation for the hardness(Y, %) to the change of an independent variable could be predicted as follow: $Y=60.88-8.92X_2-29.3X_2^2$. The optimal for the manufacturing of processed butter were determined at the content of butter of 88.22%, soybean oil of 6.71% and hydrogenated soybean oil of 2.36%, respectively. Optimum compositions were resulted in hardness of 65.78 N. Finally the reference sample(Butter in the morning, Seoul Dairy Co-op.) and processed butter manufacturing under the optimal conditions were compared with spreadability test. The spreadability scores result from reference sample and butter under optimal conditions was not found a significant difference.

Keywords : RSM, butter, light optical light microscopy, rheological properties

INTRODUCTION

Butter notoriously possesses poor spreadability at refrigeration temperatures, and poor structural stability at room temperatures(Kaylegian and Lindsay, 1992). At room temperature, butter also demonstrates oiling off and moisture migration(DeMan and Wood, 1958; Shukla *et al.*, 1994). Texture is one of the 4 quality factors that determine butter's acceptability(Bourne, 1982). It influences spreadability, taste, mouth feel, appearance, and butter's suitability for various uses(Mulder and Walstra, 1974). This has been an area of great interest and economical importance for dairy industries around the world, with the primary focus being improved butter spreadability. However, the composition and structure of the constituent milkfat are largely responsible for the rheological properties of butter(Kawanari and others). Therefore, the rheologies of milkfat as well as butter are important considerations in quality evaluations.

Spreadability and hardness as texture related properties represent important aspects in consumer acceptability of solid

* Corresponding author: Mun-Hui Suh, Institute of Dairy Food Research, Seoul Dairy Co-operative, 1059 Shingil-Dong, Danwon-Ku, Ansan-Si, Gyeonggi-Do 425-838, Korea. E-mail: hui0819@seoulmilk.co.kr

edible fats, such as butter and margarine(Frede and Precht, 1988). Spreadability and hardness result from the dispersion of solid fat crystals in liquid oil(DeMan *et al*., 1979). Prentice (1972) stated that the ease with which a plastic fat can be spread upon a substrate is the only rheological property of great practical interest. Usually, criteria closely associated with flow properties of plastic fat products such as firmness, hardness, or consistency are evaluated by a number of empirical rheological methods (DeMan *et al*., 1985). These include wire sectility testing(Mohr and Wellm, 1948; Dixon and Williams, 1977), the use of extruders (Prentice, 1954; Kawanari *et al*., 1981) and cone penetrometers which determine penetration depth and apparent yield value (Dixon and Parekh, 1979; Mortensen and Danmark, 1981) as well as, e.g., uniaxial compression tests(Kawanari *et al*., 1981) and constant speed penetration with cone- or disc-shaped devices (Dixon, 1974; Tanaka *et al*., 1971). Empirical methods with their varying operating principles investigate different rheological properties(Binder *et al*., 1971). For the sensory evaluation of textural properties of butter, structured interval scales, e.g., with 6 to 9 points(DeMan *et al*., 1979; Mortensen and Danmark, 1982) and unstructured scales(Dixon and Parekh, 1979; Pokomy *et al*., 1984) are commonly used to assess spreadability as well as hardness. Frede *et al*.(1985) included hedonic attributes for both properties. Kawanari *et al*.(1981) developed a basic texture profile sheet for butter including a 14-point spreadability scale. A general discussion of different scaling methods for quantification in sensory perception is given by Moskowitz *et al*.(1972). As a consequence, category scales have recently been partly replaced by ratio scales(Szczesniak, 1987). The present study was undertaken to evaluate the application of magnitude estimation for the determination of butter spreadability and hardness. Sensory data are compared with results obtained by four empirical rheological methods.

The aim of this study was to establish the optimal manufacturing processed butter by means of the response surface methodology. The effectiveness of optimal processed butter was evaluated as a hardness of butter.

MATERIAL AND METHODS

1. The Butter Blends Processing

The oil phase was prepared by mixing butter, soybean oil and hydrogenated soybean oil at 60℃. The aqueous phase was prepared by water. The butter blends were processed by first preparing an oil phase by stirring in a beaker. The aqueous phase(45℃) was added continuously to the oil phase(60℃) with stirring. The w/o emulsion was stirred slowly(about 400 rpm) at first and then at a speed of 1,600 rpm. The scraped blades remove crystallizing fat from the cold walls and so maintain the heat transfer characteristics of the unit while promoting nucleation of crystallization. The processed butters were packed in petri dish and stored at 5℃ for post-crystallization. After this, the processed butters were analyzed.

2. The Rheological Properties on Processed Butter: Hardness Measurement

Hardness measurements were observed under a Texture analysis system TA-plus(AMETEK Lloyd Instruments Ltd., UK). The most commonly used test to evaluate butter texture has been penetrometer(DeMan and Beers, 1987). One convenient method is cone penetrometer. In this method a cone suspended on a shaft is released from a starting position with its tip on the surface of the sample. It is difficult that tip was mounted above the surface of the butter with the come tip just touching the clean surface. Thus, a study was used test to determinate texture has been cutting penetrometer. Cutting test has also been used to derive a yield stress for butter. Hardness was determined by petri dish(4 inch diameter) and 10 ㎜ in height. Using a wire 25 ㎜ cutting penetrometer was applied to penetration depth 10 ㎜, and it moved downward at a rate of 50 ㎜/1min. The force of downward stress was recorded an N.

3. Experimental Designs for Response Surface by Least-square Regression(RSREG)

Central Composite Design designed the process optimization of the manufacturing of processed butter. The response surface methodology(RSM) was applied to optimize the manufacturing of processed butter by means of three independent variables; the content of butter(X_1), ranging from 50 to 90(%), the content of soybean oil(X_2), from 0 to 20(%), and the hydrogenated soybean oil(X_3) from 0 to 4(%). The actual variable was coded to facilitate multiple regression analysis(Table 1). The least-square regression model was adequately fitted into the responses taken from the experimental data and to define an optimization process of the yield.

The optimization conditions were studied at the centre of the design to find the accurate results of statistical experimentation. At the beginning of the studies, the second-order composite design, with fractional 2^4 factorial points(16 points), star points (6 points) and central point(1 point), was effective in searching

Table 1. Coded levels for independent variables used in developing experimental data

Variables (Ratio, w/w)	Coded X_i	Coded level					
		−2	−1	0	1	2	ΔX
Content of butter (%)	X_1	50	60	70	80	90	10
Content of soybean oil (%)	X_2	0	5	10	15	20	5
Content of hydrogenated soybean oil (%)	X_3	0	1	2	3	4	1

for the direction of the optimum domain. The regression model equation for the hardness of processed butter could be predicted as follows.

$$Y = b_0 + \sum_{i=1}^{3} biXi + \sum_{i=1}^{3} biiXi^2 + \sum_{i=1\, j=i+1}^{23} bijXiXj$$

Where, Y (%) was the hardness of processed butter; subscripts i and j took values from 1 to the number of variables (n); the b_0 was the intercept term; the b_i values were linear coefficient; the b_{ij} values were quadratic coefficient; X_i and X_j were the level of the independent variables. The analysis of data was carried out using Statistical Analysis System(SAS) program(Cary, 1990). Response surface plots were generated by the Statistical^{TM} software.

4. Sensory Evaluation : Spreadability

The reference sample(Butter in the morning, Seoul Dairy Co-op.) and processed butter manufacturing under the optimal conditions were compared with spreadability test. A ten members panel of 6 males and 4 female were evaluated texture properties. The 5℃-butter sample with a given magnitude of 10 served as standard stimulus for the basic experiment. 'Butter in the morning', conditioned at 5℃, served as reference in the comparative study. Evaluation was repeated twice. Spreadability was determined by spreading cylindrical specimens 14 ㎜ in diameter and 10 ㎜ in height with a knife on filter paper. The 7-point hedonic scale was used to compare the degreed of liking of two samples.

5. Statistical Analysis

A randomized complete block design with 44 factorial arrangements was used. Replication(n=3) was blocked and the additive treatment and the incubation time were the main treatment factors. The General Linear Model(GLM) procedure was applied to the data with a level of p<0.05 for statistical analysis(SAS, 1996) and Least Significance Difference(LSD) was used to compare the mean differences among treatment samples.

RESULTS AND DISCUSSION

1. Optimization of Manufacturing of Processed Butter by Response Surface Methodology

Based on the central composite design, the encapsulation yield of each experimental group(total 23 data points, n=3) was determined and the obtained data were analyzed by SAS. The hardness of processed butter was in the range from 29.2 to 70.8% (Table 2). The results on the regression coefficients calculated for the degree of hardness of butter by RSREG were shown in 〈Table 3〉. The linear regression was significant at the level of p<0.01, but quadratic regression(p>0.05) and cross product regression(p>0.47) were not significant. As for the processed butter, the regression model equation for the hardness(Y, %) to the change of an independent variable could be predicted as follow: Y=60.88 − 8.92X_2 − 29.3X_2^2. According to the model equation, the content of soybean oil(X_2) was believed to be the major factors affect the hardness among the variables studied. The content of butter and hydrogenated soybean oil were shown to have little effect on the hardness of processed butter. This revealed that the above regression equation was a suitable model to describe the response of the experimental parameters (independent variables) to manufacture of processed butter.

2. Response Surface Graph of Yield

The model equation was applied to obtain optimal conditions of processed butter by the three-dimensional graphical methodology. The resulting three-dimensional surface plots of hardness versus two process parameters(X_i) were presented in 〈Fig. 1∼3〉. In this analytical process, the coded level of third parameter not used for the plotting was placed at zero level to interpret the effect of two independent variables on hardness. As a result, it was unreasonable to predict the optimal point from the plots of X_1, X_2 vs yield(Fig. 1) and X_2, X_3 vs yield(Fig. 3). On the other hand, the stationary ridge shape was observed in the surface plot of X_1, X_3 vs yield(Fig. 2). Thus, it was confirmed that the content of soybean oil(X_2) was the crucial factors for

Table 2. Central composite design for the optimization of the manufacturing of process butter

Run No.	Coded variable X_1[1)]	X_2[1)]	X_3[1)]	Process variable X_1	X_2	X_3	But.	Veg.	Har.	Wat.[2)]	Hardness (N)
1	−1	−1	−1	60	5	1	60	5	1	34	45.891
2	1	−1	−1	80	5	1	80	5	1	14	70.808
3	−1	1	−1	60	15	1	60	15	1	24	31.903
4	1	1	−1	80	15	1	80	15	1	4	47.295
5	−1	−1	1	60	5	3	60	5	3	32	47.158
6	1	−1	1	80	5	3	80	5	3	12	63.111
7	−1	1	1	60	15	3	60	15	3	22	39.680
8	1	1	1	80	15	3	80	15	3	2	43.035
9	−1	−1	−1	60	5	1	60	5	1	34	35.363
10	1	−1	−1	80	5	1	80	5	1	14	58.564
11	−1	1	−1	60	15	1	60	15	1	24	41.216
12	1	1	−1	80	15	1	80	15	1	4	42.769
13	−1	−1	1	60	5	3	60	5	3	32	51.067
14	1	−1	1	80	5	3	80	5	3	12	69.918
15	−1	1	1	60	15	3	60	15	3	22	35.277
16	1	1	1	80	15	3	80	15	3	2	54.716
17	−2	0	0	50	10	2	50	10	2	38	29.203
18	2	0	0	90	10	0	90	10	0	0	55.183
19	0	−2	0	70	0	2	70	0	2	28	30.830
20	0	2	0	70	20	2	70	20	2	8	30.323
21	0	0	−2	70	10	0	70	10	0	20	41.433
22	0	0	2	70	10	4	70	10	4	16	61.230
23	0	0	0	70	10	0	70	10	0	20	36.315

But.=Butter, Har.=Hydrogenated soybean oil, Veg.=Vegetable, Wat.=Water.

1) X_1, X_2 and X_3 were the content of butter (%), soybean oil (%) and hydrogenated soybean oil (%), respectively.

2) Water(%)=100−(Butter(%)+soybean oil(%)+hydrogenated soybean oil(%)).

Table 3. Values of regression coefficients calculated for the manufacturing of process butter

Independent variable	Coefficient	Standard error	t-value	Significance level(p)
Constant	60.88	136.58	−1.63	0.13
X_1[1)]	16.84	3.43	1.56	0.14
X_2[1)]	−8.92	3.36	2.69	0.02
X_3[1)]	6.63	17.93	1.26	0.23
X_1^2	−10.81	0.02	−1.18	0.26
X_1X_2	−10.80	0.04	−1.49	0.16
X_2^2	−29.30	0.10	−2.87	0.01
X_1X_3	−3.88	0.17	−0.56	0.59
X_2X_3	−2.78	0.36	−0.38	0.71
X_3^2	−11.00	2.13	−1.29	0.22
R^2		0.8033		
F		15.7377		
Probability of F		0.0024		

1) X_1, X_2 and X_3 were the content of butter(%), soybean oil(%) and hydrogenated soybean oil(%), respectively.

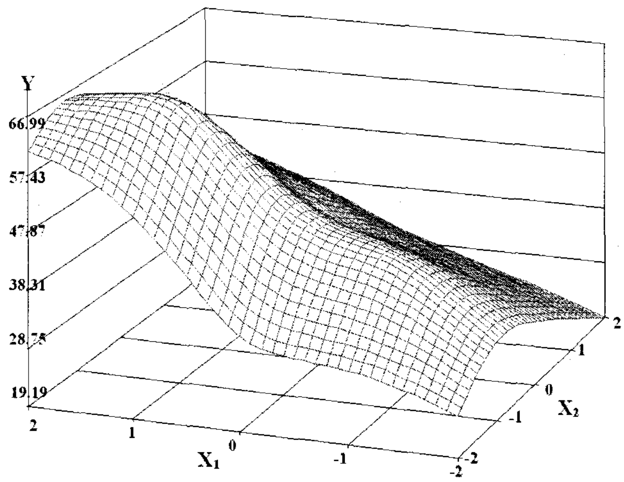

Fig. 1. Respose surface for the effect of the content of butter and soybean oil on hardness of manufacturing of processed butter.
X_1: The content of butter(%)
X_2: The content of soybean oil(%)
Y: Hardness(N)

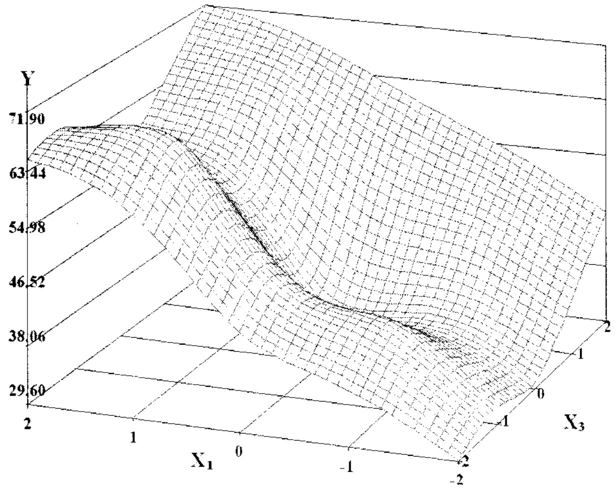

Fig. 2. Response surface for the effect of the content of butter and hydrogenated soybean oil on hardness of manufacturing of processed butter.
X_1: The content of butter(%)
X_3: The content of hydrogenated soybean oil(%)
Y: Hardness(N)

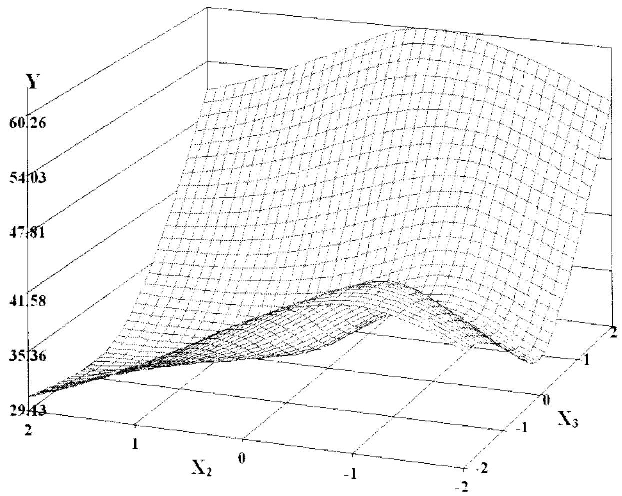

Fig. 3. Response surface for the effect of the content of soybean oil and hydrogenated soybean oil on hardness of manufacturing of processed butter.
X_2: The content of soybean oil(%)
X_3: The content of hydrogenated soybean oil(%)
Y: Hardness(N)

the yield of manufacturing of processed butter among the variables studied.

3. Canonical Analysis

Finally, the hardness of processed butter was determined at the optimum conditions calculated from the canonical analysis. As the Eigen values were all negative, the stationary point was

Table 4. Ridge of maximum response from coded radius 0.1 for optimal condition of response surface

Variable	Coded factor value	Uncoded factor value
X_1[1)]	0.91	88.22
X_2[1)]	−0.33	6.71
X_3[1)]	0.18	2.36

[1)] X_1, X_2 and X_3 were the content of butter(%), soybean oil(%) and hydrogenated soybean oil(%), respectively.

the maximal one. Therefore, critical value reflected optimal conditions for the hardness of the butter. The critical value was shown in 〈Table 4〉. The optimal conditions for the manufacturing of processed butter were determined to be the content of butter of 88.22(%), the content of soybean oil of 6.71(%) and the content of hydrogenated soybean oil of 2.36(%). From these optimum compositions, 65.78 N of hardness was obtained. These results revealed that the most spread able texture of butter would be formed with the greatest manufacturing of processed butter. This value was close to 60.63 N hardness as counted from actual experimental observations, which indicated that the predicted maximum value of the degree of the yield was about the same as that of the experimental result within ±5% of error range. The overall hardness of processed butter was somewhat less than predicted. Since not all the factors on their own, or simple interactions between them, could explain the variation in the data, there may be more complex interactions to be considered.

4. Sensory Evaluation : Spreadability

The reference sample(Butter in the morning, Seoul Dairy Co-op.) and processed butter manufacturing under the optimal conditions were compared with spreadability test. The spreadability scores of reference sample and butter under optimal conditions were 4.5 and 4.6, respectively. The spreadability scores result from two sampes was not found a significant difference.

CONCLUSION

Response surface methodology(RSM) was used to optimize hardness(%) using as independent variables; the content of butter (X_1), ranging from 50 to 90(%), the content of soybean oil(X_2), from 0 to 20(%), and the hydrogenated soybean oil(X_3) from 0 to 4(%). The results on the regression coefficients calculated for overrun by response surface by least-square regression(RSREG) were followed. It was considered that the linear regression was significant(p<0.01). As for the processed butter, the regression model equation for the hardness(Y, %) to the change of an independent variable could be predicted as follow: Y=60.88 − 8.92X_2 − 29.3X_2^2. The optimal for the manufacturing of processed butter were determined at the content of butter of 88.22%, soybean oil of 6.71% and hydrogenated soybean oil of 2.36%, respectively. Optimum compositions were resulted in hardness of 65.78 N.

REFERENCES

1. Binder, W., Sobeck-Skal, E. and Bolzer, W. 1971. Der EinfluB einiger Faktoren auf die Ergebnisse der Butterkonsistenzmessung mit dem FIRA NIRD Extruder.
2. Bourne, M. C. 1982. Food Texture and Viscosity: Concept and Measurement. New York : Academic Press.
3. Cary, N. C. 1990. SAS Institute. Statistical Analysis System, Version 6.0, The SAS Institute.
4. DeMan, J. M. and Wood, F. W. 1958. Hardness of butter. Influence of season and manufacturing method. J. Dairy Sci. 41:360-368.
5. DeMan, J. M., Dobbs, J. E. and Sherman, P. 1979. Spreadability (of butter and margarine, In Food Texture and Rheology, (P. Sherman, ed.) 42-45.
6. DeMan, J. M., Gupta, S., Kloek, M. and Timbers, G. E. 1985. Viscoelastic properties of solid fat products. J. Am. Oil Chem. Soc. 62:1672-1675.
7. DeMan, J. M. and Beers, A. M. 1987. Review : Fat crystal networks : Structure and rheological properties. J. Texture Stud. 18:303-318.
8. Dixon, B. D. 1974. Spreadability of butter: Determination-1. Description and comparison of five methods of testing. Aust. J. Dairy Technol. 29:15-20.
9. Dixon, B. D. and Williams, T. 1977. Measurement of butter firmness by sectility testing. Aust. J. Dairy Technol. 34: 177-179.
10. Dixon, B. D. and Parekh, J. V. 1979. Use of cone penetrometer for testing firmness of butter. J. Texture Stud. 10:421-434.
11. Frede, E., Precht, D. and Peters, K. H. 1985. Schnittfestigkeit und Streichflihigkeit von Butter. Dt. Milchwirtschaft 36: 976-977.
12. Frede, E. and Precht, K. H. 1988. Streichfihigkeit und Schnittfestigkeit vakuumbehandelter Butter. Dt. Molkerei Ztg. 109: 313-317.
13. Kawanari, M., Hamann, D. D., Swartzel, K. R. and Hansen, A. P. 1981. Rheological and texture studies of butter. J. Texture Stud. 12:483-505.
14. Kaylegian, K. E. and Lindsay, R. C. 1992. Performance of selected milk fat fractions in cold-spread able butter. J. Dairy Sci. 75:3307-3317.
15. Mortensen, B. K. and Danmark, H. 1981. Firmness of butter measured with a cone penetrometer. Milchwissenschaft 36: 393-395.
16. Mohr, W. and Wellm, J. 1948. Konsistenz der Butter. I. Zur Methodik der Konsistenzmessung. Milchwissenschaft 8:234-242.
17. Mortensen, B. K. and Danmark, H. 1982. Factors influencing the consistency of butter. Milchwissenschaft 37:193-196.
18. Moskowitz, H. R., Drake, B. and Akesson, C. A. 1972. Psychophysical measures of texture. J. Texture Stud. 3:135-145.
19. Mulder, H. and Walstra, P. 1974. The Milk Fat Globule. Wageningen : Centre for Agricultural Publishing and Documentation. 33-55.
20. Pokorny, J., Davidek, J., Mibiasova, S., Stern, P. and Cmoik, J. 1984. Comparison of sensory analysis and rotational rheometry in the texture evaluation of butter. J. Texture Stud. 15:395-406.
21. Prentice, J. H. 1954. An instrument for estimating the spreadability of butter. J. Lab. Practice. 3:186-189.
22. Prentice, J. H. 1972. Rheology and texture of dairy products. J. Texture Stud. 3:415-458.
23. Rohm, H. and Ulberth, F. 1989. Use of magnitude estimation in sensory texture analysis of butter. J. Texture Stud. 20:409-418.
24. Shukla, A., Bhasker, A. R., Rizvi, S. S. H. and Mulvaney, S. J. 1994. Physicochemical and rheological properties of butter made from supercritically fractionated milk fat. J. Dairy Sci. 77:45-54.
25. Szczesniak, A. 1987. Correlating sensory with instrumental texture measurements-an overview of recent developments. J. Texture Stud. 18:1-15.
26. Tanka, M., DeMan, J. M. and Voisey, P. W. 1971. Measurement of textural properties of foods with a constant speed penetrometer. J. Texture Stud. 2:306-315.

(2008년 10월 2일 접수; 2008년 11월 10일 채택)