Study on the process optimization of soft-tofu

Der Yeh Junior Collage of
Nursing and Medical
Ming-Chih Shih 施明智

ABSTRACT

This study investigated the relationship of concentration of soymilk, amount of coagulant, mixing temperature of adding coagulant, and stirring time after adding coagulant in the yield and quality of soft-tofu. Response surface methodology (RSM) was used to determine the optimum combinations of the four factors, concentration of soymilk (10~14 Brix), amount of coagulant (0.25~0.41%,W/V), mixing temperature of adding coagulant (75~91°C) and stirring time after adding coagulant (5~25 sec. for stirring speed of 285 rpm) to produce a high yield and good quality soft-tofu product. The yield, the solid and the protein content of tofu were measured. A piece of tofu was sliced into two parts, top and middle, then the textural properties of each parts were analyzed for hardness, brittleness and elasticity using an Instron Testing Instrument.

The results showed that only two factors, concentration of soymilk and amount of coagulant significantly affected the yield of tofu ($p<0.05$) and all factors except mixing temperature affected the solid and the protein content of tofu. However, the solid and the protein recovery, the brittleness and the elasticity of the top part of tofu were not influenced by all factors. All factors except stirring time affected significantly the hardness of the top part of tofu, and only two factors, concentration of soymilk and stirring time, affected the brittleness of the middle part of tofu.
According the results of superimposed contour plots, the optimum tofu processing area is: concentration of soymilk=11.8~12.3 Brix, amount of coagulant= 0.27~ 0.32%, mixing temperature= 85~ 91°C, and

stirring time= 5~ 11.3 sec.. Using this condition to make tofu found that the coefficient of variations between predicted data and observed data were acceptable (<5%), except the brittleness of middle part of tofu (~9%).

INTRODUCTION

Tofu is a traditional soybean processed food in Asia,and is a protein gel like product. There are many different types products of tofu appeared in market such as soft-tofu, regular tofu, Kori tofu etc. (Saio, 1979). A typical soft-tofu required a bland taste and fine texture with 84~90% moisture content. Soft-tofu has a soft cheeselike texture but is firm enough to retain shape after slicing (Tsai et al., 1981). The processing procedure of soft-tofu was similar to regular tofu. However, the bean curd of soft-tofu was not broken and pressed directly.

There are several factors affect the quality of tofu, such as variety of soybean (Shen et al., 1991, Sun and Breene, 1991), processing methods (Beddows and Wong,1987a,b,c, Saio,1979) and type of coagulant (Lim et al, 1990, Tsai et al., 1981, deMan,1986). The processing factors which may affect the quality of tofu include the soymilk heating rate and heating time, stirring speed and time in coagulation, temperature in coagulation, pressing time and weight (Watanabe et al, 1964, Saio, 1979, Beddows and Wang, 1987, a,b, c, Hou et al, 1995). Beddows and Wang (1987c) found the stirring speed during coagulant addition was critical during making silken tofu. Hou et al.(1995) found that the stirring time and speed affect significatly the texture of soft-tofu. Many reports noted that the concentration of soymilk also affect the quality of tofu, but different type of tofu required different concentration of soymilk (Watanabe et al.,1964, Saio,1979,Beddows and Wong, 1987a). The type and amount of coagulant also affect the quality of tofu. The most popular coagulant are $CaSO_4$, nigari and GDL, depent what kind tofu , and each kind of coagulant has different optimum concentration (Sun and Breene, 1991, Deman et al., 1986, Lim et al,1990, Shen et al, 1991, Lu et al., 1980).

Although many factors affect the quality of tofu, the process optimization of several factors for making soft-tofu has not been reported. The objectives of this study were: (1) To investigate the relationship of (a)concentration of soymilk, (b)amount of coagulant, (c)mixing temperature of adding coagulant and (d)stirring time after adding coagulant on the yield and quality of soft-tofu, and (2) to determine the optimum combinations of the four factors which mentioned above.

MATERIAL AND METHODS

Materials

Soybean of the Proto cultivar was obtained from a local seed farm. Antifoaming agent (containing 89.5% glycerol fatty acid ester, 8% lecithin, 2% $MgCO_3$, and 0.5% silicon resin) was obtained from Koah Co. (Wakayama, Japan). Food grade coagulant (nigari) was from Taiwan Salt Workers (Tainan, Taiwan).

Experimental design

Response surface methodology (RSM) was used to obtaine optimum conditions of the four factors: concentration of soymilk (X1), amount of coagulant (X2), mixing temperature of adding coagulant (X3), and stirring time after adding coagulant (X4). Each of the variables to be optimized was coded at 5 levels : -2, -1, 0, 1 and 2. Table 1 showed the variables, their symbols and levels. A total of 31 runs design, based on central composite rotatable design (CCRD) of the second order as shown on Table 2, were performed in a random order (Box et al, 1978). Eleven responses were measured : The yield (g tofu/100g soybean) (y1), the solid content of tofu (%)(y2), the protein content of tofu (%) (y3), the brittleness of the top part of tofu (g) (y4), the hardness of the top part (g) (y5), the elasticity of the top part (%) (y6), the brittliness of the middle part (g) (y7), the hardness of the middle part (g) (y8), the elasticity of the middle part (%)(y9), solid recovery (%)(y10), protein recovery (%)(y11).

The model proposed for each responses (Y) was:

$$Y=b_o+\sum_{i=1}^{4} b_iX_i+\sum_{i=1}^{4} b_{ii}X_i^2+\sum_{i=1}^{4}\sum_{j=i+1}^{4} b_{ij}X_iX_j$$

where bo was the intercept, bi, bii, and bij were the linear , quadratic and cross-product regression terms respestively. Xi and Xj were the coded independent variable, linearly related to X1, X2, X3 and X4.

Tofu making

Soybean (900 g) was washed and soaked in tap water at 15~18°C for 8 hours. Hydrated soybean was draind and ground with tap water in a high speed grinder (Chan Shen Machinery Co., Taoyuan, Taiwan), which was equipped with an automatic centrigugal filter to separate the residue and soymilk. The concentration of soymilk as a degree of brix was determined by a refractometer (AutoAbbe, Model 10500, Buffalo, NY). Soymilk was adjusted by tap water to obtain the desired concentration (10~14 Brix) . After adding antifoaming agent , 4.5L soymilk was cooked to 95°C and kept 5 minunt. After cooling to desired temperature (75~91°C), the diffenent amount of coagulants (0.25~0.41%,w/v) were adding and stirring at 285 rpm by a stirrer (Model RZR1, Caframo LTD., Ontaria, Canada) 5~25 minunt. The coagulated soymilk was poured immediately into a 268 × 268 × 70 mm^3 wooden mold which already cover with a cheese cloth and a plastic sheet and hold 10 min. After 10 minunt, the plastic sheet was removed carefully and pressed with a 30 lb steel plate for 10 min. Then, pressed with 60 lb steel plate for 10 min, and finally pressed with 90 lb steel plate for 30 min. After pressed, the cloth was removed and the tofu was weighed. Finally, cutted the tofu into small pieces and immersed into cold water over night for textural analysis. The yield of tofu was expressed as the weight of tofu on the basis of weight of 100g raw soybean.

The solid and protein content of tofu

About 150 g tofu was homogenized by a tissumizer (Tekma Co.,Cincinnati, Ohio). Moisture content was determined by heating 5 g homogenized tofu and at 105°C for 24 hours to obtain the solid matter (Tsai et al., 1981). Two grams homogenized tofu was used to determined protein content according to AOAC method 955.04 (AOAC, 1990). The results were expressed as the solid content of tofu (y2) and the protein content of tofu (y3).

Solid recovery and protein recovery

Solid recovery was expressed as the amount of solid in the tofu dry matter divided by the amount of solid in the soybean multiplies 100% (y10). Protein recovery was expressed as the amount of protein in the tofu dry matter divided by the amount of protein in the soybean multiplied 100% (y11).

Textural analysis

A piece of tofu was divided into top, middle and buttom three parts. The top and middle parts were used to analyze the texture profile. Each piece of tofu was cutted into 1.5 cm height and 5 cm diameter. Texture profile of tofu was measured by an Instron Universal Testing Instrument (Model 1000, Instron Co., Canton, MA) equipped with a 500 Kg weight beam. A 5Kg load cell was used with a cross-head control at 20 mm/min.. A cylindrical plunger of 5 cm in diameter was used to compress tofu. Four pieces of tofu from each batch were measured by compressing twice to 25% of the original height of each piece. Brittleness, hardness and elasticity were calculated using the Textural Profile Analysis curve as described by Bourne (1978). The results were expressed as the brittleness of the top part (B-T) (y4), the hardness of the top part (H-T) (y5), the elasticity of the top part (E-T) (y6), the brittleness of the middle part (B-M) (y7), the hardness of the middle part (H-M) (y8), and the elasticity of the middle part (E-M) (y9).

Statistical analysis

The response surface regression procedure (RSREG) of Statistical Analysis System (SAS, 1988) was used to fit the experimental data to the quadratic polynomial equation to obtain the coefficients of equation. The fitted polynomial regression equations were expressed graphically by Surfer Access System (Version 5.0).

Verification

Optimum conditions of the four factors were calculated by the prediction equation derived by RSM. Tofu was made by the optimum conditions and analysed for yield, hardness of the top part, and brittleness of the middle part. The experimental values and predicted values from the model was compared. The coefficient of variation (C.V.) between predicted and observed value was calculed according to the method of Montgomery(1984).

RESULTS AND DISCUSSION

Models fitting from RSM

The result of ANOVA were shown on Table 3. The models fitted for the yield (y1) and the brittleness of the middle part (y7) were significantly by the F-test at the 5% confidence level. The modles fitted for solid content (y2) , protein content (y3), the hardness of the top part (y5) and middle part (y8) were at the 1% confidence and the elasticity of the middle part (y9) was at the 0.1% confidence level. However, the brittleness of the top part (y4), the elasticity of the top part (y6), solid recovery (y10) and protein recovery (y11) were not significantly by the F-test.

All model showed no lack of fit except the brittleness of the top part (y4). The coefficient of determinations (R^2) for fit of the model were shown in Table 3. Results indicated that the model developed for response variales (y1, y2, y3, y5, y7, y8, and y9) were adequate.

Response surface plotting

The regresion coefficient of the second degree polynomial were given in Table 4. According to regression models, a series of contour plots were obtained.

The contour plot of the yield, solid and protein content of tofu was shown as a function of concntration of soymilk and amount of coagulant at the condition of X3=1 (87°C) and X4= -1 (10sec) (Fig. 1). Increasing coagulant concentration was accompanied by decreasing the yield, the solid and the protein content of tofu. Increasing concentration of soymilk, the solid and the protein content of tofu were increasing , but the yield of tofu was decreasing. Lim et al. (1990) reported a positive correlation between the protein content of the soymilk and protein of the tofu. Sun and Breene (1991) reported a negative correlation were found between coagulant concentration and both yield and protein content in tofu. These results were as same as this experiment.

The contour plot of the elasticity of the middle part, the hardnesss of the top and middle part (Fig. 2) and the brittleness of the middle part (Fig.3) were shown as a function of concentration of soymilk and amount of coagulant at the condition of X3=1 (87°C) and X4=-1 (10sec) (Fig. 2). Increasing coagulant concentration was accompanied by increasing the elasticity of the middle part, the hardnesss of the top and the middle part. When the concentration of soymilk increasing, the elasticity of the middle part, the hardnesss of the top and the middle part decreased then increased. The higher concentration of soymilk was used, the higher the brittlensee of the middle part was obtained.

Schaefer and Love (1992) reported that the higher protein of soymilk generally produced tofu that had a firmer, more springy texture. According to this experiment, the tofu made by lower concentration of soymilk was more coarse then by medium concentration. Therefore, the tofu made by lower concentration of soymilk had the higher hardness but the lower the brittleness of the middle part of tofu. The tofu made by higher concentration of soymilk was very smooth and tough, so the hardness, the brittleness and the elasticity of tofu were higher then the tofu made by medium concentration soymilk.

The superimposed contour plot for the yield, the hardness of the top part and the brittleness of the middle part at the condition of X1=1 (87°C) and X4=-1 (10 sec.) was shown as Fig.4. The shaded region shown the optimum area. When the hardness of the top part of soft-tofu was lower than 2200g and the brittleness of the middle part was lower than 1100g, the tofu would be too soft to mantain the shape after slicing. If the hardness of the top part of ssoft-tofu was higher than 3000g, the structure of tofu will be very coarse. According to above mentioned reason, the region between the hardness of the top part (>2200g), the brittleness of the middle part (>1100g), and as higher as the yield of tofu (>530g) was selected as the optimum area of concentration of soymilk and amount of coagulant (Fig.4, crosshatched).

The contour plot of the brittleness of the middle part, the solid and the protein content of tofu as a afunction of mixing temperature of adding coagulant and stirring time after adding coagulant at the condition of X1=0 (12 Brix) and X2=-1 (0.29%) was shown as Fig.5. The results shown that the higher stirring time eas used, the lower the hardness of the middle part, the solid and the protein content of tofu were obtained. The mixing temperature did not affect the hardness of the middle part, the solid and the protein content of tofu. Meanwhile, The mixing temperature and stirring time did not affect the yield of tofu (Table 4). Hou et al. (1995) reported that the effect of stirring time on yield of the tofu was not significant different among 5~25 sec treatment. The result was similar as this experiment. Wang and Hesseltine (1982) reported that the moisture content of the curd decreased as the temperature increased from 60 to 80°C.

The contour plot of the hardness of the top part of tofu as a function of mixing temperature of adding coagulant and stirring time after adding coagulant at the condition of X1=0 (12 Brix) and X2=-1 (0.29%) was shown as Fig. 6. The result shown that the higher the mixing temperature was, the higher the hardness of the top parts obtained. Wang and Hesseltine (1982) reported that increasing hardness of the curd was noted as the temperature increasing. The result was similar as this experiment. But Watanabe et al. (1964) reported that the hardness increasing as the temperature increased from 40 to 80°C, but decreased in 90°C. That result shown that the hardness decreased when temperature increasing from 80 to 90°C.

The superimposed contour plot for the hardness of the top part and the brittleness of the middle part at the condition of X1=0 (12 Brix) and X2=-1 (0.29%) was shown as Fig.7. The shaded region shown the optimum area. The region between the hardness of the top part >2200g, and the brittleness of the middle part >1100g was the optimum area of mixing temperature and stirring time when X1=0 (12 Brix) and X2=-1 (0.29%)(Fig.7 crosshatched). Combined the result of Fig.5 and Fig.8, the optimum area was below area: concentration of soymilk=11.8 ~12.3 Brix, amount of coagulant=0.27~0.32%, mixing temperature=85~91 °C and stirring time=5~11.3 sec..

To confirm predicted values of yield and textural properties of touf, a verification experiment was performed using soymilk solid 12 Brix, coagulant concentration 0.29%, mixing temperature 87℃ and stirring time 10sec, within the optimum range. The coefficient of variation (C.V.) of yield and hardness of the top part were lower than expected (<5%), and that of brittleness of the middle part was about 9%. Verification experimental result and predicted values of RSM modle were not different at 10% significance level. This indicated that the optimum processing range for soft tofu making developed by RSM model was adequate and useful.

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Table 1. Levels of variables in soft tofu making according to ratatable central composite design.

Factors	Coded levels	Levels -2	-1	0	1	2
Concentration of soymilk (Brix)	X1	10	11	12	13	14
Amount of coagulant (%,W/vol. soymilk)	X2	0.25	0.29	0.33	0.37	0.41
Mixing temp. of adding coagulant(°C)	X3	75	79	83	87	91
Stirring time after adding coagulant (sec.)	X4	5	10	15	20	25

Table 2. Experimental design and responses.

	Variable level					Respopnses									
run	X1	X2	X3	X4	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
1	1	1	1	1	482	11.3	5.97	1107	3358	43.4	734	977	30.8	54.3	70.4
2	1	1	-1	1	482	11.6	6.19	1271	3270	35.3	960	896	22.3	56.1	73.1
3	1	-1	1	1	489	11.6	6.24	1373	2661	26.7	878	792	24.0	56.8	74.8
4	1	-1	-1	1	493	11.5	6.03	1341	2163	30.0	1043	607	20.0	56.7	72.9
5	-1	1	1	1	400	13.8	7.30	4985	4985	63.4	919	1200	45.0	50.9	71.5
6	-1	1	-1	1	541	11.2	5.80	851	2772	39.3	617	922	31.3	60.5	76.4
7	-1	-1	1	1	570	10.6	5.53	1132	2186	32.6	899	587	22.0	60.1	77.2
8	-1	-1	-1	1	566	10.0	5.33	1046	2032	35.3	772	498	18.7	56.7	74.0
9	1	1	1	-1	479	11.7	6.08	1357	3100	30.0	1047	917	23.3	56.2	71.4
10	1	1	-1	-1	489	11.6	6.18	1433	2546	34.7	1107	723	22.0	56.9	74.0
11	1	-1	1	-1	493	12.3	6.43	1530	2212	39.3	1118	758	22.0	60.4	77.6
12	1	-1	-1	-1	496	12.2	6.55	1620	2115	34.0	1230	581	20.0	60.3	79.6
13	-1	1	1	-1	533	10.3	5.31	1162	3297	35.3	924	716	19.2	54.7	69.3
14	-1	1	-1	-1	545	10.1	5.40	1280	2679	36.0	953	528	20.0	55.1	72.1
15	-1	-1	1	-1	554	10.0	5.25	1203	2187	34.0	959	496	17.3	55.3	70.9
16	-1	-1	-1	-1	553	10.2	5.33	1253	2496	34.7	964	510	19.3	56.4	72.2
17	2	0	0	0	460	12.1	6.46	1691	2601	21.7	1232	784	24.7	55.7	72.8
18	-2	0	0	0	516	10.7	5.02	4012	4012	62.0	488	1102	35.0	55.2	65.9
19	0	2	0	0	503	11.6	6.00	1205	3500	44.7	697	1045	28.7	58.4	73.9
20	0	-2	0	0	530	10.8	5.66	1247	1895	34.7	937	505	17.3	57.0	73.4
21	0	0	2	0	503	10.9	5.81	1191	3350	44.0	795	988	30.7	55.0	71.6
22	0	0	-2	0	530	11.0	5.68	1360	2165	32.0	1084	527	17.3	58.2	73.7
23	0	0	0	2	503	11.3	5.85	760	2498	40.0	494	830	26.7	56.7	72.1
24	0	0	0	-2	526	10.9	5.79	1392	2547	36.0	980	685	22.0	57.4	74.6
25	0	0	0	0	500	10.9	5.80	977	2647	36.0	738	850	23.3	54.8	71.0
26	0	0	0	0	522	11.2	5.86	1436	2719	31.3	1029	674	18.0	58.3	74.9
27	0	0	0	0	533	11.7	6.14	1472	2584	40.0	1132	755	24.0	62.1	80.2
28	0	0	0	0	499	11.4	6.02	1449	2794	34.7	1059	683	23.3	56.7	73.3
29	0	0	0	0	533	11.1	5.97	1306	2361	28.7	1029	578	19.3	59.2	77.9
30	0	0	0	0	530	11.1	5.97	1683	2130	49.3	1278	615	24.7	58.7	77.5
31	0	0	0	0	526	10.6	5.60	1223	2535	41.3	902	696	21.3	55.9	73.2

Table 3. ANOVA and model fitting for the response variables.

Source	df	Sum of square for Y1	Y2	Y3	Y4	Y5	Y6	Y7
Model	14	26275*	14.7**	5.08**	13.2E6	10.4E6	1423	7.9E5
Linear	4	16563**	6.6**	2.69***	2.6E6	7.8E6***	943	6.0E5**
Quadratic	4	1776	0.2	0.02	4.3E6	1.0E6	20	1.1E5
Crossproduct	6	7936	7.9**	2.37**	6.3E6	1.6E6	460	0.7E5
Residual	16	8911	3.5	1.14	7.8E6	2.3E6	876	3.7E5
Lack of fit	10	7593	2.9	0.96	7.5E6	2.0E6	590	2.0E5
Pure error	6	1318	0.6	0.18	0.3E6	0.3E6	286	1.7E5
R^2 (%)		74.7	80.7	81.7	63.0	82.2	61.9	67.9

Source	df	Sum of square for Y8	Y9	Y10	Y11
Model	14	8.7E5**	893**	74.6	171
Linear	4	6.9E5***	546***	24.8	50
Quadratic	4	0.7E5	82	13.6	52
Crossproduct	6	1.1E5	265	36.0	69
Residual	16	2.3E5	181	82.8	106
Lack of fit	10	1.9E5	143	47.4	44
Pure error	6	0.5E5	38	35.5	62
R^2 (%)		78.9	83.1	47.4	61.7

*** : $p<0.001$
** : $p<0.01$
* : $p<0.05$

Table 4. Regression coefficients of the second order polynominals for response values.

Coef.	Y1	Y2	Y3	Y5	Y7	Y8	Y9
bo	520.4***	11.1***	5.9***	2539***	1024***	693***	22.0***
b1	-19.6***	0.4***	0.3***	-168*	108**	7	-1.2
b2	-13.2*	0.2*	0.1	465***	-45	130***	3.1***
b3	-9.1	0.1	0.1	262**	-31	88**	2.4***
b4	-6.9	0.2	0.1	112	-102 **	64*	2.5**
b11	-7.9	0.1	-0.0	181*	-23	50*	1.7*
b12	11.6	-0.3**	-0.2**	-107	-15	-31	-1.6
b22	-0.7	0.0	0.0	29	-34	8	-0.1
b13	8.2	-0.2	-0.1	-90	-60	6	0.1
b23	-10.1	0.1	0.1	190	9	19	1.0
b33	-0.7	-0.0	-0.0	44	-3	3	0.2
b14	6.1	-0.4**	-0.2**	10	-18	-42	-2.0*
b24	-10.2	0.3*	0.2*	171	-8	61	2.4*
b34	-7.3	0.2	0.1	125	15	6	1.8*
b44	-1.2	0.0	0.0	-15	-54	3	0.3

*** : $p<0.001$
** : $p<0.01$
* : $p<0.05$

Table 5. Comparison of predicted value from RSM model and observed value from experiment of soft tofu making.

	Yield (%)	Hardness of the top part(g)	Brittleness of the middle part (g)
Predicted data	534	2386	1126
Observed data	528	2345	1286
C.V.(%)*	0.8	1.7	9.4

*C.V. : Coefficient of variation.

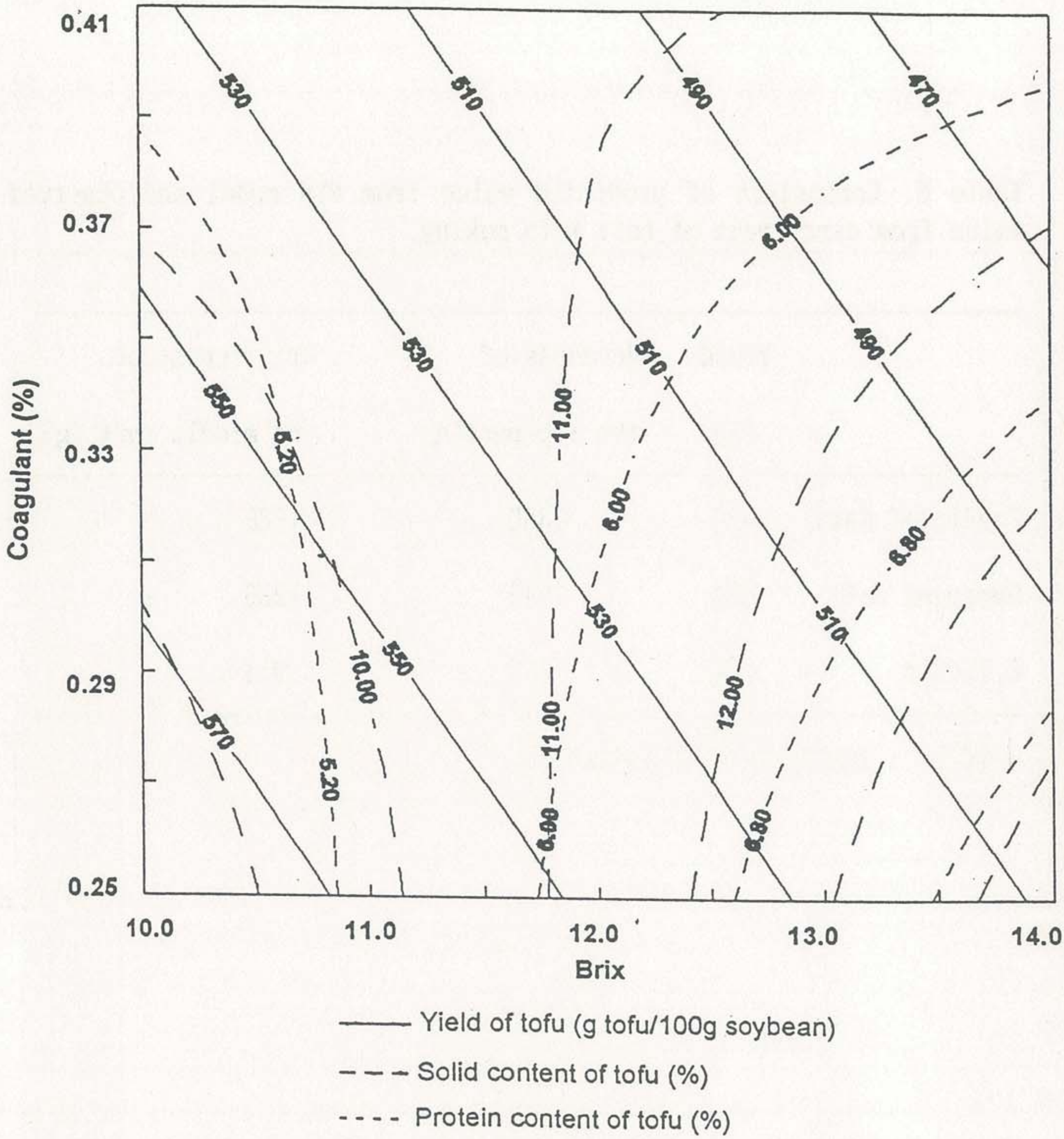
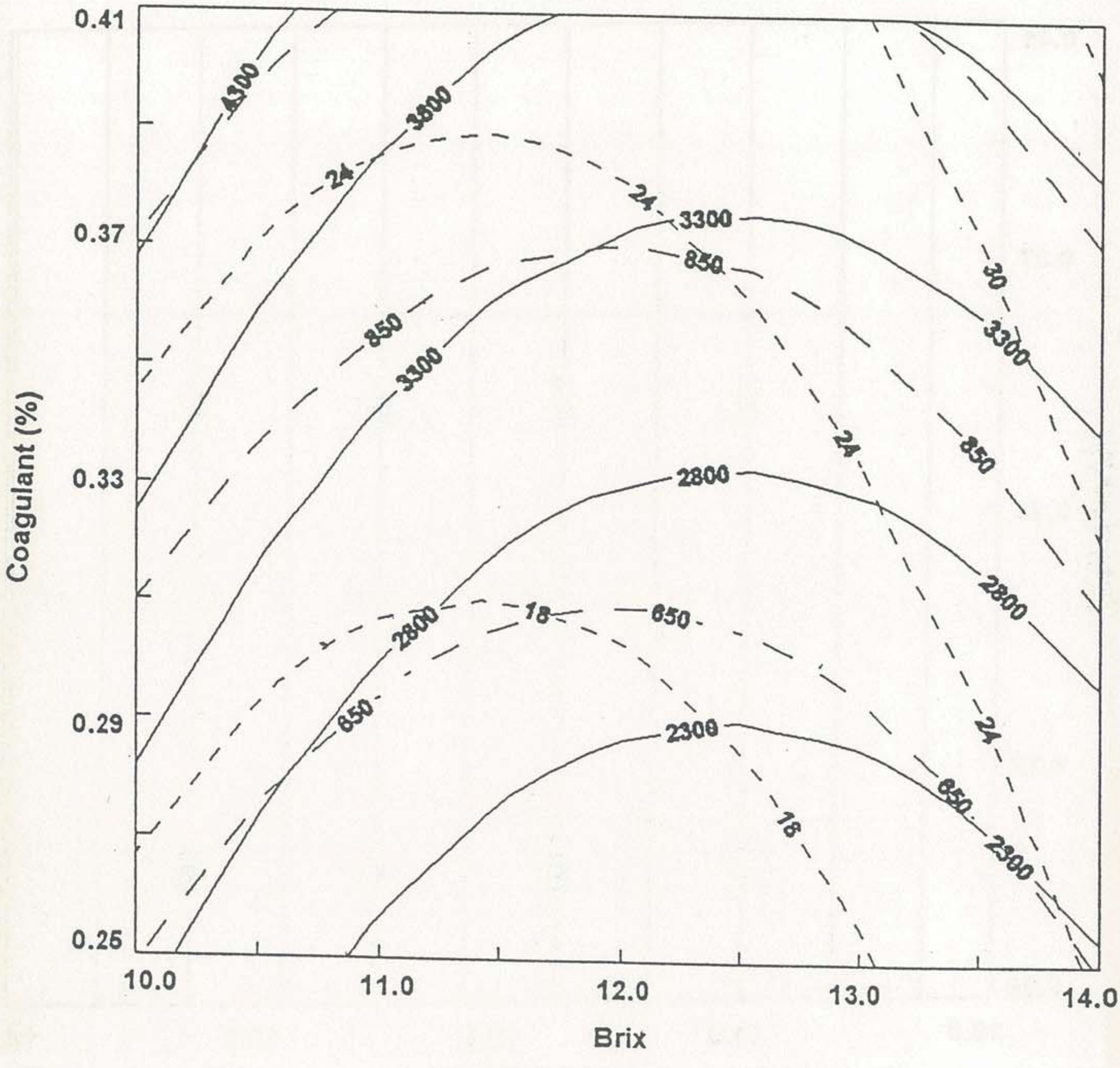


Figure 1. Superimposed contour plots of yield, solid and protein content of tofu as a function of soymilk solid content (°Brix) and coagulant concentration (%, w/v) at mixing temperature 87 °C (X3=1) and stirring time 10 sec (X4= -1).



—— Hardness of the top part (g)

– – – Hardness of the middle part (g)

- - - - Elasticity of the middle part (%)

Figure 2. Superimposed contour plots of elasticity of the middle part, hardness of both the top and the middle part as a function of soymilk solid content (°Brix) and coagulant concentration (%, w/v) at mixing temperature 87 °C (X3=1) and stirring time 10 sec (X4= -1).

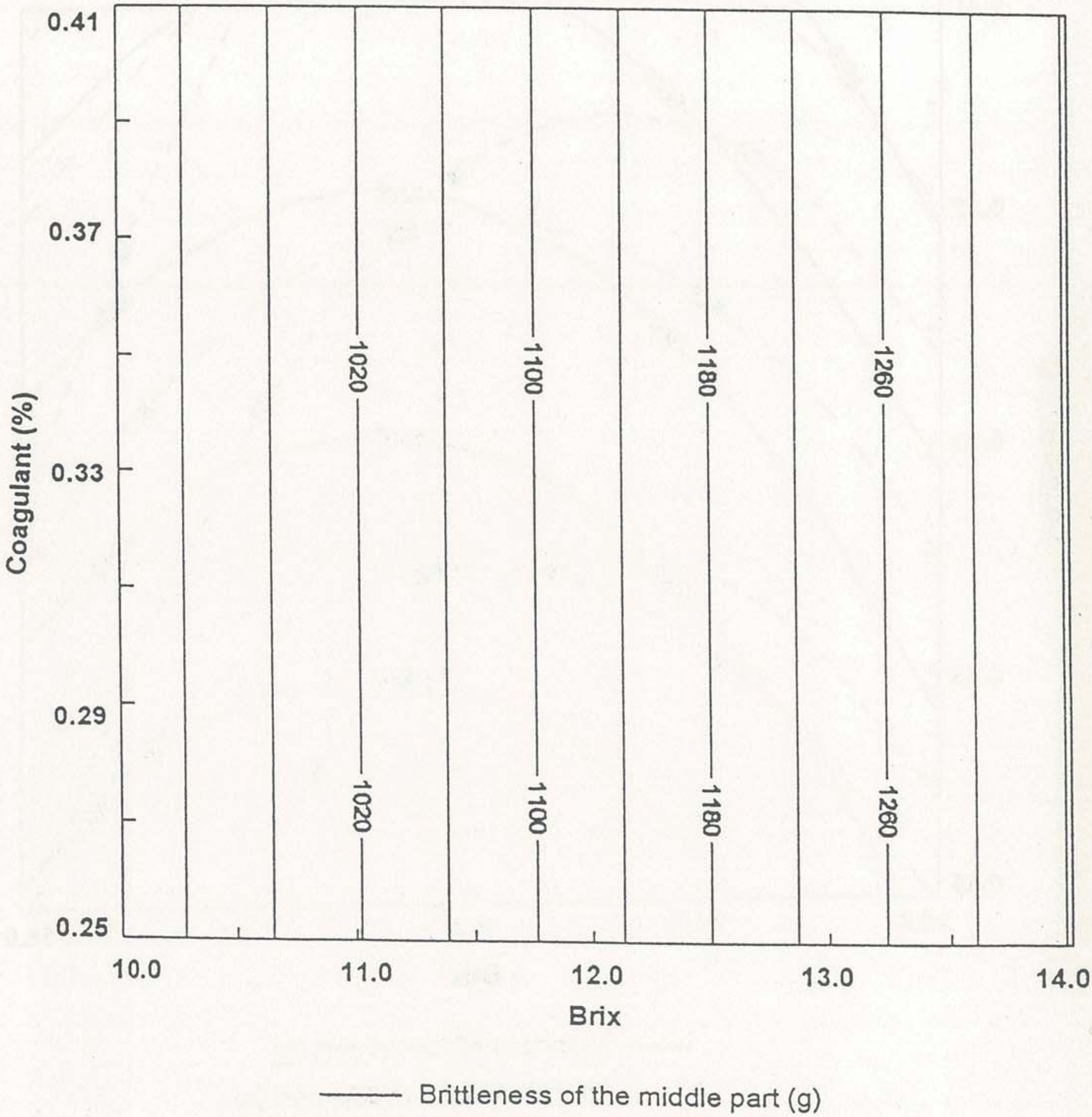


Figure 3. A contour plots of brittleness of the middle part, as a function of soymilk solid content (°Brix) and coagulant concentration (%, w/v) at mixing temperature 87 °C (X3=1) and stirring time 10 sec (X4= -1).

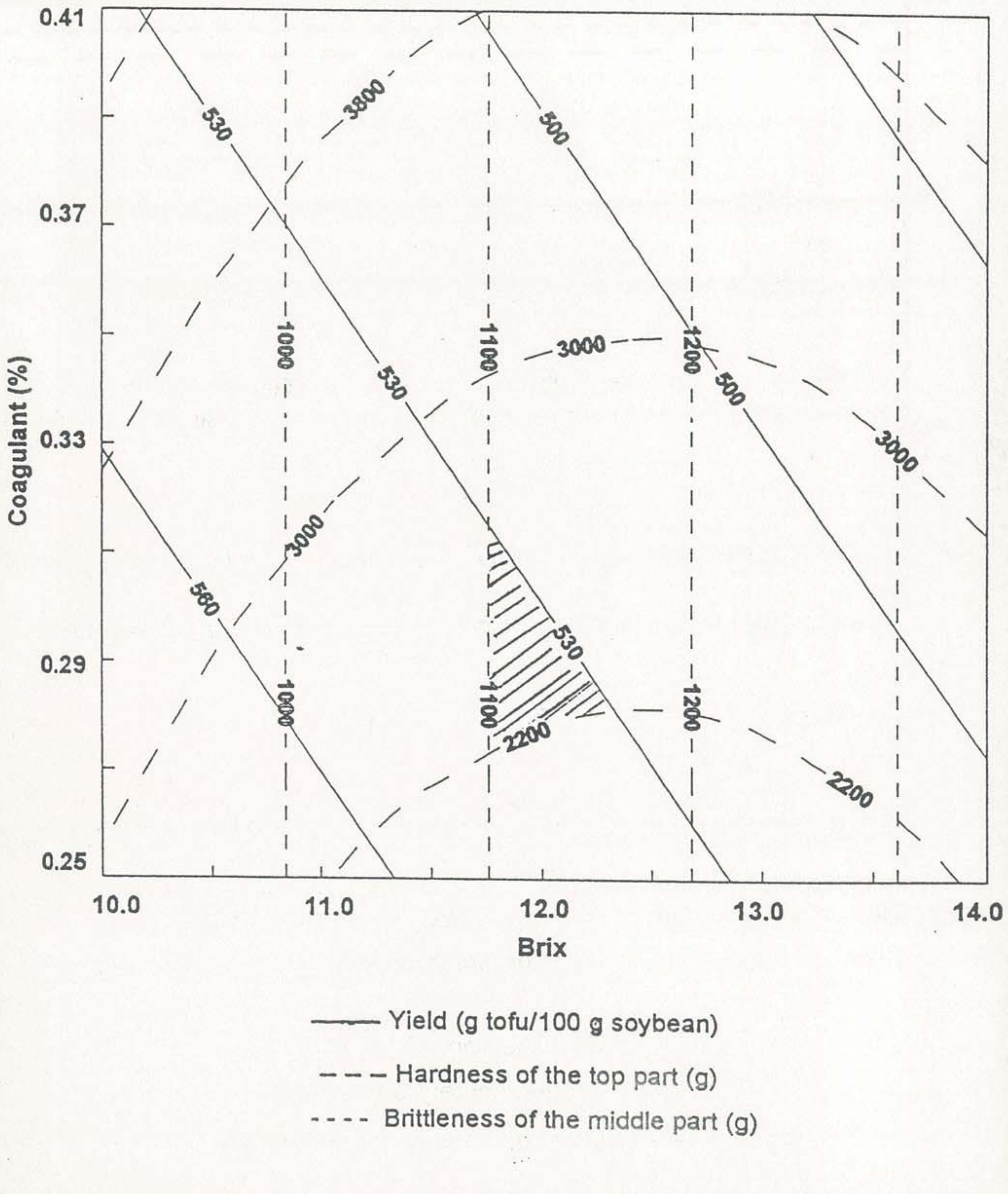


Figure 4. Superimposed contour plots for yield, hardness of the top part and brittleness of the middle part as a function of soymilk solid content (°Brix) and coagulant concentration (%, w/v) at mixing temperature 87 °C (X3=1) and stirring time 10 sec (X4= -1). Shaded region is the optimum area.

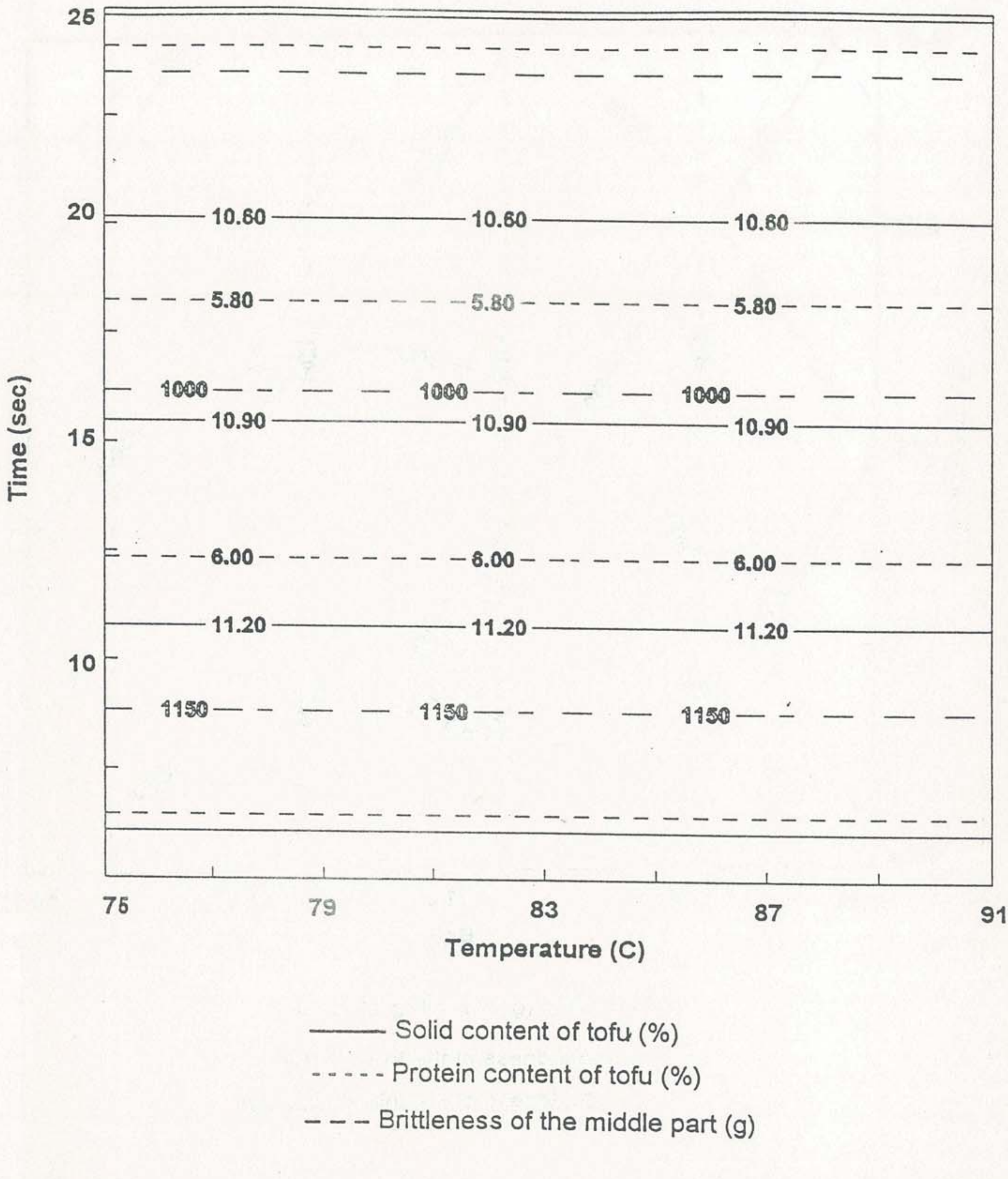


Figure 5. Superimposed contour plots of brittleness of the middle part, solid and protein content of tofu as a function of mixing temperature (°C) and stirring time (sec) at soymilk solid content 12 °Brix (X1=0) and coagulant concentration 0.29% (X2= -1).

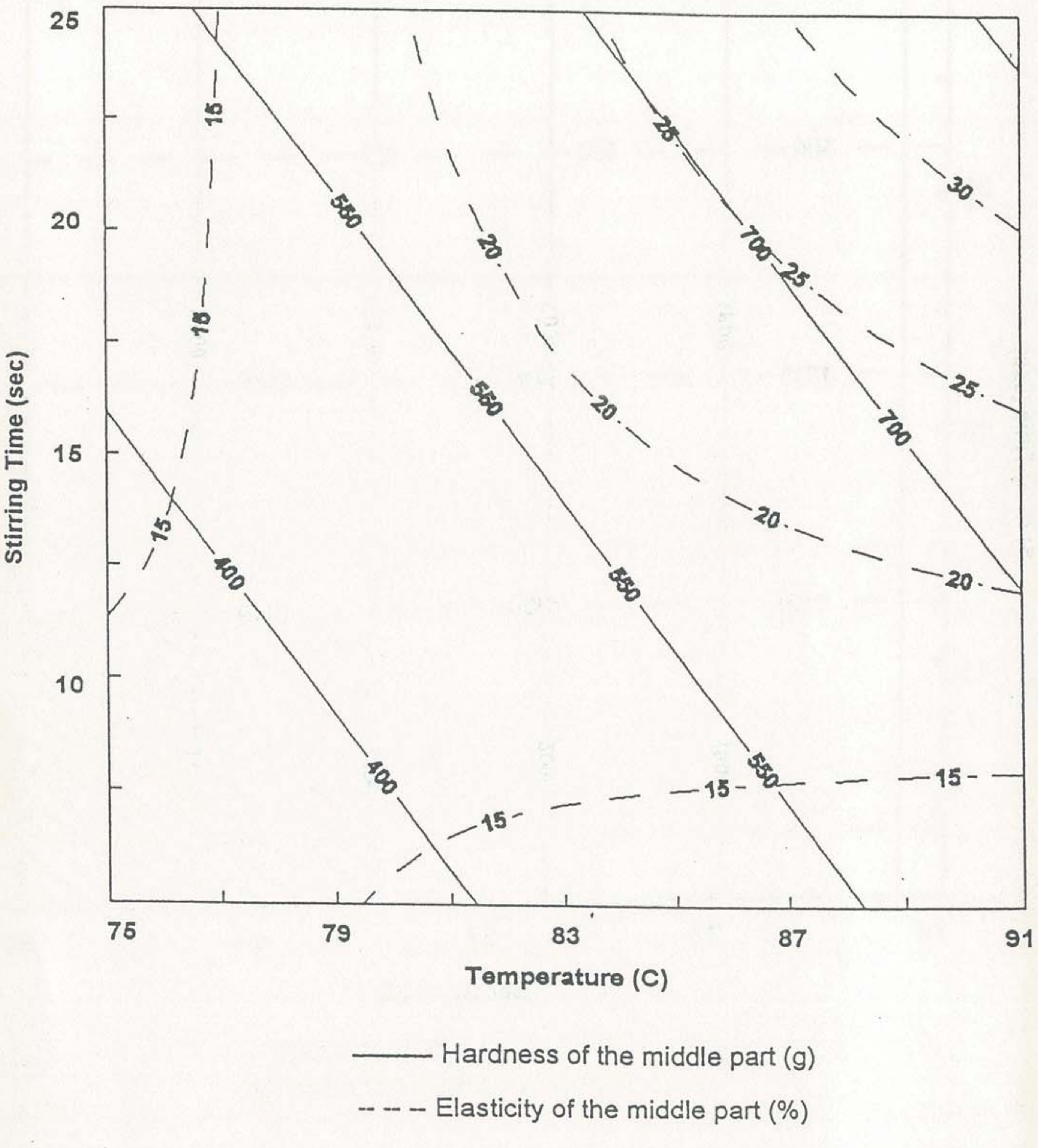


Figure 6. Superimposed contour plots of hardness and elasticity of the middle part of tofu as a function of mixing temperature (°C) and stirring time (sec) at soymilk solid content 12 °Brix (X1=0) and coagulant concentration 0.29% (X2= -1).

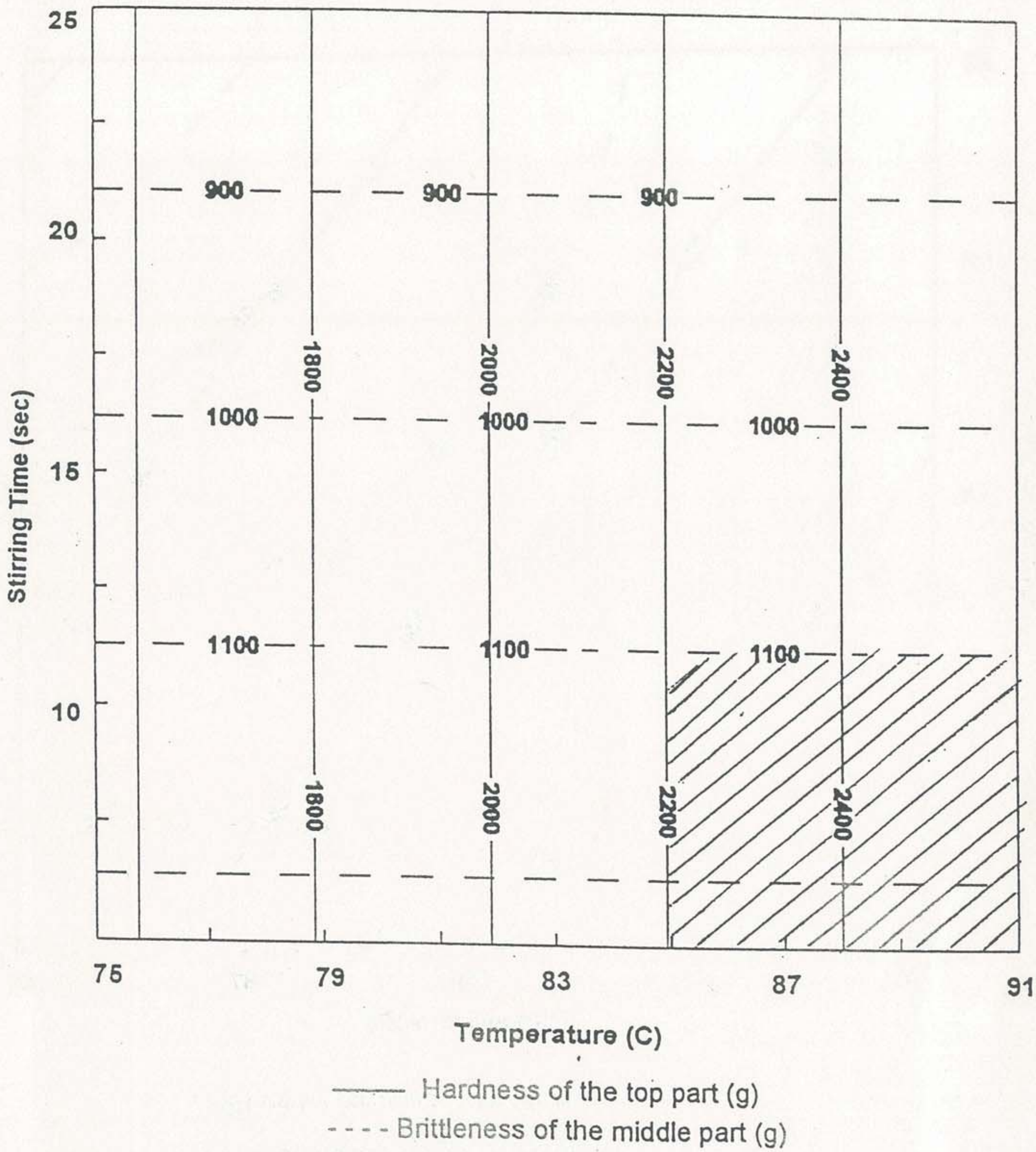


Figure 7. Superimposed contour plots for hardness of the top part and brittleness of the middle part as a function of mixing temperature (°C) and stirring time (sec) at soymilk solid content 12 °Brix (X1=0) and coagulant concentration 0.29% (X2= -1).