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Physicochemical and Sensory Textural Properties of Rice Extrudate Depending on Extrusion Conditions

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Abstract

Extrusion conditions for production of rice extrudate were studied. The optimal production conditions of rice extrudate were determined by the relationship between dependent variables such as expansion ratio, shear strength and color change and independent variables such as moisture content of raw material, screw speed, and die temperature of extruder. The textural quality of rice extrudate was significantly affected by the moisture content of raw material (x_1), screw speed (x_2) and die temperature (x_3) of extruder. The expansion ratio of rice extrudate showed the highest value at the moisture content of 18% of raw material, and the lowest at 24%, and whose regression equation was $Y=34.8967 - 3.219X_1 - (0.623\times10^{-2})X_2 + 0.136X_3 + (0.648\times10^{-1})X_1^2 + (0.138\times10^{-3})X_1X_2 + (0.456\times10^{-4})X_2^2 + (0.719\times10^{-3})X_1X_3 - (0.151\times10^{-3})X_2X_3 - (0.552\times10^{-3})X_3^2$. The most desirable texture of rice extrudate determined by shear test and sensory evaluation was obtained at the following extrusion conditions: moisture content of 18% of raw material, screw speed of 210 rpm and die temperature of 110°C. The rice extrudate prepared under the above conditions showed the lowest shear force of 954 g at which the highest sensory score was obtained.

Key words: rice exturdate, extrusion, physicochemical properties

INTRODUCTION

Varieties of snacks and cereal products from wheat and corn have been produced by means of extrusion cooking recently (1-4). Most rice has been consumed as a staple food in the pattern of cooked rice or rice cake which were made through relatively less advanced processing steps. Many studies have been done to produce gelatinized rice powder which is used as an intermediate food material for the production of instant food such as baby food and soup. Randuall et al. (5) reported that the quality of rice bran oil can be improved by the stabilization of rice bran using extrusion cooking. They showed that the shelf life of the rice bran oil can be prolonged by the reduction of oxidation. A high-fiber product like crispbread was prepared by extrusion cooking with a dry mixture of wheat bran, starch and gluten (6-9). They described the potentiality of dietary fiber in reducing colonic cancer, in lowering serum cholesterol and in preventing hyperglycemia in diabetic patients. Spadaro et al. (7) produced breakfast cereal from brown rice fortified with defatted soy bean flour, resulting in an increase of protein content of up to 20%. However it showed limitations for long-term storage due to oxidation and for keeping textural quality when products are prepared from mixtures of milk and water (8-12). Miller (13) tried to produce snacks using a twin-screw extruder with a low moisture content of raw material from 12.49% to 7.9%. These products showed a decrease of textural uniformity up to 45%.

In an attempt to produce rice extrudate from aged rice which is not desirable for cooked rice, the processing suitability of rice to make texturized snack products with a desirable texture and taste using extrusion cooking was evaluated. Extrusion conditions for the production of rice snacks and the physicochemical properties of products were studied.

MATERIALS AND METHODS

Materials

Rice (japonica type) used in this experiment was stored for 4 years at the storage room after harvesting in Korea. Rice was grounded to get the particle size of 30~60 mesh to be used for extrusion.

Preparation of extrudate

The premixture of rice and other ingredients were prepared by using a hobart mixer (Model No H62O, USA) and tempered at refrigerated temperature over night. A single extruder (Nam Seoung Industrial, Taejon, Korea) was used. The central composite design to get the optimal production conditions was introduced for response surface methodology (RSM). The experimental parameters for RSM were the moisture content of raw material (X_1), screw speed (X_2) and the die temperature of the extruder (X_3) as independent variables, and the physicochemical properties of the extrudate such as expansion ratio, shear strength and the degree of gelatinization were the dependent variables (Table 1).

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Table 1. Variables and levels of variation of the extrusion parameter

Independent variables	Symbol	Coded level				
		-a	-1	0	1	a
Moisture content (%)	X_1	18	20	22	24	26
Screw speed (rpm)	X_2	150	180	210	240	270
Die temperature (°C)	X_3	90	100	110	120	130

Design point	Independent variables		
Run	X_1	X_2	X_3
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
9	0	0	0
10	0	0	0
11	-a	0	0
12	a	0	0
13	0	-a	0
14	0	a	0
15	0	0	-a
16	0	0	a

Measurement of physicochemical properties of extrudate

Expansion ratio

The extrudate specimen was cut out into a size of 10 cm and the degree of longitudinal expansion was measured by calipers. The expansion ratio was calculated by dividing the diameter of the die in the extruder.

Shear strength

The specimen was cut out with a blade (2 mm thickness) attached to an Instron Testing Machine (Model 1140, USA). The shear strength was the force required to break the extrudate. The operational conditions for the Instron Testing Machine were 5 kg of compression scale, and 100 mm/min of crosshead speed.

Water absorption index (WAI)

The water absorption index (WAI) is expressed as grams of water contained per gram of dry sample. It was determined by the method of Andersson et al. (6). 2.5 g of powdered extrudate (under 80 mesh) was dispersed in 30 ml of distilled water, agitated for 30 min in a 30°C water bath and centrifuged for 10 min at 3000 g. The precipitate was weighed for determination of the WAI.

Measurement of color

The color of the extrudate was measured by a Hunter colorimeter (Model, UC 600 IV, Yasuda Seiki, Japan). The color standard for L, a, b was 89.2, 0.92 and 0.78, respectively.

Determination of the degree of gelatinization

The degree of gelatinization for the extrudate was determined by the method of Wotton and Munk (14).

Sensory evaluation

The sensory evaluation of the rice extrudate was conducted by a group of 10 panelists. The textural characteristics evaluated were appearance, color, taste, texture, and overall acceptability. The panelists were asked to score the intensity and desirability of the each textural parameter on a 9-point scale. The results of the sensory evaluation were analyzed by the Statistical Analysis System Program (15) in the textural properties of various extrudates.

Response surface analysis

The relationship between independent and dependent variables was analyzed by the response surface methodology (16). In a given experimental design, the effect of two different independent variables with fixation of one independent variable was analyzed in a three dimensional way.

RESULTS AND DISCUSSION

Establishment of extrusion conditions

The screw condition for the production of snacks using the extruder generally requires high shearing. The dimension of screw used for this experiment was a 45 cm length with a L/D ratio of 7.5, 45 cm of length with a L/D ratio of 5.0 and a 60 cm length with a L/D ratio of 10.0. When the extrudate was produced at the condition of 45 cm of screw length with a L/D ratio of 7.5, it showed a good aspect in forming character but was poor in degree of expansion and textural quality. When the screw condition of the extruder was 30 cm of length with a L/D ratio of 5.0, the extrudate showed fair in appearance but excellent in expansion and textural properties. The criteria for good and poor in forming characteristics and texture were in the appearance and shape of the extrudate. Three different dimensions of die in terms of height (H), width (W) and thickness (T) were tested to discover the optimal conditions for snack production. The dimensions for die involved were 2 mm H× 40 mm W×8 mm T, 2.5 mm H×30 mm W×5 mm T and 1.2 mm H×30 mm W×5 mm T. The extrudate produced under the first and second conditions of die showed a shrinked and unstable surface especially with increasing die temperature. It was concluded that the third condition of die was the most suitable for the production of rice snacks compared to the other conditions of die.

Physicochemical properties of extrudate

The physicochemical properties of the flat-type rice extrudate prepared under various conditions of moisture content, screw speed and die temperature are shown in Table 2. The effects of moisture content on the expansion ratio, shear

Table 2. Physicochemical properties of rice extrudate

MC (%)	SS (rpm)	DT (°C)	ERL	ERO	SHE (°C)	WAI	WSI (%)	CL	CA	CB	DG (%)
20	180	100	1.787	0.934	1370	4.94	24.06	63.84	7.09	21.63	74.049
20	180	100	1.785	0.936	1356	4.93	24.04	63.88	7.06	21.62	74.049
24	180	100	1.107	0.745	2240	5.51	19.75	66.10	6.46	20.61	82.134
24	180	100	1.108	0.744	2258	5.50	19.77	65.92	6.45	20.63	82.138
20	240	100	1.867	0.928	1396	5.45	22.81	79.35	1.29	24.08	73.722
20	240	100	1.865	0.927	1407	5.45	22.80	79.30	1.29	24.10	73.724
24	240	100	1.113	0.717	1739	5.79	13.84	74.04	1.52	25.27	90.590
20	180	120	1.841	0.923	1343	5.72	21.20	64.24	6.02	24.35	57.546
20	180	120	1.842	0.922	1357	5.73	21.18	64.31	6.03	24.34	57.543
24	180	120	1.115	0.928	1914	5.83	21.55	77.16	0.80	26.44	88.031
24	180	120	1.113	0.927	1809	5.83	21.55	77.16	0.80	26.44	88.031
20	240	120	1.633	0.847	1501	4.39	21.89	60.87	6.37	21.25	70.094
24	240	120	1.046	0.741	1880	5.70	21.17	60.68	6.03	24.79	74.728
24	240	120	1.045	0.712	1891	5.72	21.18	60.69	6.04	24.78	74.731
22	210	110	1.536	0.736	1925	6.54	28.70	72.16	3.89	20.38	58.459
22	210	110	1.534	0.734	1937	6.55	28.69	72.19	3.87	20.39	58.460
22	210	110	1.345	0.833	1387	5.64	24.13	70.75	3.41	20.66	84.668
22	210	110	1.346	0.834	1390	5.65	24.18	70.72	3.42	20.66	84.614
18	210	110	3.886	1.056	954	5.13	16.67	68.45	5.10	23.30	76.854
18	210	110	3.885	1.057	958	5.14	16.68	68.44	5.11	23.31	76.861
26	210	110	1.067	0.729	1489	6.07	46.68	73.79	1.89	24.02	88.108
26	210	110	1.068	0.730	1479	6.06	45.68	73.82	1.90	24.04	88.094
22	150	110	1.640	0.816	1320	5.83	49.10	70.03	3.40	21.37	47.794
22	150	110	1.643	0.817	1332	5.85	49.09	70.03	3.40	21.37	47.794
22	270	110	1.566	0.829	1869	6.16	10.59	54.08	8.43	24.01	81.589
22	270	110	1.568	0.528	1874	6.16	10.57	54.12	8.42	24.02	81.673
22	210	90	1.232	0.800	1720	6.19	6.82	64.69	4.70	22.38	80.643
22	210	90	1.233	0.801	1733	6.20	6.83	64.69	4.72	22.38	80.632
22	210	130	1.207	0.879	2234	6.03	20.09	62.93	5.82	22.17	75.298
22	210	130	1.205	0.880	2241	6.01	20.09	62.94	5.81	22.17	75.271

MC: moisture content, SS: screw speed, DT: die temperature, ERL: longitudinal expansion ratio, ERO: latitudinal expansion ratio, SHE: shear force, WSI: water absorption index, WSI: water solubility index, CL: lightness, CA: redness, CB: yellowness, DG: degree of gelatinization.

strength and degree of gelatinization of the extrudate were examined. The longitudinal expansion ratio showed the highest value as 3.886 at 18% of moisture content and the lowest as 1.067 at 26% of moisture content. The latitudinal expansion ratio showed a similar trend to the longitudinal expansion ratio. The optimal moisture content of the extrudate to give a high expansion ratio and a soft texture of rice snack was 18%. The degree of gelatinization of the extrudate showed the highest value as 76.85% at 18% of moisture content. The shear strength of the extrudate showed the highest value as 2,240 g at 24% of moisture content and the lowest value as 954 g at 18% of moisture content.

The result of the effect of screw speed on the expansion ratio and the shear strength showed that the longitudinal expansion ratio was 1.56 at the highest speed of 270 rpm and 1.64 at the lowest speed of 150 rpm. The shear strength was 1,869 g at 270 rpm and 2,240 g at 180 rpm.

In evaluating the effect of die temperature on the extrudate, it was found that die temperature affected more in color changes than expansion ratio and shear strength of the extrudate. The highest lightness (L value) of the extrudate was 79.35 and 77.13 when die temperatures were 100°C and 120°C, respectively, while the lightness was as low as 64.99 and 62.93 when die temperatures were 90°C and 130°C, respectively.

Determination of significant difference of independent variables against dependent variables

Table 3 showed the effect of independent variables such as moisture content, screw speed and die temperature on dependent variables which are the physicochemical properties of the extrudate. Moisture content was negatively related to the expansion ratio and yellowness while positively related to shear strength. The expansion ratio, lightness and redness were affected by the screw speed of the extruder. On the other hand, die temperature only affected redness. It was a fact that the moisture content of the extrudate showed as a major factor on the physicochemical properties of the extrudate among independent variables, expecially expansion ratio and shear strength. The degree of gelatinization, WAI and WSI were not significantly affected by the extrusion condition. Conclusively, the main factors giving a desirable appearance and texture were the moisture content of the raw material and the die temperature in the extruder.

Effects of independent variables on dependent variables of extrudate

Longitudinal expansion ratio

When the screw speed was fixed at 210 rpm, the lon-

Table 3. Effects of Independent variables on dependent variables

	Dependent variables								
	ERL (Y_1)	ERO (Y_2)	SHE (Y_3)	WAY (Y_4)	WSI (Y_5)	CL (Y_6)	CAL (Y_7)	CB (Y_8)	DG (Y_9)
Liner									
MC (X_1)	(-)***	(-)***	(-)***	ns	ns	ns	ns	(-)***	ns
RPM (X_2)	ns[1)]	(-)***	ns	ns	ns	(-)***	(-)***	ns	ns
TEMP (X_3)	ns	ns	ns	ns	ns	ns	(-)***	ns	ns
Quadralic									
MC2 (X12)	(-)***	(-)***	(-)***	ns	ns	ns	ns	(-)***	(-)***
RPM2 (X22)	ns	ns	ns	ns	ns	(-)***	(-)***	(-)***	ns
TEMP2 (X32)	ns	ns	(-)***	ns	(-)***	(-)***	(-)***	(-)***	ns
Crossproduct									
MC.RPM (X1X2)	ns	ns	(-)***	ns	ns	(-)***	(-)***	(-)***	ns
MC.TEMP (X1X3)	ns	(-)***	ns	(-)***	ns	(-)***	(-)***	(-)***	ns
RPM.TEMP (X2X3)	ns	(-)***	ns	ns	(-)***	(-)***	(-)***	ns	ns

[1)]ns : not significant
***Significantly different at 0.1%

gitudinal expansion ratio was rapidly increased by the decrease of moisture content below 20%, while it was not significantly affected by die temperature. When the die temperature was fixed at 110°C, the longitudinal expansion ratio showed an increasing trend with decreasing moisture content. The longitudinal expansion ratio seems to increase with decreasing screw speed, with lowering moisture content, and with increasing screw speed at high moisture content. When the moisture content was fixed at 22%, the effect of the screw speed and die temperature on the longitudinal expansion ratio is shown in Fig. 1. The maximum longitudinal expansion ratio was obtained at a screw speed of 210 rpm and a die temperature of 115°C, instead of an extremely high screw speed and die temperature. The saddle point for the longitudinal expansion ratio was 1.051 at the extrusion condition with respect to a moisture content of 24.3%, screw speed of 213 rpm and die temperature of 109°C. The regression equation was as follows: $Y=34.8967-3.219X_1-(0.623\times10^{-2})X_2+0.136X_3+(0.648\times10^{-1})X_1^2+(0.138\times10^{-3})X_1X_2+(0.456\times10^{-4})X_2^2+(0.719\times10^{-3})X_1X_3-(0.151\times10^{-3})X_2X_3-(0.552\times10^{-3})X_3^2$, $R^2=0.8875$

Shear strength

The maximum shear force was obtained at a screw speed of 270 rpm and a die temperature of 130°C as well as a screw speed of 150 rpm and a die temperature of 90°C (Fig. 2). It was postulated that the screw speed inversely affected the shear force of the extrudate depending on the die temperature. When the effects of independent variables on shear force was evaluated, the saddle point for shear force was 1,787.8 g, which was obtained at the condition of moisture content of 24%, screw speed of 181 rpm and die temperature of 113°C,

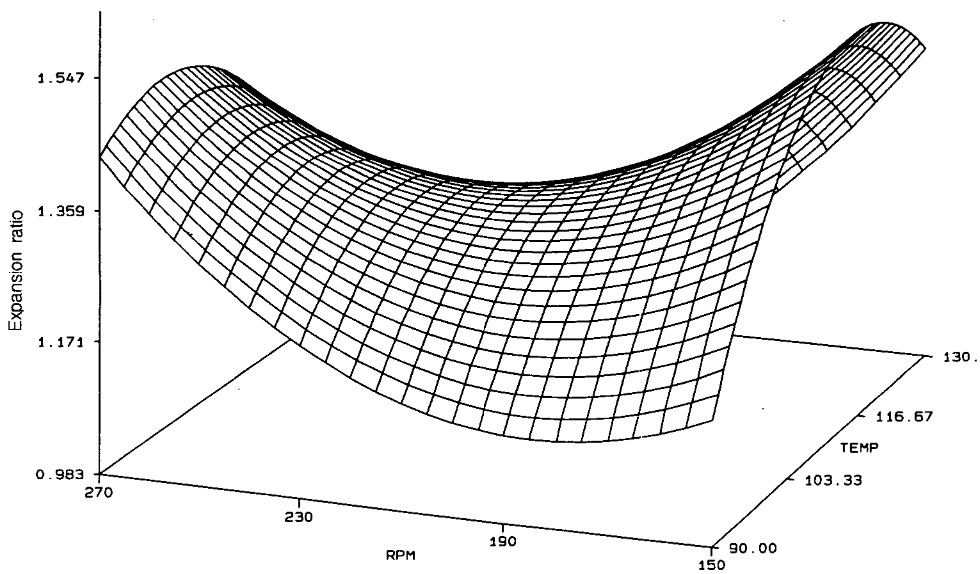

Fig. 1. Response surface on the degree of expansion ratio of rice extrudate versus screw speed and die temperature at fixed moisture content.

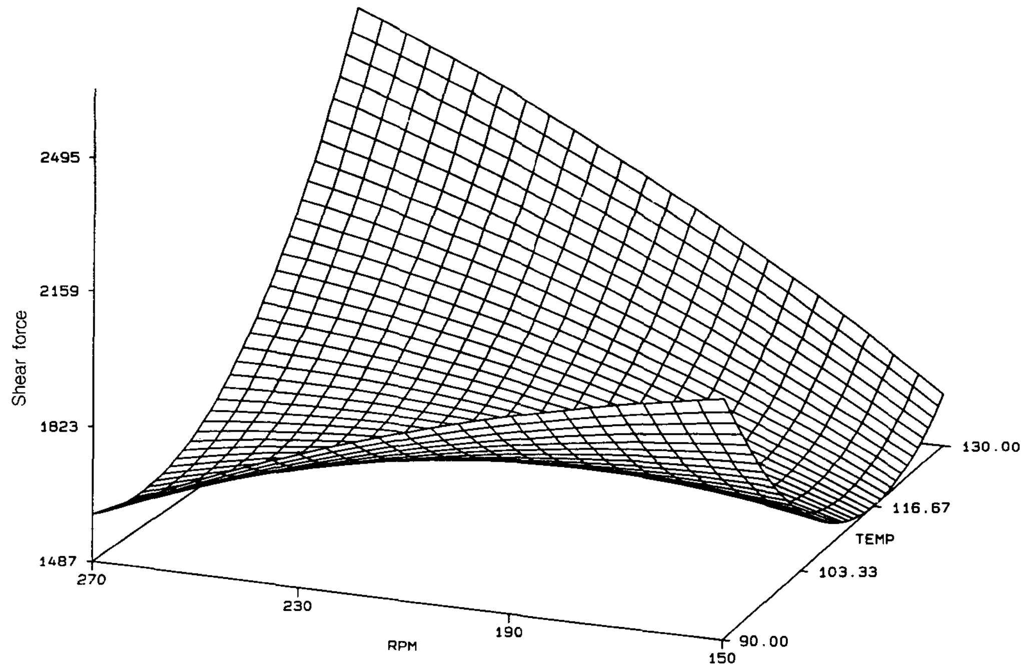

Fig. 2. Response surface on the degree of shear force of rice extrudate versus screw speed and die temperature at fixed moisture content.

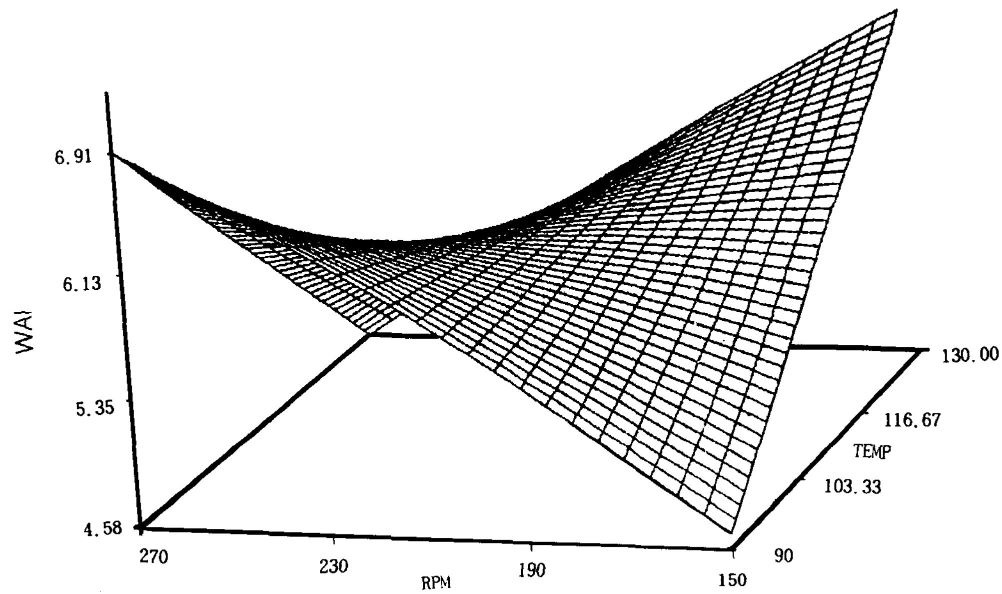

Fig. 3. Response surface on the degree of water absorption index of rice extrudate versus screw speed and die temperature at fixed moisture content.

where the regression equation was $Y=-9213+1847X_1+10.1X_2-183.3X_3-27.4X_1^2-1.45X_1X_2-(1.69\times10^{-2})X_2^2-2.3X_1X_3^2+0.28X_2X_3+0.8X_3^2$, $R^2=0.7594$.

Water absorption index

When screw speed was fixed at 210 rpm, the highest WAI was obtained at the moisture content of 25%, showing a reducing trend with lower moisture content and die temperature. When the die temperature was fixed at 110°C, the WAI was increased with the increase of screw speed at the higher level of moisture content of raw material, while it decreased with the increase of screw speed at the lower level of moisture content of raw material. When the moisture content was fixed at 22%, the WAI was increased with increase of die temperature at a lower screw speed of the extruder (Fig. 3). The WAI was more affected by the die temperature than the screw speed of the extruder. The saddle point for the WAI was 5.993 whose value is shown at a screw speed of 216 rpm, a moisture content of 24.6% and a die temperture of 115°C. The regression equation was as follows: $Y=-23.3+0.71X_1+$

$(6.9\times10^{-2})X_2+0.12X_3-(3.09\times10^{-2})X_1+(2.03\times10^{-3})X_1X_2-(2.63\times10^{-5})X_2^2+(3.2\times10^{-3})X_1X_3^2-(9.35\times10^{-4})X_2X_3+(3.15\times10^{-5})X_3^2$, R^2=0.8875.

Lightness of rice extrudate

When the screw speed was fixed at 210 rpm, the lightness of the extrudate was increased with increases of both moisture content of the raw material and die temperature at the same time. However, it showed an increasing trend if only one of the two parameter, was changed. When the die temperature was fixed at 110°C, the lightness of the exturdate was increased in case of increasing moisture content or decreasing screw speed. When the moisture content of the raw material was fixed at 22%, the lightness of the extrudate was increased by either an increase of screw speed and decrease of die temperature or a decrease of screw speed and increase of die temperature (Fig. 4). The saddle point for lightness shown in Fig. 4 was 71.3, which value was obtained at a moisture content of 21.5% and a die temperature of 107°C. The regression equation was as follows: $Y=71.1+0.85X_1-5.21X_2-1.29X_3-0.33X_1^2-16.9X_1X_2-9.38X_2^2+14.65X_1X_3-14.96X_2X_3-7.64X_3^2$, R^2=0.7261.

Degree of gelatinization

When the screw speed was fixed at 210 rpm, the degree of gelatinization was increased at a higher level of moisture content in the raw material. The lowest degree of gelatinization was shown at a moisture content below 20% and a die temperature of 115°C. When the die temperature was fixed at 110°C, the degree of gelatinization was increased by the increase of screw speed. It was decreased by a lower level of moisture content and a decreased screw speed. When the moisture content was fixed at 22%, the lowest degree of gelatinization was shown at the die temperature of 110°C and the highest degree of gelatinization was shown at the screw speed of 230 rpm (Fig. 5). It was postulated that the increase of both screw speed and die temperature increases the degree of gelatinization. The saddle point for the degree of gelatinization was 71.78% at the extrusion conditions with respect to a moisture content of 20°C, a screw speed of 250 rpm and a die temperature of 125°C. The regression equation was as follows: $Y=141-26.98X_1+2.14X_2-4.39X_3+0.68X_1^2-(3.5\times10^{-2})X_1X_2+(1.89\times10^{-3})X_2^2+(6.3\times10^{-2})X_1X_3-(3.7\times10^{-3})X_2X_3+(1.6\times10^{-2})X_3^2$, R^2=0.6044.

Sensory evaluation

Rice extrudates for sensory evaluation were prepared with different levels of moisture content which is considered as one of the most important variables for extrusion cooking. The result showed that the highest appearance score was 5.6 at the moisture content of 18% without significant difference, while the score for texture and flavor was 7.3 and 6.1 with significant difference, respectively. The overall desirability was significantly affected by the moisture content (Table 4).

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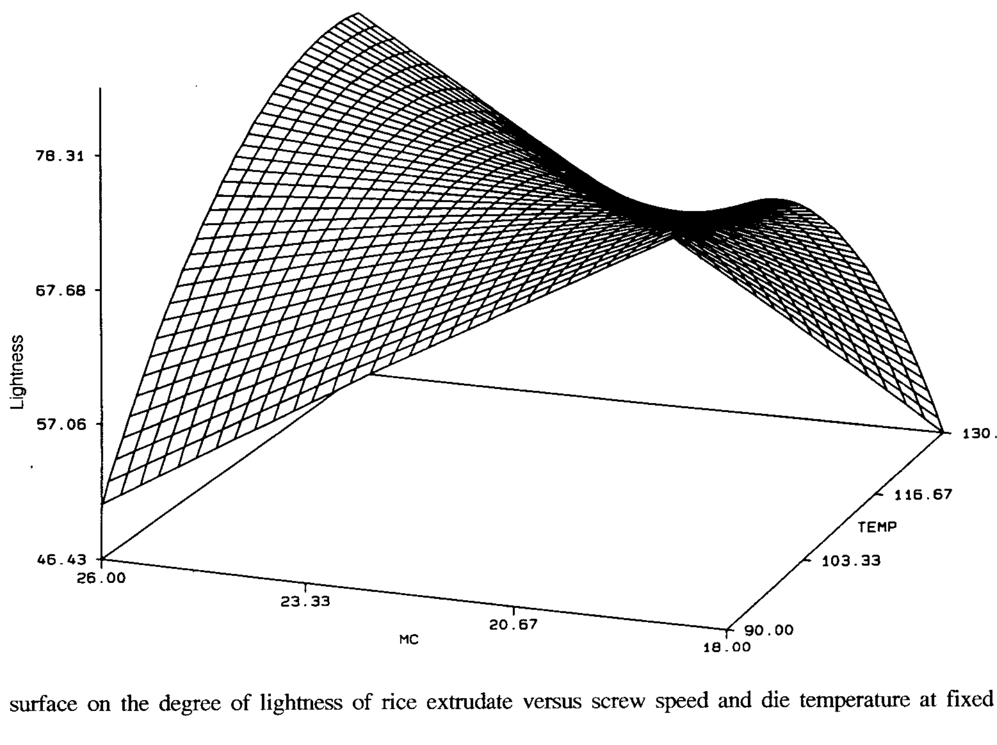

Fig. 4. Response surface on the degree of lightness of rice extrudate versus screw speed and die temperature at fixed moisture content.

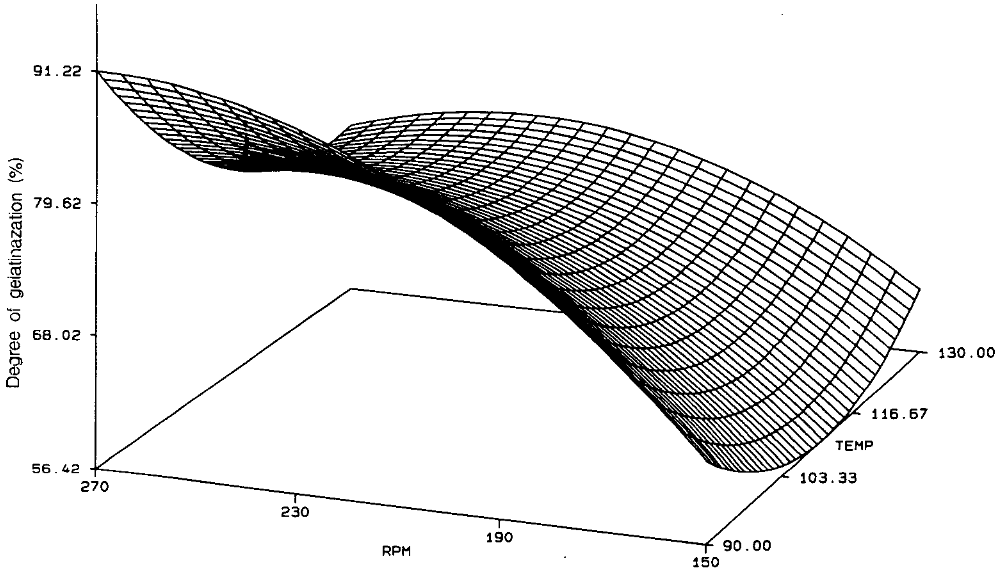

Fig. 5. Response surface on the degree gelatinization of rice extrudate versus screw speed and die temperature at fixed moisture content.

Table 4. Sensory textural properties of rice extrudate depending on moisture content

Moisture content of sample (%)	Appearance	Flavor	Texture	Desirability
18	5.6[a1)]	6.1[a]	7.3[a]	6.6[a]
20	5.4[a]	5.4[c]	5.9[b]	6.0[a]
22	5.0[a]	4.6[bc]	4.5[c]	4.3[b]
24	4.7[a]	4.5[bc]	3.5[b]	3.7[b]
26	4.6[a]	3.8[c]	3.1[b]	3.5[b]
$LSD_{0.05}$	1.52	1.03	0.86	0.98

[1)]Means with different letters within the same column are significantly different (p<0.05%).

cooking of wheat starch and flour I. Effect of moisture and flour type on extrudate protein. *Cereal Chem.*, **59**, 529 (1982)
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