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Properties of Barley for Extrusion Processing

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보리의 Extrusion 가공적성

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抄 錄

피스톤형의 extruder를 사용하여 조건별 보리의 extrusion 가공적성을 검토하였다. 비교 검토된 가공조건으로서는 원료 보리가루의 수분함량 15, 25, 35%, 겉보기 전단속도 118, 534, 1169sec^{-1}, extrusion 온도 90, 120, 150, 180°C가 조합되어 사용되었다. extrusion에서의 보리가루의 물성적 특성과 가공된 제품의 품질을 측정하였다. 사용된 전단속도 범위에서 보리가루는 평균유동계수 0.28을 갖는 의가소성의 물성적 특성을 보여주고 있었다. 제품의 종합적 외관, 다이 팽윤(die swell), 밀도, 가수복원성, 복원시 팽윤, 호화도등을 고려하고, 실제의 extrusion가공시 전단속도의 조정을 감안한다면 수분함량 25~35%와 120°C extrusion 온도 조건이 국수류와 같은 제품에 적합한 가공조건이었고, 수분함량 25%와 150°C extrusion온도 조건이 스넥이나 후레이크 제품의 가공에 좋은 것으로 나타났다. 고온의 고수분함량에서의 extrusion시 extrusion제품의 수분함량은 에너지수지로부터 상당히 잘 예측될 수 있었다.

Introduction

Barley is the secondly most important cereal in Korean food consumption pattern. Recently because of surplus of barley, wider utilization of barley became a task to be solved for demand-supply equilibration and enhancement of self-sufficiency of food. One of the possibilities for this purpose is the extrusion processing. Versatility, high productivity, low cost, unique product shape and high product quality of extrusion process would be suffice condition to transform barley into various products suitable for expansive untraditional utilization[1]. As preliminary step for extrusion, piston type extruder can be used for characterization of material properties[2]. In this study properties of barley for extrusion processing was investigated using piston type extrusion rheometer.

Materials and Methods

Milled barley grain of variety "Sedohagawa" was powdered into 140 mesh flour and used for the whole experiment. To this flour calculated water was sprayed by small amounts to have 15%, 25% and 35% moisture content respectively. After being stood at room temperature overnight for equilibrization, the moistened flour was stored in the refrigerator (4°C). Actually attained moisture content was 15.5%, 24.5% and 33.2% respectively.

Moistened barley flour was extruded using Instron Capillary Rheometer System (Model 3211). Capillary of diameter 0.127cm, length 3.048cm and entrance angle 45° was used. Sample was filled into barrel with interrupting tamping at room temperature to exclude air. Applied extrusion temperatures and plunger speeds were 90°C, 120°C, 150°C, 180°C and 2cm/min, 6cm/min, 12cm/min respectively. Barrel was heated to desired temperature and temperature was euqilibrated by waiting 3 minutes. And sample was extruded at desired plunger speed. Because of limitation of load cell, extrusion could not be performed at 15% moisture, 90°C temperature and 12cm/min plunger speed. 35% moisture flour at 180°C and all plunger speeds, and 25% moisture flour at 180°C and 2cm/min was unable to be extruded due to puffing before starting of extrusion.

Shear stress was calculated from plunger reading as equation (1).

$$T_w = F/4A_p(I_c/d_c) \quad -(1)$$

Where T_w : wall shear stress (dyne/cm²)
F : plunger force reading(dyne)
A_p : Barrel cross section area(cm²)
I_c : capillary length (cm)
d_c : capillary diameter (cm)

Wall shear rate was calculated using equation (2) and equation (3).

$$\gamma_{app} = 2V_{XH}\, d_b^2/15d_c^3 \quad -(2)$$

$$\gamma_{true} = (3n+1)8V/4nd_c \quad -(3)$$

Where γ_{app} : apparent wall shear rate(sec⁻¹)
γ_{true} : corrected wall shear rate(sec⁻¹)
V : $V_{XH}d_b^2/60d_c^2$
d_b : barrel diameter(cm)
V_{XH} : plunger speed(cm/min)
n : power law index

Apparent viscosity was calculated by equation (4).

$$\eta = T_w/\gamma_{true} \quad -(4)$$

Where η : apparent viscosity(poise)

Extrudate just after starting of extrusion was taken for quality assessment in order to have same residence time effect. Moisture content was measured by drying at 105°C to constant weight. Estimated extrudate moisture content was obtained from equation (5) modified from Harper's energy balance[3].

$$m_1c_1T_1 = (m_1 - m_e)c_2T_2 + m_e\lambda \quad -(5)$$

Where m_1 : initial mass before extrusion(g)
m_e : evaporated water during extrusion(g)
T_1 : extrusion temperature(°C)
T_2 : temperature after extrusion(25°C)
λ : latent heat of water evaporation (kcal/g)
c_1, c_2 : specific heat (kcal/g°C) assumed from Mohsenin[4]

Die swell was presented as the ratio of the diameter of cooled extrudate just after extrusion to capillary diameter. Density was calculated from weight and volume of dried sample on the assumption that extrudate is the cylinder. After rehydration with tap water for 5 hours at room temperature, rehydrated sample was weighed on aluminium foil for water uptake measurement and the diameter of rehydrated sample was measured by caliper for rehydration swell calculation. Water uptake was calculated in (water uptake/dry weight of extrudate). Rehydration swell was calculated in (diameter of rehydrated extrudate/diameter of extrudate).

Gelatinization degree was measured in soluble starch after extrusion[5]. 100ml water was added to about 0.5g extrudate. The mixture was shaken for 3 hours at 37°C, centrifuged at 3000rpm for 30 minutes and 10ml supernatent was taken. 0.5ml of 0.1N Iodine solution and 1ml 6N HCl were added sucessively and mixture was filled up to 100ml. Optical density was read at 600 nm after 30minutes. Data were presented at basis of dry extrudate weight 0.5g.

Results and Discussion

1. Rheological properties of barley for extrusion

Apparent shear rate-shear stress relationship during extrusion is shown in Fig.1. Shear stress was high at low moisture content and low temperature. Power law index was in the range of 0.17 to 0.48 with average value of 0.28. Apparent shear viscosity-true wall shear rate relationship is shown in Fig.2. Under the conditions used in this study, the barley flour exhibits a pseudoplastic behavior. For the applied corrected shear rate range of 190~1200sec^{-1}, the calculated apparent viscosity is in the range of 120~55000 poise. Apparent shear viscosity decreases with temperature, moisture content and shear rate. But at higher temperature, these trend is not clear because of vapor pressure buildup in the barrel.

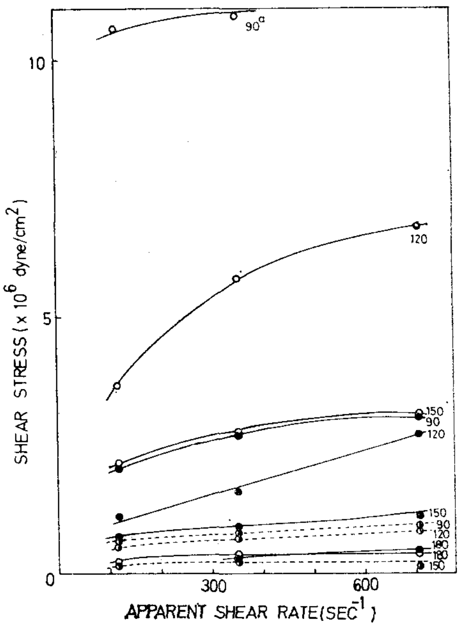

Fig. 1. Shear stress vs. apparent shear rate for various extrusion conditions.
—○—○— 15% moisture,
—●—●— 25% moisture
···◑···◑··· 35% moisture,
a; extrusion temperature

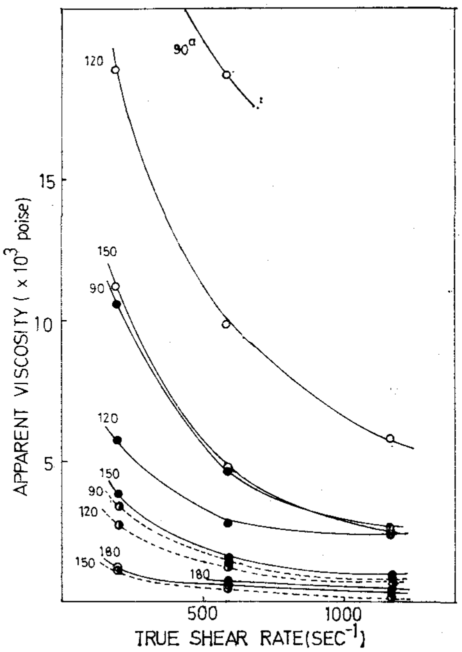

Fig. 2. Apparent viscosity vs. true shear rate for various processing conditions.
—○—○— 15% moisture,
—●—●— 25% moisture
···◑···◑··· 35% moisture,
a; extrusion temperature

The apparent viscosity is related to applied shear rate, processing temperature and moisture content. Harper's viscosity model[6] about cereal dough could not be applied, showing so wide range of parameters. Viscosity at wide moisture and temperature range is so complicated that simple model cannot describe the flow behavior of extruded material. For rheological description of food as function of shear rate, time and temperature, more comprehensive model accounting vaious factors such as vapor pressure effect and cooking reaction should be developed.

2. Appearance of extrudate

Shear rate under same temperature and moisture content gave no great difference in the appearance of extrudate. Table 1 shows the general appearance of the extrudate at various temperature and moisture content. Above 150°C gelatinized flavor could be felt and the product was puffy and porous. Low moisture content

Table 1. General appearance of the extrudate for various processing conditions.

Moisture Content (%)	General Appearance Temperature(°C)			
	90	120	150	180
15	white, stiff, partially dispersed when rehydrated,	white but a little yellow, stiff, partially dispersed and divided into pieces when rehydrated	dark brown, partially puffed, gelatinized flavor	brownish gray, very brittle, almost dissolved when rehydrated, gelatinized flavor
25	white, fragile partially dispersed when rehydrated	yellow, chewy	light yellow porous, a little flexible. gelatinized flavor	gray, porous slightly brittle gelatinized flavor
35	a little yellow, chewy flexible	yellow, chewy flexible	a little brown chewy, flexible gelatinized flavor	

produced very stiff products. At 120°C chewy products like noodle were obtained. Higher temperature gave the product more browny color.

3. Moisture content, Die swell and Density of the extrudate

Table 2 shows the moisture content of the extrudate for various extrusion conditions. Initial moisture content affects greatly the moisture content of the extrudate. Moisture content of extrudate decreases with shear rate and temperature. Barrel temperature is thought to be the main cause of vapor flashing during extrusion. Also viscous heat dissipation seems to contribute a little to moisture evaporation. The calculated moisture content from equation(5) were pretty well agreed with measured value at higher temperature and higher moisture content.

Table 3 shows the die swell for various extrusion conditions. Die swell was in the range of 0.83~1.95 for these extrusion conditions. Die swell generally, but not clearly, increases with

Table 2. Moisture content of the extrudate for various extrusion conditions

Moisture Content (%)	Apparent Shear rate (sec^{-1})	Moisture Content of the Extrudate(%) Temperature(°C)			
		90	120	150	180
15	118	13.5	13.7	11.7	3.4
	534	13.0	13.3	11.9	3.7
	1169	—	13.0	10.5	3.1
		(10.3)	(8.1)	(5.6)	(3.0)
25	118	19.6	19.1	17.8	—
	534	19.4	18.7	14.2	9.3
	1169	19.8	18.8	12.2	8.2
		(18.6)	(16.0)	(13.2)	(10.2)
35	118	25.1	23.7	20.4	—
	534	23.1	24.6	17.6	—
	1169	24.6	23.3	18.2	—
		(27.0)	(24.3)	(21.3)	

( ); calculated value from energy balance eq.(5)

shear rate and temperature. 25% moisture content gave larger die swell and sharper temperature effect than any other moisture content. The largest die swell was obtained at 150~180 °C of 25% moisture content as result of porous texture.

Density of the extrudate was in the range of 0.25~1.39g/cm³ as shown in Table 4. Density generally decreases with shear rate and temperature. Like die swell 25% moisture content shows sharp temperature effect on density. 90~150°C temperature range of 15% moisture shows little effect on both die swell and density. Around 25% moisture content water seems to be in most effective form during extrusion.

Table 3. Die swell for various extrusion conditions

Moisture content (%)	apparent shear rate (sec^{-1})	Die swell (cm/cm) temperature(°C)			
		90	120	150	180
15	118	1.08	1.07	1.08	0.83
	534	1.09	1.12	1.11	1.17
	1169	—	1.17	1.50	1.15
25	118	1.04	1.08	1.60	—
	534	1.10	1.13	1.85	1.44
	1169	1.08	1.27	1.44	1.95
35	118	0.95	0.95	1.32	—
	534	0.94	1.04	1.04	—
	1169	1.04	1.19	1.08	—

Table 4. Density of the extrudate for various extrusion conditions

Moisture content (%)	apparent shear rate (sec^{-1})	Density (g/cm³) temperature (°C)			
		90	120	150	180
15	118	1.20	1.21	1.27	0.30
	534	1.23	1.20	1.23	0.29
	1169	—	1.25	0.83	0.25
25	118	1.09	1.39	0.62	—
	534	1.03	1.09	0.39	0.40
	1169	1.07	0.97	0.40	0.28
35	118	1.12	1.15	0.90	—
	534	1.15	1.06	0.70	—
	1169	1.10	1.02	0.89	—

Consequently the physical properties of the extrudate is very complex function of moisture content, extrusion temperature and shear rate. The water evaporation, die swell and density have complicate interrelation. Moisture evaporation is responsible for extrudate density with correlation of −0.73. Die swell shows correlation of coefficient 0.89 with moisturre evaporation. Die swell and density have the negative relation of correlation coefficient −0.54 as expected.

4. Water uptake and rehydration swell of extrudate

Table 5 shows water uptake of extrudate. Water uptake increases first and then decreases with temperature. Temperature can enhance the water uptake up to moderate temperature, but going further above high temperature, high solubilization of extrudate lowered the water uptake. Shear rate usually increases the water uptake. Moisture content effect is varying with temperature and shear rate. For extrusion process water uptake should be high enough and reduced water uptake due to solubilization would not be desirable except for some particular purpose. From this consideration, there exists optimum temperature for product of high water uptake.

Table 5. Water uptake of the extrudate for various extrusion conditions.

Moisture content (%)	Apparent shear rate (sec^{-1})	Water Uptake(g/g) temperature(°C)			
		90	120	150	180
15	118	2.70	3.51	3.21	*
	534	2.95	3.42	3.18	*
	1169	—	3.75	3.48	*
25	118	2.43	2.24	3.10	—
	534	2.40	2.92	3.72	2.22
	1169	2.68	3.36	5.26	1.56
35	118	2.18	3.11	2.19	—
	534	2.31	3.39	3.01	—
	1169	2.76	3.41	2.38	—

*Almost dissolved in water when rehydrated

The rehydration swell of extrudate was in the range of 1.18~2.50. The rehydration swell was generally higher at 15% moisture content than any other moisture content. This is considered to be related to the state of starch. Effect of shear rate and temperature was not clear.

5. Gelatinization degree of extrudate

Table 6 shows gelatization degree of extrudate for various extrusion conditions. Higher gelatinization was gained at higher temperature. There is no difference among shear rates. Below 120°C. moisture helps the gelatinization like Chaing's results[7]. But at higher temperature these effects seem to have maximum at certain point. In case of the gelatinization degree meaured in soluble starch, the high temperature may result in over-dextrinization into erythrodextrin and achrodextrin accompanying decrease in soluble starch of extrudate[8]. The other possible explanation is the gelatinization kinetics of starch at high temperature. At low moisture content and high temperature range as in HTST extrusion, gelatinization consists of two mechanisms-swelling and melting of starch granule[9]. The combination of these two mechanisms at certain temperature and moisture content may determine the extent of the gelatinization. For complete explanation further kinetic study and thermal analysis are suggested.

Table 6. Gelatinization degree of the extrudate for various extrusion conditions

Moisture content (%)	apparent shear rate (sec^{-1})	Gelatinization Degree (O.D. at 600nm) temperature(°C)			
		90	120	150	180
	118	0.02	0.04	0.45	1.99
15	534	0.03	0.05	0.37	2.03
	1169	—	0.07	0.43	2.09
	118	0.02	0.12	0.90	—
25	534	0.01	0.13	0.89	1.48
	1169	0.02	0.12	0.80	1.72
	118	0.05	0.22	0.52	—
35	534	0.06	0.12	0.59	—
	1169	0.06	0.14	0.55	—

Considering apparent shear rate range of 100 ~1200sec^{-1}, control of residence time in practical extrusion and overviewed quality of extrudate, extrusion process of barley can be designed from above results. For noodle-like product which have some instantized and chewy quality, 25~35% moisture and 120°C extrusion temperature would be good. To process into snack food which has crisp puffy texture and is well rehydrated, 25% moisture and 150°C would be the best of extrusion conditions of this study.

Abstract

Using piston type extruder, barley flour was extruded at various processing conditions. The used variables were three shear rates (apparent shear rate 118, 534, 1169sec^{-1}), four extrusion temperatures (90, 120, 150, 180°C) and three moisture contents (15, 25, 35%). The rheological properties and the extrudate quality were monitored in extrusion. Barley flour showed pseudoplastic behavior having average power law index 0.28 in used shear rate range. When viewed from general appearance, die swell, density, water uptake, rehydration swell and gelatinization degree of extrudate, 25~35% moisture and 120°C temperature was suitable processing condition for noodle-like product, and 25% moisture and 150°C temperature was good for snack or flake product. Moisture content of the extrudate can be pretty well estimated from energy balance at higher temperature and higher moisture content.

Reference

1. Harper, J.M. and Harmann D.V.: Trans ASAE., 16(5) : 941(1973)
2. Ronnie, G., Dwayne, A.S. and Vincent, E. S.: J. Food Process Eng., 2 : 65(1978)
3. Harper, J.M.: Crit. Rev. Food Sci. Nutr., 11(2) : 155(1979)

4. Mohsenin, N.N.: Thermal properties of food and agricultural materials, p. 321 Gordon and Breach Science Publishers, New York, (1980)

5. Wootton, M. and Chaudhry, M.A.: J. Food Sci., 45(6) : 1783(1980)

6. Harper, J.M., Rhodes, T.P. and Wanninger, L.A. Jr.: Chem. Eng. Prog. Symp. Ser., 67 (108) : 40(1971)

7. Chaing, B.Y. and Johnson, J.A.: Cereal Chem., 54(3) : 436, (1977)

8. Aurand, L.W. and Woods, A.E.: Food Chemistry, p 80 AVI (1973)

9. Biliaderis, C.G., Maurice, T.J. and Vose, J.R.: J. Food Sci., 45 : 1669(1980)