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Extrusion Process of Barley Flour for Snack Processing

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스낵제조를 위한 보리의 압출성형공정

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Abstract

To expand the utility of barley the experiments on the extrusion characteristics of barley flour for snack processing were carried out and the effects of the extrusion conditions on the quality of the extrudates were investigated. The optimum moisture content of barley flour for snack processing was 20%. The moisture content and the density of the extrudates decreased with increasing extrusion temperature and decreasing die size. The die swell ranged from 0.98 to 2.18 according to various extrusion conditions and decreased with increasing temperature above 150°C. The lightness, redness and yellowness increased at higher temperature. The water absorption index and the water solubility index showed their maximum values at 180°C.The gelatinization degree of the extrudates increased with increasing temperature. The fracture fore, Young's modulus and maximum fiber stress decreased, but the deformation to fracture increased, with increasing temperature and decreasing die size. The yield force in puncture test showed lower values at higher temperature. The size and the fraction of the air cells increased with increasing temperature and decreasing die size. The optimum extrusion conditions of barley for snack processing were at the temperature of 180°C, with the die size of 4.5*mm* when processed at 160 rpm.

Introduction

Barley is the second most important cereal next to rice in Korean diet. Korea has a great surplus of barley because of the preference of rice to barley in the dietary habits of the people. Korea is now under pressure to expand the utilization of barley to equilibrate the demand with the supply. The recent development of barley-based food products has led to increased utilization of barley as a major food source. This could logically enhance the self-sufficiency of grains in Korea.

Recently extrusion has become one of the most popular new processes developed by the food and feed industries.(1-10) Its basic principle is to convert a solid material to a fluid state by applying moisture and heat, then to extrude the material through a die to form a product of predetermined geometric and physical characteristics.

In this experiment the extrusion of barley flour to a puffed product was investigated and the extrusion characteristics of barley flour were examined. These studies were carried out as they are directly related to the expanded utilization of barley.

Material and Methods

Sample Preparation

Pearled barley purchased in market was ground with a hammer mill and used for this experiment.

Chemical Composition and Size Distribution of Barley Flour

The chemical compositions of barley flour were determined by approved AACC methods(11). The particle size and distribution of the barley flour were measured with a Particle Size Analyzer (Microtrac Model 7991-01, Leeds & Northrup Co., FL, U.S.A.)

Extrusion of Barley Flour

Water was added to barley flour to be of a set water content for extrusion and mixed with a 10-quart Hobart mixer and tempered overnight at 4°C and processed.

A Laborator Extruder (Model 2003, CW Brabender Instruments Inc., South Hackensack, NJ, U.S.A) was used for this experiment. The L/D ratio of the extruder was 20:1 and the compression ratio of the screw was 3:1. Barley flour was extruded at various conditions designated as each point in 3 dimensional coordinates in Fig. 1. The rotating speed of the screw was set 160 rpm throughout this experiment.

Barley flour was fed to the extruder with a hopper assembly (Model 75, CW Brabender Instruments Co., NJ, U.S.A.) and the hopper screw rotating speed was set at 90 rpm.

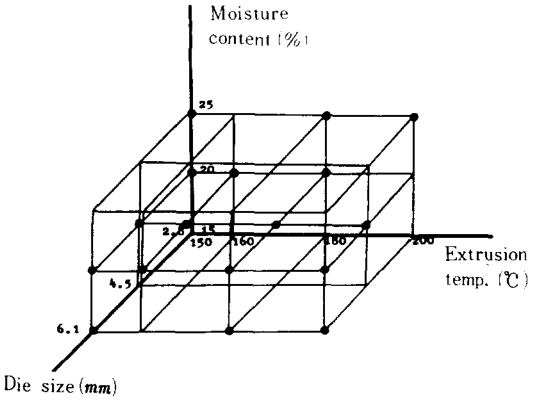


Fig. 1. Operation conditions of barley extrusion

Characteristics of the Extrudates

The moisture content of the extrudates were measured by AACC Method 44-15A(11).

Die swell was expressed as the ratio of the diameter of the cooled extrudate to the diameter of the die(12). The diameters of the extrudates were measured with vernier calipers ten times randomly and the values were averaged.

Density was calculated from the weight and the volume of the extrudates on the assumption that the shapes of the extrudates were cylindrical. The volumes of the extrudates were calculated by multiplying their cross-sectional areas by lengths.

The color of ground extrudates was measured by a Color Difference Meter (XL 10 CDM, Gardener Lab. Inc., MD, U.S.A).

Water absorption index and water solubility index of the extrudates were measured by a modification of the method of Anderson *et al.*(13). On a dry basis 1*g* of ground sample was transferred to a 50*ml* tared centrifuge tube. 20*ml* of distilled water was then added and the ground extrudate was dispersed by a glass rod. The tube was put in 30°C water bath for 30 min and centrifuged at 3000xg for 10 min. The supernatant was transferred to an evaporating dish (tared) and the tube was left to drain upside down on a paper towel for ^{15} min and then weighed. The water absorption index was expresed as the weight of gel. The supernatant was dried at 110°C overnight and the weight of dried supernatant was expressed as water solubility index.

The degree of gelatinization of the extrudates was determined by the method of Wotton and Chaudhry(14). 50*ml* of distilled water was added to 0.25*g* of the sample (dry basis) and shaken for 3 hrs at 37°C and centrifuged at 3000 x g for 30 min. 10*ml* of the supernatant was added to a 100*ml* volumetric flask. To this were added 0.5*ml* of 0.1 *N* iodine solution and 1 *ml* of 6 *N* HCl in succession. The flask was then filled to 100 *ml* with distilled water. Optical density was read at 600 *nm* after 30 min in a spectrophotometer.

Mechanical Properties and Microstructure of the Extrudates

Young's modulus and the maximum fiber stress of the extrudates were measured by a bend test with an Instron Universal Testing Machine (Model 1000, Instron Corp., MA, U.S.A.). From the force-deformation curve the fracture force and the deformation to fracture were read and Young's modulus and the maximum fiber stress were calculated by the following equations(15):

$$E=\frac{PL^3}{12\pi r^4 D_f}\times 10^6 \cdots\cdots (1)$$

$$\sigma\max=\frac{PL}{\pi r^3}\times 10^6 \cdots\cdots (2)$$

where, E = Young's modulus (*Kg/m²*)
P = Fracture force (*kg*)
D_f = Deformation to fracture (*mm*)
L = Span length (*mm*)
σ max = Maximum fiber stress (*Kg/m²*)
r = Radius of the sample (mm)

The conditions of the bend test were as below:
Span length (L) = 6.52 *cm*
Thickness of the blunt knife = 3.3 *mm*
Crosshead speed = 10 *mm*/min
Chart speed = 100 *mm*/min

A puncture test with a needle (dia.: 0.9 *mm*) was also done and the yield force was measured. The crosshead speed and the chart speed were same as in the bend test.

The internal microstructures of the extrudates were investigated with a JOEL JSM-35 Scanning Electron Microscope (JOEL, Peabody, MA, U.S.A). The extrudates were fractured to expose the inner surfaces for a cross sectional views and mounted in the stubs with silver conducting paint. All samples were spatter-coated with gold/platinum (60/40) approximately 180-200 *nm* thick and representative areas were photographed.

Results and Discussion

Characteristics of Barley Flour

The chemical composition and the particle size distribution of barley flour are shown in Tables 1 and 2, respectively.

Table 1. Chemical compositions of the barley flour

Composition	Content (%)
Moisture	11.58
Protein	9.30
Fat	1.05
Ash	1.20
IDF	5.88
Sugars	70.99

Table 2. Particle size distribution of the barley flour

Size (μ)	Histogram (%)
300 - 212	26.33
212 - 150	17.37
150 - 75	16.20
75 - 38	6.60
38 - 19	11.67
19 - 9.4	16.97
<9.4	4.86

General Appearance of the Extrudates

The barley flour tempered to moisture content of 15, 20 and 25% were extruded under various operating conditions. Table 3 summarizes the general appearance of the extrudates. The barley flour of 20% moisture content was most suitable for snack processing by extrusion. And the extrusion at the temperature higher than 180°C was desirable for snack processing.

Moisture Content of the Extrudates

The moisture contents of the extrudates from barley flour of 20% moisture content under various operating conditions are shown in Fig. 2. The moisture content of the extrudate decreased as the extrusion temperature in-

Table 3. General appearance of the extrudates

Moisture content of feed (%)	Extrusion temp. (℃)	Dia. of die (*mm*)	General Appearance
15	150	6.1	-*
	180	6.1	-
	200	6.1	-
20	150	6.1	very hard and stiff
	150	4.5	hard and stiff
	150	2.8	crispy, but a little hard
	180	6.1	a little hard and tough
	180	4.5	crispy, crunch
	180	2.8	crispy, but burst into bits, kinky
	200	6.1	puffed well, but burst into bits
	200	4.5	burst into bits, kinky
25	150	2.8	tough, chewy, hard
	180	2.8	tough and hard
	200	2.8	-

* not extruded easily or jammed during extrusion

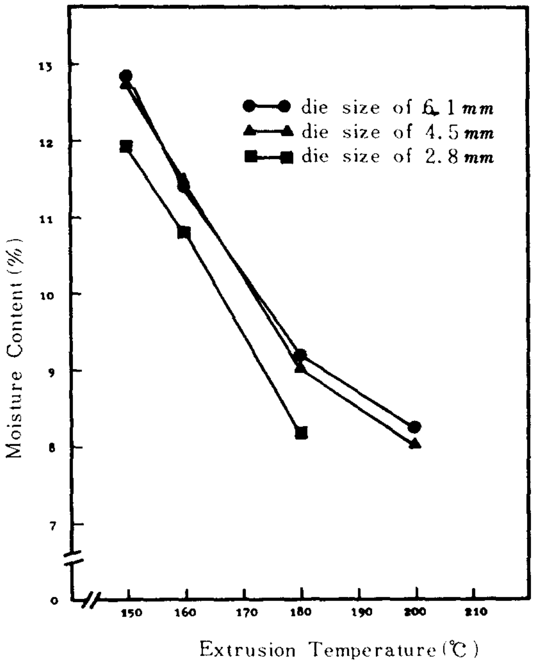


Fig. 2. Moisture content of the extrudates from the barley flour of 20% moisture content in various extrusion conditions

creased. Extrusion temperature, therefore, is thought to be the main cause of vapor flashing during extrusion. The smaller the die size was, the lower the moisture content of the extrudate was shown. This can be explained by the effect of pressure generated inside the barrel during extrusion.

Harper(16) set the equation estimating the moisture content of the products from energy balance like below:

$$M_2 = \frac{M_1 \Delta H_{fg} - C_p (T_1 - T_2)}{\Delta H_{fg}} \qquad (3)$$

where, C_p = Specific heat of raw material (*cal/g/*°C)

H_{fg} = Latent heat of vaporization at ambient temperature

M_1 = Moisture fraction of raw material

M_2 = Moisture fraction of extrudate

T_1 = Extrusion temperature (°C)

T_2 = Temperature of extrudate after die (°C)

The differences between measured and estimated moisture content were less than 5% at the extrusion temperature of 150-180℃ and 9.3% deviation was shown at 200°C as in Table 4.

Table 4. Difference in moisture contents of the extrudates from barley flour of 20% moisture content between measured and estimated

Extrusion temp. (℃)	Average % deviation
150	4.80
160	3.38
180	4.67
200	9.36

Table 5. Die swell of the extrudates made from the barley flour of 20% moisture content

Extrusion temp (℃)	Dia. of die (*mm*)	Die swell
150	6.1	1.09
150	4.5	1.61
150	2.8	2.18
160	6.1	1.09
160	4.5	1.47
160	2.8	1.90
180	6.1	0.98
180	4.5	1.17
180	2.8	–*
200	6.1	–
200	4.5	–

* not measurable because of burst

Bie Swell

Table 5 shows the die swells of the extrudates at various extrusion temperatures and die sizes. die swells were in the range of 0.98-2.18 under these conditions and decreased slightly when temperatures rose over 150°C. These results coincide with those of Lee(17), which showed maximum die swell at 150°C with slight decrease in swell when temperature rose above 150°C.

When the cooked dough with modified chemical constituents extrudes out of the die the superheated water in the plastic hot extrudate is still a liquid because of the high pressure developed in the extruder, which evaporates into steam and expands the dough. The expansion of the dough starts within the die and proceeds in a longitudinal direction. Transverse expansion occurs when the dough is completely out of the die. Then, a transverse shrinking occurs on cooling because of vapor bubble collapse while the dough is still plastic and extensible, and this continues until the dough becomes, sufficiently rigid, on cooling, to resist shrinking(18). The amount of evaporating vapor which induces the collapse of the extrudates increases as the temperature increases. Therefore, more shrinking of the diameter of

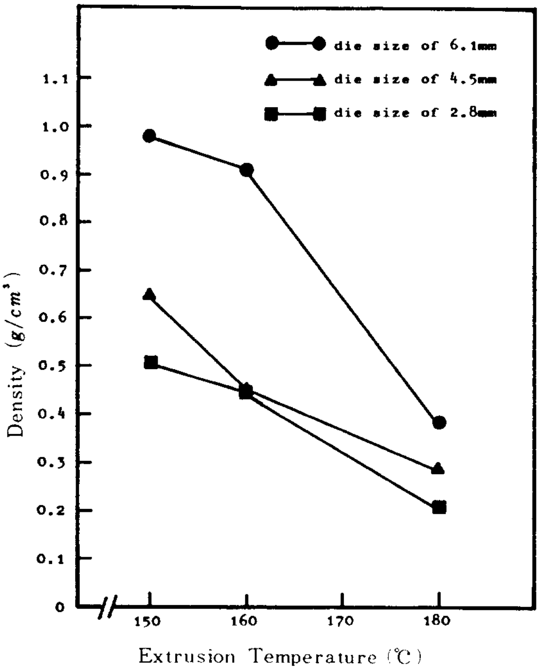


Fig. 3. Density of the extrudates made from the barley flour of 20% moisture content

the extrudates occurs at higher temperature. The decrease in die swell over 150°C could be explained by this theory.

Density

the density of the extrudate (Fig. 3) ranged from 0.22 to 0.91 *g/cm*³. Density decreased with temperature and decreasing die size. This phenomenon is thought to occur because the generated pressure is in inverse proportion to the opening size of the die and lower density product produced at higher pressures. The die swell showed a different changing trend from density with respect to temperature. This means that the density is dependent not only on transverse expansion but also on longitudinal expansion. It can be extracted from this phenomenon that the longitudinal expansion is greater than the transverse expansion during extrusion.

Color

The L, a and b values of extrudates under various extrusion conditions are shown in Table 6. The lightness increased with extrusion temperature. This is thought to occur because extrudates are puffed to a greater degree at higher temperatures and this surface effect can contribute to the lightness. The redness and the yellowness increased slightly with temperature.

Table 6. Color of the extrudates made from the barley flour of 20% moisture content

Extrusion temp. (℃)	Dia. of die (*mm*)	L	a	b
150	6. 1	74. 6	0. 2	12. 6
	4. 5	77. 1	1. 9	12. 2
	2. 8	77. 6	0. 3	13. 2
180	6. 1	77. 9	1. 4	13. 5
	4. 5	80. 3	1. 0	12. 2
	2. 8	75. 0	2. 2	13. 2
200	6. 1	79. 0	1. 6	13. 2
	4. 5	79. 0	1. 5	13. 7

Water Absorption Index and Water Solubility Index

Water absorption index and water solubility index are shown in Figures 4 and 5, respectively. The water absorption index increased with temperature to a maximum at 180°C, then decreased. The water solubility index showed similar trend. These results coincide with those of Anderson *et al.*(13), which indicates that extrusion at 180°C is most satisfactory for processing of barley snack.

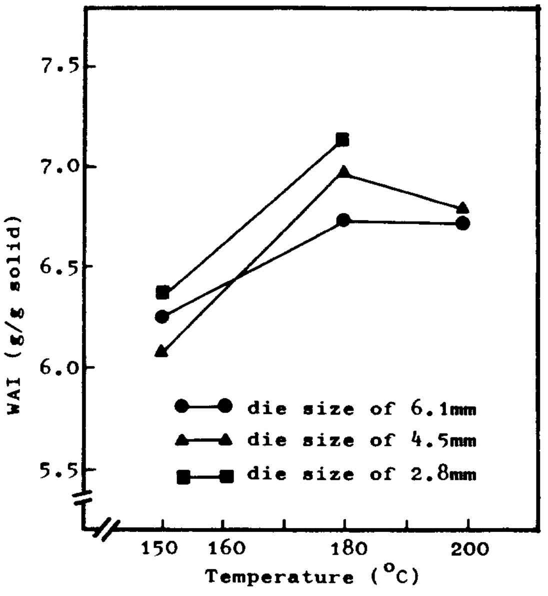


Fig. 4. Water absorption index of the extrudates from the barley flour of 20% moisture content

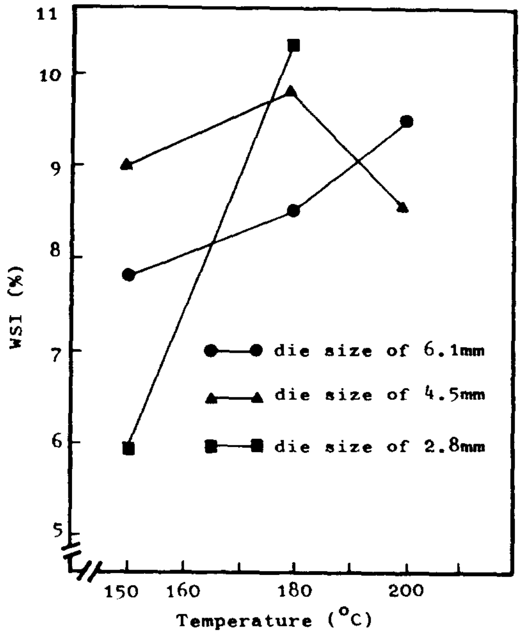


Fig. 5. Water solubility index of the extrudates made from the barley flour of 20% moisture content

Table 7. Gelatinization degree of the extrudates

Moisture content of feed (%)	Extrusion temp. (℃)	Dia. of die (*mm*)	Gelatinization degree (OD at 600 *nm*)
20	150	6.1	0.76
	150	4.5	0.87
	150	2.8	0.76
	180	6.1	0.78
	180	4.5	0.84
	180	2.8	0.82
	200	6.1	1.14
	200	4.5	0.89
25	150	2.8	0.46
	180	2.8	0.41

Degree of Gelatinization

Table 7 shows the degree of geatinization of the extrudates under various extrusion conditions. The degree of gelatinization of the extrudates increased as extrusion temperature increased. There was no conspicuous difference in degree of gelatinization with respect to different die size.

The degree of gelatinization of the extrudate from 25% moisture content barley flour was lower than that from 20% moisture content barley flour. This was because the specific heat increased and the viscosity decreased with respect to moisture content(19). And the internal friction in 25% moisture content barley flour was less vigorous than that in 20% moisture content barley flour in the extruder.

Mechanical Properties of the Extrudates

The mechanical properties of the extrudates are shown in Table 8. The fracture force, Young's modulus and the maximum fiber stress of the extrudates decreased with increasing temperature and decreasing die size. The deformation to fracture, on the other hand, increased at higher temperature and with larger dies. These results indicate that the structure of higher temperature extrudate are brittler than lower temperature extrudate. And the extrudates from the barley flour of 25% moisture content showed more flexible characteristcs than those from the barley flour of 20% moisture content.

The yield force of the extrudates in puncture test

Table 8. Mechanical properties of the extrudates

Moisture content of feed (%)	Extrusion temp. (℃)	Dia. of die (*mm*)	Fracture force (*Kg*)	Deformation to fracture (*mm*)	Young's modulus (Kg/m^2)	Max. fiber stress (Kg/m^2)
20	150	6.1	2.14	1.87	6.89×10^7	1.21×10^6
	150	4.5	1.26	2.50	2.15×10^7	5.49×10^5
	150	2.8	0.30	2.86	8.89×10^6	2.19×10^5
	180	6.1	0.53	2.52	1.93×10^7	4.10×10^5
	180	4.5	0.52	3.77	8.52×10^6	3.00×10^5
	180	2.8	–*	–	–	
25	150	2.8	0.24	3.23	2.18×10^7	4.44×10^5
	180	2.8	0.26	3.80	1.75×10^7	4.33×10^5

*not measurable because of burst

Table 9. Yield force of the extrudates in puncture test

Moisture content of feed (%)	Extrusing temp. (℃)	Dia. of die (*mm*)	Yield force (*Kg*)
20	150	6. 1	2. 30
	150	4. 5	1. 83
	150	2. 8	0. 65
	180	6. 1	0. 79
	180	4. 5	0. 53
	180	2. 8	0. 35
25	150	2. 8	2. 80
	180	2. 8	3. 33

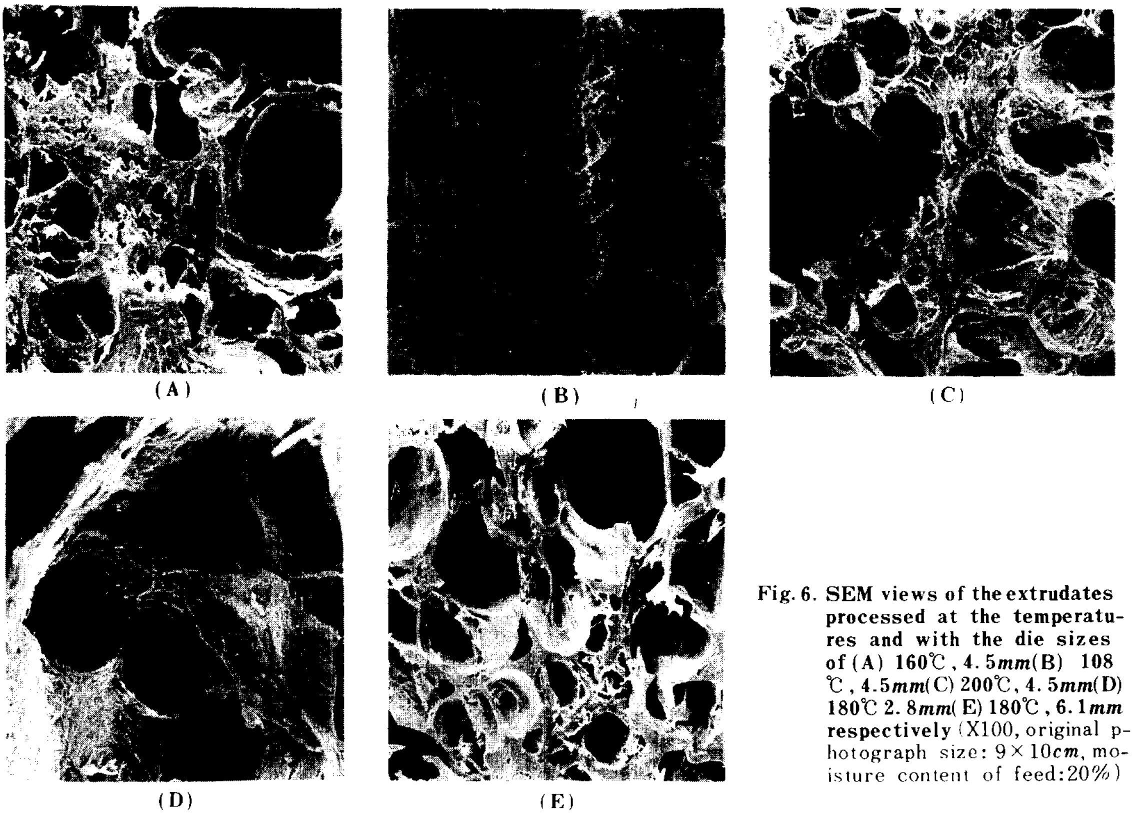
decreased with temperature and with decreasing die size as shown in Table 9. Therefore, it could be concluded that the extrudate at higher temperature had more desirable textural characteristics of a snack food. The optimum operating condition of barley snack extrusion was at 180°C and with 4.5*mm* die size and from 20% moisture content barley flour in consideration of the easiness of processing and the quality of the products.

Microstructure of the Extrudates

The microstructures of the extrudate are shown in Fig 6. The size and the fraction of air cells inside the extrudates increased with temperature and decreasing die size. Brennan *et al.*(20) and Bourne (21) noted a tendency for crisp foods to be cellular. These cells could be air cells or cavities in dry crisp foods(22). In this respect crisper extrudates can be produced at higher temperature and with smaller die.

요 약

스낵가공을 위한 보리의 압출성형특성을 조사하였고 가공조건이 제품의 품질에 미치는 영향을 분석하여 다음과 같은 결과를 얻었다. 압출성형을 위한 원료 보리의 적정 수분함량은 20%였으며 extrudate의 수분함량은 extrusion온도가 증가할수록 die크기가 감소할수록 낮았으며 Harper의 실험식에 의한 예측수분함량과 잘 일치하였다. Die swell은 0. 98-2. 18정도의 값을 나타내었으며 150℃이상에서 온도가 증가함에 따라 감소하였다. Extrudate의 밀도는 온도가 높을수록 die크기가 작을수록 감소하였다. 또한 색택은 온도가 증가함에 따라 L, a, b치가 큰 값을 나타내었다. 흡수율과 용해율은 180℃에서 최대치를 나타내었으며 호화도는 온도가


(A) (B) (C)

(D) (E)

Fig. 6. SEM views of the extrudates processed at the temperatures and with the die sizes of (A) 160℃, 4. 5*mm* (B) 108 ℃, 4.5*mm* (C) 200℃, 4. 5*mm* (D) 180℃ 2. 8*mm* (E) 180℃, 6. 1*mm* respectively (X100, original photograph size: 9×10*cm*, moisture content of feed: 20%)

증가함에 따라 증가하였다. Extrudate의 파괴응력, 영률, 최대응력은 온도가 높을수록 die 크기가 작을수록 감소하였으며 파괴점까지의 변형은 반대양상을 나타내었다. 또한 온도가 증가함에 따라 extrudate의 내부기공의 크기 및 비율이 증가하였다. 이상의 결과를 종합하여 볼때, 보리 스낵가공을 위한 최적 extrusion 조건은 스크류 회전속도 160 rpm에서 원료수분함량 20%, 온도 180℃, die 크기 4.5 *mm*인 경우이었다.

References

1. Harper, J.M.: *Food Technol.*, **32**(7), 67 (1978)
2. Johnston, G.L.: *Technical and Practical Processing Conditions with Single Screw Cooking Extruders*, International seminar on cooking and extruding techniques., Solingen-Grafrath, Germany, Nov. 27-29 (1978)
3. Smith, O.B.: *Extrusion Cooking*, New Protein Foods, Academic Press, New York (1976)
4. Bruin, S., Van Zuilichem, D.J. and Stolp, W.: *J. Food Process Engineering*, **2**, 1 (1978)
5. Remsen, C.H. and Clark, J.P.: *J. Food Process Engineering*, **2**, 39 (1978)
6. Clark, J.P.: *Food Technol.*, **32**(7), 73 (1978)
7. Mottern, H.H., Spadaro, J.J. and Gallo, A.S.: *Food Technol.*, **23**(4), 567 (1969)
8. Williams, M.A.: *Cereal Foods World*, **23**, 152 (1977)
9. Anderson, Y.: *Cereal Chem.*, **58**, 370 (1981)
10. Lorenz, K.: *J. Food Sci.*, **39** 572 (1974)
11. American Association of Cereal Chemists: Approved Methods of AACC (1983)
12. Cabrera-Laverde, J.A.: *M.S. Thesis*, Kansas State University U.S.A. (1978)
13. Anderson, R.A.: *Cereal Sci. Today*, **14**, 1, 4 (1969)
14. Wotton, M. and Chaudhry, M.A.: *J. Food Sci.*, **45**, 1783 (1980)
15. Shigley: *Mechanical Engineering Design*, McGraw-Hill Publishing Co. (1982)
16. Harper, J.M.: *Extrusion of Foods*, p. 86, CRC Press Inc. (1981)
17. Lee, D.S.: *J. Korean Agric. Chem. Soc.*, **25**, 119 (1982)
18. Park, K.: *Ph.D. Thesis*, University of Illinois, U.S.A. (1976)
19. Heldman, D.R.: *Food Process Engineering*, AVI Publishing Co. (1973)
20. Brennan, J.G.: A paper presented at the 4th International Congress of Food Science and Technology, Madrid, Spain, Sep 22-27 (1974)
21. Bourne, M.C.: *Fabricated Foods*, Inglett, G.E., (ed.), Avi Publishing Co. (1975)
22. Vickers, Z and Bourne, M.C.: *J. Food Sci.*, **41**, 1153 (1976)

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