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Effects of Water Activity on Crispness and Brittleness, and Determination of Shelf-life of Barley Flake

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보리 후레이크의 水分活性度가 Crispness와 Brittleness에 미치는 影響 및 품질수명의 결정

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Abstract

The texture characteristics, crispness and brittleness, of the barley flake developed by FRI in 1980 were measured with both sensory and instrumental methods. Bend and penetration test were done to determine those characteristics instrumentally, and compared each other and with sensory evaluation. And the changes in those characteristics with various water activity were studied, and the textural critical water activity was acquired. The shelf-life was also estimated with various packaging materials.

It was found that crispness could be represented as the reciprocal of deformation and brittleness as that of fracture force in the barley flake. Both crispness and brittleness decreased as water activity increased. And the results from the penetration test correlated better with those from the sensory evaluation than the bend test's. The average shelf-life of the barley flake was 43 days in PE film and 9400 days in laminated Al foil on the basis of only textural characteristics.

Introduction

Korea has a great surplus of barley because of the recent increase in production and the preference of rice to barley in dietary habit of the people. Korea is under pressure to expand the utilization of barley to equilibrate the demand and supply.

In 1980, the Food Research Institute developed the barley flake for breakfast cereal as one of barley processed foods. The most influencing factors for the commercial value of barley flake are texture characteristics such as crispness and brittleness.

Crispness and brittleness are a very complicated texture characteristic and are very hard to be defined with one word in Korean. Many foreign researchers defined and measured crispness and brittless of foods in last two decades[1~9].

Two theories were proposed on the instrumental measurement and analysis of crispness in food samples. Katz[10] and Bourne[11] proposed that the slope of force-deformation curve is the indicator of crispness. On the other hand, Brennan *et al*[7], and Iles and Elson[6] proposed the deformation to fracture correlated best with the crispness in snap test of crackers and friable foods. They also suggested that sensory crispness is a different sensation in fruits and vegetables from that in friable foods. Crispness in friable foods is dependent upon the amount of deformation the food undergoes at the initial bite before breaking. Crispness in fruits and vegetables, on the other hand, depends on the force necessary to produce a deformation. Vickers and Bourne[12] reported a review on the crispness in foods.

Wasserman[13] found that an increase in maximum breaking force, which occurred at higher humidities, corresponed to a decrease in sensory crispness. Nielsen[14] concluded that crispness is a salient textural characteristic for most fresh dry cereal and starch-based snack food products, and its loss due to absorption of moisture is a major cause of snack food product rejection by consumers. Bourne *et al*[11]. studied potato chips at different moisture contents and observed a decreasing initial slope from the force-deformation curve as water content increased. Katz and Labuza[10] studied the effect of water activity on the cripess of snack food products.

As mentioned by above researchers, the moisture content and the water activity are the leading factors on the quality of friable foods including the barley flake. This work was, therefore, undertaken to determine the optimum water activity for the barley flake and critical water activity where the barley flake become organoleptically unacceptable due to either a lack of crispness or poor overall texture, and to select the suitable packaging material for the barley flake and to estimate the shelf-life with various packaging materials.

The results obtained in sensory and instrumental crispness and brittleness measurement and their application to the determination of the quality and the shelf-life of the barley flake are presented here.

Materials and Methods

Materials

The barley flake was processed as shown in Fig. 1.

Naked Barley
↓
Soaking in water for 2 hr
↓
Dehydration with double drum drier
  Inlet steam: 70 dsig
  Clearance between two drums: 0.12 *mm*
  Drying time: 16 sec
↓
Deep fat frying for 40 sec at 180°C
↓
Deoiling
↓
Packaging

Fig. 1. A flow diagram of the drum dried barley flake

Methods

a. Initial moisture content

Initial moisture content of the barley flake was determined by drying method at 105°C under atmospheric pressure.

b. Initial water activity

Initial water activity of the barley flake was determined with graphic interpolation method[15] at 40°C.

c. Moisture sorption isotherm

Moisture sorption isotherms were prepared by equillibrating 2~3 *g* of wholly vacuum-dried samples over saturated salt solutions in evacuated dessiccators at 40°C. The salts used were, $CaCl_2$ ($A_w=0$), LiCl (0.11), CH_3COOK (0.23), $MgCl_2$

(0.32), K_2CO_3 (0.44), NaBr (0.57), $CuCl_2$ (0.67), NaCl (0.75), KCl (0.83), $BaCl_2$ (0.87) and K_2SO_4 (0.96). BET monolayer values were determined from the isotherm data as described by Labuza[16].

d. Sensory analysis

The magnitude estimation technique couple to a verbal concept scale[17] was used to determine the crispness intensity, brittleness intensity and overall textural hedonic scales. At each testing session, the judges were presented a series of samples for barley flake conditioned and equillibrated over various saturated salt solutions. The panels consisted of 23 male and 14 female and all of them were working in the Food Research Institute and not trained for this specific study. The verbal concept scale for sensory evaluation of crispenss, brittleness and hedonic score are presented in Table 1, 2 and 3, respectively.

Table 1. The concept and the score for sensory evaluation of crispness intensity

Concepts	Score
Extremely crisp	4
Very crisp	3
Moderately crisp	2
Slightly crisp	1
Not crisp	0

Table 2. The concept and the score for sensory evaluation of brittleness intensity

Concepts	Score
Extremely brittle	4
Very brittle	3
Moderately brittle	2
Slightly brittle	1
Not brittle	0

It was proposed to use molars to determine sensory crispness intensity and incisors for the determination of brittleness as Brennan *et al*[7] did to their panels. Sensory data from the crispness and brittleness intensity study were normalized by dividing each judge's values by the geometric mean of his/her concept scores.

Table 3. The concepts and the hedonic score for the sensory evaluation of barley flake

Concepts	Score
Like extremely	+4
Like very much	+3
Like moderately	+2
Like slightly	+1
Neither like nor dislike	0
Dislike slighly	−1
Dislike moderately	−2
Dislike very much	−3
Dislike extremely	−4

e. Instrumental measurement of crispness and brittleness of the barley flake

Bend and penetration tests were introduced for the measurement of crispness and brittleness of the barley flake with Instron Universal Testing Machine (Table Model 1140).

The conditions of bend test or snap test are presented in Fig. 2. A direct bend test apparatus using a center load and end support was mounted on the Instron Universal Testing Machine. The supports consisted of two Teflon cubes with each side of 1.0 *cm* set at a span length of 6.85*mm*. Center loading was done with a blunt knife-edge 6.0 *mm* wide and 0.525 *mm* thick. The width of the loading edge meant that all of the barley flake samples had to be cut down to a width of 6.0 *mm* using very sharp scissors to avoid sample notching. And the thickness and the width variations were measured using a micrometer screw gauge.

The conditions of penetration test are presented

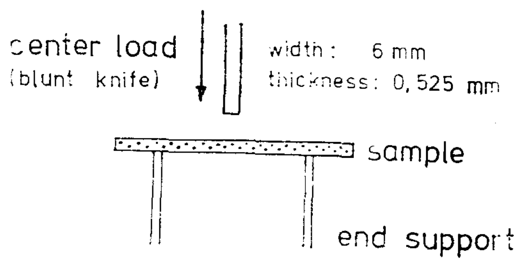

Fig. 2. The mechanism and the conditions of bend test of the barley flake

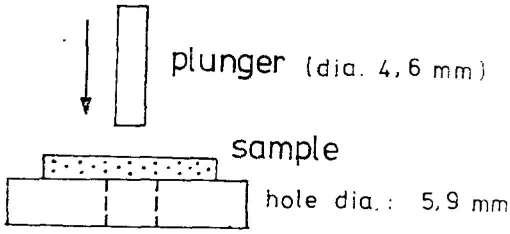

Fig. 3. The mechanism and the conditions of the penetration test of the barley flake

in Fig. 3.

In penetration test, the barley flake sample size were $1.6\pm0.1\times1.0\pm0.1\times0.035\pm0.005$ *cm*. And the cross head speed and chart speed in both tests were 5 *cm/min* and 100 *cm/min*, respectively.

The force necessasy to produce a breakdown of sample (hereafter it called fracture force) and the deformation of sample to fracture (hereafter it abbreviated to deformation) were measured in both tests. The maximum fiber stress and the modulus of elasticity were calculated from the results in the bend test by using Equations (1) and (2)[7], respectively.

$$\sigma_{max}=\frac{3F_fL}{2b\ h^2}\ g\ 10^2$$

$$E=\frac{F_fL^3}{4D_fb\ h^3}g\ 10^2$$

where;

F_f=the fracture force [*kg*]

L=the span length [*cm*]

D_f=the deformation to fracture [*cm*]

E=modulus of elasticity [N/m^2]

σ_{max}=the maximum fiber stress [N/m^2]

b=the width of the barley flake sample [*cm*]

h=the thickness of the barley flake sample [*cm*]

g=the acceleration due to gravity 980.6[cm/sec^2]

The results obtained in both bend and penetration test were compared with those from sensory evaluation and each other.

f. Water vapor permeability

PE film and laminated Al foil were used for the packaging materials of the barley flake. And the water vapor permeability of those packaging materials were measured by the method of Korean Industrial Standards[18]. A desiccator in which supersaturated Na_2HPO_4 solution was put

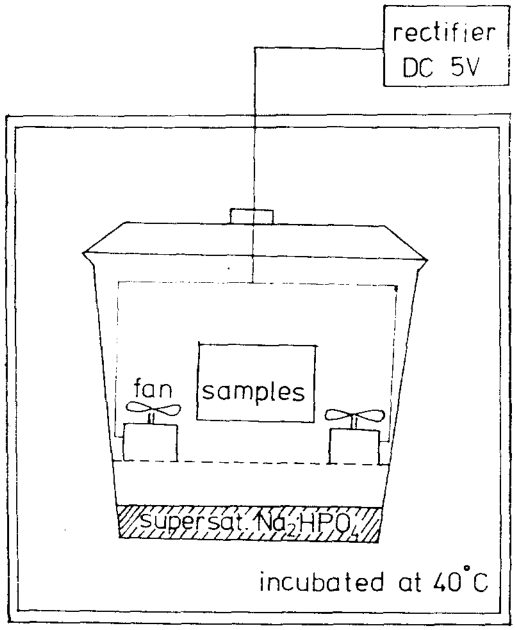

Fig. 4. An apparatus for the determination of water vapor permeability

was used and incubated to obtain the tropical condition (40°C, 90% RH) as shown in Fig. 4.

g. Estimation of shelf-life for the barley flake

The shelf-life of the barley flake in tropical condition was determined by Paine's method[19]. And it was converted to that in practical conditions of various seasons in Korea by Equation 3.

$$T_2=T_1\left(\frac{P_1}{P_2}\right)K\left(\frac{R_1-\dfrac{R_0+R_c}{2}}{R_2-\dfrac{R_0+R_c}{2}}\right) \qquad (3)^{(20)}$$

where; T_1 and T_2=the shelf-lives in condition 1 and 2, respectively [days]

P_1 and P_2=the water vapor pressures in condition 1 and 2, respectively [*mm* Hg]

R_1 and R_2=the relative humidities in condition 1 and 2, respectively [%]

R_0 and R_c=the initial Aw×100 and textural critical Aw ×100, respectively

K=the constants of packaging material, 1.3 for laminated Al foil and 1.0 for PE film[21]

Results and Discussion

Sorption Isotherm

The crispness and the brittleness, the desirable textural characteristics in most snack foods, are very sensitive to moisture gain. Thus the initial moisture content, the water activity of the barley flake and the moisture sorption isotherm were measured. The initial moisture content and the water activity of the barley flake were 2.6% and 0.19, respectively. And the absorption curve of barley flake is presented in Fig. 5.

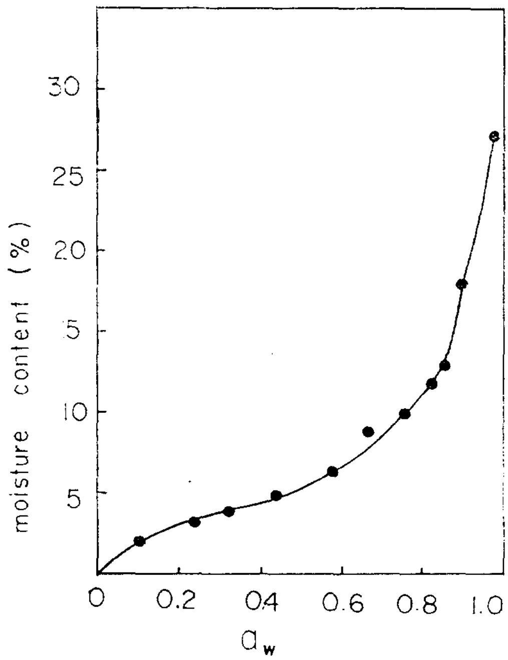

Fig. 5. The moisture absorption curve of the barley flake at 40°C

The BET monolayer value was calculated from the slope and the intercept of the line plotted in Fig. 6. The monolayer value of the barley flake was 0.0255 gH_2O/g solid, and the water activity was 0.17 at this point. The corresponding Aw's to monolayer value of most of dry snack foods are in the range from 0.15 to 0.25[10]. And the initial moisture content of the barley flake was slightly above the monolayer value.

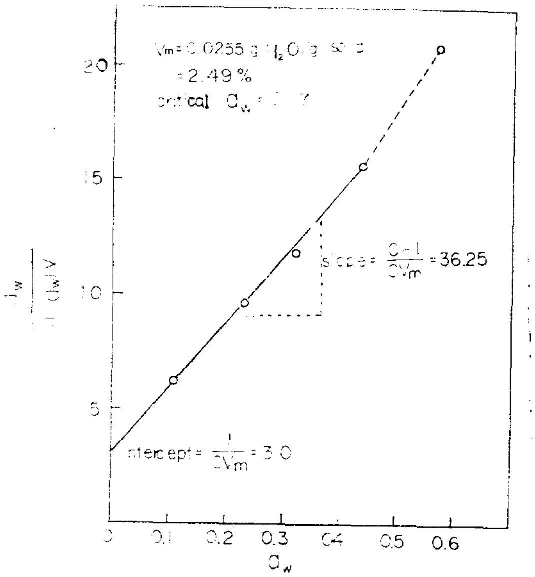

Fig. 6. BET plot for the determination of the monolayer value in the barley flake

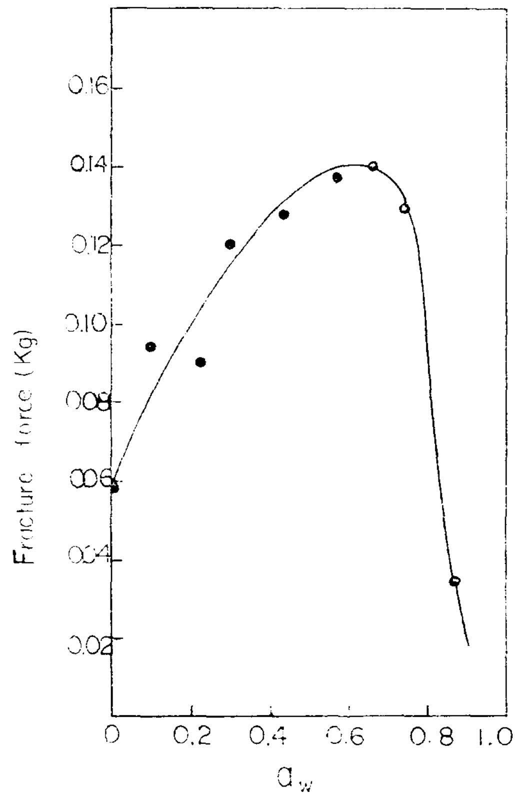

Fig. 7. Fracture force of barley flake vs. water activity in bend test

Table 4. Median crispness intensity, brittleness intensity and textural hedonic scores for the barley flake as a function of water activity

Aw	0	0.11	0.23	0.31	0.44	0.57	0.67	0.75
Crispness intensity	1.747ᵃ	1.622ᵃ	1.293ᵇ	1.026ᶜ	N.T.*	0.573ᵈ	0.102ᵉ	0.125ᵉ
Brittleness intensity	2.055ᵃ	1.548ᵇ	1.551ᵇ	0.848ᶜ	N.T.	0.440ᵈ	0.165ᵉ	0.125ᵉ
Hedonic score	2.784ᵃ	2.081ᵇ	2.027ᵇ	1.216ᶜ	N.T.	−0.486ᵈ	−1.297ᵉ	−1.351ᵉ

ᵃMedians followed by the same letter are not significantly different from each other ($p<0.05$)
*N.T. means not tested.

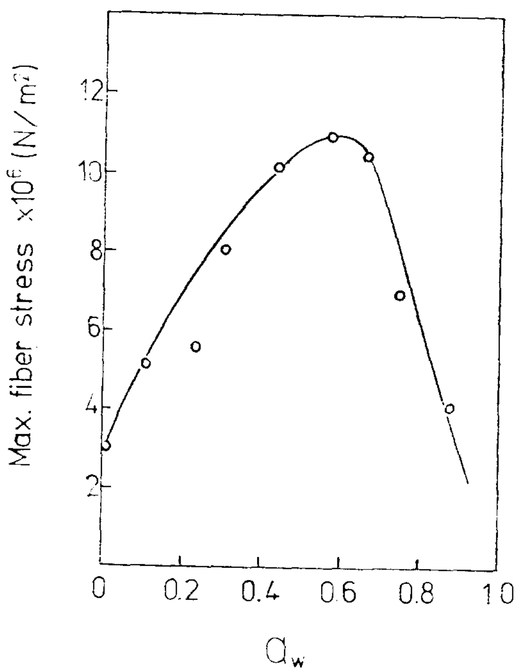

Fig. 8. Relationship between maximum fiber stress and water activity of the barley flake in bend test

Sensory Analysis

The sensory analysis on the crispess intensity, brittleness intensity and hedonic score for the barley flake with various water activity are shown in Table 4. All of the sensory crispness intensity, brittleness intensity and hedonic score for the barley flake were decreased as the water activity increased. These results are consistent with those by Wasserman[13], Nielsen[14] and many other researchers.

Instrumental Analysis

a. Bend test

The relationships between water activity and fracture force, and fiber stress indicate significant parabolic for barley flake in bend test as shown in Fig. 7 and 8, respectively.

In monolayer and multilayer zone, the fracture force and maximum fiber stress increased with increasing water activity. And there was no conspicuous change in decreasing phenomena between mono and multilayer zone. However, both fracture force and maximum fiber stress decreased suddenly with water activity greater than 0.75, which is thought in capillary zone. Therefore, it could be concluded that a drastic change in physical property of the barley flake occurred between multilayer and capillary zone. The lowest fracture force and fiber stress were at $Aw=0$ and the values were 0.058 Kg and 2.781 N/m^2, respectively. The highest values of those were found at $Aw=0.67$.

The brittleness could be expressed with the reciprocal of fracture force and decreased with increasing water activity. As shown in Fig. 9, the barley flake was deformed more until it was fractured as the water activity increased. And the barley flake was deformed very much in capillary zone (above $Aw=0.75$) in comparison with mono and multilayer zone. Crispness could be represented as the reciprocal of deformation and decreased with increasing water activity

The modulus of elasticity decreased gradually as the water activity increased in mono- and multilayer zone as Fig. 10. In capillary zone, however, it decreased rapidly. And the variations in the modulus of elasticity with water activity indicated inverse curvilinear relationships. The maximum modulus of elasticity was $1.38\times10^8\ N/m^2$ at $Aw=0$.

b. Penetration test

As mentioned above, crispness and brtitleness

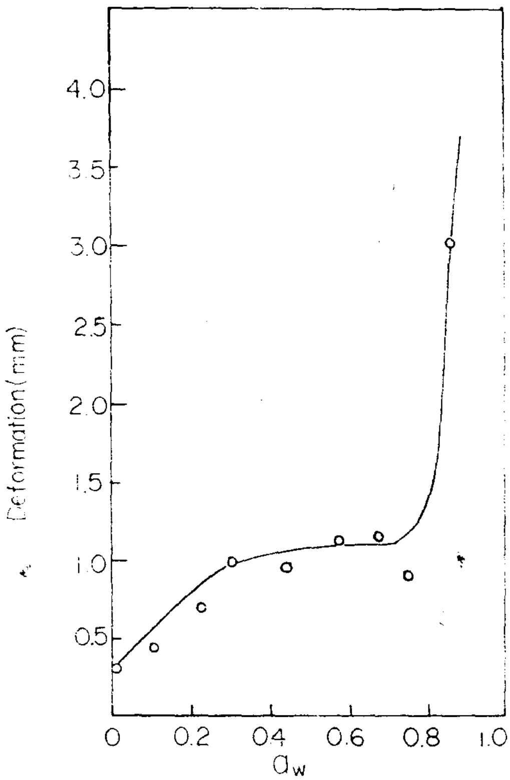

Fig. 9. Relationship between deformation and water activity of barley flake in bend test

were represented as the reciprocals of deformation and fracture force, respectivly. And both of them decrased with increasing water activity of barley flake as shown in Fig. 11 and 12.

The reciprocal of deformation coincided very well with the crispness intensity in sensory evaluation. The slope of force-deformation curve, on the other hand, little correlated with the crispness intensity. This result is fully consistent with that from Brennan *et al.*[7] and Iles and Elson[6], but different from Katz's[10] and Bourne's[11]. From the results in this study, it can be concluded that the crispness of barley flake correlates strongly with how much it deforms before fracture in penetration test.

c. Comparison of two tests

The results of both bend and penetration test were examined and compared with those of sensory evaluation. Their correlation coefficients with

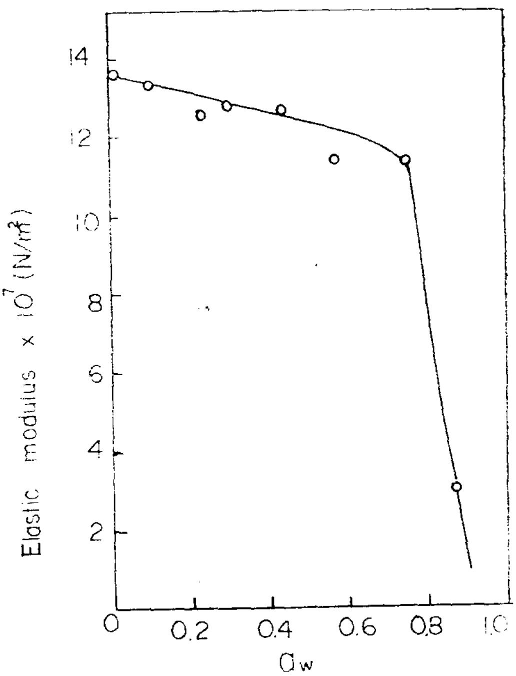

Fig. 10. Relationship between modulus of elasticity (apparent stiffness) and water activity of barley flake in bend test

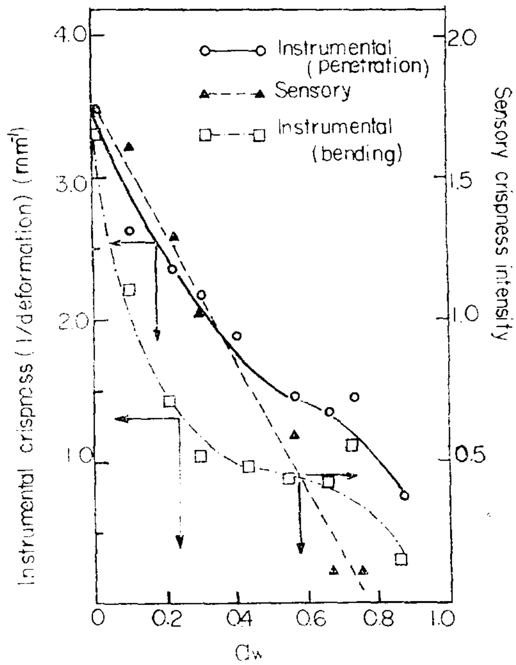

Fig. 11. Crispness of barley flake in penetration test and its comparison with those in bend test and sensory evaluation

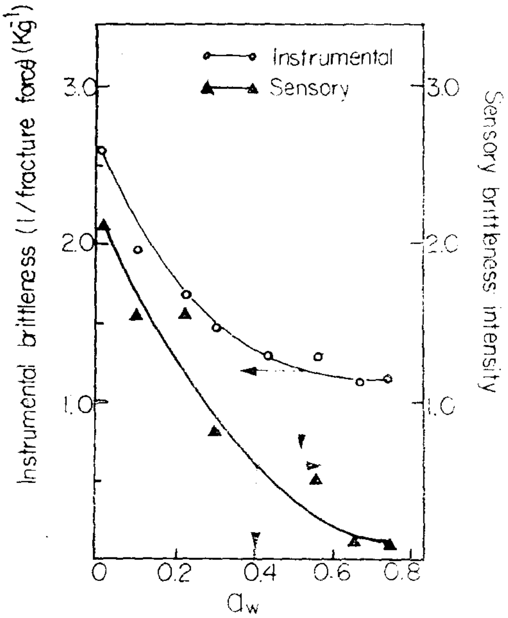

Fig. 12. Brittleness of barley flake in penetration test and its comparison with that in sensory evaluation

Table. 5 Correlation coefficients between sensory evaluation and both penetration and bend test

	Penetration test	Bend test
Crispness	0.9380	0.8695
Brittleness	0.9345	0.6806

sensory evaluation are described in Table 5. Sensory evaluation correlated better with penetration test for both crispness and brittleness than the bend test.

The texture in friable foods consists of crispness and britteness at the same time. The products of crispness and brittleness in penetration test were compared with the textural hedonic scores for barley flake, and shown in Fig. 13. The correlation coefficient between them was 0.8714, and it indicated that they correlated pretty well each other.

The minimum acceptable product of crispness and brittlenes was 2.05 Kg^{-1} mm^{-1} and the textural critical water activity for the quality of the barley flake was 0.48. And the moisture content was 5.6 % at this point.

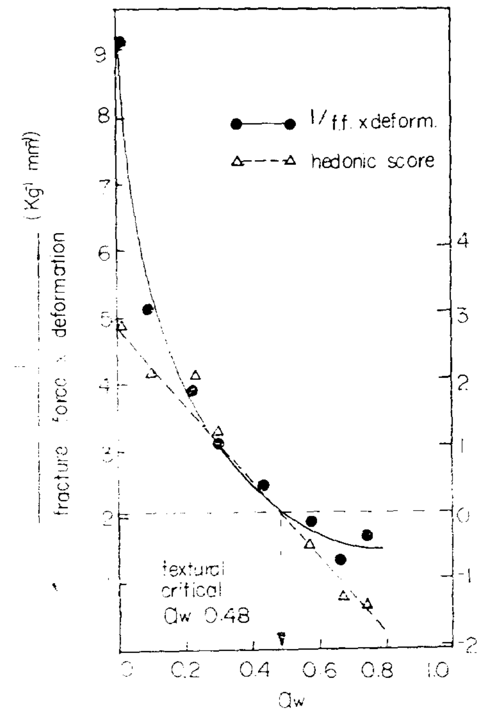

Fig. 13. Inverse energy required in penetration test (the product of crispness and brittleness) and its comparison with hedonic score in sensory evaluation

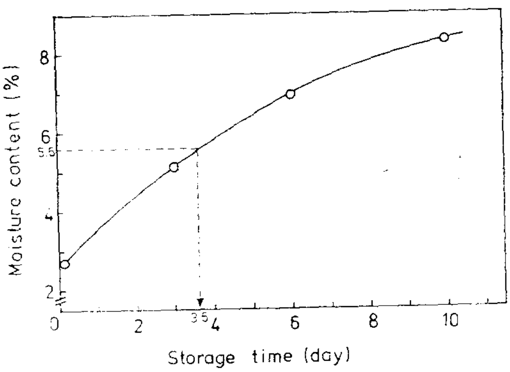

Fig. 14. Changes in moisture content of barley flake packaged in PE film in tropical condition

Determination of water vapor permeability and shelf life of barley flake with various packaging materials

The water vapor permeabilities of PE film and laminated Al foil were 0.001213 and 0.00001 *g*

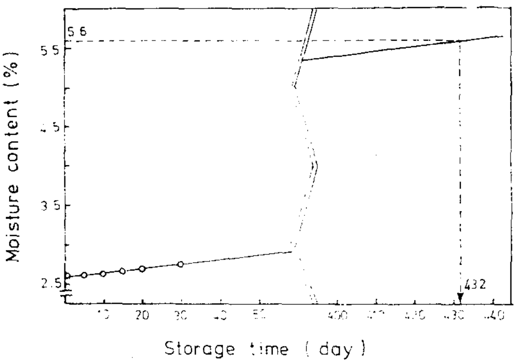

Fig. 15. Changes in moisture content of barley flake packaged in laminated Al. foil in tropical condition

$H_2O/cm^2/24$ hr, respectively. Both PE film and laminated Al foil of 470 cm^2 surface area were used to package 50 g of barley flake and stored in tropical condition, and the changes in their weight were measured periodically. The changes in moisture content of barley flake in PE film and laminated Al foil are in Fig. 14 and 15, respectively.

The shelf lives of barley flake packaged in PE film and laminated Al foil in tropical condition were 3.6 days and 423 days, respectively. And the calcuated those from the water vapor permeability were 2.9 days in PE film and 355 days in larminated Al foil in tropical condition. The shelf lives of barley flake in various seasonal conditions were estimated by using equation (3) and described in Table 6.

Laminated Al foil was recommended for the packaging material of the barley flake. The barley flake was expected to be stored for very long time in laminated Al foil without serious deterioration of its texture, and for 43 days in PE film on the average.

요 약

보리후레이크의 수분활성도에 따른 crispness와 brittleness를 bend test와 침투시험을 행하여 기기적으로 측정하였으며 이를 관능검사 결과와 비교하였다. 또한 조직감을 기준으로 하여 상품적 가치가 유지될 수 있는 임계수분활성도를 구하였고 이를 기초를 포장재별 품질수명을 측정하였다.

힘-변형 곡선에서 crispness는 1/변형, brittleness는 1/소요된 힘으로 각각 표시될 수 있었으며 침투시험이 bend test 보다 관능검사 결과와 더 잘 일치하였고, 수분활성도가 증가함에 따라 crispness와 brittleness는

Table 6. Estimated shelf-life of the barley flake with various packaging materials in various seasonal conditions

Packaging material	K*	Shelf-life in tropical condition (days)	Months	Average temperature (°C)**	Average R.H. (%)	Vapor pressure of water at the average temperature (mm Hg)***	Initial Aw	Textural critical Aw	Estimated shelf-life (days)
PE film	1.0	3.6	Jan.～Mar.	1.8	54	5.219	0.19	0.48	105.2
			Apr.～Jun.	16.8	69	14.347			22.1
			Jul.～Sep.	23.6	83	22.244			10.2
			Oct.～Dec.	12.4	65	10.799			33.1
									Average; 43 days
Laminated foil	1.3	432	Jan.～Mar.	1.8	54	5.219	0.19	0.48	25625
			Apr.～Jun.	16.8	69	14.347			3974
			Jul.～Sep.	23.6	83	22.244			1612
			Oct.～Dec.	12.4	65	10.799			9480
									Average; 6400 days

*Data from Oswin(21)

**These values are the average temperature and R.H. in Seoul, Busan and Dagu in each 3 months around year, and from the Central Meterological Office.

***From the Handbook of Chemistry and Physics(22)

감소하였고 임계수분활성도는 0.48이었다.

PE film으로 포장하였을 때 조직감 만을 기준으로 한 품질수명은 평균 43일이었으며 적층 Al foil로 포장하였을 때는 9400일로 추정되었다.

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