KOREAN J. FOOD SCI. TECHNOL
Vol. 15, *No.* 2 (1983)

A Kinetic Study on the Hydration Process of Barley Kernels with Various Polishing Yields

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(Received February, 19, 1983)

도정수율별 보리의 水和工程에 關한 速度論的 硏究

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(1983년 2월 19일 수리)

Abstract

The hydration characteristics of barley kernels with various polishing yields were investigated at temperatures of 20-60 °C and their sorption kinetics were studied. The moisture gain in initial stage of hydration was directly proportional to square root of hydration time and there was a break point at the moisture gain of 0.45-0.55g H_2O/g solid. The hydration rate was great in order of polishing yield of 50, 70, 95, 90 and 100%, and increased with increasing hydration temperature. The diffusivity of water into barley kernels followed Arrhenius equation, and the activation energies in hydration reaction of polished barley were ranged from 6.9 to 9.5 *Kcal/mole* and that of non-polished one was 11.6*Kcal/mole*.

Introduction

Korea has a great surplus of barley because of the recent increase in its production and the preference of rice to barley in dietary habit of the people. Fortunately various barley-based processed foods have been developed recently, which increased the demand of barley and seem to enhance the self-sufficiency of major grains. In addition, such products that are processed of whole grain of barley including bran are being produced on commercial scale. It seems to contribute to food conservation and to save foreign currency required for import of major grains.

The hydration is essential and first step in almost every cereal processing. The penetration of water into the kernels is a problem of both theoretical and practical importance to the grain processing industries. Studies on the hydration process of wheat, rice, corn and other grains were carried out by previous researchrs[1-8]. However, no comprehensive study on hydration characteristics of barley was established yet, which hinders determining the optimum processing conditions, designing continuous manufacturing process and analyzing the physico-chemical changes in kernel during hydration.

In this study, therefore, the hydration characteristics of barley kernels with various polishing yields are investigated and its sorption kinetics are studied.

Theoretical Aspects

Becker[1] demonstrated that Fick's second law equation could be integrated and arranged with first-order approximation in terms of experimental variables as the following equation:

$$\bar{m} - m_0 = K_1\sqrt{t} \qquad (1)$$

where $K_1 = 2/\sqrt{\pi}\,(m_s - m_0)\ (S/V)\ \sqrt{D} \qquad (2)$

Equation (1) shows that, if this mathematical model is applicable, a linear relationship exists between $(\bar{m} - m_0)$ and $\sqrt{t}$

The diffusivity, D, can be obtained from

$$D = \left[\frac{K_1}{\frac{2}{\sqrt{\pi}} \frac{S}{V} (m_s \quad m_0)} \right]^2 \qquad (3)$$

using experimentally determined values of K_1, (S/V) and $(m_s - m_0)$.

To calculate the surface area and volume of barley kernel the shape of barley kernel was assumed to be a prolate spheroid. The volume and the surface area a barley kernel could be calculated by equation (4) and (5), respectively[10,11].

$$V = (4/3)\,\pi a b^2 \qquad (4)$$

$$S = 2\pi b^2 + 2\pi(a\,b/e)\,\sin^{-1} e \qquad (5)$$

where $e = (\sqrt{a^2 - b^2}\,)/a \qquad (6)$

Materials and Methods

Materials

Barley kernel of variety *'Sedohadaka'* was polished with various polishing yields with Satake Grain Testing Mill (Satake Engineering Co., Japan) and used for this experiment.

Methods

Determination of barley kernel size

The major and minor radius of barley kernel was determined with caliper on the screen of profile projec- the object 20 times. And the volum and the surface area were calculated by equation (4) and (5), respectively.

Hydration process

The absorption of water by barley kernel was studied as functions of time, temperature and initial moisture content. Experiments were carried out at temperatures ranging from 20 to 60°C and for immersion periods from 1 min. to 24 hrs. For each run 1 g of barley was put into the small stainless steel wire gauze basket and immersed in a circulated water bath controlled within ±0.05°C of the set temperature. At the end of each immersion, sample was quickly removed from the water bath and superficially dried on a large filter paper. After the surface water on the kernels was removed, the sample was weighed. Moisture gain was calculated from the weight of the water absorbed by the samples and was plotted as a function of $\sqrt{t}$ and K_1 was acquired from the slope of the line. The diffusivity was calculated by equation (3).

Results and Discussion

Determination of the effective surface moisture content

Equations (1) and (2) show that if the diffusivity is independent of moisture content in the range studied, the product of the slope K_1 and the kernel volume-to-surface ratio V/S should be a linear function of the initial moisture content and the effective surface moisture content, m_s, can be estimated from the intercept at K_1 V/S = 0 when this linear function is extrapolated. Figure 1 shows that the data fulfills this expectation reasonably well and indicates that the effective surface moisture content of barley kernel immersed in water is ranging from 0.6 to 0.9g per g depending on the polishing yields. And the effective surface moisture content and volume-to-surface ratio of barley kernel with various polishing yields are presented in Table 1.

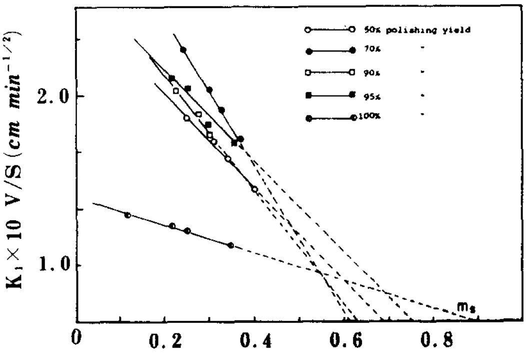

Fig. 1. K_1 V/S as a function of initial moisture content during hydration at 20°C

Table 1. Effective surface moisture content and volume-to-surface ratio of barley kernel

Polishing yield (%)	Effective surface moisture content (m_s, g H_2/g solid)	V/S *(cm)*
50	0.6831	5.433×10^{-2}
70	0.6093	5.729×10^{-2}
90	0.6319	6.454×10^{-2}
95	0.7503	6.456×10^{-2}
100	0.8890	6.558×10^{-2}

The effective surface moisture content of barley kernel was nearly equal to that of wheat and corn by Becker(1) and Fan *et al.*,(8) respectively, and greater than that of rice, 0.27–0.33 *g/g*, which was reported by Cho *et al.* (5).

The volume-to-surface ratio was calculated by equations (4) and (5), and the major and minor radii were evaluated at the initial moisture content. The volume-to-surface ratio increased with increasing polishing yields.

Sorption of liquid water into barley kernels

The moisture gain in initial stage of hydration was proportional to square root of hydration time as expected by equation (1). The lines have break point at the moisture gain of 0.45–0.55 *g* H_2O/*g* solid as shown in Fig. 2. This phenomenon was also found in case of hulled barley(12, 13), rice(2) and corn(6). Equation (1) is effective in case that the steeping time is short(1), thus, the data only in the first part of hydration was adopted for analysis.

The moisture gain of barley kernel with 50% polishing yield at various hydration temperature was presented in Fig 3. The lines have non-zero intercept, and this means that there is a very rapid initial absorption of water. The nature of this phenomenon is evident from the structure of the barley kernel and the outer layer was damaged and cracked partly during polishing and should quickly become saturated by capillary imbibition. This phenomenon was found in case of other cereals(1–6).

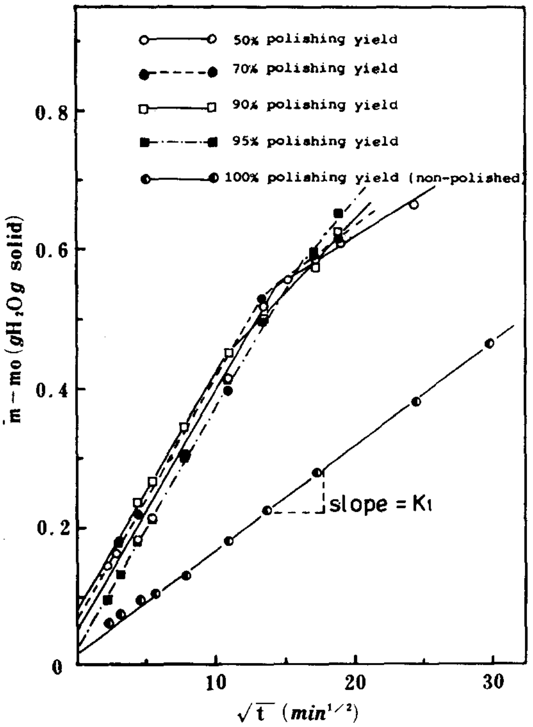

Fig. 2. Relation between the moisture gain and the square root of the hydration time during hydration of barley with various polishing yields at 20°C

The initial moisture gain of barley kernels increased with increasing hydration temperature. Bandyopadhyay and Roy(3) analyzed previous worker's data and concluded that the initial moisture gain increased linearly with increasing hydration temperature until the grains gelatineized.

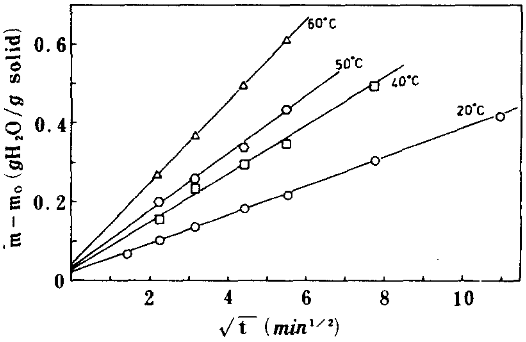

Fig. 3. Moisture gain of barley of 50% polishing yield during hydration at various temperatures

The slope of the lines, K_1, and the diffusivities, D, of the barley kernel with various polishing yields and at various hydration temperatures are presented in Table 2.

The hydration rate was great in order of polishing yield of 50, 70, 95, 90 and 100%, which was much smaller. And the value of K_1 increased as the hydration temperature was higher.

The diffusivity was great in order of polishing yield of 70, 90, 95, 50 and 100%. The difference between the orders of K_1 and the diffusivity was due to the difference in initial and effective surface moisture content and volume-to-surface ratio as shown in Table 1. The diffusivity of non-polished barley was nearly equal to that of non-polished wheat by Becker(1). However, the diffusivity of polished barley was smaller than that of polished rice, which had the value of 3.02–3.18 x 10^{-6} and 4.7–6.0 x 10^{-6} *cm²/sec* at 20 and 40°C, respectively(5).

Table 2. Diffusivity of water into barley kernel during hydration at various temperatures

Polishing yield (%)	Initial moisture content (*g* H_2O/*g* solid)	Hydration temperature (°C)	$K_1 \times 10^2$ (*min*$^{1/2}$)	$D \times 10^8$ (*cm²/sec*)
50	0.1273	20	3.526	15.552
		40	5.180	33.564
		50	6.465	52.282
		60	8.127	82.618
70	0.1236	20	3.257	19.318
		40	4.616	38.805
		50	6.637	80.222
		60	8.668	136.830
90	0.1205	20	3.165	20.885
		40	4.924	50.548
		50	5.565	64.567
		60	7.285	110.650
95	0.1174	20	3.614	18.256
		40	5.024	35.279
		50	5.480	41.974
		60	7.851	86.153
100	0.1255	20	1.432	1.939
		40	2.579	6.290
		50	3.197	9.666
		60	5.025	23.878

The outermost layer of barley kernel, testa, possesses a suberised cuticle on the outer surface and sometimes on the inner surface and is only slowly permeated by water(14,15). And the starch in endosperm of grain contains more polar sites for attraction of water molecules than does the cellulose(16). This allows a larger amount of moisture to be absorbed by starchy material than cellulosic material which consists of outer layer of barley kernel(17).

The discrepancy in hydration rate between polished and non-polished barley originates from the differences in their structure and consisting substances as described above. Thus, it is recommended that the outermost layer of barley kernel should be removed to ease its processing and reduse the consuming time for appropriate hydration, although the products are to be processed with whole grain.

The diffusivities were plotted against the reciprocal of the absolute temperatures on a semi-logarithmic scale as in Fig. 4. The results show that the relation between diffusivity and absolute temperature follows the Arrhenius-type equation as in case of other grains(4,9), and the slopes of the lines are -E/R.

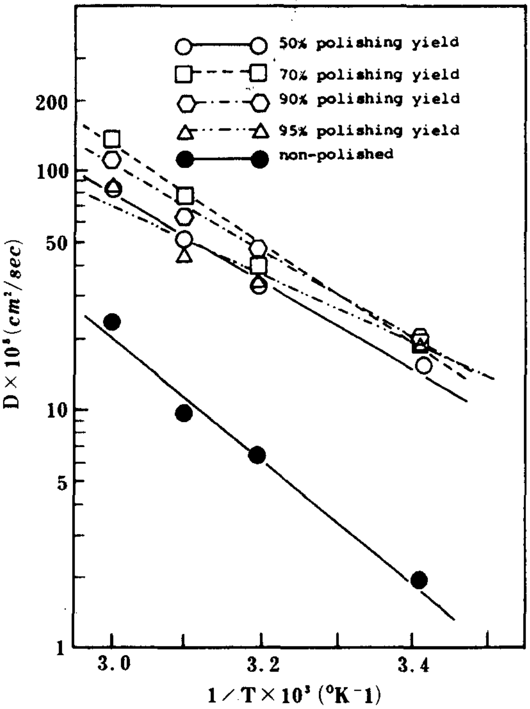

Fig. 4. **Diffusivity as a function of reciprocal of temperature for barley with various polishing yields**

The activation energies in hydration of barley kernels with various polishing yields are listed in Table 3.

Table 3. The activation energy in hydration of barley kernels

Polishing yield (%)	E *(Kcal/mole)*
50	7.99
70	9.45
90	7.79
95	6.93
100	11.63

The activation energies in hydration of polished barley were ranged from 6.9 to 9.5 *Kcal/mole.* On the other hand, that of non-polished barley was much greater than polished barley, and the value was 11.6 *Kcal/mole.* This means that the hydration reaction of cellulosic material is more temperature-dependent than starchy material and the structure of outer layer of barley kernels is very different from that of inner parts. And there is no conspicuous difference in activation energy in hydration reaction among polished barley kernels however much they are polished, if their outermost layer were removed. The activation energy in hydration reaction of non-polished barley was nearly equal to that of non-polished wheat, which had the value of 12.3 *Kcal/mole* by Becker,[1] and that of polished barley was greater than that of polished rice, 4.0-5.7 Kcal/mole by Cho *et al*[5]

Nomenclature

a: major radius of barley kernel (*cm*)
b: minor radius of barley kernel (*cm*)
D: diffusivity (*cm*^{2}*/sec*)
E: activation energy (*Kcal/mole*)
e: eccentricity
K_1: the slope of line in Eq. (1) (*min*$^{-1/2}$)
m_0: initial moisture content of barley (*g* H_2/*g* sold)
$\bar{m}$: moisture content at the hydration time t (*g* H_2O/*g* solid)
m_s: effective surface moisture content (*g* H_2O/*g* solid)
R: gas constant (1.987 *cal/°K/mole*)
S: surface area of barley kernel (*cm*^{2})
T: absolute temperature (*°K*)
t: hydration time (*min*)
V: volume of barley kernel (*cm*^{3})

要　約

도정수율별 보리의 水和特性을 20～60℃ 범위에서 조사하고 속도론적으로 해석하였다.

吸水量은 水和時間의 평방근에 비례하였으며 吸水様相은 吸水量 0.45～0.55*g* H_2O/*g* solid 이후에서 변화하였다.

水和速度는 도정수율 50>70>95>90%> 무도정맥의 순서였으며 水和溫度가 높을수록 증가하였다. 이 때 穀粒內部로의 물의 擴散度는 Arrhenius방정식에 의거하여 변화하였으며 활성화에너지는 도정맥의 경우 6.9～9.5*Kcal/mole.*, 무도정맥의 경우 11.6*Kcal/mole.*이었다.

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