

Effect of Chemical Pretreatments and Lactic Acid on the Rate of Water Absorption and Starch Yield in Corn Wet-Milling

M. Haros¹ and C. Suárez^{1,2}

ABSTRACT

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The relative effectiveness of dehulling, potassium hydroxide dipping (alkali concentrations 0.2, 0.5, and 1.0 %), and ethyl oleate spraying (aqueous emulsion 1%, v/v) to increase the rate of water absorption by dent and flint corn during steeping was compared with untreated corn samples. These pretreatments increased the water absorption rate of both hybrids when compared with the untreated control samples. To evaluate the observed increase, the diffusion coefficients of pretreated and untreated corn samples were estimated. Corn grains steeped in SO₂ aqueous solution and variable lactic acid concentrations (0.2, 0.5, and 1.0%, v/v) were per-

formed. Absorption rates for lactic acid concentrations were ≈0.5% higher than those steeped only in SO₂ solution. This effect was more marked for dent than for flint corn. Corn samples pretreated with potassium hydroxide had lower starch yields than the control. However, the presence of lactic acid in steepwater increased the starch yield of dent and flint corn, particularly for the samples treated with alkaline solution. This procedure was particularly beneficial for flint corn. An effective release of the starch granules was achieved within 24 hr of steeping.

Since the pioneering works of Watson and Sanders (1961) and Fan et al (1965) on the function of sulfur dioxide as a steeping agent, many investigations have been conducted to reduce the time required for steeping by increasing the rate of water absorption. The effect of the concentration of SO₂ in steepwater on the starch recovery was analyzed by Roushdi et al (1981). They found that samples steeped in low concentrations of SO₂ containing lactic acid produced high starch yields with low protein content. Also the separation of hull, fiber, and protein from the steeped grains was very easy. On the other hand, Eckhoff and Tso (1991) reported that the application of gaseous SO₂ in corn wet-milling and the addition of lactic acid resulted in an increase in the starch yield.

As steeping is, by far, the most time-consuming step in the wet-milling process, typically requiring 36–52 hr, various investigations were conducted to reduce the steeping time. Roushdi et al (1979) found that scratching presteeped corn grains facilitates penetration of the steeping water, reducing the steeping period by 40%. Wall and Paulis (1978) found that the treatment of corn with alkali disintegrates and disperses the matrix proteins, as well as facilitating the release of starch granules. Mistry and Eckhoff (1992) developed an alkali-debranning process where the pericarp was chemically removed and found that debranned kernels absorbed water more rapidly, reducing steeping time. More recently, Singh et al (1997) investigated the effect of sodium hydroxide, calcium hydroxide, and potassium hydroxide on corn debranning. According to those authors, the removal of the pericarp was due to total solubilization of the pericarp rather than loosening and removing by chemical action.

Steinke and Johnson (1991) proposed other modifications to the classical wet-milling procedure. They found that steeping for 24 hr in a solution of multiple enzymes (cellulase, hemicellulase, pectinase, bromelin, and β-glucanase) and SO₂ produced milling results equivalent to those obtained by steeping for 48 hr in a 0.20% SO₂ solution alone. The enhancement of fraction separations in wet-milling were mainly attributed to the action of the enzymes on the pericarp of the grain.

It is known that the ethyl esters of fatty acids increase the drying rate of some waxy fruits such as grapes and berries (Radler 1964, Ponting and McBean 1970). Suárez (1987) also found that dipping sweet and field corn in ethyl oleate increased the drying rate of the

grain. However, the action of the ethyl esters on the waxy cuticle is not well known. Some authors believe that the esters remove the waxy bloom of fruits such as grapes (Riva and Masi 1986), while others have found that no wax is removed and that the effect is reversible by washing (Grncarevic and Radler 1971).

Little information exists in the literature concerning the wet-milling characteristics of flint corn. As Neryng and Reilly (1984) have pointed out, the cultivar of the corn has a strong effect on yield, purity, and ease of milling. Flint corn, widely cultivated in Argentina, has hard kernels due to a large amount of corneous endosperm. While the conventional wet-milling of dent corn requires a steeping time of ≈30–40 hr, flint corn does not soften much even after 60 hr of steeping (May 1991), and the starch-gluten separation and starch filtration are more difficult (Mazzoni and Robutti 1990).

Based on the present considerations, the effect of certain chemical agents such as KOH, ethyl oleate, and lactic acid on wet-milling was investigated. Also, the effect of dehulling on the rate of water absorption was analyzed. Potassium hydroxide and ethyl oleate were used as chemical pretreatments before steeping, and the rate of water absorption during steeping and the yield of wet-milling fractions were evaluated. The present study was conducted with two local cultivars of flint and dent corns in order to evaluate the response of different cultivars to the proposed treatments.

MATERIALS AND METHODS

Materials

Pioneer hybrid 3379 (dent) and Cargill hybrid T-42 (flint) corn cultivars were used in this study. They were produced at the Estación Experimental Agropecuaria (INTA), Pergamino, Buenos Aires Province, Argentina. The grains were harvested with a 10.5% moisture content and 13.2 g of water/100 g of dry solid, for flint and dent corn, respectively. The moisture content of the grains was determined by AOAC method 14004 (1980).

Starch, protein, and oil content were documented. Starch was measured using the Twers method (Egan et al 1987). Protein (N × 6.25) was determined by the macro-Kjeldahl method with a Büchi 430 digester and Büchi 320 distiller (AOAC 1980). Oil was removed by Soxhlet extraction with hexane for 24 hr (Bertoni et al 1994).

The grains used for water absorption tests were previously screened to obtain grains of a uniform size, free of broken kernels and foreign material. Only the fractions retained between screens 8.5–9.0 mm were used. Equivalent spherical radius of whole kernels was determined by chlorohexene displacement; a total of 20 kernels were used in each measurement ($n = 3$). Maximum length, including the tipcap (a), thickness (b), and width (c) of 100 samples

¹ Departamento de Industrias, Facultad de Ciencias Exactas y Naturales, Ciudad Universitaria, (1428) Capital Federal, Argentina.

² Corresponding author. E-mail: suarez@di.fcen.uba.ar

were measured using a micrometer. The ethyl oleate used in this work was synthesized in the laboratory following the procedure of Hildipgh and Williams (1964).

Pretreatments

Dehulled corn kernels were used as a control for the pretreatment corn samples. Dehulling was done manually by rubbing off the pericarp with small knife. To avoid damage to the kernel and facilitate the dehulling, the kernels were soaked in distilled water at room temperature for 3 min.

Two kinds of pretreatments were performed. One consisted of dipping corn samples (≈ 20 g) in 200 mL of aqueous solution of KOH at different concentrations (0.2, 0.5, and 1.0%) for 5 min. During dipping, the temperature was held constant at 52°C and the sample was gently agitated. After this pretreatment, the corn kernels were rinsed with tap water to remove any excess alkali from the surface of the kernel and cooled at room temperature.

The other pretreatment consisted of spraying the grains with an aqueous emulsion of ethyl oleate 1% (v/v). After that, the grains were held at 40°C for 20 hr before steeping.

Water Absorption Procedure

Control (unpretreated) and pretreated corn samples (≈ 10 g) were soaked in 0.25% SO₂ aqueous solution prepared by dissolving the appropriate amount of sodium bisulfite in distilled water. The samples were placed in 100-mL vessels with screw caps. The grains were gently agitated to reduce film resistance in the steeped solution.

The soaking temperature was held at 52 ± 0.5°C by immersing the flasks in a stirred water bath. At regular time intervals, the flasks were removed from the bath to determine water uptake. The grains were quickly removed from the flasks and superficially dried by manually rolling the kernels on a large piece of filter paper until they lost the glistening appearance associated with the presence of a surface film of water. The grains were then weighed to determine the moisture uptake. Water absorption curves were determined by replicate.

Corn samples (10 g) were soaked for different time intervals in flasks with 0.25% SO₂ and variable concentrations of lactic acid (0.2, 0.5, and 1.0%, v/v) and water absorption were evaluated. The soaking temperature was maintained at 52°C. Two replicates were performed in all cases.

To determine the amount of water absorbed in each soaking experiment, a known amount of corn kernels were dried in a vacuum oven at 70°C, in presence of P₂O₅ as desiccant, to constant weight. Constant weight was attained when the weight of the kernels between successive measurements changed <0.5 mg over 24 hr. This method of moisture determination previously gave accurate results (Haros et al 1995)

Wet-Milling Procedure

A modification of the laboratory-scale wet-milling process developed by Neryng and Reilly (1984) was used for the untreated and pretreated samples. Corn samples (50 g), untreated and pretreated with 1.0% KOH, were batch-steeped in 250 mL of sufficient sodium bisulfite solution (SO₂ concentration of 0.25%) at pH 3.5–4.0. The samples were held at 52°C with gentle agitation. Steeping times of 24 and 48 hr were used. After that, the steepwater was decanted and the excess water was removed from the corn by blotting. Two replicates were run for each cultivar and treatment.

Steeped corn with 100 mL of added distilled water was ground with a blender for 5 min and screened, in turn, with 40, 200, and 270 U.S. standard sieves (0.420-, 0.074-, and 0.053-mm openings, respectively). The overs of the 40-mesh sieve, mainly fiber and germ, were washed with 300 mL of water. After that, the material was ground twice more with a mortar and pestle with extra water added (100 mL), screened, and then washed again with 300 mL of water each time. Overs of the 200- and 270-mesh sieves were washed

with distilled water 10 times with volumes of 200 mL each time to more completely separate starch from gluten. The starch slurry passing through 200- and 270-mesh sieves was centrifuged at 2,000 rpm for 20 min using a Rolco 350T centrifuge.

All fractions were predried for 24 hr at room temperature in a forced-air convection-drying oven. After that, the fractions were dried in a vacuum oven at 70°C in the presence of P₂O₅ to a constant weight. The yield of wet-milling fractions was determined as the percentage of initial corn dry solid material. The protein content of the recovered fraction of starch was determined by the macro-Kjeldahl method (AOAC 1980). Untreated and samples pretreated with alkali (KOH 1.0%) were steeped with 0.25% SO₂ to which was added 0.5% (v/v) lactic acid (steeped solution was pH 2.5–2.7). The steeping temperature, steeping times, and wet-milling procedure were the same as above.

Total Solids Leached

The mass of solids leached after steeping in an aqueous SO₂ solution was determined by the method of Steinke and Johnson (1991). A 10-mL sample of the steepwater (previously well agitated) was placed in a preweighed flask and air-dried in an oven at 65°C for 24 hr. After that, the sample was fully dried at the same temperature in a vacuum oven until at a constant weight in the presence of P₂O₅ desiccant. The amount of solids leached was calculated as g of solids/g of dry kernels. Three replicates were used for each wet-milling procedure. No significant differences in total solids were found between replicates.

Calculation of Water Diffusivity

To compare the rate of water absorption of untreated and pretreated samples of flint and dent corn, the diffusion of water into the kernel was estimated. For this purpose, the analytical solution of Fick's second law of diffusion in solids of arbitrary shape was used. According to Luikov (1968), the diffusion in a body of arbitrary shape can be reduced to the analytical solution corresponding to a sphere by defining adequate shape factors. Following this idea, Tolaba et al (1989) found that water migration in corn kernels can be described by means of the equation:

$$u^* = \frac{(u - u_s)}{(u_o - u_s)} = \frac{6}{\pi^2} \sum_{k=1}^{\infty} \frac{1}{k^2} \exp\left(-k^2 \pi^2 \Psi Fo\right) \quad (1)$$

where u , u_0 , and u_s = mean, initial, and saturation moisture concentrations (kg of water/kg of dry solid); $Fo = Dt/R_e^2$ = Fourier number (dimensionless); t = time (sec); R_e = equivalent radius (radius of a sphere having the same volume as the grain) (m); D = diffusion coefficient (m²/sec); and Ψ = shape factor (dimensionless). The equation used to calculate the shape factor (Tolaba et al 1989) was:

$$\Psi = \left[\frac{c(a+b)}{16 R_e^2} \left\{ \frac{a+b}{2c} + \frac{\arcsin \left[1 - \left(\frac{a+b}{2a} \right)^2 \right]}{\left[1 - \left(\frac{a+b}{2a} \right)^2 \right]} \right\} \right]^2 \quad (2)$$

where a , b , and c are the parameters. To estimate the diffusion constant, Equation 1 was programmed on a digital computer and the values of D were calculated by a nonlinear regression technique that varied the value of D until the difference between experimental and predicted moisture concentrations was at a minimum.

RESULTS AND DISCUSSION

For flint corn, the starch, protein, and oil contents were 71 ± 1, 9.2 ± 0.1, and 1.5 ± 0.1 g/100 g (db), respectively. For dent corn, the respective contents of starch, protein, and oil were 76 ± 2, 6.3

± 0.1, and 1.2 ± 0.1 g/100 g (db), respectively. Equivalent spherical radii of whole kernels for flint and dent corn was 3.8 ± 0.2 and 4.1 ± 0.1 mm, respectively.

The values of maximum length, thickness, and width for flint corn were (mean values ± standard deviation) $a = 10.1 \pm 0.4$ mm, $b = 8.4 \pm 0.3$ mm, and $c = 4.8 \pm 0.5$ mm; for dent corn $a = 12.1 \pm 0.5$ mm, $b = 8.6 \pm 0.1$ mm, and $c = 4.6 \pm 0.4$ mm. The Ψ values for flint and dent corn were 1.30 ± 0.06 and 1.39 ± 0.28 , respectively. The saturation moisture contents used for flint and dent corn were 62.3 and 71.7 g of water/100 g of dry solid, respectively, which corresponded to 48 hr of steeping.

The values of the diffusion coefficients for flint and dent hybrids resulting from the different pretreatments are summarized in Table I. Also included are the diffusion coefficients of untreated grains. The value of D for flint corn (untreated) is lower than that for dent corn (untreated). This is mainly attributed to the large proportion of corneous endosperm present in the flint cultivar, where the starch granules are strongly compacted compared with the loosely packed granules of the floury endosperm (Watson and Sanders 1961). Structural differences in the protein matrix in which starch is embedded may also account for these values (Robutti 1980).

The absence of the pericarp increased the diffusion coefficient for both flint and dent corn kernels. For both hybrids, the increase was ≈23% (Table I). This result corroborates the fact that corn pericarp provides a diffusion barrier to water molecules (Cox et al 1944, Fan et al 1965).

The pretreatment with alkali had a beneficial effect on the rate of water absorption by both hybrids, particularly for the highest concentration of alkali investigated. This can be attributed to the loosening action of the KOH on the pericarp, which reduces the resistance to water entering the kernel. In fact, alkaline pretreatments to remove the pericarp from the corn have been proposed by Mistry and Eckhoff (1992). More recently, Singh et al (1997) found that during soaking of corn kernels in KOH solution, there is a dramatic increase of soluble dry matter loss that was attributed to the fact that the alkali removes pericarp from the corn. The alkaline pretreatment with 1.0% KOH solution resulted in much higher diffusion coefficients than samples with hand-peeled pericarp kernels (for both hybrids the increase of D was as much as 20%).

Ethyl oleate treatment produced no significant differences among the hybrids in water absorption rate; both hybrids had higher diffusion coefficients than the control (Table I). The pretreatment with ethyl oleate was more efficient for flint than for dent corn. In fact, an increase in the value of D of ≈40% was obtained compared with the control.

Effect of Lactic Acid on Water Absorption

The diffusion coefficients for dent and flint corn steeped with 0.2% (v/v) lactic acid and SO₂ were similar to those obtained from corn samples steeped in SO₂ alone (Table II). The beneficial effect of lactic acid becomes significant at concentrations of 0.5% (v/v) for both hybrids. The value D increases ≈14% for dent corn and 5.5% for flint corn. However, this effect does not seem to increase when the concentration of lactic acid is doubled. The combined

effect of alkaline pretreatment followed by lactic acid steeping increases the diffusion coefficient by ≈40% for both dent and flint corns.

Wet-Milling Yield

The yield of the wet-milling fractions from control and pretreated flint and dent corn are reported in Tables III and IV. Starch yields for dent corn (untreated samples) were slightly higher than those reported in the literature for laboratory conditions (Neryng and Reilly 1984) and are comparable with industrial practices. Mazzoni and Robutti (1990) reported starch yields from flint corn of <60% (db) using a laboratory-scale process and corn samples that were treated with only SO₂ for 48 hr. The present study found a slight increase in starch yield for the flint corn control with an increase steeping time (Table III). In contrast, starch protein content was too high (5–7%) and differed from typical values found in industry (Anderson and Watson 1982). This discrepancy was attributed to the washing process, where the sieve had an abrasive effect on the soft gluten, reducing the particle size and allowing it to pass through the sieve. The separation procedure used in this study was reproducible according to the relatively low standard deviations reported in Tables III and IV. Therefore, we believe that the wet-milling procedure used here served well as a basis for comparing different pretreatments.

The alkaline pretreatment reduced the starch yield for both hybrids, more so in flint than in dent corn. In both cases, the increase in steeping time had a beneficial effect on starch yields. The lower starch yield and the increase of fiber, germ, and gluten fractions compared with control samples, particularly in the case of flint corn, may be due to protein denaturation caused by alkaline pretreatments, which could cause an incomplete release of starch granules from the matrix. Starch granules may have been retained with the fiber and gluten fractions, reducing the starch yield, and resulting in lower solids losses during steeping.

On the other hand, the alkaline pretreatment may cause a localized increase in pH on the surface of the kernels. The pH measurements on the untreated and alkaline-dipped milled flint corn filtrates were 6.3 and 6.9, respectively. The pH increase in the dent corn was 6.0–6.8. Sulfurous acid in its nonionized form can effectively penetrate the kernel, while the ionized forms are likely to be hindered by the charged surfaces of cellular membranes and cell walls (Lindsay 1985). The high increase in pH level of the kernel surface may impede the action of the nonionized form and reduce the flux of SO₂ within the kernel. Such a reduction may be the principal cause of the poor separation reported in Tables III and IV for corn samples pretreated with the KOH solution.

The yields of flint corn steeped in lactic acid 0.5% (v/v) were similar for both 24 and 48 hr. The starch yields were significantly superior to those obtained from corn steeped only in SO₂. This effect became more marked with those corn samples pretreated for 5 min with KOH 1.0% solution (Table III). Gluten yields were lower for flint samples steeped in the presence of lactic acid compared with those steeped in SO₂ alone (untreated sample). Although the role of lactic acid is not well understood, some authors attribute its

TABLE I

Diffusion Coefficients of Pretreated Corn Hybrids Steeped in 0.25% SO₂^a

Pretreatment	$D \times 10^{11}$ (m ² /sec)	
	Dent	Flint
None	4.86 ± 0.09	4.17 ± 0.09
Hand-peeled pericarp	6.01 ± 0.11	5.13 ± 0.08
KOH		
0.2%	5.45 ± 0.19	4.59 ± 0.21
0.5%	5.75 ± 0.11	4.70 ± 0.06
1.0%	7.19 ± 0.05	6.13 ± 0.10
Ethyl oleate emulsion(1%, v/v)	5.85 ± 0.07	5.78 ± 0.12

^a Mean values ± standard deviation ($n = 22$). Significant at $P < 0.05$.

TABLE II

Diffusion Coefficients of Corn Hybrids Steeped in 0.25% SO₂ and Various Concentrations of Lactic Acid^a

Lactic Acid Concentration (v/v)	$D \times 10^{11}$ (m ² /sec)	
	Dent	Flint
None	4.86 ± 0.09	4.17 ± 0.09
0.2%	4.88 ± 0.10	3.99 ± 0.08
0.5%	5.68 ± 0.12	4.39 ± 0.07
1.0%	5.54 ± 0.11	4.40 ± 0.05
Pretreated ^b	6.89 ± 0.08	5.84 ± 0.07

^a Mean values ± standard deviation ($n = 22$). Significant at $P < 0.05$.

^b Pretreated with KOH (1%) and steeped with lactic acid (0.5%, v/v).

action to weakening the endosperm cell walls (Earp et al 1985, Ruan et al 1992). It is probable that weakening the cell walls facilitates the reduction of the protein matrix by SO₂, improving the starch-protein separation. It is curious that in the presence of lactic acid, the 24 and 48 hr treatments produced similar yields for flint and dent corn. However, the beneficial effect of lactic acid seems to be more important for flint than for dent corn. Flint corn steeped for 24 hr in lactic acid had a starch yield that was 10.4% higher than those obtained with untreated samples, while for dent corn the increase was only 7.3% (Table III). Starch yields for both pretreated flint and dent corn increased when samples were steeped in the presence of lactic acid. The lactic acid decreased the pH of steepwater, which increased the levels of the nonionized form of SO₂ and neutralized the remaining alkali in the kernel, allowing more SO₂ to be absorbed.

CONCLUSIONS

The rate of water absorption in aqueous SO₂ solution, measured in terms of the diffusion coefficients, was much higher for dent than for flint corn because of the high proportion of corneous endosperm in the flint cultivar.

Dehulling the kernels increased the water absorption during steeping for both hybrids. Alkaline pretreatments with aqueous solutions of KOH (alkali concentrations of 0.2, 0.5, and 1.0%) also increased the water uptake, particularly for the highest alkali concentration used, which may be attributed to the action of the alkali on the corn pericarp. However, this pretreatment reduced the starch yields for both hybrids. The increase in water uptake

during steeping does not correlate with a reduction in the steeping time. Soaking corn kernels in ethyl oleate emulsion increased the rate of absorption; water diffusion coefficients were similar to those obtained with 0.5% KOH solution in both hybrids. The use of ethyl esters instead of alkaline solutions to increase the water uptake may be more convenient, given the less severe action of these chemicals on the kernels.

The incorporation of lactic acid into the steeping solution slightly affected the rate of water absorption of dent and flint corn, particularly for the highest concentration used. However, the rate of absorption of both hybrids was higher when the kernels were soaked in KOH solution before steeping.

Lactic acid facilitated the separation of starch and the protein matrix, and increased the starch yields of both hybrids. Lactic acid reduced the effective steeping time of both hybrids from 48 to 24 hr. Starch yields were much higher when corn kernels were pretreated with KOH solution and steeped in presence of lactic acid. Thus, the presence of lactic acid in the steepwater reduced the surface alkalinity of the pretreated kernels, facilitating the entrance of the nonionized form of SO₂. This effect, together with the increase of pericarp permeability caused by the KOH pretreatment, would be the main contributors to the increase in starch yields of both hybrids.

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TABLE III
Wet Milling Yields (%) from Flint Corn Steeped in 0.25% SO₂ for Different Times and Treatments^{a,b}

Treatment	Steeping Time (hr)	Fiber and Germ (%)	Gluten (%)	Water Solids ^c (%)	Starch Yield (%)	PPS ^d
None	24	8.3 ± 0.4	11.0 ± 0.2	5.0 ± 0.1	67.6 ± 0.3	6.3 ± 0.1
	48	9.2 ± 0.4	8.5 ± 0.2	6.0 ± 0.1	68.9 ± 0.4	5.8 ± 0.1
Pretreated (KOH 1%, 52°C, 5 min)	24	13.1 ± 0.5	13.8 ± 0.3	3.3 ± 0.1	59.2 ± 0.5	7.0 ± 0.1
	48	11.2 ± 0.4	12.1 ± 0.2	4.3 ± 0.1	62.8 ± 0.5	6.2 ± 0.1
Lactic acid in steepwater (0.5%, v/v)	24	8.8 ± 0.3	5.1 ± 0.2	4.0 ± 0.1	74.9 ± 0.5	7.0 ± 0.1
	48	8.8 ± 0.3	5.1 ± 0.2	5.1 ± 0.1	74.4 ± 0.4	6.8 ± 0.1
Pretreated (KOH and lactic acid in steepwater)	24	8.1 ± 0.4	5.3 ± 0.2	7.9 ± 0.1	76.0 ± 0.3	5.9 ± 0.1
	48	8.7 ± 0.4	4.2 ± 0.3	8.0 ± 0.1	76.1 ± 0.4	6.0 ± 0.1

^a Mean values ± standard deviation (*n* = 2).

^b All yields are expressed on a % dry solid basis.

^c Solid content in steepwater after steeping.

^d Percentage of protein in starch.

TABLE IV
Wet Milling Yields (%) from Dent Corn Steeped in 0.25% SO₂ for Different Times and Treatments^{a,b}

Treatment	Steeping Time (hr)	Fiber and Germ (%)	Gluten (%)	Water Solids ^c (%)	Starch Yield (%)	PPS ^d
None	24	8.3 ± 0.3	5.0 ± 0.2	6.0 ± 0.1	74.5 ± 0.4	4.8 ± 0.1
	48	8.3 ± 0.3	5.0 ± 0.1	6.3 ± 0.1	74.0 ± 0.5	5.5 ± 0.1
Pretreated (KOH 1%, 52°C, 5 min)	24	9.4 ± 0.4	8.4 ± 0.2	3.6 ± 0.1	71.6 ± 0.4	5.7 ± 0.1
	48	9.2 ± 0.3	7.4 ± 0.2	4.7 ± 0.1	72.3 ± 0.4	5.3 ± 0.1
Lactic acid in steepwater (0.5%, v/v)	24	10.5 ± 0.4	4.9 ± 0.2	4.0 ± 0.1	77.1 ± 0.5	5.4 ± 0.1
	48	9.8 ± 0.4	4.6 ± 0.2	5.3 ± 0.1	77.6 ± 0.4	5.2 ± 0.1
Pretreated (KOH and lactic acid in steepwater)	24	8.3 ± 0.4	4.4 ± 0.2	8.3 ± 0.1	79.5 ± 0.5	5.6 ± 0.1
	48	9.0 ± 0.4	4.2 ± 0.2	8.4 ± 0.1	79.3 ± 0.5	5.3 ± 0.1

^a Mean values ± standard deviation (*n* = 2).

^b All yields are expressed on a % dry solid basis.

^c Solid content in steepwater after steeping.

^d Percentage of protein in starch.

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