

# Filtration Characteristics of Maize and Wheat Starch Hydrolysates

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## ABSTRACT

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Starch hydrolysates were prepared by one- or two-stage hydrolysis with  $\alpha$ -amylase. The filtration rate of wheat starch hydrolysates was considerably lower than that of maize starch hydrolysates. Omitting the second conversion step lowered the filtration rates of wheat and maize starch hydrolysates. Increasing the incubation time or the enzyme dosage resulted in an increase of the filtration rate of maize starch hydrolysates due to the increase in the dextrose equivalent. These process variables did not influence the filtration rate of wheat starch hydrolysates. Wheat starch hydrolysates had very poor filtration characteristics: low filtration

rates, almost no removal of undesired components, and obstruction of the filter cake. On the contrary, maize starch hydrolysates showed good filtration characteristics: a high filtration rate and removal of the largest part of the undesired components. On storage, wheat starch hydrolysates separated into three layers. The intermediate fraction had a higher filtration rate than the total hydrolysate. Adding small amounts of the upper or lower layers to dextrose solutions decreased the filtration rate to that of a wheat starch hydrolysate. This was due to an increase of the protein and lipid concentration.

Hydrolysis products are the largest end use of starch. With acid or enzymatic processes, starch is converted into various products. Currently, enzymatic conversion of starch is the dominant process for the production of glucose. There are many processes but they all include a heating and a conversion step. Some of them include a second conversion step at higher temperature followed by a second dosage of the enzyme and a second incubation. After the conversion the hydrolysate is filtered, for example through a rotary vacuum precoat filter, to remove the insoluble impurities. Activated carbon and ion-exchange resins are used for further refining of the hydrolysates (Schenck and Hebeda 1992).

Starches from various botanical sources are used as raw materials for the preparation of hydrolysis products. Maize starch is the main source of starch for conversion. However the use of wheat starch (a coproduct of vital gluten production) has increased significantly in Europe. Wheat starch hydrolysates can have a much lower filtration rate than that of corn starch hydrolysates (Bowler and Towersey 1985, Derez 1987, Ducroo 1987, Konieczny-Janda and Richter 1991). There are many theories about the factors that influence the filtration rate of maize and wheat starch hydrolysates. After the enzymatic conversion, maize starch hydrolysates contain insoluble particles of 0.2–1.0  $\mu\text{m}$ . These particles consist of nongelatinized starch (Brumm et al 1989) or amylose-lipid complexes (Hebeda and Leach 1974) that can alter the filtration characteristics. These components can also influence the filtration rate of wheat starch hydrolysates (Bowler and Towersey 1985). Konieczny-Janda and Richter (1991) suggested that the lysophospholipids in wheat starch have a negative influence on the filtration rate by forming complexes with amylose or proteins in the hydrolysate. Wheat starch also contains pentosans, which are polymers of xylose with branches of arabinose. These arabinoxylans have a high water-absorbing capacity and can increase the viscosity. In this manner, they can influence the filtration rate of wheat starch hydrolysates (Bowler and Towersey 1985, Derez 1987, Ducroo 1987, Konieczny-Janda and Richter 1991).

Nongelatinized starch, pentosans, amylose-lipid complexes, and complexes between lysophospholipids and amylose or proteins, are supposed to have a negative effect on the filtration rate of wheat starch hydrolysates. It is still unknown which of these components has the largest effect on the filtration characteristics.

In the starch industry, combinations of enzymes are used to improve the filtration rate of wheat starch hydrolysates. Most enzyme products include pentosanases, cellulases, and phospholipases (Schenck and Hebeda 1992). Even when using these enzyme products, large variations in filtration characteristics occur between different batches of wheat starch hydrolysates. These variations are difficult to explain because of the lack of knowledge of the exact causes of the poor filtration characteristics of wheat starch hydrolysates. Therefore, we started a research project to investigate the major causes of the poor filtration characteristics of wheat starch hydrolysates. In this article, we describe the influence of several processing conditions on the filtration rate and the composition of hydrolysates and filtrates of maize and wheat starch. By a fractionation of these hydrolysates, we studied the effect of (groups of) components on the filtration rate. A future article will describe a model-based approach on the influence of the different components on the filtration characteristics.

## MATERIALS AND METHODS

### Materials

Maize starch was a gift from Cargill (Bergen op Zoom, The Netherlands) and wheat starch was obtained from Cerestar (Sas van Gent, The Netherlands). Termamyl 120L (Novo Nordisk, Denmark) was used as the source of  $\alpha$ -amylase.

### Preparation of the Hydrolysates

Liquefaction was performed in a laboratory-scale jet-cooker. Unless otherwise indicated, the following standard procedure was used. A 30% suspension of starch in water to which 300  $\mu\text{L}$  of enzyme/kg of suspension and 400 mg of  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ /kg of suspension was added, was heated in the jet-cooker at 105°C and subsequently incubated in a water bath at 95°C for 130 min (one-stage conversion) or 40 min (two-stage conversion). In two-stage conversion, a second heat treatment at 140°C in the jet-cooker was applied. The flow rate in the jet-cooker was 20 g/sec which corresponded with a residence time in the jet-cooker of 9.2 sec in the first heating step and 11.5 sec in the second step. It was assumed that the enzyme was inactivated at this high temperature. Therefore, a second enzyme dosage (300  $\mu\text{L}$ /kg of suspension) was added after the jet-cooker treatment, followed by a second incubation for 100 min in the water bath (two-stage conversion). Subsequently, the pH of the hydrolysate was adjusted to a value of 4–4.5 with 1N HCl.

### Filtration

The filtration rate was measured with a laboratory-scale vacuum filter with a filter aid (Dicalite, Grefco). This filter consists of a grid plate with a filtrate outlet, a vacuum gauge, and a cake-retain-

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ing ring. A filter septum is placed in the cake-retaining ring and a filter cake is made with a suspension from the filter aid in water and a vacuum pump. This filter cake has an area of  $92.8 \times 10^{-4} \text{ m}^2$ . The height of the cake-retaining ring can be adjusted by a screw thread that allows the removal of the top layer of the filter cake. The hydrolysate was filtered through the filter with a vacuum pump. Large-scale filtration was imitated by a filtration cycle that consisted of: 1) 40 sec of immersion of the filter in the hydrolysate under vacuum; 2) 40 sec of vacuum suction of the filter while the filter was not in the hydrolysate; 3) 40 sec during which 50  $\mu\text{m}$  of the top layer of the filter was cut off under vacuum to remove the insoluble particles and to expose a fresh surface.

The temperature of the hydrolysates during the filtration was  $60^\circ\text{C}$ , the vacuum achieved ranged from  $-0.44 \text{ bar}$  (water) to  $-0.94 \text{ bar}$  (wheat starch hydrolysate).

The filtration rate was calculated from the weight of the filtrate after five filtration cycles (two replicates). The removed top layers of the cake were combined for analysis. The porosity of the filter was determined by filtering water through the filter and by using the Blake-Kozeny equation (Bird et al 1960):  $v_0 = \Delta P/L \times D_p^2/150\eta \times \epsilon^3/(1 - \epsilon)^2$ , where  $v_0$  is the superficial velocity or volumetric flow rate/area of the filter ( $\text{m sec}^{-1}$ );  $L$  is the length of the filter (m);  $D_p$  is the particle diameter (m);  $\epsilon$  is the porosity;  $\Delta P$  is the pressure difference (Pa);  $\eta$  is the viscosity of the fluid (Pa sec).

### Analytical Methods

Dextrose equivalent (DE) was determined in the hydrolysates from the ratio of the total carbohydrate and the number of reducing end groups. Total carbohydrate content was measured by the anthrone method (Morse 1947). The Nelson-Somogyi method was used for the determination of the number of reducing end groups (Nelson 1944). The hydrolysates and the filtrates were freeze-dried. The protein and lipid contents of these powders were analyzed. Protein content ( $\text{N} \times 5.7$ ) was measured by means of the Kjeldahl method for nitrogen. Total lipid content was determined by the method of Anness (1983) in which the sample is hydrolyzed, the lipids are transesterified, and the amount of fatty acid methyl esters (FAME) are determined by capillary gas chromatography. Lipid content is expressed as total fatty acid content. Insoluble carbohydrate was measured with the anthrone method (Morse 1947) after washing the dry powders with water. The viscosity of the hydrolysate was determined with an Ubbelohde capillary viscometer (approximate flow time with hydrolysates is 100 sec). Ash content of cake fractions was calculated from the difference in weight after heating at  $900^\circ\text{C}$ .

### Influence of Processing Conditions

A filtration rate of  $211 \text{ g sec}^{-1} \text{ m}^{-2}$  was measured for a maize starch hydrolysate prepared according to the standard conditions described above. On the other hand, we measured a filtration rate of only  $37.8 \text{ g sec}^{-1} \text{ m}^{-2}$  for a wheat starch hydrolysate made under the same conditions. The DE of both hydrolysates was 23. When using only  $\alpha$ -amylase for the production of starch hydrolysates, wheat starch gave a much lower filtration rate than maize starch.

The influence of the processing conditions on the filtration rate was investigated for the enzyme dosage, the length of the incubation time, a two-stage jet-cooker treatment instead of a single conversion at  $105^\circ\text{C}$ , and the pH of the hydrolysate (Table I). For maize starch, increasing the incubation time or the enzyme dosage resulted in a large increase of the filtration rate. However, these process variables did not affect the filtration rate of wheat starch hydrolysates. Both for maize and for wheat starch hydrolysates, the filtration rate decreased considerably when the second conversion was omitted. The pH of the hydrolysates was varied between 2.5 and 5.5. These variations in pH did not affect the filtration rate of maize and wheat starch hydrolysates.

Changes in the DE could be the explanation of the influence of the process variables on the filtration rate. The DE will increase with increasing incubation time and enzyme dosage due to the progressive hydrolysis of the starch. The DE is related to the viscosity of the hydrolysates and therefore with the filtration rate. Other factors that can influence the viscosity are the solids concentration, temperature, and carbohydrate profile. Figure 1 shows the filtration rate as a function of the DE for maize starch hydrolysates. At the same DE, the filtration rate is lower for hydrolysates prepared by a one-stage conversion than for those that were made by a two-stage conversion at 105 and  $140^\circ\text{C}$  as soon as the DE exceeds 20. There is a positive correlation between the DE and the filtration rate for the hydrolysates made by a two-stage conversion, while this correlation was absent for the hydrolysates where the second conversion was omitted. For wheat starch, Fig. 2 shows that the rate of hydrolysates made by a one-stage conversion is lower than that of hydrolysates made by a two-stage conversion. Contrary to the maize starch hydrolysates, the wheat starch hydrolysates made by a two-stage conversion showed no correlation between the DE and the filtration rate.

From the above results, it can be concluded that introducing a second conversion at  $140^\circ\text{C}$  strongly improves the filtration rate of maize and wheat starch hydrolysates. This could not be explained by

TABLE I  
Filtration Rates of Maize and Wheat Starch Hydrolysates Prepared with Different Incubation Times, Enzyme Dosages, or pH Values<sup>a</sup>

Starch	Parameter	One-Stage Conversion			Two-Stage Conversion				
		1	2	3	4	5	6	7	8
Maize	T1	130	160	190	40	40	40	40	40
	T2	...	...	...	0	40	70	100	130
	S	129	163	150	134	252	168	211	243
	E	...	600	...	200	400	500	600	700
	S	...	111	...	196	274	364	232	353
	pH	...	...	...	2.7	3.5	4.1	4.5	5.2
	S	...	...	...	181	183	168	154	195
	Wheat	T1	130	...	...	40	40	40	40
T2	...	...	...	0	40	70	100	130	
S	14.1	...	...	29.7	28.9	30.6	37.8	34.2	
E	500	...	700	200	...	500	...	700	
S	21.6	...	27.9	34.2	...	35.4	...	41.3	
pH	...	...	...	2.6	...	4.0	...	5.5	
S	...	...	...	31.7	...	26.7	...	30.7	

<sup>a</sup> T1, T2 = incubation time for first and second heating step (min); E = enzyme dosage ( $\mu\text{L/kg}$ ); S = filtration rate ( $\text{g sec}^{-1} \text{ m}^{-2}$ ). Standard conditions: E = 300  $\mu\text{L/kg}$  (twice this amount for two-stage conversions), filtration pH = 4.0–4.5, T1 = 130 min (one-stage) or 40 min (two-stage conversion), T2 = 100 min. Standard conditions were used unless indicated otherwise.

an increase in DE due to the second conversion. Figures 1 and 2 show that hydrolysates with the same DE made by one-stage conversion had a lower filtration rate than hydrolysates made by two-stage conversion. We suppose that besides the DE and therefore the viscosity, a small amount of retrograded starch can lower the filtration rate due to obstruction of the filter. For maize as well as for wheat starch hydrolysates, filter residues from one-stage conversions contained much more insoluble carbohydrate than when a two-stage conversion was used, whereas the protein and lipid content of the filter residues were affected in a much less systematic way (Table II). This suggests that the second conversion at 140°C causes a solubilization of these retrogradation products that are hydrolyzed during the subsequent incubation with  $\alpha$ -amylase.

We determined the protein and lipid contents of maize and wheat starch hydrolysates prepared under different processing conditions, and we investigated the correlation between the amounts of these components and the filtration rate. There was a clear distinction between the hydrolysates made by one-stage conversion and those made by two-stage conversions. Within each group, there was no correlation between the protein and lipid content and the filtration rate (data not shown).

Therefore, we conclude that the positive effect of various processing conditions on the filtration rate is not related to the protein and lipid content but rather to the removal of insoluble carbohydrate.

### Filtration Efficiency

Differences in the processing conditions could not explain the large distinction between the filtration rates of maize and wheat starch hydrolysates. Therefore, we investigated the filtration process in more detail. Table III shows the filtration rate of the hydrolysates and the resulting filtrates. These filtrates were again filtered through a freshly prepared filter cake. The filtration rates of the filtrates were only slightly higher than those of the original hydrolysates. Hence, filtration does not remove the components that cause the lower filtration rate of wheat starch hydrolysates. Table III also shows the composition of the hydrolysates and the filtrates. The protein and lipid contents of the maize starch filtrate were obviously lower than those of the original hydrolysate. Therefore, it can be concluded that the filtration of maize starch hydrolysates showed good characteristics with the removal of the major part of the noncarbohydrate components in a relatively short time (due to the high filtration rate). For wheat starch there was only a minor difference between the protein and the lipid contents of the hydrolysate and the filtrate. Not only was the filtration rate very low for wheat starch hydrolysates, but the efficiency of the filtration was also insufficient to remove the undesirable components.

Table IV shows some properties of the filter and the hydrolysates. The viscosity of a maize starch hydrolysate was 81% of

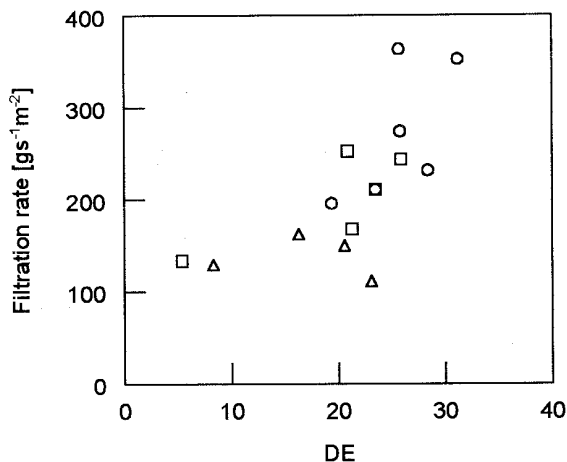


Fig. 1. Filtration rate as a function of the dextrose equivalent (DE) of maize starch hydrolysates made with different enzyme dosages (○), different incubation times (□), and a single conversion (△).

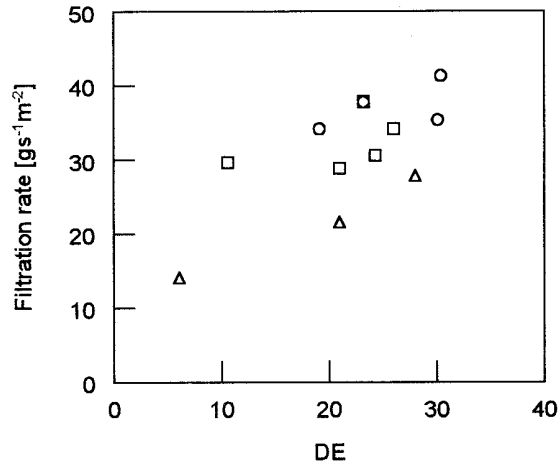


Fig. 2. Filtration rate as a function of the dextrose equivalent (DE) of wheat starch hydrolysates made with different enzyme dosages (○), different incubation times (□), and a single conversion (△).

TABLE II  
Raw Syrup Dextrose Equivalent (DE) and Composition of Filter Residues (Corrected for Ash) from One-Stage and Two-Stage Conversions of Maize and Wheat Starch<sup>a</sup>

Starch	Parameter	One-Stage Conversion				Two-Stage Conversion				
		1	2	3	4	5	6	7	8	9
Maize	T1	130	160	190	130	40	40	40	...	...
	T2	...	...	...	...	100	130	100	...	...
	E	300	300	300	300	300	300	600	...	...
	DE	8.3	16.3	20.6	23.1	23.5	25.9	28.4	...	...
	Protein (%)	20.6	42.1	18.9	6.2	20.5	19.7	23.9	...	...
	Lipid (%)	18.4	37.4	18.7	12.9	20.6	21.6	25.2	...	...
	IS	7.6	14.1	11.0	9.4	5.4	3.6	1.9	...	...
Wheat	T1	130	130	130	...	40	40	40	40	40
	T2	...	...	...	...	40	70	100	100	100
	E	300	500	700	...	300	300	300	500	700
	DE	6.1	21.0	28.0	...	21.0	24.3	23.2	30.1	30.4
	Protein (%)	0.94	0.58	0.58	...	1.0	0.41	0.66	0.58	0.33
	Lipid (%)	1.2	0.50	0.37	...	1.7	0.47	0.57	0.72	0.41
	IS	6.5	1.4	0.56	...	0.59	0.47	0.39	0.32	0.36

<sup>a</sup> T1, T2 = incubation time for first and second heating step (min); E = enzyme dosage ( $\mu$ L/kg); DE = dextrose equivalent; IS = insoluble carbohydrate (%). Standard conditions: E = 300  $\mu$ L/kg (twice this amount for two-stage conversions), filtration pH = 4.0–4.5, T1 = 130 min (one-stage) or 40 min (two-stage conversion), T2 = 100 min.

**TABLE III**  
Filtration Rates ( $\text{g sec}^{-1} \text{m}^{-2}$ ) and Lipid and Protein Concentrations (% of dry matter) of Maize and Wheat Starch Hydrolysates and Filtrates<sup>a</sup>

	Maize		Wheat	
	Hydrolysate	Filtrate	Hydrolysate	Filtrate
Filtration rate	207	241	37.8	44.8
DE	23.5	23.3	23.2	23.5
Lipid	0.19	0.01	0.32	0.21
Protein	0.26	0.06	0.22	0.18

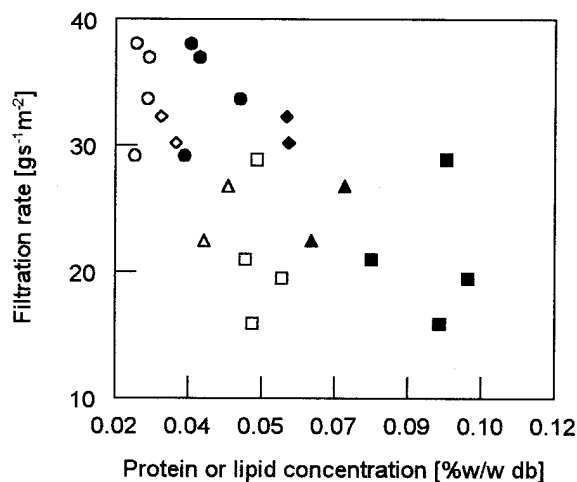
<sup>a</sup> Hydrolysates prepared according to standard conditions. DE = dextrose equivalent.

**TABLE IV**  
Filtration Rate ( $\text{g sec}^{-1} \text{m}^{-2}$ ) and Parameters<sup>a</sup> of Maize and Wheat Starch Hydrolysates<sup>b</sup>

	Rate	$\eta$	$\Delta P$	$\epsilon$
Maize	211	2.6	79	0.32
Wheat	37.8	3.2	80	0.13

<sup>a</sup>  $\eta$  = Viscosity of the hydrolysates (m Pa sec);  $\Delta P$  = pressure difference over the filter ( $10^3$  Pa);  $\epsilon$  = filter porosity.

<sup>b</sup> Hydrolysates prepared according to standard conditions.

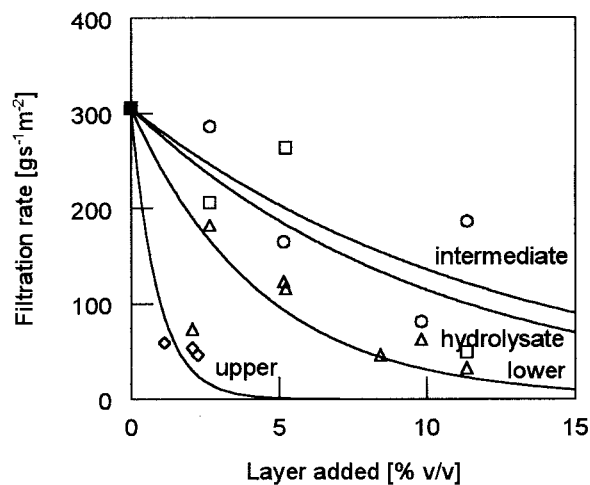


**Fig. 3.** Filtration rate as a function of the protein (open symbols) or lipid concentration (filled symbols) of wheat starch hydrolysates ( $\square, \blacksquare$ ), intermediate layers ( $\circ, \bullet$ ), and combinations of intermediate and lower layers ( $\triangle, \blacktriangle$ ), or upper and intermediate layers ( $\diamond, \blacklozenge$ ).

that of a wheat starch hydrolysate. This difference is too small to explain the lower filtration rate of wheat starch hydrolysates. The filter porosity was determined with water after filtration of the hydrolysates. The porosity of a freshly prepared filter (0.32) was equal to the porosity of a filter used for the filtration of a maize starch hydrolysate. Therefore, the size of the pores in the filter remains unaffected by the filtration of maize starch hydrolysates. However, the filtration of wheat starch hydrolysates decreased the porosity by a factor of 2.5. This suggests that the pore structure of the filter was disturbed by the filtration of wheat starch hydrolysates.

After the filtration of maize or wheat starch hydrolysates, the filters were separated in three fractions: 1) residue, which is the top layer of the filter removed during the filtration experiments; 2) upper 0.5 cm; and 3) lower 2.5 cm of the filter.

Table V shows the protein, lipid, and insoluble carbohydrate contents of these fractions. For maize starch hydrolysates, there was a clear decrease of these contents going from the top fraction (the residue) to the lower fractions. These results agreed with the good filtration performance for maize starch hydrolysates. During the filtration, the undesired components were collected in the residue. Therefore, the bulk of the filter cake remained free from im-



**Fig. 4.** Filtration rate of 25% dextrose solution as a function of added volume percentage of wheat starch hydrolysate ( $\square$ ), intermediate layer ( $\circ$ ), upper layer ( $\diamond$ ), or lower layer ( $\triangle$ ). Lines are inserted for clarity.

purities and the porosity of the filter was unaffected. Wheat starch hydrolysates, on the other hand, showed opposite filtration characteristics. Although the concentrations of protein and lipid in the filter were significantly higher than in the hydrolysate or the filtrate (Table III), the concentrations of these components were almost equal in the different parts of the filter. This suggests that significant removal of these components from wheat starch hydrolysates by filtration is not possible. This is in agreement with the fact that protein and lipid concentration of the original hydrolysate and the filtrate were almost equal (Table III). Wheat starch hydrolysates have very poor filtration characteristics with low filtration rates, almost no removal of undesired components, and obstruction of the filter cake. Our results strongly suggest that the components responsible for the poor filtration characteristics are water soluble.

#### Reconstitution Experiments with Wheat Starch Hydrolysate Fractions

The above results showed that the poor filtration characteristics of wheat starch hydrolysates were not caused by differences in process variables. Wheat starch probably contains components that cause the poor filtration characteristics. We investigated the effect of groups of components on the filtration rate by separating wheat starch hydrolysates into two or three fractions. After 16 hr of standing, three layers were visible in the hydrolysate: 1) a dark brown upper layer, 2) a large clear intermediate layer, and 3) a white-yellow lower layer. The formation of the upper layer was dependent on the DE, temperature, and concentration. A fractionation into three layers was promoted by a relatively low DE and standing at room temperature. We measured the filtration rate of different combinations of layers as such. The results are shown in Table VI. The filtration rate of the intermediate layer was higher than that of the hydrolysate. Removing the upper or the lower layer improved the filtration rate. Removing the lower layer had a larger effect than removing the upper one. However, the volume of the upper layer was generally much smaller. Removing both layers resulted in the highest filtration rate.

One explanation of these results could be the different composition of the layers. Figure 3 shows the filtration rate of the combinations of layers as a function of the protein and lipid concentrations. Removal of the upper or lower layer resulted in a decrease in protein and lipid concentration, which explains the negative correlation of the filtration rate with protein and lipid contents. Separating the effects of protein and lipid on the filtration rate is not possible due to the nearly constant ratio in which these com-

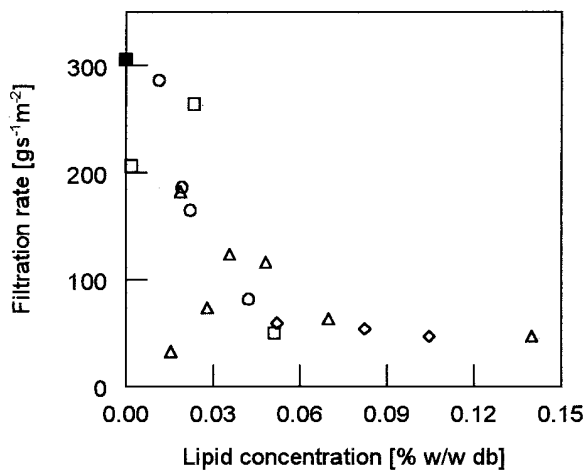


Fig. 5. Filtration rate as a function of the lipid concentration of 25% dextrose solution with added wheat starch hydrolysate (□), intermediate layer (○), upper layer (◇), or lower layer (△).

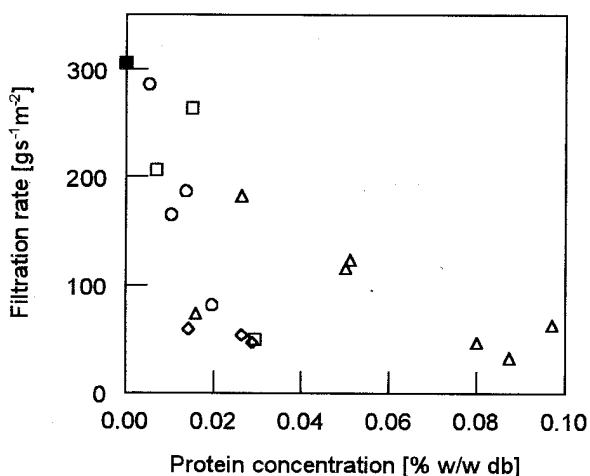


Fig. 6. Filtration rate as a function of the protein concentration of 25% dextrose solutions with added wheat starch hydrolysate (□), intermediate layer (○), upper layer (◇), or lower layer (△).

ponents are present in the recombined layers ( $r = 0.97$ ). It is worth noting that the filtration rate of the intermediate layers is still far below that of a maize starch hydrolysate, although the amounts of lipid and protein in the latter are three times higher.

We added different amounts of the separate layers to a 25% dextrose solution, which we considered as a model for a starch hydrolysate with ideal filtration properties. Figure 4 shows the filtration rate as a function of the additional level. Addition of the layers caused a marked decrease in the filtration rate. The upper layer had the largest effect. The highest added level of upper or lower layer corresponded to the amount of that layer in the original hydrolysate. The filtration rates at these levels were of the same order as that of the hydrolysate. This suggests that these layers contain the components that cause the low filtration rate of wheat starch hydrolysates. However, addition of the intermediate layer to a dextrose solution also caused a remarkable reduction of the filtration rate. This layer, therefore, also contained these components but in smaller amounts.

The filtration rate was plotted as a function of the lipid content (Fig. 5) and the protein content (Fig. 6). From Fig. 5 it can be concluded that there is a negative correlation between the filtration rate and the lipid content. At lipid concentrations  $>0.05\%$ , the filtration rate of the dextrose solution is comparable to that of a wheat starch hydrolysate. Below this concentration, the filtration rate is inversely related to the amount of lipid. The relationship

TABLE V  
Protein, Lipid, and Insoluble Carbohydrate (IS) Contents<sup>a</sup> of Fractions of Filters Used for the Filtration of Maize and Wheat Starch<sup>b</sup>

Starch	Fraction	Protein	Lipid	IS
Maize	Residue	17.15	nd <sup>c</sup>	17.52
	Upper 0.5 cm	3.41	nd	0.29
	Lower part	0.29	nd	0.17
Wheat	Residue	0.66	0.57	0.39
	Upper 0.5 cm	0.48	0.70	0.60
	Lower part	0.51	0.71	0.52

<sup>a</sup> % of dry matter, corrected for ash content.

<sup>b</sup> Hydrolysates prepared according to standard conditions.

<sup>c</sup> Not determined.

TABLE VI  
Filtration Rate ( $\text{g sec}^{-1}\text{m}^{-2}$ ) of Wheat Starch Hydrolysates and Different Combinations of Intermediate (i), Upper (u), and Lower (l) Layer Fractions<sup>a</sup>

Layers Formed <sup>b</sup>	Hydrolysate	i	i + l	u + i
u + i + l	21.0	29.2	nd <sup>c</sup>	nd
u + i + l	15.9	38.1	22.5	32.3
u + i + l	28.9	33.7	nd	nd
u + i + l	19.5	37.0	26.8	30.2
i + l	29.5	40.6	na <sup>d</sup>	na
i + l	31.2	31.0	na	na

<sup>a</sup> Hydrolysates prepared according to standard conditions.

<sup>b</sup> After 16 hr of rest.

<sup>c</sup> Not determined.

<sup>d</sup> Not applicable.

between the filtration rate and the protein content is less clear. There is indeed a negative correlation between the filtration rate and the protein content. However, this relationship is not the same for all layers. Increasing the protein concentration by adding the lower layer led to a smaller decrease in the filtration rate than by adding the upper layer. For lipid, there is a negative correlation between the concentration and the filtration rate that is the same for all layers. For protein, on the other hand, this correlation is dependent on the layer added. These experiments indicate that lipid can explain qualitatively the poor filtration characteristics of wheat starch hydrolysates, and that the influence of the protein is a derivative of that of the lipid. However, because the relative amounts of lipid and protein could not be varied independently in these experiments, it is necessary to investigate the influence of the individual components in another fashion. A future article will describe a model-based approach on the influence of the individual wheat starch components on the filtration characteristics.

## CONCLUSIONS

Our results show that the filtration of maize starch hydrolysates is an efficient operation that removes the bulk of the impurities. The filtration rate can be enhanced by increasing the incubation time and the enzyme dosage, which results in a lower viscosity. The most effective measure is to include a second conversion step at  $140^\circ\text{C}$ , which reduces the amount of retrograded starch.

The filtration of wheat starch hydrolysates is a highly inefficient operation that removes only a minor part of the impurities. Even after a second filtration, the filtration rate remains much lower than that of maize starch hydrolysates. This implies that a larger part of these impurities is water soluble. Although the filtration is impaired by both protein and lipid, it appears that the latter has the largest effect.

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