Baking Functionality of Reconstituted Rye Flours Having Different Nonstarchy Polysaccharide and Starch Contents

M. C. KÜHN[1] and W. GROSCH[2]

ABSTRACT

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The variation of baking properties of rye flour with composition was investigated using fractionation-reconstitution techniques. Fractions rich in nonstarchy polysaccharides (NSP; soluble, fraction Ib; insoluble, IIa) and starch (prime, III; second grade, IIb) were varied to study the effect of omitting one or two fractions, the ratio of Ib to IIa, and the ratio of NSP to starch. Minibaking tests (using 10 or 20 g of reconstituted flour) resulted in a greater bread specific volume by omitting IIa and IIb or increasing the Ib/IIa ratio or the NSP/starch ratio. Except for the NSP/starch ratio, these parameters also flattened the bread. A softer bread crumb was obtained by omitting III, Ib+IIa, increasing the Ib/IIa ratio, or decreasing the NSP/starch ratio. Overall, Ib and III had positive influences, whereas IIa and IIb were deleterious to the baking functionality of rye flour.

Knowledge of the role of flour components in dough making and bread baking is important for the optimization of baking results. Compared with our understanding of wheat flour, much less is known about the baking functionality of rye flour components. Among the main flour constituents (starch, nonstarchy polysaccharides [NSP], and protein), only starch has a similar baking functionality in wheat and rye. Starch forms the basic skeleton of bread crumb (Drews 1970a), contributes to gas retention, and is responsible for bread staling (Rotsch 1958). Rye starch has a lower swelling temperature than wheat starch, thus allowing a more intensive enzymatic degradation during fermentation. This results in a moister bread crumb of larger pore size (Drews 1973).

In rye flour, NSPs (predominantly pentosans, hence both terms are used interchangeably) are functionally more important than protein (Weipert and Zwingelberg 1979). The reason is that rye proteins cannot form gluten (Weipert and Zwingelberg 1979). Moreover NSPs are present in higher amounts in rye (8%) than in wheat (3% of flour; Doerner 1950, Drews 1965, Weipert and Zwingelberg 1979).

The NSPs of flour are classified as water soluble or water insoluble, depending on their solution behavior after centrifugation in a flour-water suspension. Both soluble and insoluble NSPs have very high water-binding capacities (Drews 1970b; Meuser and Klinger 1979a,b). Through their water-binding properties, the NSPs influence the water requirement of the flour for dough making (Drews 1970b), regulate the water distribution during baking (Rotsch 1966) and the degree of starch gelatinization (Drews 1970b), and hence the crumb characteristics (Weipert and Zwingelberg 1980) and shelf life of bread (Drews 1973).

Soluble and insoluble pentosans are similar in composition (Montgomery and Smith 1955) but affect the dough and baking properties of rye flour differently. The soluble rye NSPs influence the viscosity and gas retaining ability of doughs and influence the bread crumb and crust characteristics (Podrazky 1965) as well as color and taste (Meuser and Suckow 1986). The insoluble NSPs increase the dough resistance to kneading and improve dough stability (Casier and Soenen 1967). According to Meuser and Suckow (1986), the insoluble NSPs are actually responsible for the typical rye bread flavor and texture; they confer a darker color, a dull crumb surface, and a bitter taste. They also improve shelf life (Casier and Soenen 1967).

Less information is available on the effect of the ratio of soluble to insoluble NSPs on the baking properties of rye flour. Drews (1965) found that an excessively high ratio of soluble to insoluble NSPs impaired baking results.

The effect of the NSPs on bread volume, shelf life (in the case of the soluble NSPs), and overall baking results has been controversial. Differences between flours and in NSP extraction and purification methods contribute to the differences in experimental results published so far (Kühn 1987).

The effect of the ratio of NSPs to starch on the baking properties of rye flour was first suggested by Drews in 1965. He found that rye flours ground to different degrees of fineness (finer flours having a lower NSP to starch ratio) gave widely differing dough viscosities, bread volumes, and crumb properties. He related these differences to the variation in pentosan-to-starch ratio of the flours. Weipert and Zwingelberg (1979) found that the best baking results were obtained from rye flours having a pentosan-to-starch ratio of 1:16 to 1:18, the optimum ratio depending on the properties of the pentosans.

The functionality of rye flour components has now been further investigated by mixing the six enriched fractions obtained by fractionation of rye flour according to the method described by Kühn and Grosch (1985). Three of these fractions (Ia, Ib, and Ic) were water soluble and were obtained by ethanol fractionation of the supernatant after centrifugation of a flour/water slurry. The soluble NSPs were concentrated in fraction Ib. The three insoluble fractions were obtained from the two precipitate layers, fractions IIa and IIb arising from the upper residue layer known as squeegee and fraction III being the lower residue layer. The insoluble NSPs were concentrated in fraction IIa, whereas starch was the main component of fraction IIb (second grade) and III (prime). The major components of all fractions are given in Table I.

The resulting flours were reconstituted by omitting one (or two) of the six flour fractions or by changing either the pentosan-to-starch or the soluble-to-insoluble pentosan ratio.

MATERIALS AND METHODS

Rye Flour Fractions

Rye flour (type 1150; crop year 1983) was stored at −28°C until use. Six different flour fractions (Ia, Ib, Ic, IIa, IIb, and III) were obtained by fractionation of rye according to the method of Kühn and Grosch (1985).

The levels of pentosan, starch, protein, and the α-amylase activity of the six flour fractions were determined using respectively the methods of Douglas (1981), Anonymous (1983), ICC (1980), and Pharmacia Diagnostics (1983), as described by Kühn and Grosch (1985).

Starch damage was determined according to the standard method of the American Association of Cereal Chemists (AACC 1972). The α-amylase solution was prepared from 104.2 mg of a Rohalase enzyme preparation (Röhm, Darmstadt, Fed. Rep. Germany) having 48,000 SKB units/g. Prime starch was calculated by subtracting damaged starch from the total starch content.

The glucose and fructose contents of fraction Ic were determined

[1]Present address: Unilever Research Laboratorium, Postbus 114, 3130 AC Vlaardingen, The Netherlands.
[2]To whom correspondence should be addressed. Deutsche Forschungsanstalt für Lebensmittelchemie, and Kurt-Hess-Institut für Eiweissforschung, Lichtenbergstr. 4, 8046 Garching, West Germany.

enzymatically before and after mild acid hydrolysis of the sample. The hydrolysis was carried out by adding 10 ml of 4.8% (v/v) sulfuric acid to 100 mg of the sample and heating for 2 hr in a boiling water bath under constant stirring. The sample was cooled and neutralized (pH 7.0), and an aliquot was taken for the determination (method of Boehringer Mannheim 1986). The results were corrected for losses during hydrolysis using correction factors obtained with glucose and fructose standard solutions.

Rye Flour Reconstitution

Three sets of flours were reconstituted by 1) omitting one of the fractions Ib, IIa, IIb or III, or Ib+IIa; 2) having different ratios of the soluble to insoluble pentosan-rich fractions Ib to IIa (Ib/IIa); and 3) having different pentosan to starch (P/S) ratios.

The reconstitution was performed by mixing (1 min) the required amounts of all fractions (except Ic), followed by sieving (mesh size: 0.4 mm). Fraction Ic was dissolved in water together with the bakers' yeast and the lactic acid and added during kneading.

Flours Deficient in One or Two Fractions

The composition of these flours (flours B–F; Table II) was based on the reconstituted control flour A (Table II), which contained all fractions in the same proportions as the unfractionated rye flour. The composition of the five test flours was calculated by omitting the fraction under study while increasing the other fractions proportionally to their levels in flour A. The compositional data for each flour are given in Table II.

Flours with Different Ib/IIa Ratios

Flours G–J (Table III) having different Ib/IIa ratios but a constant P/S of 1:15 were prepared from flour M (Table IV). The weight of each fraction for flour reconstitution was calculated as follows: The weight sum of fractions Ib and IIa in flour M, 0.34 g, was set at 100%. Flour G contained this total amount as fraction

TABLE I
Major Components of the Six Rye Flour Fractions Used for Flour Reconstitution[a]

Fraction	Major Component(s)	Concentration (%)[b]
Soluble		
Ia	Crude protein	34.1
	Pentosan	30.0
Ib	Pentosan	69.6
	Crude protein	26.8
Ic	Mono- and oligosaccharides[c]	56.6
	Crude protein	17.5
Insoluble		
IIa	Pentosan	64.4
IIb	Starch	67.9
III	Starch	82.0

[a] Adapted from Kühn and Grosch (1985).
[b] Determined as g/100 g fraction (dry basis).
[c] The analysis of fraction Ic is reported in the Results section of this paper.

TABLE II
Composition of the Reconstituted Rye Flours Deficient in Fraction Ib, IIa, IIb, III, or both Ib and IIa (10-g flour batches, dry basis)

Fraction or Component	Flour A	B	C	D	E	F
Weight of the Fractions for Flour Reconstitution (g, dry basis)						
Ia	0.06	0.06	0.06	0.07	0.10	0.10
Ib	0.48	···	0.52	···	0.78	0.80
Ic	1.00	1.05	1.07	1.13	1.62	1.65
IIa	0.68	0.72	···	···	1.10	1.12
IIb	3.83	4.02	4.11	4.33	···	6.33
III	3.95	4.15	4.24	4.47	6.40	···
Chemical Composition of the Reconstituted Flours						
Pentosan, g	0.94	0.65	0.55	0.20	1.29	1.56
soluble, %	37	3	69	10	45	38
insoluble, %	63	97	31	90	55	62
Starch, g	5.93	6.22	6.27	6.60	5.39	4.44
prime, %	90	90	91	91	94	85
damaged, %	10	10	9	9	6	15
Protein, g	0.75	0.66	0.75	0.64	0.66	1.25
soluble, %	42	30	47	34	80	43
insoluble, %	58	70	53	66	20	57
SMC,[a] g	7.65	7.54	7.57	7.44	7.34	7.25
α-Amylase, PU[b]	3.5	3.7	3.3	3.5	0.7	5.8

[a] Sum of the major constituents (pentosan + starch + protein).
[b] PU = Phadebas units.

TABLE III
Composition of the Reconstituted Rye Flours Having Different Ratios of Soluble to Insoluble Pentosans (fractions Ib/IIa) (10-g flour batches, dry basis)

Fraction or Component	Flour G	H	I	J
Weight of the Fractions for Flour Reconstitution (g, dry basis)				
Ib, %	100	67	33	0
IIa, %	0	33	67	100
Ib, g	0.34	0.23	0.11	···
IIa, g	···	0.11	0.23	0.34
Ia, g	0.06	0.06	0.06	0.06
Ic, g	1.09	1.09	1.09	1.09
IIb, g	4.18	4.18	4.18	4.18
III, g	4.32	4.32	4.32	4.32
Chemical Composition of the Reconstituted Flours				
Pentosan, g	0.43	0.42	0.41	0.41
soluble, %	60	43	22	5
insoluble, %	40	57	78	95
Starch, g	6.38	6.39	6.41	6.42
prime, %	91	91	90	90
damaged, %	9	9	10	10
Protein, g	0.71	0.69	0.67	0.65
soluble, %	42	39	36	32
insoluble, %	58	61	64	68
SMC,[a] g	7.52	7.49	7.49	7.48
α-Amylase, PU[b]	3.3	3.4	3.5	3.6

[a] Sum of the major components (pentosan + starch + protein).
[b] PU = Phadebas units.

TABLE IV
Composition of the Reconstituted Rye Flours Having Different Pentosan/Starch Ratios (10-g flour batches, dry basis)

Fraction or Component	Flour (Pentosan/Starch Ratio, w/w) K (1:5)	L (1:10)	M (1:15)	N (1:20)
Weight of the Fractions for Flour Reconstitution (g, dry basis)				
Ia	0.06	0.06	0.06	0.07
Ib	0.60	0.26	0.14	0.07
Ic	0.96	1.06	1.09	1.11
IIa	0.86	0.37	0.20	0.10
IIb	3.70	4.06	4.18	4.26
III	3.82	4.19	4.32	4.39
Chemical Composition of the Reconstituted Flours				
Pentosan, g	1.14	0.60	0.42	0.31
soluble, %	39	33	29	23
insoluble, %	61	67	71	77
Starch, g	5.75	6.24	6.41	6.50
prime, %	90	90	91	90
damaged, %	10	10	9	10
Protein, g	0.80	0.71	0.68	0.66
soluble, %	44	38	37	36
insoluble, %	56	62	63	64
SMC,[a] g	7.69	7.55	7.51	7.47
α-Amylase, PU[b]	3.5	3.5	3.5	3.5

[a] Sum of the major components (pentosan + starch + protein).
[b] PU = Phadebas units.

Ib. The other flours H–J contained increasing proportions (33, 67, or 100%) of fraction IIb at the expense of fraction Ib. The amounts of the other rye flour fractions (Ia, Ic, IIb, and III) were kept constant for all flours. Data on the composition of these flours are given in Table III.

Flours with Different P/S Ratios

The weight of the six fractions for reconstitution of flours labelled K–N and having P/S ratios of 1:5, 1:10, 1:15, or 1:20 was calculated for 10-g flour batches (dry basis) as follows: Arbitrary weights for the sum of fractions Ib+IIa were chosen (i.e., 0.1, 0.5, 1, 2, and 4 g). The weight of the other fractions (Ia, Ic, IIb, and III) was then calculated in proportion to their level in the control flour A (Table II). The P/S for each batch was then calculated on the basis of the chemical composition of each fraction (Kühn and Grosch 1988) and plotted against the sum of Ib+IIa (Fig. 1). This curve was used to obtain the weight of fractions Ib+IIa for a particular P/S. The weight of each of the six flour fractions for the desired P/S was then calculated. The ratio of Ib/IIa was kept constant at 0.7. The chemical composition of each flour was verified. The compositional data for these flours are given in Table IV.

Dough Consistency

Doughs from the reconstituted flours were kneaded at a constant water volume of 7.5 ml/10 g of flour (dry basis) in a Brabender Farinograph. After 2 min of kneading the dough consistency was recorded in Brabender units (BU).

Mini-Scale Bread Testing

All baking trials were performed in duplicate, according to the method of Kieffer et al (1984). Dough consistency was adjusted to 400 BU. Rounded minibreads from 10 g of reconstituted flour (dry basis) were baked without a baking pan and used to study dough and bread properties, as reported previously (Kühn and Grosch 1988). Miniloaves from 20 g of flour were baked in a pan and used to determine crumb firmness and specific crumb weight. Both of these properties were measured on cylindrical crumb samples (height = diameter = 2 cm). Firmness was taken as the force required to compress the crumb sample by 50% (Kühn and Grosch 1988). The color of the crust and crumb of the minibreads were recorded as well.

RESULTS

Chemical Composition of the Fractions and Flours

The levels of pentosan, starch, and protein of the the six rye flour fractions were reported previously (Kühn and Grosch 1988). Because fraction Ic contained only minor amounts of these compounds, it was analyzed further for glucose and fructose content. After mild acid hydrolysis, these two sugars were found to be 56.6% of the total fraction (Table I). These sugars are originally present as oligomers, since the unhydrolyzed sample contained only approximately 4% monomers.

The content of damaged starch in the fractions IIa, IIb, and III was found to be 4, 10, and 4%, respectively. The damaged starch content was independent of the method used for drying (lyophilization or air-drying) or grinding (with an ultracentrifugal mill or with a mortar).

Common features of all flours were a starch damage of ~10% (except for flours D and E), a protein content between 0.64 and 0.80 g (except for flour E), and an α-amylase activity of ~3.5 Phadebas units (except for flours D and E). The three main components reported constituted ~75% of the flour composition.

Dough Consistency

The dough consistency of a flour at a fixed amount of water added is a measure for the water binding ability of the flour. The results for the first set of flours (Table V) showed that the softest doughs were obtained when the NSP-rich fractions Ib and IIa were omitted from the flour. Omission of fraction IIb resulted in a smaller decrease in dough consistency. Hence, these four flours (B–E) required a smaller water volume for achieving constant dough consistency (Table VI).

A stiffer dough than the control resulted when the prime starch fraction III was omitted. For a constant dough consistency with flour F, therefore, water had to be increased in comparison with the control (Table VI).

Flours G–J, having different Ib/IIa ratios, gave doughs of similar consistencies (~220 BU, Table V). The low dough consistency value can be explained by the low total pentosan content of these flours (~4%; Table III) in comparison with the original rye flour (~9%; flour A, Table II).

Increasing the proportion of starch with respect to NSPs in the reconstituted flour (flours K–N) caused a gradual and marked

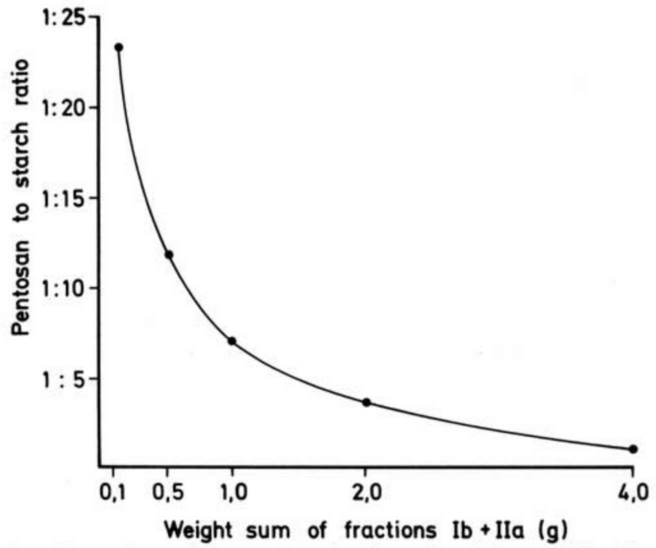

Fig. 1. Dependence of pentosan/starch ratio on the weight sum of fractions Ib+IIa. Calculation based on 10 g of reconstituted rye flour (dry basis).

TABLE V
Dough Consistency (DC) of the Reconstituted Rye Flours A–N Kneaded at Constant Water Addition[a]

Flour Set 1			Flour Set 2			Flour Set 3		
Flour	Fraction Omitted	DC (BU)[b]	Flour	Ib/IIa[c]	DC (BU)	Flour	P/S[d]	DC (BU)
A	Control	365	G	100:0	227	K	1:5	412
B	Ib	267	H	67:33	210	L	1:10	298
C	IIa	262	I	33:67	220	M	1:15	237
D	Ib+IIa	110	J	0:100	217	N	1:20	192
E	IIb	310						
F	III	475						

[a] Doughs mixed with 7.5 ml water and 10.0 g of flour (dry basis).
[b] Brabender units.
[c] Ratio expressed as percent of their sum in flour M (Ib+IIa = 0.34 g).
[d] Pentosan to starch ratio.

softening of the dough (Table V). The volume of water required for a constant dough consistency of these flours therefore had to be decreased accordingly.

Baking Trials

Flours deficient in one or two fractions. Results of the baking tests are presented in Table VI. The specific volume of the minibreads increased only when the insoluble fractions IIa and IIb were omitted from the reconstituted flours (C and E). This was accompanied by a spreading of the minibread form (Table VI, Fig. 2) and a slight decrease in crumb firmness and in specific weight.

Omission of the soluble NSP-rich fraction Ib (flour B) resulted in an 11% decrease in specific volume compared to the control. When the insoluble NSP-rich fraction IIa was also omitted (flour D), the decrease in specific volume amounted to 20%.

The form ratio, which was not changed by omission of fraction Ib, largely decreased when both Ib and IIa were omitted. The rounder bread form is clearly seen in Figure 2.

In general, the crumb firmness and the bread specific volume were correlated: the lower the specific volume, the firmer and heavier the crumb sample.

Similar to the changes in flours B and D, omission of the prime starch fraction III (flour F) decreased specific volume and form ratio and increased specific crumb weight. The crumb firmness increased only slightly.

The change in crumb properties of flours B, D, and F was also similar (Fig. 2); all showed a tightening of the crumb structure, the effect being greater after omission of fraction Ib alone.

Flours with different Ib/IIa ratios. Increasing the amounts of fraction IIa over Ib in the reconstituted rye flours resulted in minibreads with smaller specific volume and a rounder form, together with an increased crumb firmness, specific crumb weight, and tighter crumb structure (Table VII). The changes in form ratio were mainly due to a smaller minibread diameter but also to a slightly greater height of the minibreads. As in the previous baking series, lowering the level of fraction Ib caused a tightening of the crumb structure (Fig. 3).

Flours with different P/S ratios. The specific volumes of the minibreads baked from flours K and L, possessing relatively low P/S ratios, were higher than those of flours containing a higher level of starch (Table VIII). This is possibly due to the higher water volumes required for constant dough consistency, since at a constant water addition the flours with a higher starch content (M and N) resulted in higher specific volumes (data not shown).

The greatest form ratio (i.e., flattest bread) was found for the minibread containing a P/S = 1:10. Increasing the P/S to 1:5 resulted in a shorter bread, as indicated by the lower form ratio (Fig. 4). If the P/S of the flour was decreased to 1:15 or 1:20, the minibreads were also of shorter form, but in this case the effect was less marked.

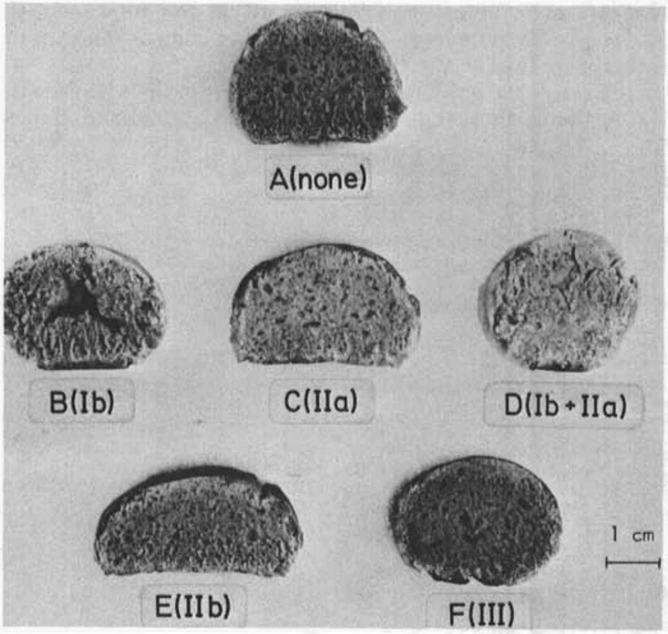

Fig. 2. Minibreads baked from the reconstituted rye flours A–F, deficient in fraction Ib, IIa, IIb, III, or both Ib+IIa. The omitted fraction is given in parenthesis (Tables II and VI).

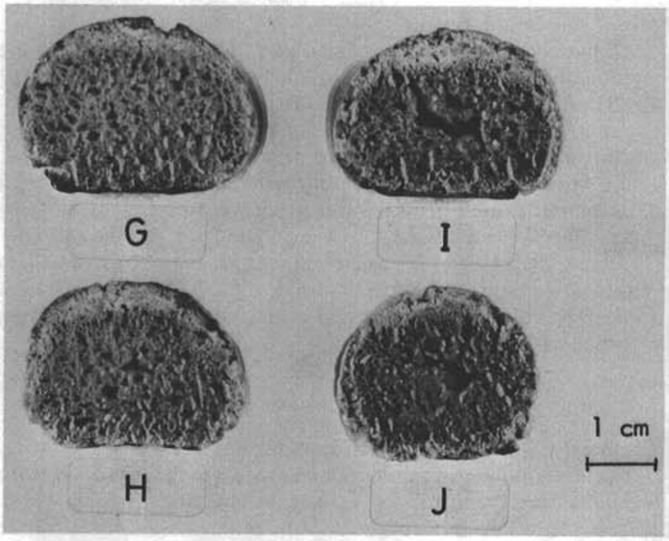

Fig. 3. Minibreads baked from the reconstituted rye flours having different ratios of the soluble to insoluble pentosan-rich fractions Ib/IIa (Tables III and VII).

TABLE VI
Baking Properties of the Reconstituted Rye Flours Deficient in Fraction Ib, IIa, IIb, III, or both Ib+IIa[a]

			Minibread Properties				Crumb Properties	
Flour	Fraction Omitted	Water Volume (ml)	Specific Volume (cm^3/g)	Diam. (cm)	Ht (cm)	Form Ratio[c]	Firmness (N)	Specific Wt (g/cm^3)
A	Control	7.24	1.32	3.22	2.53	1.27	25	0.69
B	Ib	6.50	1.17	3.07	2.39	1.28	32	0.81
C	IIa	6.62	1.41	3.47	2.37	1.47	21	0.66
D	Ib+IIa	4.75	1.06	3.02	2.63	1.15	54	0.87
E	IIb	6.42	1.42	3.36	2.44	1.38	23	0.65
F	III	8.30	1.21	3.08	2.56	1.20	27	0.81
SEM[d]			0.08	0.25	0.18	0.20	3	0.03
CV[e]			7	7	9	15	10	5

[a] Baking tests from 10 g reconstituted rye flour (dry basis) per minibread. The results are the mean values of duplicates.
[b] Dough of 7.5 ml water and 10 g of flour (db) kneaded 2 min.
[c] Diameter/height.
[d] Maximal standard error of the mean for the baking series.
[e] Maximal coefficient of variation for the baking series.

Flour K, having the highest NSP content, resulted in the firmest, most compact crumb of highest specific weight. The crumb properties of flours L–N were practically the same.

Relation Between Crumb Firmness and Other Flour or Minibread Parameters

The values for crumb firmness of all minibreads were plotted against the major flour components (pentosan, starch, and protein) and also against P/S. The scatter of the points indicated no direct relationship between these parameters. Only crumb firmness was found to be directly related to the specific crumb weight (Fig. 5). This result agrees with the findings of Wassermann and Vogt (1977), who found a direct relationship between specific crumb volume and crumb firmness.

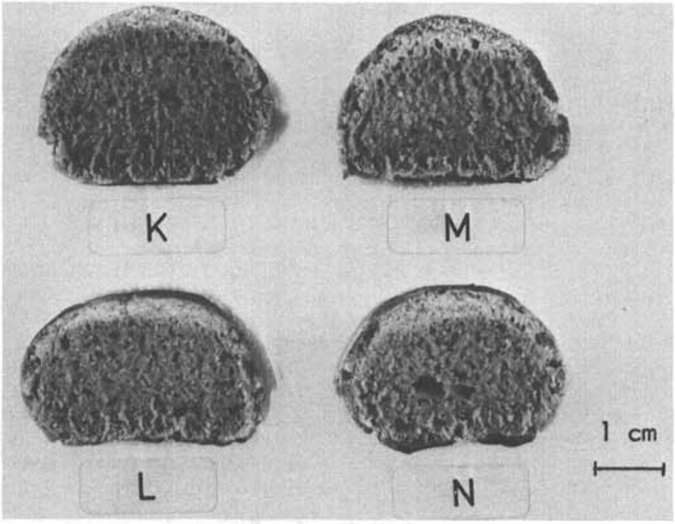

Fig. 4. Minibreads baked from the reconstituted rye flours having different pentosan/starch ratios (Tables IV and VIII).

DISCUSSION

Flour Preparation

The rye fractionation/reconstitution method proved to be a powerful tool for the study of the functionality of the rye NSPs and starch-containing fractions. It showed a large degree of versatility for the preparation of reconstituted flours of predefined composition, whereby only one parameter (i.e., pentosan/starch ratio) was varied while all others were kept constant.

The fractionation was achieved only by physical techniques. This resulted in enriched fractions, having still significant levels of minor components. Further purification would have required destructive treatments (e.g., enzymatic or chemical hydrolysis) that would have caused a permanent change of the fraction(s). Because

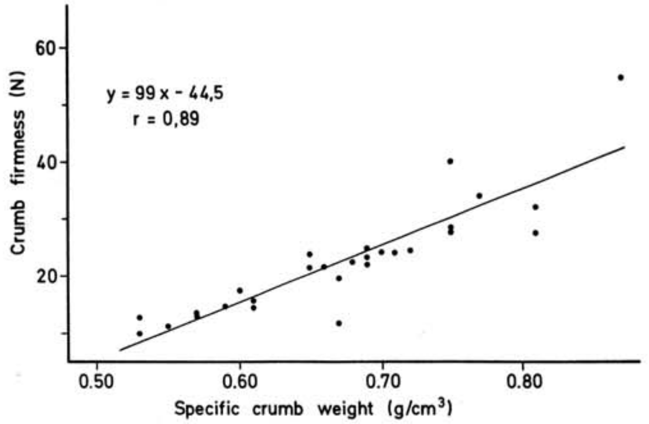

Fig. 5. Relationship between the specific weight (g/cm^3) and firmness of the minibread crumb baked from reconstituted flours A–N.

TABLE VII
Baking Properties of the Reconstituted Rye Flours Having Different Ratios of Soluble to Insoluble Pentosan-Rich Fractions Ib/IIa[a]

			Minibread Properties				Crumb Properties	
Flour	Ib/IIa Ratio[b]	Water Volume (ml)	Specific Volume (cm^3/g)	Diameter (cm)	Height (cm)	Form Ratio[c]	Firmness (N)	Specific Wt (g/cm^3)
G	100:0	6.50	1.36	3.36	2.40	1.40	17	0.60
H	67:33	6.22	1.30	3.25	2.40	1.35	21	0.65
I	33:67	6.20	1.20	3.19	2.38	1.33	22	0.68
J	0:100	6.10	1.17	3.07	2.44	1.26	27	0.75
SEM[d]			0.11	0.10	0.14	0.11	3	0.08
CV[e], %			9	3	6	9	19	12

[a] Baking tests from 10 g of reconstituted rye flour (dry basis) per minibread. The results are the mean values of duplicates.
[b] Ratio of the fractions Ib/IIa, expressed as percent of their sum in flour M (Ib+IIa = 0.34 g).
[c] Diameter/height.
[d] Maximal standard error of the mean for the baking series.
[e] Maximal coefficient of variation for the baking series.

TABLE VIII
Baking Properties of the Reconstituted Rye Flours Having Different Pentosan/Starch (P/S) Ratios[a]

			Minibread Properties				Crumb Properties	
Flour	P/S Ratio	Water Volume (ml)	Specific Volume (cm^3/g)	Diameter (cm)	Height (cm)	Form Ratio[b]	Firmness (N)	Specific Wt (g/cm^3)
K	1:5	7.65	1.32	3.14	2.56	1.23	28	0.75
L	1:10	6.70	1.32	3.28	2.39	1.38	23	0.69
M	1:15	6.38	1.24	3.29	2.42	1.36	24	0.70
N	1:20	6.05	1.27	3.22	2.41	1.34	22	0.69
SEM[c]			0.12	0.11	0.20	0.16	6	0.08
CV[d], %			10	2	8	12	29	12

[a] Baking tests from 10 g of reconstituted rye flour (dry basis) per minibread. The results are the mean values of duplicates.
[b] Diameter/height.
[c] Maximal standard error of the mean for the baking series.
[d] Maximal coefficient of variation for the baking series.

of these minor components, variation of a parameter (e.g., ratio of fractions Ib/IIa) sometimes resulted not only in the desired change (e.g., ratio of soluble to insoluble NSPs) but to a lesser extent in change of the minor components. These effects were only marginal.

Dough and Bread Properties

Increasing the total pentosan content (i.e, high pentosan/starch ratio) caused a stiffening of the dough. A marked softening of the dough was observed when the pentosan-rich fractions Ib and IIa were omitted from the reconstituted flour. Both results can be explained by the high water-binding capacity of the pentosans; these strong swelling substances bind water in the dough leaving less water for the other components, thereby causing an increase in dough consistency. Increasing the pentosan level at constant dough consistency thus demands an increase in water added. This effect was directly proportional to the total pentosan content as well as to the protein content of the flours. Since the total pentosan level determines P/S, this effect was also proportional to this ratio, as Drews (1965) proposed.

Both water soluble and insoluble pentosans of the rye flour affected the dough consistency similarly, indicating that they have a similar water binding capacity at the levels present.

Decreasing the level of the insoluble fractions IIa and IIb resulted in increased minibread specific volume, flatter bread shape, and softer and lighter crumb properties. Both of these fractions originate from the squeegee of rye flour (i.e., the upper precipitate layer after centrifugation). Thus, as for wheat (Kulp 1968), it can be concluded that in rye flour the squeegee fraction has the most negative influence on baking performance.

It is noteworthy that the starch-rich fraction IIb behaves similarly to the NSP-rich fraction IIa; this indicates that minor components (e.g., 4% NSP and 9.5% protein in fraction IIb; Kühn and Grosch 1988) may play an important role on the baking functionality of a flour fraction.

The soluble NSP-rich fraction Ib had an overall positive effect on bread and crumb properties. Shifting the NSP ratio in its favor resulted in minibreads having greater specific volume, firmer crumb, and flatter form. If fraction Ib was omitted from the flour, the dough stiffened, and the bread specific volume decreased while the crumb firmness increased.

Although simultaneous omission of fractions Ib+IIa weakened dough consistency additively, the effect of omission of fraction Ib on bread and crumb properties was dominant.

Crust color was affected by both the pentosan content and by the pentosan type present in the flours. Increased proportions of total pentosan or of the soluble over the insoluble pentosan resulted in a darker bread crust. The crumb color, on the other hand, did not vary much and was only slightly darker when the flour contained more total pentosan.

The baking properties of rye flour were found to depend on the total pentosan content (and hence on the P/S ratio) as well as on the type of pentosan present. The optimum P/S depended on the volume of water used during dough making, being 1:10 if the water addition was adjusted to a constant dough consistency for all flours. In contrast, if the water volume was constant for all flours, the optimum P/S was 1:15, which agrees with the findings of Drews (1965) and Weipert and Zwingelberg (1979, 1980).

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