Wheat Starch, Cassava Starch, and Cassava Flour Impairment of the Breadmaking Potential of Wheat Flour

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ABSTRACT

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Optimum mixing time and water absorption levels of composite wheat flours were evaluated by response surface methodology. Water absorption was correlated with loaf volume in breadmaking where wheat flour was substituted at 0, 15, or 30% by wheat starch, cassava starch, or cassava flour. The significance of the mixing time was less clear-cut. Baking results showed that the reduced breadmaking potential of wheat flour with partial substitution is not solely a function of gluten dilution. Indeed, loaf volume data showed that the breadmaking potential of a substituted wheat flour is determined by the degree of substitution as well as the type of substitute. Clear differentiation of the substitutes occurs during baking, not at the fermentation stage of the dough. Differential scanning calorimetry showed no drastic differences in the gelatinization properties of the doughs made from substituted flours.

The unique breadmaking properties of wheat flour can be attributed mainly to the ability of its gluten proteins to form a viscoelastic network when mixed with water. The reduction of viscoelectric properties of a wheat flour dough upon substitution by starch or nonwheat flour reduces breadmaking potential. This phenomenon can be explained as a reduced capacity of the gluten network to slow down the rate of carbon dioxide diffusion (Hoseney 1984).

Although a large amount of research has investigated the possibilities of wheat flour substitution by other starch sources (Kim and de Ruiter 1969, Dendy et al 1970, Bushuk and Hulse 1974, Ciacco and D'Appolonia 1978, Olatunji and Akinrele 1978, Crabtree and Dendy 1979, Almazan 1990), little information is available concerning the (respective) impact of the substitutes on the mixing requirements and on the gas retention capacity during the fermentation and baking stage of the composite flour dough.

In this work, we investigated the extent of influence on the breadmaking potential of a wheat-flour dough substituted with wheat starch, cassava starch, or cassava flour at a 15 or 30% level. Mixing time and water absorption ranges for manageable doughs were determined. Response surface methodology was used to evaluate the optimum water absorption and mixing time for the different composite flours. Gas production and differences in gas-retention capacity during the subsequent steps of the breadmaking process were recorded to obtain a better insight into the specific influence of the respective substitutes. We also used differential scanning calorimetry to investigate the relationship between breadmaking potential and gelatinization properties.

MATERIALS AND METHODS

Materials

Wheat flour, protein content 10.4% dmb (N × 5.7), (Uno, Ceres, Brussels, Belgium); wheat starch (Meriwit, Amylum, Aalst, Belgium); commercial cassava starch (Remy, Leuven, Belgium); nonfat dry milk (Gloria, Nestle, Vevey, Switzerland); shortening (Crisco, Procter and Gamble, Cincinnati, OH); and dry yeast (Fermipan, Gist-Brocades, Delft, The Netherlands) were used. Cassava flour was obtained from the International Institute of Tropical Agriculture (Ibadan, Nigeria) courtesy of M. Bokanga. Cassava roots were harvested 15 months after planting and processed into flour.

Breadmaking Procedure

Two percentages of wheat flour (15 and 30%) were substituted by starch or nonwheat flour. Pup loaves (100 g of flour, 14% mb) were baked according to the straight-dough procedure described by Finney (1984) using 180-min fermentation and 55-min proof times. Doughs were mixed with 4% nonfat dry milk and optimum potassium bromate (20 ppm for the 100% wheat-flour dough, 17 ppm for the 15% substitution, and 14 ppm for the 30% substitution).

Optimal Mixing and Water Absorption

Response surface methodology (Box et al 1978) was used to optimize mixing time and water absorption of the dough loaf volumes. The data obtained were analyzed using the GLM and RSREG procedures of SAS (1987). We defined the area of mixing and absorption levels that produced doughs with handling properties varying from rather dry to sticky but workable. Then the defined area was submitted to RSM.

We set up a central composite design (Box et al 1978) to analyze the contribution of mixing time and water absorption to the loaf volume of the resulting breads. Our baking experiment tested four axial points, four star points, and three center points. Data obtained are the result of triplicate experiments; breads resulting from the center points were baked nine times. Mixing time and water absorption levels were coded in a −1.41, +1.41 interval. The dough mixing order was randomized. The design of the experiment is illustrated in Figure 1.

Gas Production and Gas Retention Capacity in the Different (Composite) Flour Doughs

Gas production was measured with a Risograph instrument

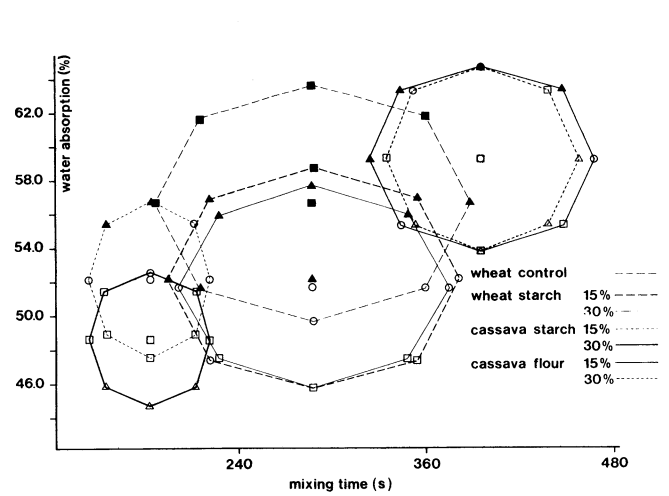

Fig. 1. The effect of variable mixing times and absorption levels (14% mb) on loaf volume potential for different dough formulations. Octagons for a particular formulation were constructed around the center points. Experimental loaf volumes are indicated as △ (390–470ml), □ (470–550 ml), ○ (550–630 ml), ▲ (630–710 ml), and ■ (710–790 ml).

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(R Design, Pullman, WA). Ingredients were the same as those used in the breadmaking procedure. However, the water levels were adjusted to 150 ml (14% mb), and potassium bromate was omitted. A Kitchen Aid mixer (5K45SSAL) with a flat beater was used to prepare the slurry, which was mixed for 5 min. Gas production was recorded for a 120-min period on 125 g of slurry.

To measure gas retention capacity during fermentation, doughs (10 g of flour) were prepared as outlined in the breadmaking procedure. After 180 min of fermentation, gas retention capacity was recorded as a function of proof time. The fermented and punched doughs were placed into graduated glass cylinders (45 mm, i.d.), and dough height (including the initial dough height value) was measured as a function of time in 5-min intervals.

Dough Expansion During Baking

Dough expansion during baking was recorded by time-lapse photography as described by He and Hoseney (1991).

Gelatinization Properties of the Doughs

A calorimeter (DSC 120, Seiko, Japan) was used to record the gelatinization properties of doughs. Doughs were mixed as outlined in the breadmaking procedure, except that yeast was omitted. Samples (about 55 mg) were weighed in stainless steel pans and then heated in the calorimeter from 20 to 120°C at 2°C/min.

RESULTS AND DISCUSSION

Optimal Mixing Time and Water Absorption

There was no drastic change in the water absorption ranges for the substitutions investigated. However, the tolerated mixing times appeared to be influenced to a larger extent, as illustrated in Figure 1 and Table I.

The prediction equations for the resulting loaf volume and the corresponding r^2 to the response surface are presented in Table II. The significance level of the independent variables is presented in Table III. Water absorption level was positively correlated with loaf volume, and it was highly significant in all cases investigated. The significance of mixing time value was less clear-cut, and its effect proved to be negatively correlated with loaf volume.

Water absorptions were evaluated up to levels at which the doughs were rather sticky. Although such absorptions resulted in larger loaf volumes, these water levels could not be considered optimal because the workability of the doughs was impaired.

In the 100% wheat-flour dough, as well as in the wheat starch substitutes, optimal conditions were estimated between the points with coded absorption and mixing variables (+1.00, +1.00), (+1.00, −1.00) and (0.00, 0.00). While the lower absorption level was estimated to be close to optimal, the higher levels resulted in loaves with a slightly uneven crust. Optimal conditions corresponded to the coded absorption and mixing values of +0.50 and 0.00, respectively.

Optimal dough mixing conditions and the resulting loaf volumes (experimental and estimated) are summarized in Table IV.

Wheat starch. Optimum mixing time was not influenced when wheat starch was used as flour substitute. Water absorption was lowered by about 5%.

Cassava starch. Substitutions with cassava starch resulted in a very restricted mixing range with short mixing times (Fig. 1 and Table I). Such influence corresponds with the findings of Keya and Hadziyev (1985), who reported a shorter dough development time and an inferior mixing tolerance for a cassava starch-

TABLE I
Combinations of Water Absorptions and Mixing Times Expressed as Coded and Decoded Values at 15 and 30% Levels of Substitution[a]

				Substitution													
				Wheat Starch Level				Cassava Starch Level				Cassava Flour Level					
Coded Variables		Control Decoded		15%		30%		15%		30%		15%		30%			
WA[a]	MT	WA (%)	MT (sec)	WA (%)	MT (sec)	WA (%)	MT (sec)	WA (%)	MT (sec)	WA (%)	MT (sec)	WA (%)	MT (sec)	WA (%)	MT (sec)		
Axial points																	
−1.00	−1.00	51.6	216	47.5	222	47.3	227	48.8	155	45.8	155	55.2	345	55.2	353		
−1.00	+1.00	51.6	360	47.5	354	47.3	349	48.8	211	45.8	211	55.2	447	55.2	439		
+1.00	−1.00	61.6	216	56.7	222	55.9	227	55.4	155	51.4	155	63.0	345	63.0	353		
+1.00	+1.00	61.6	360	56.7	354	55.9	349	55.4	211	51.4	211	63.0	447	63.0	439		
Star points																	
+1.41	0.00	63.6	288	58.6	288	57.7	288	56.7	183	52.5	183	64.6	396	64.6	396		
0.00	+1.41	56.6	390	52.1	381	51.6	374	52.1	222	48.6	222	59.1	468	59.1	457		
−1.41	0.00	49.6	288	45.6	288	45.5	288	47.5	183	44.7	183	53.6	396	53.6	396		
0.00	−1.41	56.6	186	52.1	195	51.6	202	52.1	144	48.6	144	59.1	324	59.1	335		
Center point																	
0.00	0.00	56.6	288	52.1	288	51.6	288	52.1	183	48.6	183	59.1	396	59.1	396		

[a] WA = water absorption on a 14% moisture basis, MT = mixing time (sec). WA and MT are decoded variables.

TABLE II
Prediction Equations for the Loaf Volume of Wheat Flour and Composite Flour Doughs and the Corresponding r^2

Substitution, %	Equation[a]	r^2
None	$LV = 706.0 + 54.6WA - 5.1MT + 13.5WA*MT - 11.9WA^2 - 8.5MT^2$	0.883
Wheat starch		
15	$LV = 625.5 + 73.1WA - 11.3MT + 4.7WA*MT - 9.2WA^2 - 3.5MT^2$	0.986
30	$LV = 600.2 + 68.1WA - 4.3MT + 7.9WA*MT - 21.2WA^2 - 7.5MT^2$	0.958
Cassava starch		
15	$LV = 587.8 + 50.4WA - 6.1MT - 3.7WA*MT - 2.7WA^2 - 1.6MT^2$	0.980
30	$LV = 480.5 + 56.1WA - 2.4MT - 0.1WA*MT - 3.1WA^2 - 3.7MT^2$	0.968
Cassava flour		
15	$LV = 630.7 + 47.6WA - 18.7\ MT + 2.4WA*MT - 8.9WA^2 + 1.3MT^2$	0.912
30	$LV = 483.5 + 67.8WA - 22.2MT - 5.1WA*MT - 4.1WA^2 + 2.5MT^2$	0.944

[a] LV = loaf volume (cm^3), WA = water absorption on a 14% moisture basis, MT = mixing time. WA and MT are coded variables.

gluten system when compared to that of a wheat starch-gluten system. Substitution of wheat flour by cassava starch decreased the optimum mixing time remarkably and also reduced the optimum water absorption. The reduced absorption is, however, not in accordance with results obtained by Kim and de Ruiter (1969), who noticed an absorption increase of 4% when wheat flour was substituted with 30% cassava (or corn) starch.

Cassava flour. Comparisons of mixing ranges for the cassava flour and cassava starch substitutions in the dough show that cassava flour makes the dough more tolerant to mixing. The mixing times required for cassava-flour dough workability were higher than those required for wheat-flour doughs, with and without wheat starch substitution. Cassava flour had no influence on the optimum water absorption, but the optimum mixing time was increased at both substitution levels investigated. This is unlike what was reported by Olatunji and Akinrele (1978), who observed a decreased mixing time for wheat-tropical tuber (cassava, yam, cocoyam) composite flours. Almazan (1990) reported an increment of 2.5% water for each 10% increase of cassava flour between 10 and 40% in a cassava and wheat-flour dough.

Baking

Typical loaves obtained after substitution of wheat flour by wheat starch, cassava starch, or cassava flour at 15, or 30% levels are illustrated in Figure 2. Loaf volumes, weights, and specific volumes are listed in Table V. Although crumb structures were not drastically impaired upon substitution of wheat flour by 15 or 30% of the title compounds (except for a 30% cassava-flour substitution), the decrease in loaf volumes was more remarkable. It was clear that both cassava starch and cassava flour impaired loaf volume to a larger extent than did wheat starch. At a 30% substitution level, a differentiation between cassava starch and cassava flour was noticed. The higher suitability of cassava starch than that of cassava flour that we observed here was noticed also in wheatless breadmaking by Kim and de Ruiter (1968), de Ruiter (1978) and at this laboratory. One can speculate that nonstarch polysaccharides or protein material is responsible for the effect, although more work will be needed to substantiate such interpretations.

Gas Production and Gas Retention Capacity in the Different (Composite) Flour Doughs

Gas production in the different doughs was very comparable. Figure 3 shows the dough height measured under standardized conditions as a function of proof time for both the control dough and the doughs prepared with 30% of the title compounds. Wheat-flour doughs had a better gas retention capacity than did the composite flour doughs. This was already evident at a 15% substitution level. The gas retention capacity of the doughs substituted with 15% of the title compounds was less impaired than that of the doughs substituted with 30%.

TABLE III
Significance Level for the Independent Variables

Substitution (%)	Independent Variable[a]				
	WA	MT	WA × MT	WA^2	MT^2
None	***	NS	*	*	NS
Wheat starch					
15	***	***	NS	**	NS
30	***	NS	NS	***	*
Cassava starch					
15	***	**	NS	NS	NS
30	***	NS	NS	NS	NS
Cassava flour					
15	***	***	NS	*	NS
30	***	***	NS	NS	NS

[a] WA = water absorption, MT = mixing time. *** $P = 0.0001$, ** $P = 0.0005$, * $P = 0.05$, NS = not significant.

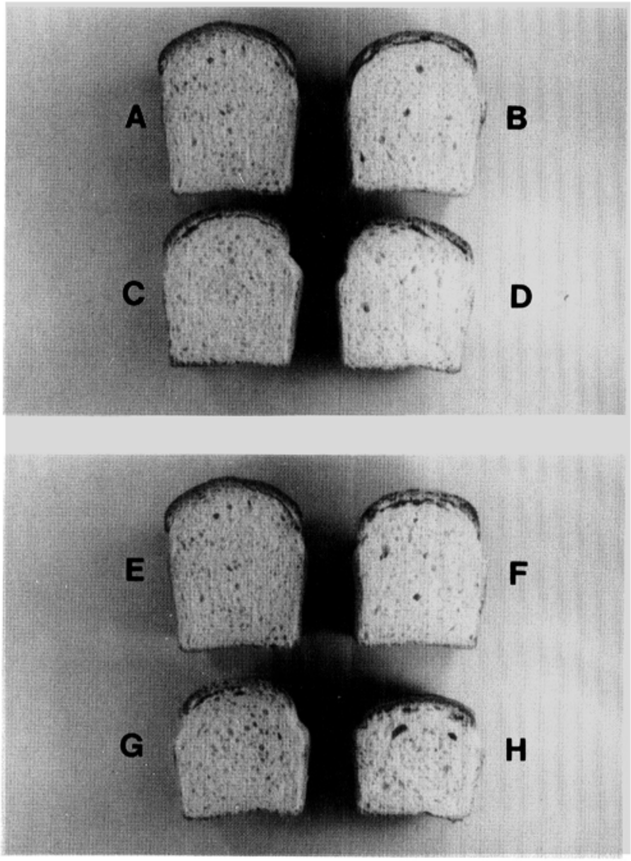

Fig. 2. Typical crumb structures of bread baked with unsubstituted wheat flour (**A** and **E**), and wheat flour substituted by wheat starch (**B** and **F**), cassava starch (**C** and **G**), or cassava flour (**D** and **H**). Substitution levels 15% (**A–D**) and 30% (**E–H**).

TABLE IV
Optimal Water Absorption and Mixing Time of a Wheat Flour Dough and Composite Flour Doughs as Determined by Response Surface Methodology and the Corresponding Estimated and Experimental Loaf Volumes

Substitution (%)	WA[a] (%)	MT (sec)	Coded Variables		Loaf Volume, cm^3	
			WA	MT	Estimated	Experimental
None	59.1	288	+0.50	0.00	730	732
Wheat starch						
15	54.4	288	+0.50	0.00	660	693
30	53.7	288	+0.50	0.00	629	651
Cassava starch						
15	56.7	183	+1.41	0.00	653	656
30	52.5	183	+1.41	0.00	553	559
Cassava flour						
15	59.1	324	0.00	−1.41	660	652
30	59.1	335	0.00	−1.41	520	528

[a] WA = water absorption on a 14% moisture basis, MT = mixing time.

TABLE V
Weights, Volumes, and Specific Volumes of Wheat Flour Bread and Composite Flour Bread[a]

Substitution (%)	Weight (g)	Volume (cm^3)	Specific Volume (cm^3/g)
None	145.1 ± 1.0	732 ± 16	5.04
Wheat starch			
15	143.5 ± 0.4	693 ± 10	4.83
30	142.6 ± 0.0	651 ± 11	4.56
Cassava starch			
15	143.9 ± 0.0	656 ± 6	4.56
30	143.3 ± 0.6	559 ± 6	3.90
Cassava flour			
15	147.9 ± 0.3	652 ± 2	4.41
30	148.2 ± 0.2	528 ± 8	3.56

[a] Averages of triplicate baking experiments.

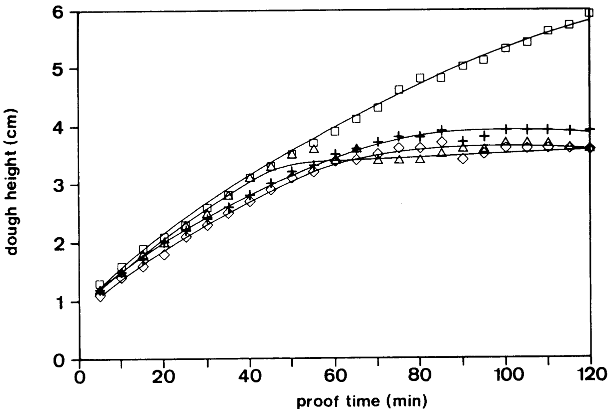

Fig. 3. Dough height as a function of proof time for a control dough (□) and doughs prepared with 30% wheat starch (+), cassava starch (◇), or cassava flour (△).

Dough Expansion During Baking

Dough expansion during baking for control dough and doughs prepared with 30% of the title compounds is illustrated in Figure 4. It is clear that both cassava starch and cassava flour impair dough expansion to a larger extent than does wheat starch. Additional evidence is presented in Table V. The 15% cassava starch or cassava flour substitutes resulted in loaves of about the same volume as a composite-flour dough containing up to 30% wheat starch.

Gelatinization Properties of the Doughs

Measurement of the gelatinization properties of a control dough and of a dough substituted with 30% wheat starch or cassava flour showed that the thermograms are not drastically altered (Fig. 5). Three endothermic peaks were registered at about 70, 90, and 111°C. Eliasson and Hegg (1980) ascribed the first peak to the gelatinization of starch. Ghiasi et al (1983) found that the second peak also can be ascribed to the starch gelatinization process in low-water systems. As noted by Donovan (1979) and Spies and Hoseney (1982), the gelatinization of starch in limited water results in the appearance of a second endothermic peak. Finally, the third endothermic peak is attributed to the melting of amylose-lipid complexes as mentioned by Kugimiya et al (1980).

CONCLUSIONS

Substitution of wheat flour by wheat starch, cassava starch, or cassava flour at 15 or 30% leads to a reduced breadmaking potential. The degree of reduction depends on the substituent. No clear differentiation between the samples occurs at the fermentation stage; it does appear at the baking stage of the doughs. The differentiation was more pronounced at a 30% substitution than at a 15% substitution. Differences in loaf volumes were consistently larger at a 30% substitution.

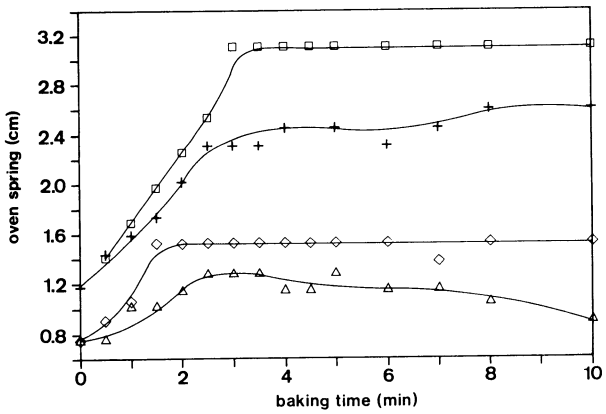

Fig. 4. Oven spring during the first 10 min of baking for a control dough (□) and doughs prepared with 30% wheat starch (+), cassava starch (◇), or cassava flour (△).

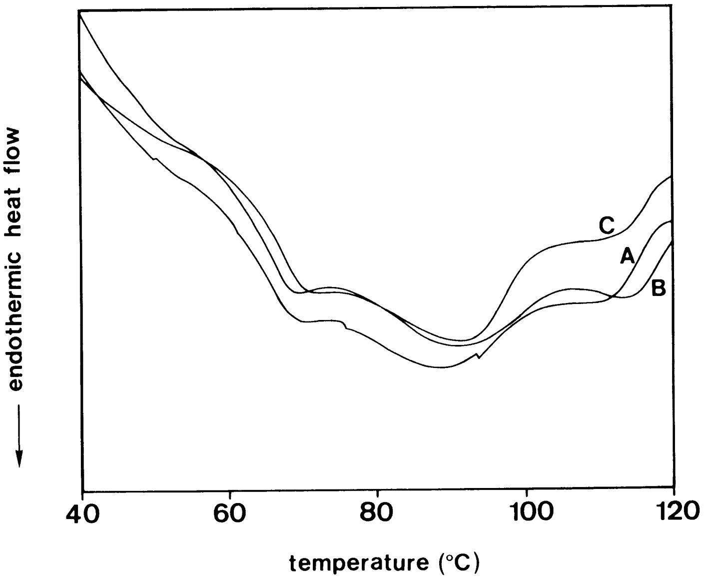

Fig. 5. Thermograms of a wheat-flour dough (**A**), dough prepared with 30% wheat starch (**B**), and dough prepared with 30% cassava flour (**C**).

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