BAKING STUDIES WITH CASSAVA AND YAM. II. RHEOLOGICAL AND BAKING STUDIES OF TUBER-WHEAT FLOUR BLENDS[1]

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ABSTRACT

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Rheological and baking properties of flour blends containing various levels of either cassava flour, cassava starch, or yam flour with hard red spring wheat flour were investigated. As the tuber flour level was increased, developing time and stability of dough decreased. Incorporation of sodium stearoyl-2-lactylate (SSL) increased dough strength for blends containing cassava starch or yam flour. Extensigram data showed an increase in the proportional number as the percentage of cassava starch or yam flour in the blend was increased. With blends containing more than 15% cassava starch, however, the proportional number tended to level off. In all cases, the area under the extensigram curve decreased as the percentage of tuber flour in the blend increased. With the conventional breadbaking procedure, acceptable bread could be produced up to the 15% level of incorporation of cassava starch or yam flour. Although acceptable bread could be produced with 10% cassava flour, difficulties were encountered with the dough handling properties. Blends containing yam flour, up to the 10% level, produced the best French-type bread, while those containing 5 and 10% cassava starch produced the best white pan bread. Blends containing cassava starch showed the best results with the continuous breadbaking procedure. Addition of 0.5% SSL to the cassava starch blends improved the internal characteristics of the continuous bread. Blends with yam flour produced the poorest continuous bread. Regardless of the type of breadbaking procedure, blends containing cassava starch showed a better baking response than did those with cassava flour.

Greater emphasis has been placed on the use of composite flours in breadbaking during the last ten years. Partial replacement of wheat flour, the cereal unique for producing bread, with flour of indigenous crops would decrease the amount of wheat required for import for nearly all of the developing countries. Among the various crops cultivated in these countries, starchy tubers

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such as cassava and yam have been investigated as a possible source for partial replacement of wheat flour (1–6).

In general, the conventional breadbaking procedure has been used to evaluate the baking response of tuber wheat composite flours. The data have shown that from 5 to 15% of the tuber flour may be substituted for wheat flour without serious detrimental affects on bread quality. Certain bread improvers or strengtheners, however, such as sodium stearoyl- or calcium stearoyl-2-lactylate (SSL or CSL), or glyceryl monostearate should be included in the bread formula.

Dendy *et al.* (1) and Pringle *et al.* (7) studied the performance of cassava-wheat composite flour in different methods of bread production. They found that mechanically (Chorleywood) developed doughs produced better bread than the no-time dough or conventional breadbaking system.

The purpose of our investigation was to study primarily the physical dough properties and the baking response of tuber-wheat flour blends (TWFB) using various levels of cassava flour, cassava starch, or yam flour as the tuber source with and without incorporation of SSL. The baking response was investigated according to the type of bread produced and to the breadbaking system used.

MATERIALS AND METHODS

Tuber Source

Commercial samples of cassava flour and starch (*Manihot utilissima*) and arrowroot starch (*M. arundinacea*) obtained from Brazil were used throughout the study. Yam (*Dioscorea alata*) flour was also obtained from Brazil. This flour was prepared in the laboratory from peeled and tunnel-dried yam tubers.

Wheat Flour

A composite of hard red spring (HRS) wheat flours (Waldron variety) was used for flour blending to investigate physical dough properties and baking response using the conventional breadbaking system. A commercial sample of high-gluten HRS wheat flour was used to prepare the TWFB for evaluation by the continuous breadbaking procedure.

Preparation of Tuber-Wheat Flour Blends

TWFB were prepared with 5, 10, 15, and 20% levels of either cassava starch or yam flour. Blends containing cassava flour had 5, 10, and 15% of the tuber flour. The blends were used for both physical dough testing and baking studies.

Physical Dough Testing

The farinograph and extensigraph were used to determine the physical dough properties of different TWFB with and without incorporation of SSL. For the farinograph studies the 50-g bowl with a 50-g sample was used and with the extensigraph a 100-g sample was used. Doughs were mixed in a National mixer (National Mfg. Co., Lincoln, NB) using a 100–200-g bowl. For both tests, measurements were made with and without incorporating SSL (0.50%).

Baking Studies

Conventional Breadbaking Procedure. The various TWFB were baked using the conventional straight-dough procedure. A white pan bread and a French-type bread were produced. The baking formulas used, with ingredients expressed on a flour basis, were as follows:

Ingredients	*White Pan Bread*	*French-Type Bread*
Flour	100 g (14% mb)	250 g (14% mb)
Salt	2.0%	2.0%
Sugar	5.0%	1.2%
Compressed yeast	3.0%	2.0%
Shortening	3.0%	1.0%
Malt	0.05%	0.025%
Potassium bromate	10 ppm	15 ppm
SSL	0.5% (when used)	0.5% (when used)
Water	Variable	Variable

The amount of water used was estimated from the farinograph absorption and by the feel of the dough during mixing. A 3-hr fermentation period was used for both types of bread. The fermented doughs were proofed for 55 min at 30° C and 80% relative humidity. A baking time of 25 min at 230° C was used. Volume was measured by rapeseed displacement after cooling. Bread grain, texture, and crust and crumb color were scored the following day by comparison with the control (100% wheat flour bread).

Continuous Breadbaking Procedure. The method of D'Appolonia (8) was used for the continuous breadbaking procedure. A Wallace & Tiernan

TABLE I
Farinograph Data of Tuber-Wheat Flour Blends

Source	**Blend (%)**	**Absorption**[a]		**Arrival Time (min)**		**Dough Developing Time (min)**		**Stability (min)**	
		No SSL	**0.5% SSL**	**No SSL**	**0.5% SSL**	**No SSL**	**0.5% SSL**	**No SSL**	**0.5% SSL**
Control (HRS wheat flour)	...	63.2	62.1	3.0	4.0	5.5	9.0	11.0	18.5
Cassava flour	5	67.4	65.8	3.5	1.5	6.5	2.5	7.5	6.5
	10	74.4[b]	71.0	4.5[b]	1.5	6.0[b]	2.0	4.5[b]	2.0
	15	79.5[b]	76.4	5.0[b]	1.5	6.0[b]	2.0	4.5[b]	1.5
Cassava starch	5	62.2	61.3	2.5	1.5	5.0	10.5	12.5	20.5
	10	62.5	60.2	2.5	1.0	5.5	9.0	9.5	22.0
	15	60.2	59.4	1.5	1.5	4.5	2.5	11.0	17.5
	20	60.0	59.3	0.5	0.5	4.0	2.0	9.5	17.5
Yam flour	5	62.6	62.0	3.5	3.5	6.5	8.0	8.0	13.5
	10	62.6	62.5	2.5	2.5	5.5	8.0	8.5	11.5
	15	62.8	61.8	2.5	2.0	5.0	7.0	8.5	12.5
	20	63.0	61.9	2.5	2.0	4.5	6.5	6.5	12.5

[a]Values expressed on 14.0% mb.
[b]Farinograms contained two peaks, with data shown based on second peak.

Laboratory model continuous unit (Baker Process Co., Belleville, NJ) was used to make the continuous bread. The baking formula, with percentage of ingredients based on flour weight, was as follows:

Flour	5,000 g
Sugar	8.0%
Salt	2.25%
Milk	2.0%
Shortening	3.25%
Yeast food	0.5%
Compressed yeast	2.75%
Potassium bromate	60 ppm
Potassium iodate	12 ppm
SSL	0.5% (when used)
Water	Variable

The broth, which contained 60% of water based on the flour weight, plus sugar, salt, milk, yeast food, and yeast, was allowed to ferment for 2 hr. This material was then transferred to the mixing bowl of a Hobart mixer and the remaining water added, plus the flour, liquid shortening, and oxidation solution. Baking absorption was 2–4% higher than for the farinograph absorption. Mixing only to incorporate the ingredients thoroughly was allowed at this stage. The premixed dough was transferred to the cylinder of the continuous unit. The dough was forced into the developer head by water pressure where it was subjected to mechanical development. Two different impeller speeds (rpm) were

TABLE II
Extensigraph Data of Tuber-Wheat Flour Blends

Source	Blend	No SSL				0.5% SSL			
	(%)	45-min A[a]	Rest B[b]	180-min A	Rest B	45-min A	Rest B	180-min A	Rest B
Control (HRS wheat flour)	...	263	0.29	235	0.45	253	0.32	230	0.53
Cassava flour	5	265	0.20	227	0.29	241	0.28	250	0.32
	10	...	...	...	...	...	...	...	...
	15	...	...	...	...	...	...	...	...
Cassava starch	5	245	0.28	232	0.45	233	0.33	210	0.53
	10	226	0.31	186	0.57	212	0.40	190	0.66
	15	175	0.35	185	0.55	202	0.41	173	0.73
	20	219	0.30	185	0.60	213	0.35	165	0.72
Yam flour	5	232	0.34	200	0.64	257	0.36	182	0.70
	10	225	0.39	203	0.63	228	0.42	152	0.98
	15	200	0.51	150	0.80	155	0.73	115	1.43
	20	182	0.45	153	0.66	162	0.59	133	1.03

[a]A = extensibility in millimeters.

[b]B = proportional number, or $\frac{\text{resistance to extension}}{\text{extensibility}}$

used for each batch of dough. The doughs were extruded into bread pans, proofed under controlled temperature and relative humidity for 55 min, and baked for 20 min at 230° C. Volume was measured by rapeseed displacement after cooling. Bread grain, texture, and crust and crumb color were scored the following day by comparison with the control.

RESULTS AND DISCUSSION

Physical Dough Testing

Table I shows the farinograph data for the control wheat flour and the various TWFB with and without incorporation of SSL. Absorption of the blends containing cassava flour increased as the percentage of tuber flour was increased. This result agrees with the high amount of damaged starch present in cassava flour that was reported previously (9). Abnormal-type farinogram curves (two peaks) were obtained with the incorporation of 10 and 15% cassava flour. The blends containing cassava starch had the lowest farinogram absorptions, which progressively decreased as the level of starch increased. No appreciable variations in farinogram absorption were observed with the blends containing yam flour. The high water-binding capacity of yam starch (10) as well as the contribution due to the yam water-soluble polysaccharides (11) may have been responsible for not observing the negative absorption effect. Dough developing time decreased as the percentage of either cassava starch or yam flour in the blends was increased.

The farinogram stability in most cases decreased with an increase in wheat flour dilution, indicating an overall weakening of the dough. Particularly noteworthy was the higher stability of the blends containing cassava starch, compared with the other blends and, in some cases, with the control.

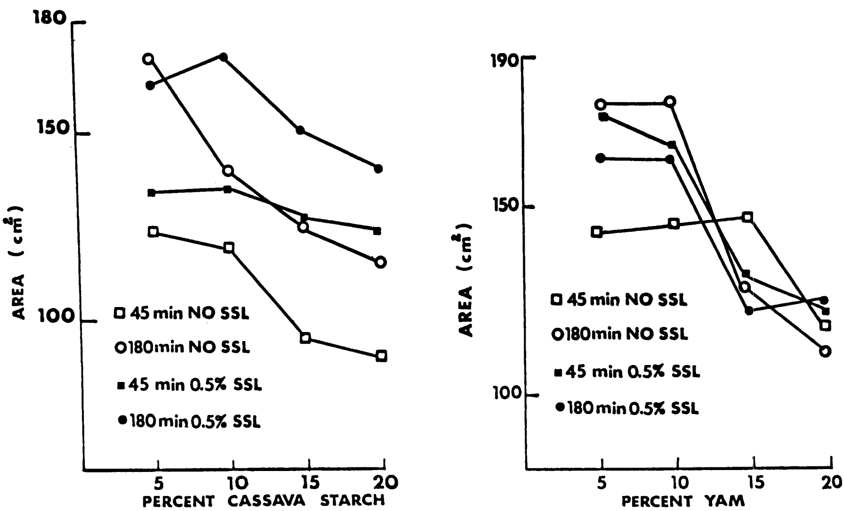

Fig. 1. a) Effect of blends containing cassava starch on extensigram area. b) Effect of blends containing yam flour on extensigram area.

TABLE III
Baking Data for Conventional White Pan Bread (100-g "Pup" Loaves) Made From Tuber-Wheat Flour Blends

Source	Blend (%)	Baking Absorption (%)		Loaf Volume (cc)		Sp Vol (cc/g)		Crust Color[a]		Crumb Color[a]		Grain and Texture[a]	
		No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL
Control (HRS wheat flour)	...	62.0	61.0	785	880	5.7	6.3	9.5	9.5	9.0	9.5	8.5	9.0
Cassava flour	5	66.0	64.6	685	825	4.8	6.1	9.0	10.0	8.0	9.0	7.0	8.5
	10	73.0	69.8	735	775	5.1	5.3	8.5	9.5	7.0	8.5	6.5	7.0
	15	78.0	75.2	700	775	4.8	5.4	8.0	8.5	6.5	7.0	5.5	6.5
Cassava starch	5	62.2	61.2	805	860	5.8	6.3	9.5	9.5	9.5	9.5	8.5	9.0
	10	62.5	60.2	760	820	5.5	6.1	9.5	9.5	9.5	10.0	8.5	8.5
	15	60.2	59.4	760	815	5.6	6.0	9.0	9.0	10.0	10.0	8.0	8.5
	20	60.0	59.3	745	760	5.3	5.6	8.0	8.0	10.0	10.0	7.5	8.0
Yam flour	5	62.0	61.0	795	780	5.9	5.9	10.0	9.5	8.0	8.5	8.5	8.0
	10	62.0	62.0	815	825	6.1	6.2	9.5	9.5	7.5	8.0	8.0	8.5
	15	62.0	61.0	795	825	6.0	6.2	9.5	9.0	6.5	7.0	8.0	8.5
	20	62.5	61.0	760	800	5.7	6.0	9.0	9.0	6.0	6.5	7.0	7.5

[a]Values are based on score of 1–10, with 10 being best score.

TABLE IV

Baking Data for Conventional French Bread Made From Tuber-Wheat Flour Blends

Source	Blend (%)	Baking Absorption (%)		Loaf Volume (cc)		Sp Vol (cc/g)		Crust Color[a]		Crumb Color[a]		Grain and Texture[a]	
		No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL
Control (HRS wheat flour)	...	62.0	61.0	2,250	2,200	7.1	7.0	8.0	8.5	9.0	9.5	9.0	9.0
Cassava flour	5	65.0	62.6	2.100	2,250	6.6	7.1	9.5	9.0	9.5	9.5	8.5	9.0
	10	71.0	67.8	2,175	2,175	6.4	6.6	9.5	9.5	9.0	9.0	7.5	8.5
	15	76.0	73.3	1,700	1,950	5.5	5.7	9.5	9.5	6.5	8.0	4.5	7.5
Cassava starch	5	60.2	59.2	2,275	2,050	7.1	6.5	8.5	8.5	9.0	9.5	8.5	8.5
	10	60.5	58.2	2,125	1,950	6.7	6.1	8.0	8.0	9.5	10.0	7.5	8.0
	15	58.2	57.4	2,100	1,800	6.5	5.8	7.5	7.5	10.0	10.0	7.0	7.5
	20	58.0	57.3	1,950	1,825	6.2	5.6	7.5	7.5	10.0	10.0	6.5	7.5
Yam flour	5	61.5	60.6	2,300	2,275	7.4	7.5	8.5	9.0	9.5	10.0	9.5	9.5
	10	61.5	61.5	1,900	2,075	6.2	6.8	9.0	9.5	8.5	9.5	8.5	9.0
	15	62.8	61.0	1,950	1,900	6.2	6.0	9.5	10.0	8.0	8.0	8.0	7.5
	20	63.7	61.5	*[b]	1,875	*	6.0	9.5	10.0	5.5	7.0	4.0	7.5

[a]Values are based on score of 1–10, with 10 being best score.

[b]Asterisk indicates dough collapsed at end of proofing period.

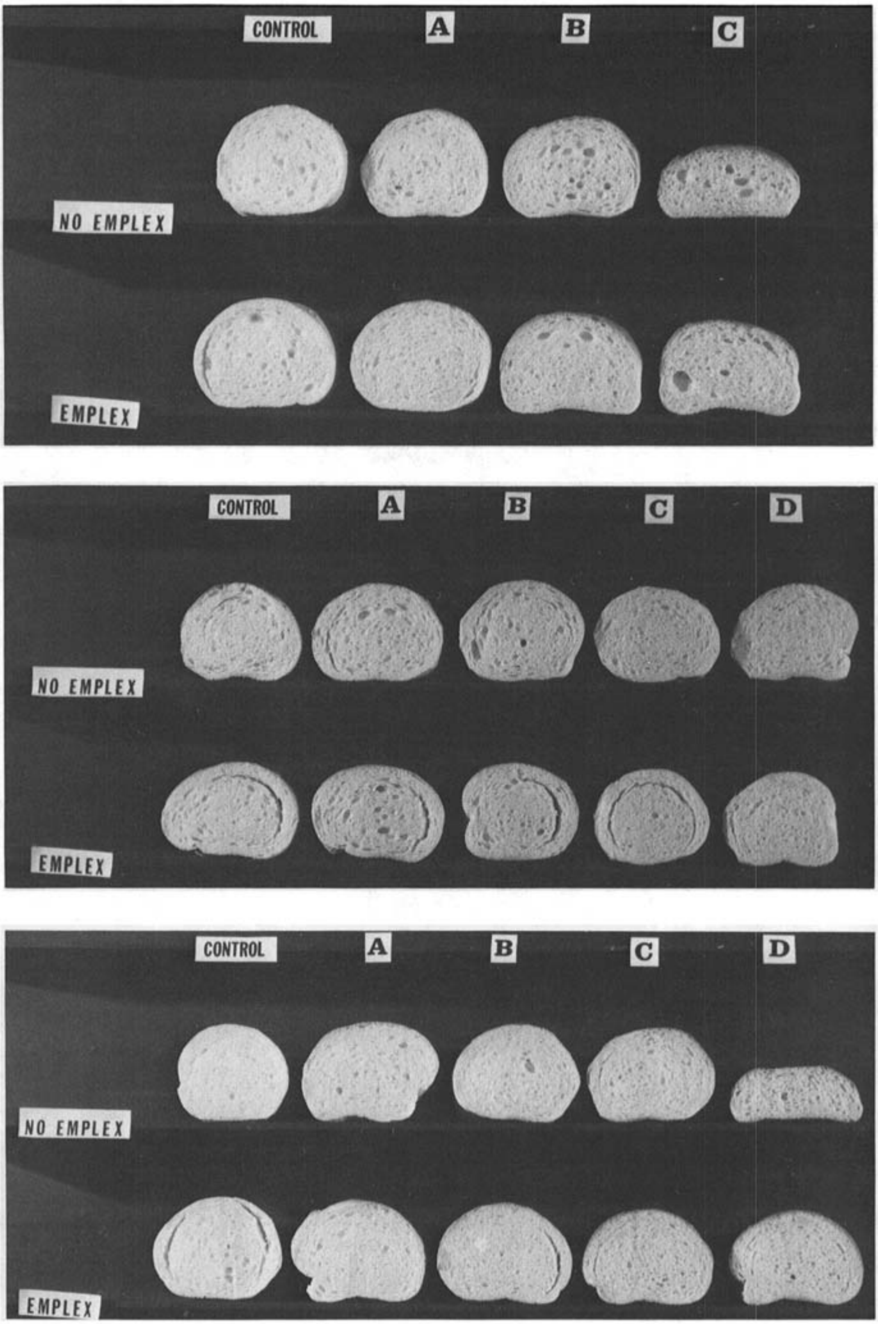

Fig. 2. Internal appearance of French-type bread containing various tuber flours. Top: Wheat-cassava flour. Middle: Wheat-cassava starch. Bottom: Wheat-yam flour. Tuber level: A, 5%; B, 10%; C, 15%; D, 20%.

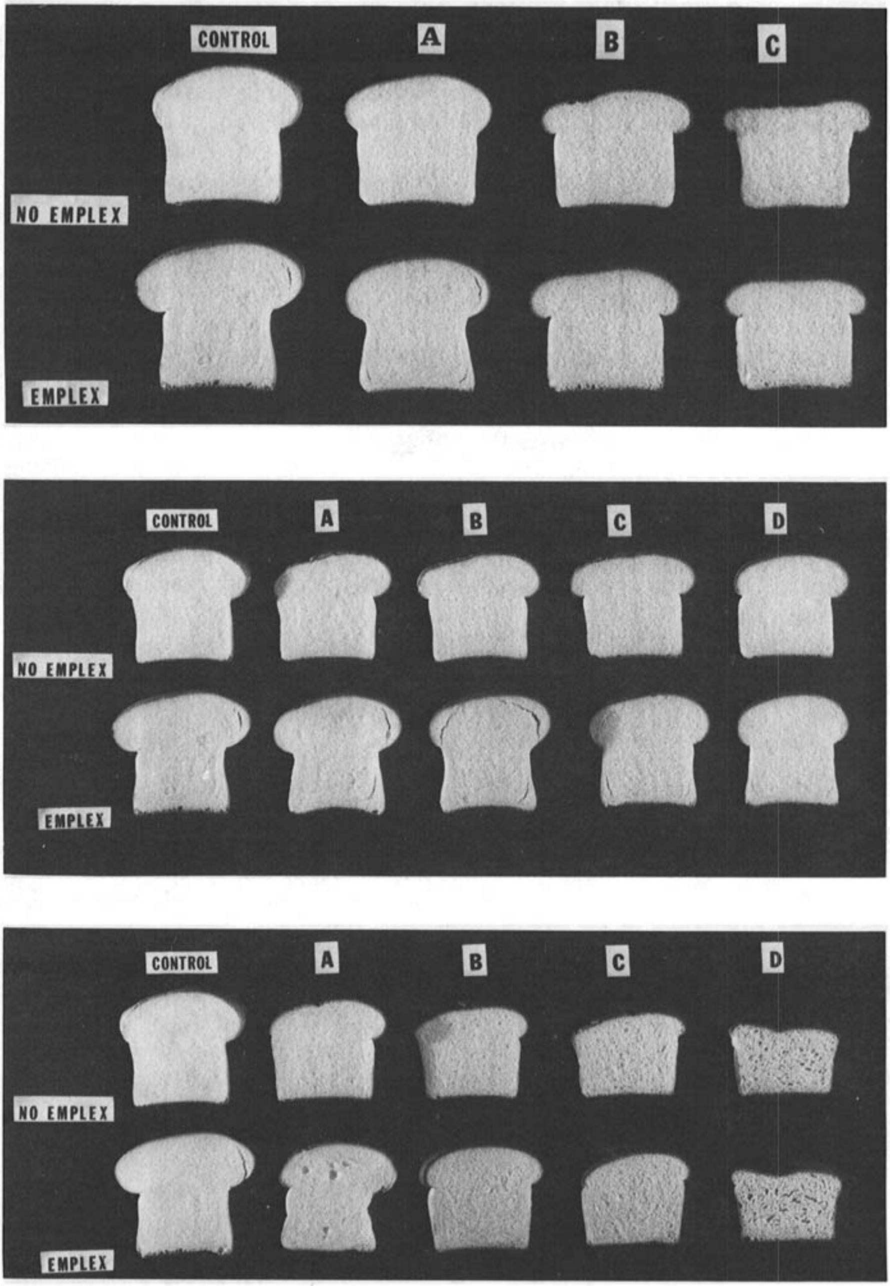

Fig. 3. Internal appearance of continuous bread containing various tuber flours. Top: Wheat-cassava flour. Middle: Wheat-cassava starch. Bottom: Wheat-yam flour. Tuber level: A, 5%; B, 10%; C, 15%; D, 20%.

Addition of 0.50% SSL based on the flour weight decreased farinogram absorption for all TWFB. Blends containing cassava flour with SSL gave lower farinogram stability and developing time values than did the corresponding blend without SSL; this reflects the abnormal-type farinogram behavior with these blends. The increase in stability for blends containing yam flour or cassava starch on addition of SSL indicated an increase in dough tolerance to mixing.

Table II shows the proportional numbers and extensibility values calculated from the extensigrams for the various TWFB with and without incorporation of SSL. Data for cassava flour blends at 10 and 15% are not given, since these doughs were sticky and impossible to mold for the extensigraph determination. An increase in the proportional number (R/E) occurred up to 15% incorporation of cassava starch or yam flour; thereafter it tended to level off. Extensigrams containing 30% cassava starch confirmed this trend. With 30% yam flour, however, a higher proportional number was obtained than with 20% yam flour. Although no unequivocal trend could be established for the yam flour blends, they had the highest proportional number values of the TWFB—the greater the proportional number, the shorter the dough.

Addition of 0.5% SSL based on flour weight increased the proportional number of all TWFB compared with the corresponding extensigraph without SSL.

Figure 1 shows the area under the extensigram curve for the various TWFB. The area decreased as the percentage of tuber in the blends was increased. In most cases, the area was greatest with the blends containing yam flour.

TABLE V
Baking Data for Continuous Bread Made From Tuber-Wheat Flour Blends

Source	Blend (%)	Optimum Developer Speed (rpm)		Baking Absorption[a] (%)		Loaf Volume (cc)		Sp Vol (cc/g)	
		No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL
Control (HRS wheat flour)	...	165	165	70.0	68.0	2,500	2,700	5.8	6.3
Cassava flour	5	160	160	70.0	67.5	2,375	2,400	5.5	5.6
	10	160	160	74.0	72.0	2,250	2,425	5.2	5.7
	15	160	160	77.0	75.0	2,150	2,075	4.9	4.8
Cassava starch	5	165	165	66.3	64.2	2,550	2,675	5.8	6.1
	10	165	165	65.2	64.6	2,600	2,600	5.9	6.0
	15	165	165	64.2	64.4	2,575	2,675	5.8	6.1
	20	165	165	63.5	63.3	2,550	2,625	5.7	6.0
Yam flour	5	150	140	64.6	64.8	2,350	2,500	5.3	5.8
	10	150	150	64.5	64.5	2,200	2,350	4.9	5.3
	15	150	160	67.8	66.7	2,125	2,250	4.8	5.0
	20	180	180	68.4	67.4	1,700	1,775	3.7	3.9

[a]Values expressed on 14% mb.
[b]Values are based on score of 1–10, with 10 being best score.

Baking Studies

Conventional Breadbaking System. Tables III and IV show the baking data for the conventional white pan and French-type bread, respectively. Baking absorption for both types of bread followed the same trend observed with the farinograph absorption. Blends containing cassava flour resulted in dough handling problems during mixing and processing. During mixing, the dough adhered to the sides of the mixing bowl, making it necessary to stop the mixer periodically and scrape the bowl. Handling of the dough after mixing was also difficult due to its sticky nature. Doughs containing cassava starch or yam flour did not present any handling problems.

Loaf volume decreased as the percentage of tuber in the blends increased. The loaf volume for the French-type bread containing the highest concentration of yam flour was not recorded, since it collapsed at the end of the proofing period. As the percentage of cassava flour and yam flour increased, the bread crust color increased in darkness. The 20% level of the yam flour bread produced the darkest crust color of the various samples. The darkening effect was due in part to the higher sugar content in cassava and yam flour (9) compared with wheat flour. In contrast, cassava starch diluted the natural sugars in wheat flour, resulting in bread with a pale crust color. The dark crust color obtained with cassava and yam flour improved the appearance of the French-type bread, whereas it was detrimental to the white pan bread. Addition of 0.50% SSL based on the flour weight improved the overall external appearance in all cases. Particularly noteworthy was the improving effect of SSL with the French-type bread for the

Crust Color[b]		Overall External Appearance[b]		Grain and Texture[b]		Crumb Color[b]		Overall Internal Appearance	
No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL	No SSL	0.5% SSL
9.0	9.5	8.5	9.0	9.0	9.0	9.0	9.5	9.0	9.8
9.5	9.5	8.5	9.0	9.0	9.0	10.0	10.0	8.5	8.5
9.0	9.0	7.5	8.0	8.5	8.5	10.0	10.0	8.0	8.5
8.0	8.0	6.5	6.5	8.0	8.0	8.0	8.5	7.5	8.0
9.0	9.5	8.0	8.5	9.0	9.5	9.5	10.0	9.0	9.5
8.5	8.0	8.0	8.5	9.0	9.5	9.0	10.0	9.0	9.5
7.0	8.0	8.0	8.5	9.0	9.5	9.0	10.0	9.0	9.5
6.0	7.0	7.5	8.5	9.0	9.5	9.0	10.0	8.0	9.5
8.0	8.5	8.0	8.0	8.5	8.5	8.5	9.5	8.5	8.5
7.5	7.5	6.5	7.0	7.5	8.0	8.5	9.0	7.5	8.0
7.5	7.5	5.0	5.5	6.0	6.0	7.5	8.0	6.0	6.0
6.5	5.5	4.0	4.0	3.0	3.0	4.5	5.0	3.0	3.0

highest level of cassava and yam flour incorporated.

Because cassava starch diluted the pigments responsible for the color in wheat flour, bread containing cassava starch had a whiter crumb color than did the control. Crumb color increased in grayness with increasing amounts of cassava and yam flours. Addition of 0.50% SSL improved crumb color of the corresponding loaf containing no SSL. Grain and texture of the bread became open and dense as the level of cassava flour and cassava starch was increased, while the grain was more circular with bread containing yam flour. Reconstitution studies (10) have shown that in a gluten-starch-water–soluble system containing either cassava or yam starch, the resulting bread had an open, round grain. In all cases, the overall internal appearance was improved on addition of SSL. Cassava flour-containing bread was the poorest. The best grain and internal appearance for French-type bread was obtained with those blends containing 5 and 10% yam flour, whereas those blends containing 5 and 10% cassava starch produced the best white pan bread.

Figure 2 illustrates the internal appearance of conventional French-type bread containing various TWFB with and without incorporation of SSL. The improving effect resulting from incorporation of SSL to 15 and 20% cassava and yam flour bread, respectively, is evident. The separation of the crumb from the crust in the bread containing the SSL was probably due to the fact that this bread was frozen and then thawed prior to photographing the loaves.

Continuous Breadbaking System. Table V shows the continuous breadbaking data of the control wheat flour and the various TWFB with and without addition of SSL.

Optimum development speed, defined as the lowest speed at which bread of acceptable quality could be produced (12), increased as the percentage of yam flour in the blends increased. No appreciable difference in development speed was observed for the other TWFB. Loaf volume of the bread containing cassava starch was somewhat similar to that of the control bread—up to the 20% level of addition. In all cases, addition of SSL improved the loaf volume for a particular blend. Cassava starch and yam flour blends produced the best and poorest continuous bread, respectively. Addition of SSL improved the overall bread quality for all TWFB. The internal appearance of bread containing cassava starch plus SSL, regardless of the tuber level, was similar or superior to the control. Figure 3 illustrates the internal appearance of the continuous bread containing the various TWFB with and without incorporation of SSL. The poor internal characteristics of the bread containing yam flour is most evident.

SUMMARY AND CONCLUSIONS

This study has shown that in addition to the effect on physical dough properties, tuber-wheat flour blends have a particular breadbaking response, depending on the type of bread produced and the breadbaking system used. The farinograph data indicated a general weakening of the dough, but the extensigraph data indicated an "oxidative" effect when the TWFB were allowed to rest.

In the conventional breadbaking procedure, acceptable bread could be produced up to the 15% level of incorporation of cassava starch or yam flour. Dough handling characteristics of the blends containing cassava flour were one of the major problems in the conventional breadbaking procedure.

Blends containing yam flour, up to the 10% level, produced the best French-type bread, while the blends containing 5 and 10% cassava starch produced the best white pan bread.

Among the tubers investigated, cassava starch blends were the most suitable for the continuous breadbaking system. Although bread containing cassava starch-SSL had internal characteristics similar to the control, dilution of wheat flour with starch may increase the staling rate (13), thus making this aspect a worthy consideration.

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