CHARACTERIZATION OF STARCHES FROM VARIOUS TUBERS AND THEIR USE IN BREAD-BAKING[1]

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ABSTRACT

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Physicochemical properties of starches isolated from yam (*Dioscorea alata*), cassava (*Manihot utilissima*), and arrowroot (*Maranta arundinacea*) were investigated in an attempt to relate these parameters to the performance of such starches in bread-baking. Molecular weight of the amylose triacetate isolated from the different starches ranged from 195,000 to 260,000, whereas intrinsic viscosity of the amylose and amylopectin ranged from 1.87 to 3.13, and from 1.55 to 2.35, respectively. Differences between the tuber starches were noted in pasting properties with the cassava starch having the lowest initial pasting temperature (49.0° C) and yam starch the highest value (73.5° C). Differences were noted in the water-binding capacity, intrinsic viscosity, absolute density, and amylose content of the tuber starches. Farinograms of starch-gluten-water-soluble blends indicated shorter dough-development time and stability with the use of cassava and arrowroot starch than with yam starch. Bread baked from the blends showed that the cassava and arrowroot produced a yellow and very gummy crumb. Amylograms of the freeze-dried bread crumb indicated that the cassava and arrowroot are gelatinized to a much greater extent during bread-baking than wheat or yam starch. The results suggest the importance of the pasting properties of the tuber starches when used in composite flours for bread-baking.

The use of composite flours for bread-baking has increased during the past 10 years. Cassava ranks sixth among the world's crops in amount of food produced. Because of this factor and also of its widely adapted growing conditions (1), this tuber has been studied extensively (2–5) for use in composite flours. The use of yam in composite flours, however, has been investigated only recently and thus the number of baking studies involving this tuber are few (3). In addition, arrowroot starch has not received attention regarding its use in bread-baking.

On a dry basis, tubers consist mainly of starch, making this biochemical constituent of composite flour quality worthy of investigation.

Studies conducted by Stamberg (6), Sandstedt *et al.* (7), and Harris and Sibbitt (8) have indicated that starch has an important role in wheat-flour quality. D'Appolonia and Gilles (9) found that starch from various wheat varieties responded differently in baking. Of the different starch properties examined, only absolute density showed a significant correlation with loaf volume of the gluten-starch loaves. Starches isolated from rice, corn, waxy corn, and potato have been shown to lack the baking quality of wheat starch (10). Seyam and Kidman (11), working with composite flours containing various levels of rice, corn, or cassava starch blended with wheat flour, found an inverse relation between loaf volume and amylograph peak height of the composite flour.

Rasper *et al.* (3) investigated the properties of starches and flours prepared from yam and cassava in bread-baking. Partial replacement of wheat flour by

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nonwheat flour showed that other components may play a more significant role than the variations in starch properties among the different nonwheat components.

The present study was undertaken to study the effect of different tuber starches in baking and to relate any differences that might be observed to the physicochemical properties of the corresponding starch. Concomitantly, the physical dough characteristics of the starches using a gluten:starch:water-solubles system were studied.

MATERIALS AND METHODS

Samples

Commercial samples of cassava (*Manihot utilissima*) and arrowroot (*M. arundinacea*) starch obtained from Brazil were used throughout the study. Yam starch (*Dioscorea alata*) was isolated experimentally from a tunnel-dried yam flour obtained from Brazil.

Gluten Isolation

Gluten, used for the physical dough-testing and -baking experiments, was isolated from a composite lot of hard red spring (HRS) wheat flour by the dough-kneading procedure (12). The protein content of the extracted gluten was 78.0% on a dry basis (13).

Isolation of Wheat Starch and Water-Solubles

Water-solubles and starch were isolated from the same flour used for the gluten isolation. Flour was mixed with distilled water in a 1:2 ratio (w/v) at low speed in a Waring Blendor (9). After centrifugation, the supernatant which represented the water-solubles was decanted, shell-frozen, and freeze-dried. The protein content was 30.0% on a dry basis. The residue was used for isolation of the starch by reslurrying with distilled water and subsequent centrifugation at 2000 × *g*. The sludge layer located on top of the prime starch was removed and the starch reslurried an additional two times. The isolated starch was allowed to air dry and then sieved on a U.S. Standard No. 70 sieve (nitrogen content was 0.02% on a dry basis).

Isolation of Yam Starch

Yam starch was isolated by slurrying yam flour (100 g) with 400 ml of a mixture of water and toluene (10% v/v) for 2 min in a Waring Blendor at low speed, followed by centrifugation at 2000 × *g* for 15 min. The floating protein-toluene layer, together with the water-soluble fraction, was decanted and the residue reslurried with the water-toluene mixture. The brown residue obtained was slurried with 350 ml of 2% NaOH solution, followed by centrifugation at 2000 × *g* for 15 min. The NaOH extracted residue was washed three times with distilled water. After each centrifugation, the brown mucilaginous layer was carefully removed from the prime starch. The white starch obtained after the third water washing was allowed to air dry and was then sieved through a U.S. standard No. 70 sieve. The nitrogen content of the yam starch was 0.04% on a dry basis.

Starch Fractionation

Starch was fractionated into amylose and amylopectin using the aqueous leaching procedure of Montgomery and Senti (14). Wheat and yam starch were leached at 98° C, whereas a temperature of 75° C was used for cassava and arrowroot.

Microscopy of Starch Granules

A Nikon microscope Model L-Ke with a built-in Koehler illuminator was used. The microscope was fitted with a Nikon automatic exposure setting Microflex Model AFM photomicrographic unit. Tuber starches were examined using a staining solution containing 0.1% potassium iodate and 0.4% iodine.

Photomicrographs of the different starches were obtained using a magnification of 400× under polarized light.

Granule size was determined using a 7.5-μ eyepiece lens calibrated against a micrometer.

Starch Physicochemical Properties

Damaged starch. Damaged starch was measured by its susceptibility to hydrolysis by α-amylase (15).

Intrinsic viscosity. Intrinsic viscosity was determined at 25° C in 1N NaOH as described by Lansky *et al.* (16).

Amylose content. The amylose content was determined by the iodine colorimetric method as described by McCready and Hassid (17).

Molecular weight of the amylose triacetate. Molecular weight of the amylose triacetate, prepared as described by Potter and Hassid (18), was determined using a high-speed membrane osmometer Model CSM-2 (Melabs Inc., Palo Alto, California). Measurements were made using chloroform as the solvent at 25° C.

Number of glucose units per segment. The number of glucose units per segment was determined by periodate oxidation as described by Potter and Hassid (19).

Starch granule density. Absolute density of the different starches was determined by the xylene displacement method (20) at 30° C. The starches were predried for 4 hr in a vacuum oven at 120° C prior to the determination.

Water-binding capacity. Water-binding capacity was determined by the modified method of Medcalf and Gilles (21).

Starch Pasting Properties

Pasting properties of the different starches were investigated with the Brabender amylograph using the carboxymethyl cellulose (CMC) method as described by Medcalf and Gilles (21). Fifteen grams of starch (dry basis) and 3.6 g of CMC in 450 ml distilled water were used. The properties measured were temperature of initial pasting, peak height, temperature of maximum viscosity, 15-min height and height after cooling to 50° C.

The amylograph was also used to examine the pasting properties of freeze-dried bread crumb containing the different starches (22). Prior to analysis, the bread crumb was ground to pass through a U.S. standard No. 30 sieve. The amylogram curves were obtained using 60.0 g (dry basis) of bread crumb in 450 ml distilled water.

Physical Dough Testing

A 50.0-g sample (14.0% moisture basis) was used to study the mixing properties in the farinograph. The curve was centered on the 500 BU line. Common lots of gluten and water-solubles were used with the different starches. The gluten:starch:water-soluble blends contained 18.0% gluten, 75.3% starch, and 6.7% water-solubles (on a dry basis).

Baking Study

The gluten:starch:water-soluble blends used for the physical dough-testing studies were baked into 25.0-g pup loaves using a lean-type baking formula.

The baking formula was as follows:

Flour	25.0 g
Salt	1.0%
Sugar	5.0%
Yeast	3.0%
Malt	0.05%
Water	Variable
Potassium bromate	Variable

Four levels of bromate (0, 10, 20, and 30 ppm) were used. The baking procedure was essentially that described by D'Appolonia *et al.* (23), with the exception that a fermentation time of 2 hr was employed and the loaves were baked for 20 min at 230° C. Baking absorption was determined by an examination of the dough during mixing and also by the feel of the dough of previous bakes at punching and panning.

Mixing time varied with the use of the different starches and was determined by physical examination of the dough. Loaf volumes were measured by rapeseed displacement after cooling. Crust color, grain, and texture, and crumb color of the different loaves were scored using the wheat-starch-containing bread as standard.

RESULTS AND DISCUSSION

Microscopy of Starch Granules

Starch granules of yam, cassava, and arrowroot under polarized light are shown in Fig. 1a to 1c. Yam starch (Fig. 1a) shows relatively homogeneously shaped granules with the majority being trigonally rounded. They ranged in width and length from 25.4 to 31.2 μ and 27.0 to 50 μ, respectively, with the polarization crosses being eccentric. Fissured granules were absent. Cassava starch (Fig. 1b) and arrowroot starch (Fig. 1c) were similar in appearance, with the majority being round. The diameter for cassava and arrowroot starches varied from 7.8 to 19.5 μ and 3.9 to 15.6 μ, respectively. Their polarization crosses were centric and some fissures were observable.

Starch Physicochemical Properties

Nitrogen content for the various starches ranged from 0.0 to 0.04% and the damaged starch content was 0.5% for all tuber starches investigated.

Table I shows some of the physicochemical properties of the different starches with data for wheat starch included for comparison purposes. Yam and cassava had the highest and lowest absolute density, respectively. The absolute densities were slightly higher than those reported for wheat starch (9). It is assumed that the water-binding capacity of a starch represents the water absorbed by the granule and/or the granular surface. Although yam starch had the highest absolute density, it also had the highest water-binding capacity. Such results may be due to the isolation procedure for yam starch and/or differences (in surface area) of the starches investigated. Although, as stated previously, the nitrogen content in the yam starch was low, the possible presence of mucilaginous material on the isolated starch also could have been responsible for the high water-binding capacity. Intrinsic viscosity for the various starches in 1 *N* NaOH solution ranged from 2.15 to 3.10. The intrinsic viscosity for arrowroot starch was similar to values reported by Medcalf and Gilles (21) for wheat starch. Yam starch had the highest intrinsic viscosity. The amylose content of the yam starch was slightly higher than the value of 21% reported by Rasper and Coursey (24), while the values for cassava and arrowroot are somewhat lower than those previously reported (25–27). Table II shows some physicochemical properties of starch fractions from the different sources. The average-unit chain length for

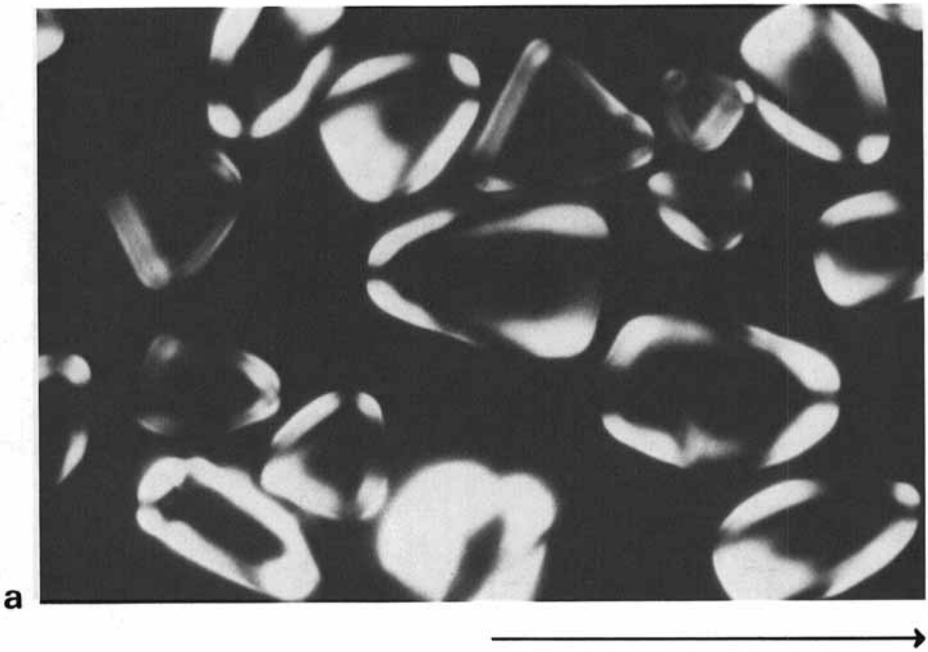

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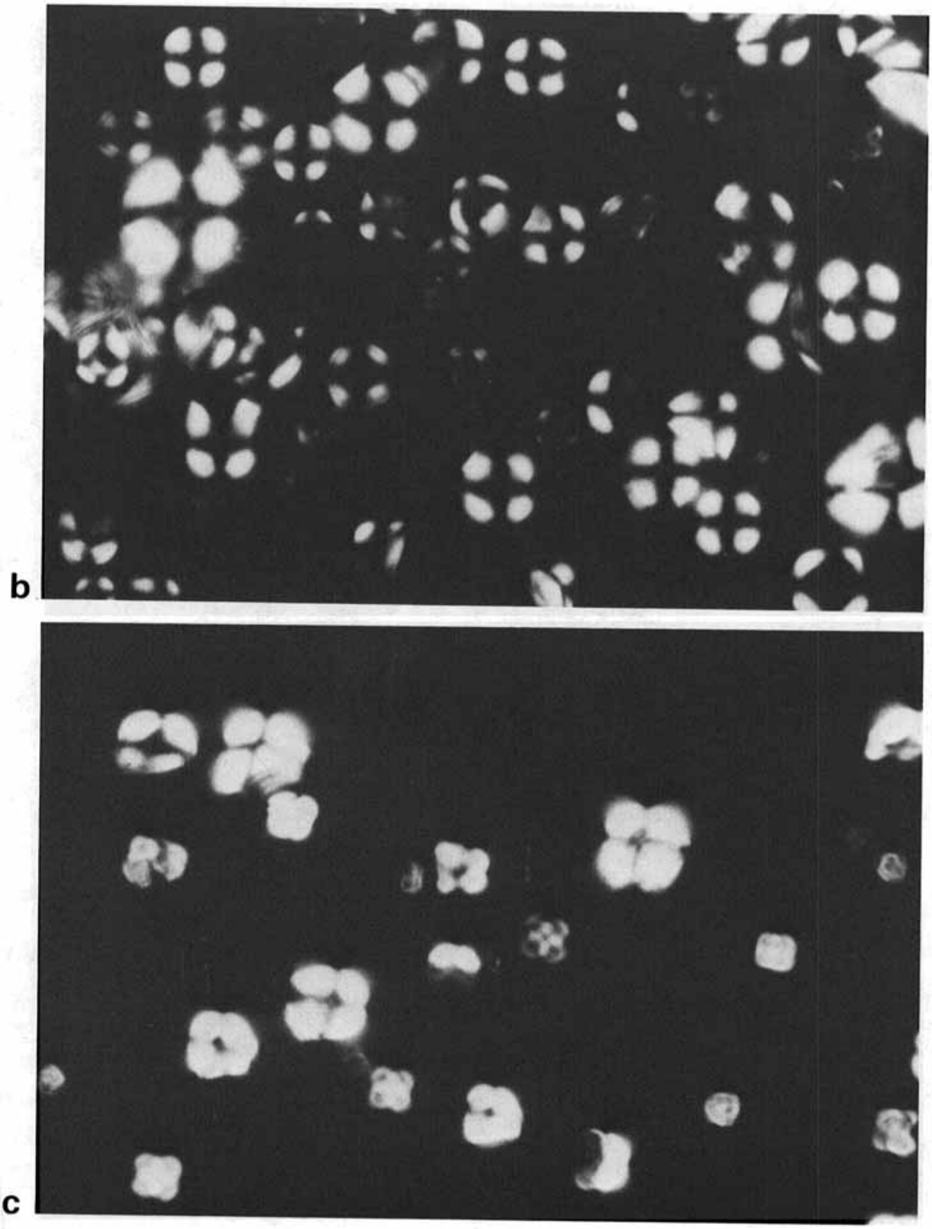
Fig. 1. a) Photomicrographs of yam starch granules. 400×. b) Photomicrographs of cassava starch granules. 400×. c) Photomicrographs of arrowroot starch granules. 400×.

yam amylopectin was higher than that obtained for cassava and arrowroot. There was no direct relation between intrinsic viscosity and molecular weight. Molecular weight of the amylose from the cassava and arrowroot starches studied was higher than that reported for wheat-starch amylose (18).



Starch Pasting Properties

Amylograph data for the different tuber starches are given in Table III. Cassava and arrowroot starch showed a lower initial pasting temperature and higher peak height than yam starch. No value for peak height for yam starch is given in Table III since no distinct peak was obtained. The drop in viscosity, when stirred for 15 min at 95° C for cassava and arrowroot, indicated that the gels are easily broken upon continuous stirring. Amylogram curves for these two particular starches showed a sharp increase in viscosity once the initial pasting temperature was reached, indicating a weak type of bonding force maintaining the granule structure.

Yam starch showed a considerably higher initial pasting temperature and a slower viscosity increase than cassava and arrowroot starch once the initial pasting temperature was reached. This could indicate a stronger type of bonding force in yam starch. This starch, unlike cassava and arrowroot, also appeared to exhibit a second stage of gelatinization at 85° C (Fig. 2). The two stages of gelatinization are characteristic of wheat starch. A direct relation between initial pasting temperature (Table III) and absolute density (Table I) was found, supporting the idea of "granule compactness."

TABLE I
Physicochemical Properties of Tuber Starches

Starch Source	Absolute Density at 30° C g/ml	Water-Binding Capacity %	Intrinsic Viscosity [n]	Amylose Content %
Yam	1.51357	107.7	3.10	23.3
Cassava	1.48568	91.0	2.45	14.5
Arrowroot	1.49473	91.6	2.15	13.8
Wheat[a]				
hard red spring	1.473–1.476	83–91	1.68–2.45	23.4–26.9

[a] Data from Medcalf and Gilles (21).

TABLE II
Physicochemical Properties of the Tuber Starch Fractions

	Glucose Units per Segment	Triacetate mol wt	Intrinsic Viscosity [n]
Yam amylose	...	260,097	1.87
Cassava amylose	...	231,979	2.35
Arrowroot amylose	...	194,275	3.13
Wheat amylose	...	250,000[b]	2.78[c]
Yam amylopectin	25	...	2.05
Cassava amylopectin	21	...	1.55
Arrowroot amylopectin	22	...	2.35
Wheat amylopectin	23[a]	...	1.83[c]

[a] Data from Potter and Hassid (19).
[b] Data from Potter and Hassid (18).
[c] Data from Berry *et al.* (29).

Physical Dough-Testing

Table IV shows pertinent farinograph data obtained from the gluten:starch:water-soluble blends. A control prepared with wheat starch was included for comparative purposes. For the sake of clarity, the term yam, cassava, or arrowroot blend indicates a reconstituted flour using one of these starches with gluten and water-solubles extracted from wheat.

Cassava and arrowroot blends showed similar farinograph data which would agree with their similar physicochemical properties (Table I). The yam starch produced an abnormal-type farinogram curve, making it difficult to determine the parameters shown in Table IV.

The farinograph absorption for the cassava and arrowroot blends was directly related to the water-binding capacity of the respective starches. Peak time was considerably lower for the cassava and arrowroot-containing blends than for

TABLE III
Pasting Properties of Tuber Starches, with Incorporation of CMC

Starch Source	Temp. of Initial Pasting °C	Temp. of Maximum Viscosity °C	Peak Height BU	15-min Hold Height BU	50°C Height BU
Yam	73.5	95.0	...	170	310
Cassava	49.0	77.5	750	290	450
Arrowroot	52.0	80.5	710	300	420
Wheat[a]					
hard red spring	56.0–59.0	95.0	550–785	500–735	700–895

[a] Data from Medcalf and Gilles (21).

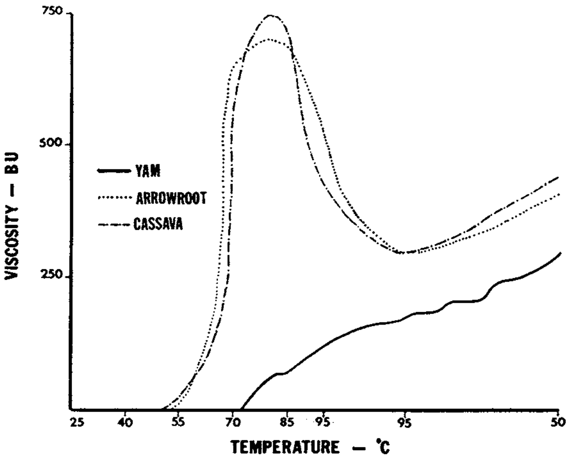


Fig. 2. Starch amylograph curves of yam, arrowroot, and cassava in the presence of carboxymethyl cellulose.

yam or wheat. Larsen (28) has shown that water absorption of wheat depends on the gluten protein and the water-binding capacity of the starch. Although gluten-water affinity is higher than wheat starch, the latter absorbs water faster than the former. Considering the high water-binding capacity of cassava and arrowroot starch, it is possible that, after their hydration, an excess of water was taken up by the gluten causing the observed drop in stability for these particular starch blends.

No difference in peak time was found between wheat and yam starch blends. Yam starch blend showed greater stability and a higher absorption than wheat starch. There was no significant relation between water-binding capacity of yam starch and farinograph absorption. However, as shown in the baking study, the absorption had to be increased considerably to achieve the proper baking consistency.

Baking Studies

Table V shows baking data for the blends containing the different starches and using a bromate level of 10 ppm—the level which produced the best loaves. Baking absorption and mixing time were the highest for the yam starch blend. A ratio of about 0.7 was found between baking absorption and water-binding capacity of the tuber starches investigated. Results of the bread evaluation indicated that the three tuber starches lack the baking quality unique to wheat starch.

On the basis of crumb color and crust color, the yam-starch blend produced

TABLE IV
Farinograph Data for Different Starch-Containing Blends[a]

Starch Source	Peak Time min	Stability min	MTI BU	Absorption %
Yam	3.5	23.0	10	60.4
Cassava	0.5	7.5	70	68.8
Arrowroot	1.0	7.5	50	68.4
Wheat	3.5	15.5	20	58.4

[a] Starch:gluten:water-soluble 75.3:18.0:6.7 (dry basis).

TABLE V
Baking Data for Different Starch-Containing Blends

Starch Source	Baking Abs. %	Baking-Mixing Time min	sp vol cc/g	Crust Color[a]	Grain and Texture[a]	Crumb Color[a]
Yam	72.1	5 1/2	6.7	9.5	7.5	9.0
Cassava	68.0	3 1/2	6.6	6.0	7.5	6.5
Arrowroot	68.0	3 1/2	7.0	6.5	7.5	6.5
Wheat	58.8	3 1/2	7.5	10.0	9.0	9.5

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

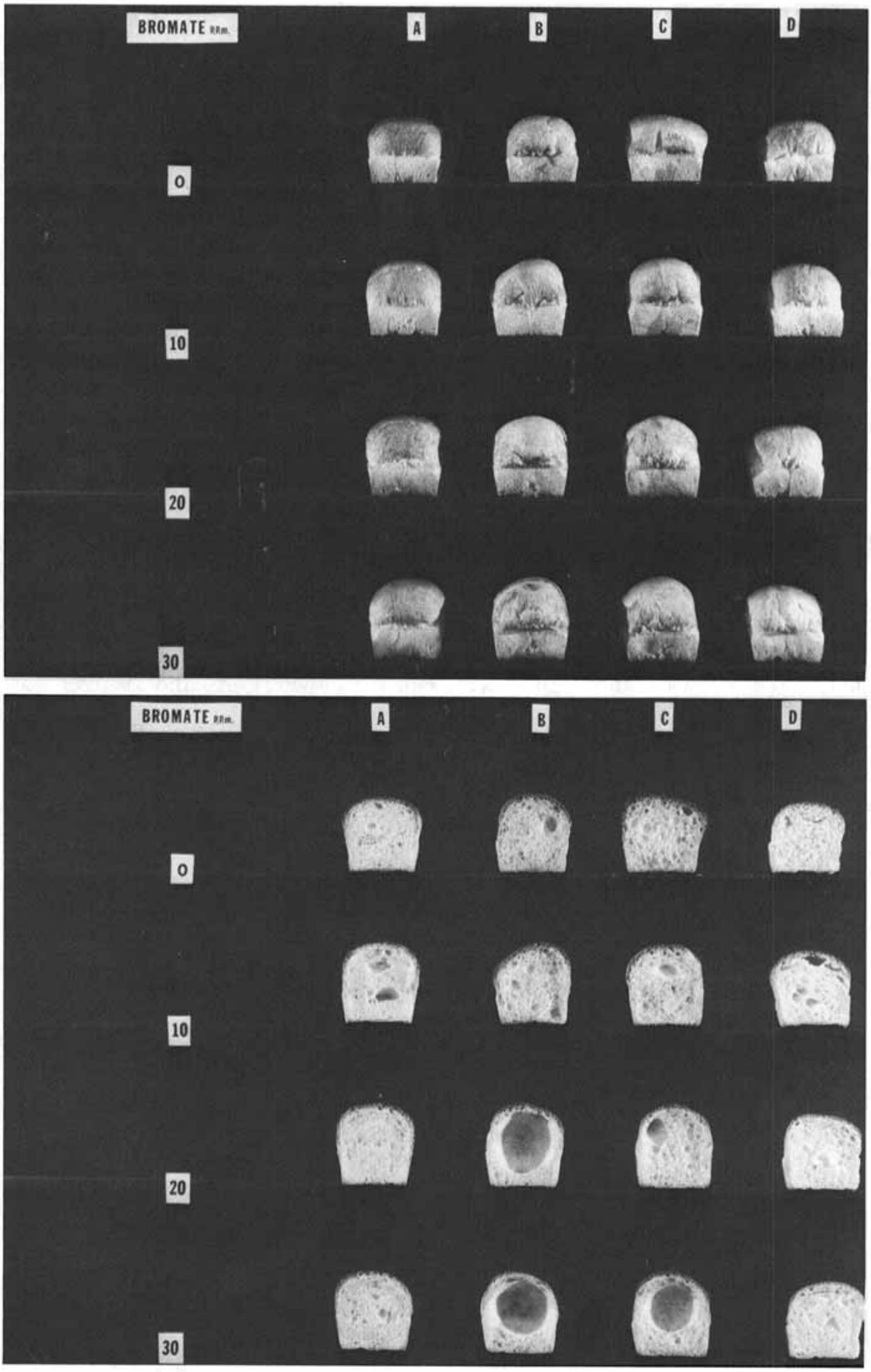


Fig. 3. a) Exterior and b) interior of gluten-starch-water-soluble bread containing different levels of potassium bromate. A, wheat starch; B, cassava starch; C, arrowroot starch; D, yam starch.

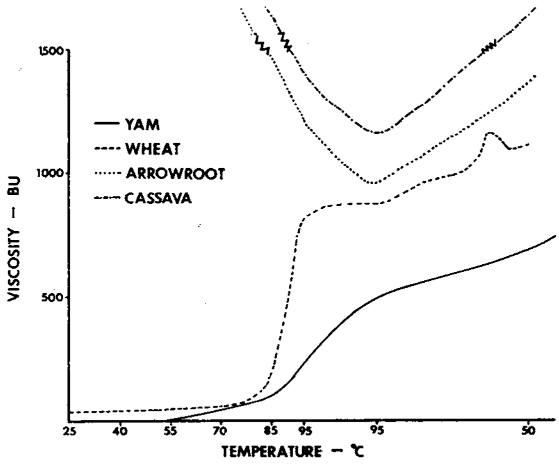


Fig. 4. Amylograph curves of yam-, wheat-, arrowroot-, and cassava-starch-containing bread crumb.

the best loaves, while cassava produced the poorest. Cassava and arrowroot blends gave loaves with a "dull" crust color, yellow crumb, and an open and gummy grain and texture.

Figure 3 shows the exterior and interior of the loaves containing 0, 10, 20, and 30 ppm bromate. The effect of the different bromate levels is very evident with the cassava and arrowroot blends. Use of bromate at 20 and 30 ppm gave loaves with a large hole for cassava-starch-containing bread, while arrowroot showed this effect at 30 ppm bromate. It could be possible that the higher levels of potassium bromate had a solubilizing or disintegrating effect on cassava and arrowroot starch.

The crumb appearance and texture suggested an essentially complete starch gelatinization when the starch source was cassava or arrowroot. Amylogram curves (Fig. 4) of the freeze-dried crumb, obtained from loaves at 10 ppm bromate and without addition of malt, showed a very high viscosity at 25° C for these starches, supporting the above observation. However, the curve for the bread crumb containing yam starch indicated that starch gelatinization during baking was considerably less than for that containing cassava or arrowroot.

The results have indicated that different starches respond differently in dough and baking properties. However, no unambiguous conclusion between physicochemical parameters and dough rheology were established. Of the parameters examined, water-binding capacity was related to baking absorption. Pasting properties of the starches were of major importance to bread crumb characteristics. The starch with the lowest gelatinization temperature caused the poorest bread crumb.

These results may indicate that physicochemical properties of nonwheat starches may be of major importance for their utilization in composite flours. High levels of bromate may be detrimental to baking properties, depending on the starch source.

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