Measurement of Hydration Capacity of Wheat Flour/Starch Mixtures

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ABSTRACT

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Methods for measuring water absorption and retention capacity of pure starches and of composite mixtures prepared by mixing wheat flour with starch were compared and the results were evaluated statistically. Although the responses to the increasing starch concentration were similar, the results were significantly dependent on the method used. The dependence of the hydration capacity of the composite mixture on the starch concentration usually reached the minimum value when approximately 30-35% of the wheat flour in the mixture was replaced by starch. Special attention was paid to a direct water absorption measurement by Baumann capillary apparatus. Over a sample weight range of 30-240 mg (with Millipore AA 0.80 μm membrane as sample carrier), the relationship between the water uptake and the weight of the sample was linear. The time required to reach the maximum reading on the capillary was approximately 10 min for flour and flour/starch mixtures and not more than 5 min for pure starches. The reproducibility was comparable with other evaluated methods (standard error 1.10 and 1.65% absorbed water for pure starch and flour/starch mixture, respectively). Unlike those of water retention techniques, the results were not affected by the leaching out of water solubles from the test material.

Determination of hydration capacity is one of the principal tests in quality evaluation of wheat flour. The relationship of the most commonly determined farinograph absorption to the actual hydration capacity as well as to the baking performance of flour has been the subject of many studies (Bushuk 1963, 1966; Shuey 1972; Sollars 1972, 1973a, 1973b). Because the farinograph test measures a rheological quality of dough prepared from the tested flour, the relationship may be affected by any treatment or addition of material that alters the rheological character of dough. Such may be the case in measuring water absorption of composite flours prepared by a partial replacement of wheat flour with starch.

In the present study, farinograph abosrption values of wheat flour/starch mixtures containing up to 40% added starch were compared with data obtained by three other methods. Two methods measured the water retention capacity against centrifugal force; the third directly measured the volume of water absorbed by a thin layer of the tested material. The reproducibility and response of the methods to increasing concentrations of starch in the flour/starch mixtures were also evaluated.

MATERIALS AND METHODS

Flours and Starches

Wheat flour was an untreated commercially milled flour (12.82% protein on 14% mb). Wheat flour/starch mixtures were prepared by replacing wheat flour with an equal amount of starch at concentrations ranging from 10 to 40% (on dry solids basis). All starches (wheat, rice, potato, tapioca) were commercially prepared undefatted thick boiling starches.

Farinograph Absorption—Method A

Farinograph absorption was determined in a 50-g stainless steel mixing bowl using a constant flour weight procedure (AACC 1969).

Centrifugal Force—Method B

Sollars' procedure (1973a) was used to determine water retention capacity against a centrifugal force of 1,000 × *g* (15 min) after 30-min hydration.

Centrifugal Force Using a Basket Centrifuge—Method C

A specially modified Fisher model 59 centrifuge with a perforated basket lined with Whatman No. 3 filter paper was used. The centrifuge and the procedure involving 17-sec hydration of the sample and 2-min 15-sec centrifugation at approximately 3,500 × *g* was described in full detail by Miller (1968).

Water Absorption—Method D

A small amount of sample (less than 240 mg) was evenly distributed in a thin layer on a Millipore AA 0.80 μm membrane (unless other type of sample carrier is mentioned), which was placed on the fritted glass plate of the Baumann capillary apparatus (Baumann 1967). The absorption was read directly from the capillary scale after the meniscus reached a maximum value.

Calculation of Water Absorption

A great range in water absorption values can be obtained with a single flour by the use of different methods of calculation (Merritt and Stamberg 1941). In this study, two ways of calculating the water absorption and retention values were used: a) the value was calculated as water uptake by the sample, using the dry matter corrected method (Merritt and Stamberg 1941) with 86% dry solids basis for flour and flour/starch mixtures and 100% dry solids basis for starch; and b) the hydration capacity was expressed as water content in the material at the completion of the test, including water originally present in the sample.

RESULTS AND DISCUSSION

Because information on the use of the capillary method (method D) is scarce and practically no data are available for the type of

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material used in this study, attention was first focused on establishing the optimum conditions for performing the measurement.

A linear relationship was found between sample weight and water uptake over a 30–240 mg sample range (Fig. 1). The straight lines obtained for two types of flour using two different sample carriers converged at the zero sample weight yielding an intercept of 14×10^{-3} ml (calculated from linear regression analysis). Since neither the type of sample carrier nor the tested material had any effect on this intercept, it was considered an instrument constant. To get results independed of sample weight, the intercept had to be subtracted from all capillary readings. Otherwise, the absorption values, when expressed as a percentage of the sample weight, appeared progressively higher as the sample weight increased.

Although the type of sample carrier had no effect on the intercept, considerably lower readings of water uptake were recorded when Millipore AT absorbent pads (approximately 0.5 mm thick) were used instead of Millipore membranes AA 0.8 μm. The latter were chosen as a standard carrier in all reported tests. With this type of sample carrier and with a sample weight not exceeding 240 mg, the time required to reach the maximum reading on the capillary was not greater than 10 min for flour and flour/starch mixtures. With starches, the water uptake was even faster; not more than 5 min was required to reach the plateau on the water uptake vs. time curve (Fig. 2).

Unlike the Baumann capillary method, water retention method B gave results significantly dependent on sample weight. Progressively lower values were obtained as the sample weight was increased from 3 to 6 g (Fig. 3). This phenomenon may be attributed to a more pronounced "squeezing out" effect of the greater mass in the centrifuge tube during centrifugation. This observation underlines the importance of constant sample weight for this test, to obtain comparable results. Loss of soluble material into the supernatant may present another problem. With 5-g samples, the average weight loss (based on 10 replicate determinations) for flour and rice starch was 5.23 ± 0.64 and $3.91 \pm 0.55\%$, respectively. This loss represents a substantial proportion of the sample, especially when flour and flour/starch mixtures with a low level of added starch are tested. For more accurate measurements, this loss should be taken into account in computing

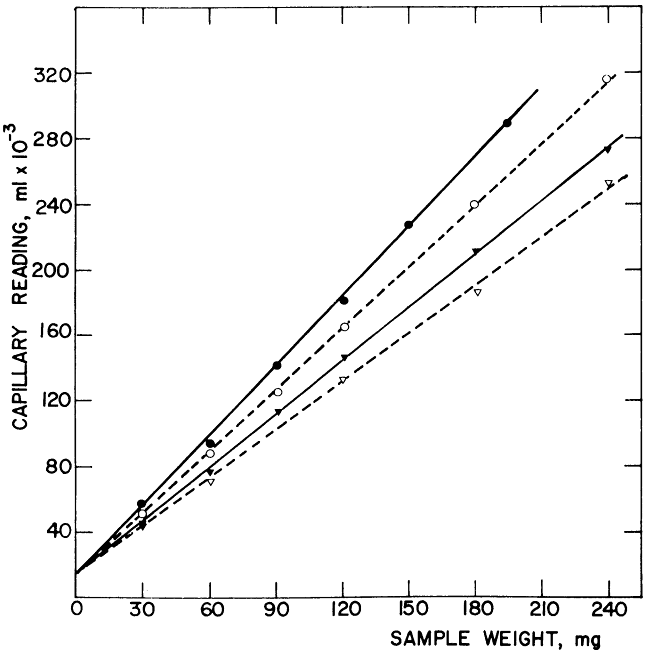

Fig. 1 Relationship between the sample weight and water uptake readings on Baumann's capillary. • = wheat flour A, Milipore AA 0.8-μm membrane; ▲ = wheat flour **B**, Milipore AA 0.8-μm membrane; o = wheat flour **A**, Milipore AT absorbent pad; △ = wheat flour **B**, Milipore AT absorbent pad.

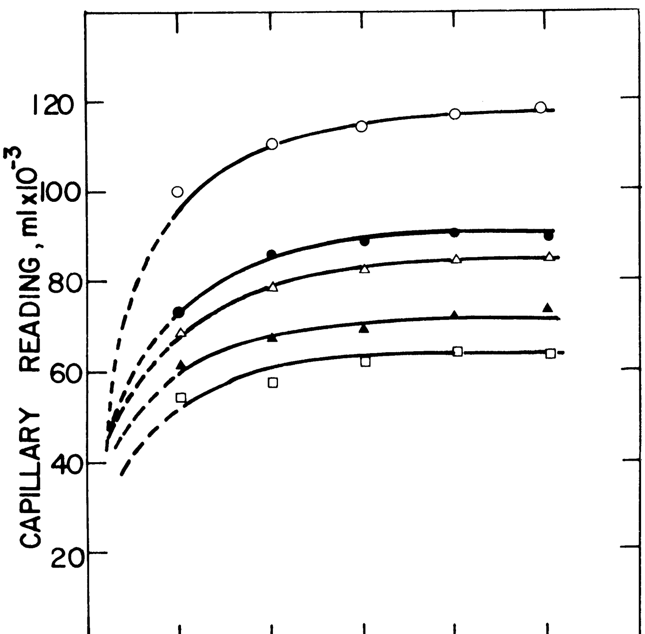

Fig. 2. Water uptake vs. time measured by Baumann capillary apparatus for different starches. o = potato starch; • = wheat starch; △ = wheat starch, Milipore AT absorbent pad; ▲ = rice starch; □ = tapioca starch. (Unless otherwise stated, Milipore AA 0.8 μm membrane was the sample carrier.)

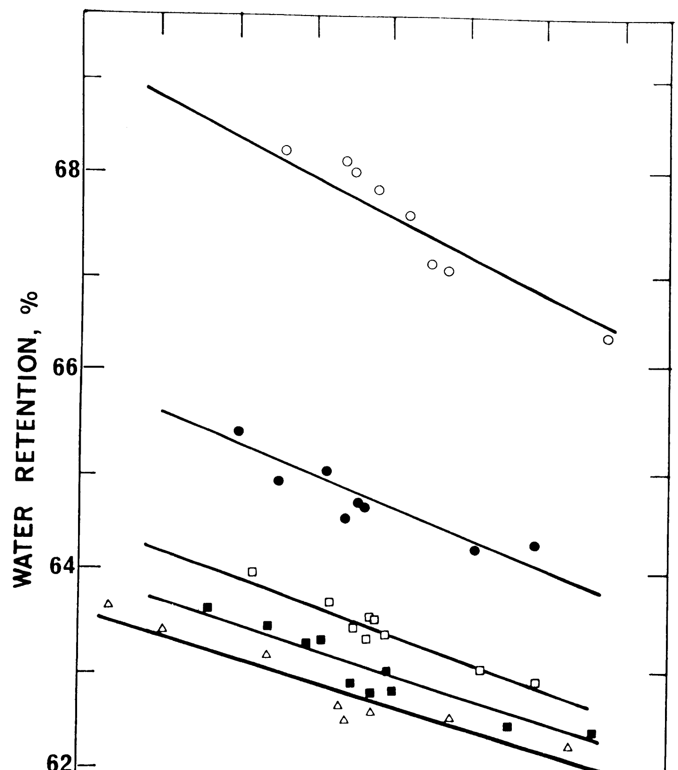

Fig. 3. Relationship between the sample weight and water retention capacity measured by Sollars' method (1973a) with flour/starch mixtures (30% replacement level). o = wheat flour, • = wheat flour/rice starch, □ = wheat flour/wheat starch, ■ = wheat flour/potato starch, △ = wheat flour/tapioca starch.

the water retention capacity of the material in the same way that it is done, for example, in determining the swelling ability of starch granules (Schoch 1965).

Statistically analyzed data obtained by methods B, C, and D with both pure starches and flour/starch mixtures are summarized in Tables I–IV. The coefficients of variation and the standard error values of the individual methods used on pure starches covered a relatively narrow range, but the values of water absorption for the respective starches were not the same when determined by different methods (Tables I and II). With methods B and D, tapioca starch appeared the least absorbant. With method C, the lowest absorption value was for potato starch. In contrast, methods B and D gave highest water uptake values for wheat starch, whereas method C gave the highest values for rice starch. Comparison of the values in Tables I and II suggests that in some instances the order of magnitude depended on the method of computing the hydration capacity data.

The flour/starch mixtures showed greater spread in the coefficients of variation and standard error values of the individual methods (Tables III and IV). The differences between the averages for the individual methods calculated irrespective of the type of test material were all significant at the 95% level (using Duncan's multiple range test).

The response of the methods to increasing concentration of added starch in the flour/starch mixtures is graphically presented in Figs. 4 and 5. The relationship between farinograph absorption and starch concentration in flour or flour/starch mixtures has been well recognized since the early days of farinograph studies (Markley 1938, Stamberg 1939). Farinograph absorption decreases with increasing starch content in the dough until a minimum is

TABLE I
Statistical Analysis of Water Absorption and Retention Data Obtained by Three Different Methods with Pure Starches: All Data Expressed as Percentage of Water Absorbed by Dry Solids of Starch

	Method								
	B			C			D		
Starch	Mean[a] ± S.D.	Coeff. of Variation	Standard Error	Mean[a] ± S.D.	Coeff. of Variation	Standard Error	Mean[a] ± S.D.	Coeff. of Variation	Standard Error
Wheat	97.12 ± 3.03	3.12	1.15	76.54 d ± 2.29	2.99	0.87	87.25 a ± 1.68	1.93	0.64
Rice	86.11 ab ± 4.19	4.87	1.58	82.02 c ± 2.86	3.49	1.08	83.31 bc ± 3.34	4.01	1.26
Potato	84.03 bc ± 1.78	2.12	0.67	69.86 ef ± 2.11	3.04	0.80	85.55 ab ± 3.35	4.15	1.27
Tapioca	72.05 e ± 2.23	3.10	1.17	76.25 d ± 2.14	2.80	1.06	68.13 f ± 3.24	4.76	1.23
Method mean	84.83	3.30	1.14	76.17	3.08	0.95	81.06	3.71	1.10

[a]Means followed by the same letter are not significantly different at the 95% level using Duncan's multiple range test. All means for individual starches are based on eight replicate determinations.

TABLE II
Statistical Analysis of Water Absorption and Retention Data Obtained by Three Different Methods with Pure Starches: All Data Expressed as Percent of Total Water Content in Starch on Completion of the Test

	Method								
	B			C			D		
Starch	Mean[a] ± S.D.	Coeff. of Variation	Standard Error	Mean[a] ± S.D.	Coeff. of Variation	Standard Error	Mean[a] ± S.D.	Coeff. of Variation	Standard Error
Wheat	52.04 ± 0.71	1.36	0.27	46.67 d ± 1.03	2.21	0.39	49.65 a ± 0.44	0.89	0.17
Rice	49.20 ab ± 1.09	2.22	0.41	48.17 c ± 0.79	1.64	0.30	48.49 bc ± 0.90	1.86	0.34
Potato	50.05 a ± 0.89	1.78	0.34	45.92 de ± 0.64	1.39	0.24	50.12 a ± 0.88	1.76	0.33
Tapioca	45.31 e ± 0.72	1.71	0.27	46.54 d ± 0.63	1.36	0.24	43.66 ± 0.72	1.65	0.27
Method mean	49.15	1.77	0.32	46.83	1.65	0.29	47.98	1.54	0.28

[a]Means followed by the same letter are not sigfnificantly different at the 95% level using Duncan's multiple range test. All means for individual starches are based on eight replicate determinations.

TABLE III
Statistical Analysis of Water Absorption and Retention Data for Flour/Starch Mixtures Determined by Three Different Methods: All Data Expressed as Percentage of Water Absorbed by Sample on 86% Dry Solids Basis

		Method								
		B			C			D		
Added Starch	Replacement Level (%)	Mean[a] ± S.D.	C.V.	Standard Error	Mean[a] ± S.D.	C.V.	Standard Error	Mean[a] ± S.D.	C.V.	Standard Error
Potato	10	68.59 a ± 1.31	1.91	0.50	59.19 b ± 2.30	3.89	0.87	90.88 ± 3.06	3.37	1.16
	30	64.24 ± 0.93	1.45	0.35	41.50 ± 1.99	4.80	0.75	81.50 ± 3.50	4.30	1.63
Rice	10	68.99 a ± 0.87	1.26	0.33	59.03 b ± 1.55	2.62	0.59	94.15 ± 5.10	5.42	2.05
	30	67.03 a ± 0.97	1.45	0.37	48.35 ± 1.28	2.64	0.48	87.30 ± 4.06	4.62	1.76
Method mean		67.21	1.52	0.39	52.02	3.48	0.67	88.45	4.44	1.65

[a]Means not followed by the same letter are significantly different at the 95% level using Duncan's multiple range test. All means for individual mixtures are based on eight replicate determinations.

TABLE IV
Statistical Analysis of Water Absorption and Retention Data for Flour/Starch Mixtures Determined by Three Different Methods: All Data Expressed as Percent of Total Water Content in the Mixture on Completion of Test

		Method								
		B			C			D		
Added Starch	Replacement Level (%)	Mean[a] ± S.D.	C.V.	Standard Error	Mean[a] ± S.D.	C.V.	Standard Error	Mean[a] ± S.D.	C.V.	Standard Error
Potato	10	48.88 a ± 0.43	0.88	0.16	44.74 b ± 0.87	1.95	0.33	54.83 c ± 0.71	1.29	0.27
	30	47.40 d ± 0.30	0.63	0.11	38.89 ± 0.88	2.26	0.33	52.39 ± 0.91	1.74	0.34
Rice	10	48.82 a ± 0.27	0.55	0.10	45.60 b ± 0.53	1.16	0.20	55.13 c ± 1.44	2.61	0.54
	30	47.89 ad ± 0.41	0.86	0.19	41.28 ± 0.51	1.23	0.19	53.59 ± 1.02	1.90	0.38
Method mean		48.25	0.73	0.14	42.63	1.65	0.26	53.99	1.89	0.38

[a]Means not followed by the same letter are significantly different at the 95% level using Duncan's multiple range test. All means for individual mixtures are based on eight replicate determinations.

TABLE V
Effect of Starch Concentration in Flour/Starch Mixture on Hydration Capacity Irrespective of the Method Applied

	Analysis of Variance of Hydration Capacity Expressed as							
	Water Uptake by Sample on 86% d.s.				Water Content in the Hydrated Mixture			
Source of Variation	DF	Mean Square	F	$P<$	DF	Mean Square	F	$P<$
Linear	1	712.11	422.73	0.001	1	83.15	485.57	0.001
Quadratic	1	63.34	37.60	0.001	1	6.73	39.28	0.001
Cubic	1	25.45	15.11	0.001	1	3.30	19.24	0.001
Quartic	1	5.62	3.34	0.074	1	0.89	5.22	0.027
Quintic	1	1.61	0.96	0.334	1	0.16	0.92	0.343
Error	45	1.69	...	...	45	0.17	...	...

TABLE VI
Difference Between Actual and Theoretical Hydration Capactiy Values as Determined by Different Methods with Flour/Starch Mixtures[a]

	Method B				Method C				Method D			
Added	Concentration of Added Starch in Mixture (%)											
Starch	10	20	30	40	10	20	30	40	10	20	30	40
Wheat	4.5	8.4	10.8	11.3	11.4	19.4	30.9	32.5	1.4	4.6	5.2	9.0
Rice	2.5	3.4	4.7	3.9	11.5	19.0	28.0	32.7	1.7	2.1	5.2	1.2
Potato	3.0	6.2	9.2	7.1	10.5	18.9	34.7	36.2	2.4	5.3	6.8	5.2
Tapioca	1.5	4.8	6.6	3.9	11.1	19.1	37.1	31.3	4.8	5.7	15.5	8.9
Average	2.9	5.7	7.8	6.6	11.1	19.1	32.7	33.2	2.6	4.4	8.2	6.1

[a]Expressed as percentage of the theoretical value.

reached; beyond this minimum, further addition of starch results in progressive increase in the measured parameter. This behavior was attributed to changes in both the actual hydration capacity and the rheological character of the system. The increase in farinograph absorption at higher starch concentrations in the dough was described as a rheological phenomenon resulting from the increase of the surface area of the incoherent phase in dough on the one hand and an excessive dilution of the continuous gluten phase on the other. The surface area of the starch phase plays a part, as evidenced by the dependence of the critical dilution of gluten (at which the minimum appears) on the average diameter of the starch granules in the mixture (Stamberg 1939).

In the present study, tapioca starch was the only one to cause reversion in the relationship between farinograph absorption and increasing concentration of starch in the mixture. Farinograph absorption decreased until the concentration of this starch reached a value between 30 and 35% (approximately 8.65% protein in the mixture). Further addition of starch led to an increase in farinograph absorption, yielding a distinct minimum on the curve of the relationship between these two parameters. Replacement of wheat flour with both wheat and potato starch resulted in a steady decrease in farinograph absorption over the whole range of starch concentration applied, and no tendency for a minimum to appear on the curves was noticed even at the highest replacement level of 40% (7.69% protein in the mixture). On the other hand, mixtures containing rice starch, which had the finest granules among the starches used, required a larger addition of water at the lowest replacement level (10%), and this trend progressively continued as the concentration of starch increased.

Against expectations, the curves of composite mixtures showed that the dependence of the hydration capacity on the starch concentration, when measured by methods other than farinographic, tended to reach the minimum value at a certain concentration of added starch. Such minima were easily detected on curves based on data obtained by method B, and their position was more or less the same for all mixtures (between 30 and 35% added starch) regardless of the type of starch. Although the shape of curves constructed from data obtained by methods C and D was less uniform, the tendency to yield a minimum was still noticeable, especially with curves of mixtures supplemented with tapioca and wheat starch. The method of computing the hydration capacity did not seem to have any effect on the observed relationship.

In spite of an apparent variability in the shape of the curves presented in Figs. 4 and 5, shape analysis of the response surface relating starch concentration to water hydration capacity irrespective of starches and methods revealed that the linear response was by far the greatest over the applied range of starch concentrations; quadratic and cubic effects, though still significant, contributed less (Table V). The differences between averages for individual methods irrespective of the type of starch and the starch concentration were all significant at the 95% level (using Duncan's multiple range test).

In agreement with earlier findings (Sollars 1973b, Unver and MacDonald 1976), the experimentally determined hydration capacity of flour/starch mixtures was decidedly lower than the calculated values based on the experimentally determined data for

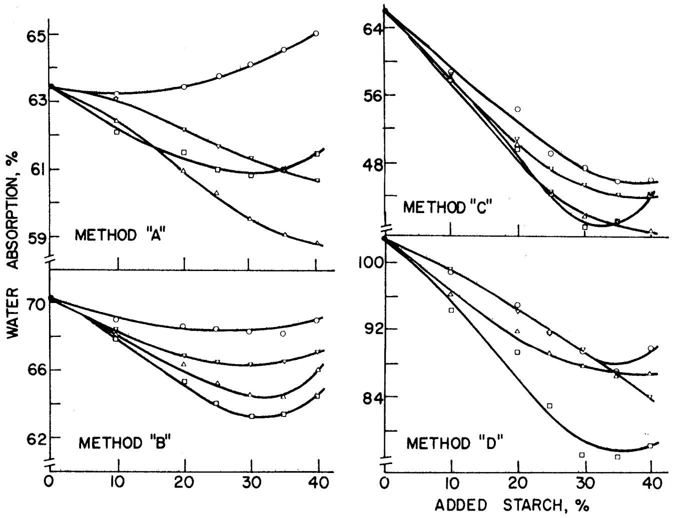

Fig. 4. Response of the methods to changes in added starch concentration in wheat flour/starch mixtures. Water absorption expressed as amount of water absorbed by the sample on 86% dry solids basis. • = wheat flour, o = wheat flour/rice starch, ∇ = wheat flour/wheat starch, △ = wheat flour/potato starch, □ = wheat flour/tapioca starch.

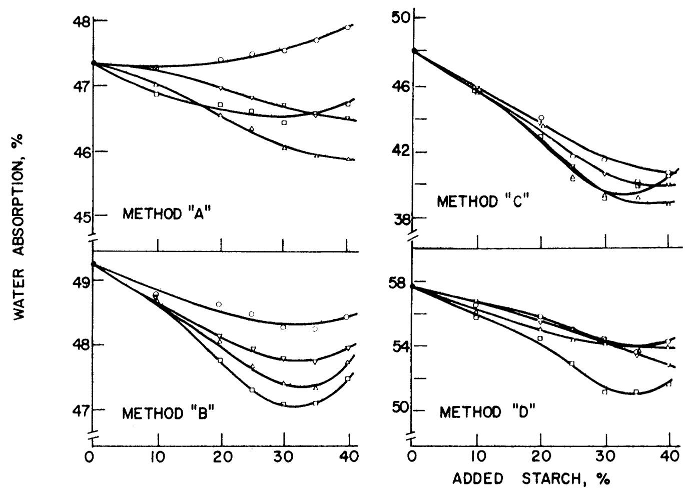

Fig. 5. Response of methods to changes in added starch concentration in wheat flour/starch mixtures. Water absorption expressed as the total amount of water in the material at completion of the test. • = wheat flour, o = wheat flour/rice starch, ∇ = wheat flour/wheat starch, △ = wheat flour/potato starch, □ = wheat flour/tapioca starch.

the individual components (Table VI). The difference was greatest with data obtained by method C. With this method, the sample is subjected to centrifugal force after a very short period of hydration. The results, therefore, primarily reflect the amount of water trapped in the interstices of the network existing in the tested system rather than of water bound by specific components. Under these conditions, changes in the capillary capacity of the system can be expected to markedly affect the results. Such changes may be induced by introducing a component with distinctly different surface area characteristics, as was the case when starch was added to wheat flour.

CONCLUSIONS

All reported data provided evidence of a significant dependence of water hydration capacity measurements on the technique used. Although the different methods showed similarities in response to increasing concentration of starch in the mixture, no satisfactory consistency appeared in the response patterns with respect to the individual types of stubstituted starches. This leads to the conclusion that, for a proper interpretation of water hydration data from wheat flour/starch mixtures, the technique used must be clearly specified unless a standard method is used.

The Baumann capillary method was simple and suitable for direct measurement of absorption capacity of materials used in the study. Its reproducibility was comparable with that of other tested methods, especially when used on pure starches. Unlike the water retention techniques applied, the method was not affected by water solubility of the test material.

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