

Effects on Pasting Viscosity of Starch and Flour from Different Operating Conditions for the Rapid Visco Analyser¹

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ABSTRACT

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Three wheat flours, three wheat starches, a regular maize starch and a waxy maize starch were subjected to a number of different RVA profiles. Five different initial temperatures were used, 40, 50, 55, 60, and 65°C, with different initial holding times (0–3 min), heating times (2fl–10 min), holding times at 95°C (0–6 min), cooling times (2–6 min), and final hold times (0–10 min) being applied. A range of final temperatures of 30–60°C was also utilized. Significant variations in viscosity were observed with these conditions, particularly in wheat starch and flour. The most important parameters causing these variations were the initial temperature, the heating rate, and the final holding time. Short initial holding times also resulted in a wider spread of values for peak viscosity although there was little effect on the mean value and no significant effect on the holding strength

or final viscosity. The final temperature was also important in that lower temperatures gave more viscous gels. Provided that the desired cooling rate could be achieved, varying the cooling time had no effect on the peak or trough viscosities and only a very minor effect on the final viscosity. If final temperatures of 40°C or lower are to be used, the cooling conditions and final hold time would need to be adjusted so that maximum viscosity could be achieved. A proposal for a standard Rapid Visco Analyser (RVA) procedure is: at least 1 min at 50°C, heat to 95°C over 4 min, hold at 95°C for 4 min, cool to 50°C in 3 min, and hold at 50°C for 4 min. These conditions should minimize variation within samples and should allow a better comparison between samples.

The Rapid Visco Analyser (RVA) was introduced as a means of rapidly measuring the degree of sprout damage in wheat affected by rain before harvest (Ross et al 1987). In this form, it was built to operate at a constant temperature (95°C), but the addition of controlled heating and cooling made the instrument more versatile and enabled its use in the measurement of starch paste viscosity (Walker et al 1988). Subsequent software and hardware development has refined the control of the heating and cooling and the instrument may be programmed to virtually any defined heating and cooling profile in a reliable way. Although the original purpose of the RVA for weather damage testing is still of interest, a more widespread use is now to observe the effects of controlled temperature on viscosity of various materials. In particular, the starch pasting function has attracted much attention and a wide range of applications has been proposed. The basic application has been for starch quality analysis, as proposed by Deffenbaugh and Walker (1989), in which the RVA is operated in a manner similar to the Brabender Viscoamylograph, but with a smaller sample size and a more rapid test cycle. Extensions of this basic test have been used for applications as diverse as the prediction of noodle-making potential in wheat (Konik et al 1992, Batey et al 1997), the evaluation of corn endosperm hardness (Suhendro et al 1996), and barley quality after storage (Bason et al 1993). The importance of starch properties to rice quality has also led to the RVA being used as an integral part of the selection process in rice breeding (Blakeney 1992, Juliano 1996). More recently, applications for protein analysis have also been developed (Turner et al 1997). Gluten quality in flour may be predicted using a complex temperature profile in the presence of ethanol (Turner et al 1998) and the firmness of tofu, a soy bean protein product, may be predicted by measuring the viscosity of ground beans in aqueous suspension (Quail et al 1996).

Standard methods for measuring sprout damage and starch pasting characteristics have been developed and approved (ICC 1995, AACC 2000). However, under different operating conditions, the ability of the RVA to discriminate between samples and to predict the quality of products may vary (Konik et al 1992, Batey et al 1997). Varying the initial temperature and the heating rates

significantly improved the correlations between RVA viscosity of wheat flour or starch and Japanese udon noodle quality. This improvement came from the variation in values obtained for viscosity under the different conditions. This article provides a detailed study of how changing the operating conditions affects RVA viscosity parameters in wheat starch, wheat flour and maize starch.

MATERIALS AND METHODS

RVA tests were conducted on three commercial bakers' flours, three wheat starches, and two maize starches. Flour samples were WF1 (Goodman Fielder Mills, Summer Hill, NSW, Australia), WF2 (George Weston Foods, Enfield, NSW, Australia), and WF3 (Defiance Mills, Toowoomba, Qld, Australia). Wheat starch samples were WS1, (George Weston Foods) WS2 (Starch Australasia, Lane Cove, NSW, Australia), and WS3 (Manildra Starches, Auburn, NSW, Australia). Maize starch samples were regular (MS) and waxy (WM) (Starch Australasia). The wheat starches were unrelated to the wheat flours used in the experiments. Unless otherwise stated, all test conditions were independently applied in triplicate to every sample.

Standard RVA conditions. The sample (3.50 g of flour or 3.00 g of starch) was dispersed in water (25.0 mL) and stirred in an RVA can at 960 rpm for 10 sec, then at 160 rpm for the remainder of the test. Sample weights used were on an as-is basis because the aim was to compare the effect of different conditions on each sample, not to compare the different samples. The standard temperature profile was held for 2 min at initial temperature, heat to 95°C over 6 min, hold at 95°C for 4 min, cool to 50°C over 4 min, and hold at 50°C for 4 min (Batey et al 1997). The total test time was 20 min, and initial temperatures of 40, 50, 55, 60, and 65°C were applied. Values measured from the pasting profile were the peak viscosity (maximum paste viscosity achieved in the heating stage of the profile), holding strength or trough (minimum paste viscosity achieved after holding at the maximum temperature), and final viscosity (the viscosity at end of run). Other viscosity parameters such as breakdown and setback are derived from these three basic parameters and were not considered in this work.

Initial hold time. Each sample of starch or flour was tested 10× using an initial hold time of 0, 1, 2, or 3 min with initial temperatures of 50 and 60°C for each hold time. Some samples were also tested with an initial temperature of 65°C. Longer holding times were not employed as the aim was to keep the total test time as short as possible.

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Heating time. Heating times of 2, 4, 6, 8, and 10 min were used to raise the temperature to 95°C from initial temperatures of 40, 50, 55, 60, or 65°C. Standard times were employed for the other stages, which meant that the total test times were 16, 18, 20, 22, and 24 min, respectively.

Heating rate. The effect of the heating rate on viscosity was tested by using two different heating rates, 7.5°C/min and 5.83°C/min, to raise the temperature from each initial temperature to 95°C. These heating rates represent the heating rates required to reach 95°C in 6 min from 50 and 60°C, respectively. Standard times were employed for the other stages, and the total test time was adjusted to accommodate the change in heating time with each heating rate. These conditions were only applied to WF3 and WS1.

Holding time at 95°C. Using initial temperatures of 40, 50, 60, and 65°C with a heating time of 6 min, the holding time at 95°C was set at 0, 1, 2, 3, 4, 5, and 6 min. The total test time varied from 16 to 22 min with the length of the other stages being maintained at the standard times described above.

Cooling time. Cooling times of 2, 3, 4, 5, 6, and 8 min were used to reduce the temperature from 95 to 50°C. Total test times were 18, 19, 20, 21, 22, and 24 min, respectively.

Final holding time. Measurement of the final viscosity after final hold times of 0, 1, 2, 3, 4, 5, 6, 7, 8, and 10 min was achieved by recording the viscosity at these times as well as the ultimate final viscosity. The other stages were maintained at the standard times and the nominal test times were 16, 18, 19, 20, 21, 22, and 24 min, respectively. This was done with every starch and flour for each initial temperature.

Final temperature. Samples were run under standard conditions except for the final temperature. In the cooling step, the test gel was cooled in 4 min to either 30, 35, 40, 45, 50, 55, or 60°C. For the temperature to reach 30, 35, or 40°C in the programmed time,

it was necessary for the cooling water to be below ambient temperature. This was achieved by passing the tube carrying the coolant through an ice water bath.

RESULTS

Initial Temperature

The peak, trough, and final viscosities of the various starches and flours are shown in Table I for viscograms with different initial temperatures. There was only minor variation in all viscosity parameters for both regular and waxy maize starch, and most of these variations were not significant.

For both wheat flour and wheat starch there were major differences between the results obtained, both with the change in the initial temperature and in the way different flours and starches responded to those changes. In general, starting at 40 or 50°C tended to give higher peak, trough and final viscosities, while starting at 55 or 60°C usually gave lower values for these parameters. There were some notable exceptions, however. For example, one wheat starch (WS2) with a 60°C start gave a slightly higher peak viscosity than starting at either 40 or 50°C, and one of the wheat flours (WF1) gave the highest final viscosity from an initial temperature of 55°C, although in this case, the value was not significantly greater than those obtained by starting at either 40 or 50°C.

Using an initial temperature of 65°C gave anomalous results with wheat starch and flour. With all wheat starch samples and one of the flours (WF2), this initial temperature gave the highest peak viscosity, yet for another of the flours (WF3) it gave the lowest value. Starting at 65°C also gave the highest values for the final viscosity with WF3 and WS1, and the lowest with WF1, WF2, and WS2. One wheat starch (WS2) and all flours gave the lowest trough with a 65°C start, while WS1 had the highest value for the trough at this temperature.

Particular note should be taken of WF3 which had its highest final viscosity, yet the lowest trough and peak viscosities when starting at 65°C. This contrasts with WF2 and WS2 for which the highest peak and the lowest trough and final viscosities were obtained with this initial temperature. WS1 had the highest values for all viscosity parameters with 65°C as the initial temperature.

TABLE I

Rapid Visco Analyser (RVA) Viscosities^a of Flour and Starch Samples^b at Different Initial Temperatures^c

RVA Parameter and Sample	Initial Temperature				
	40°C	50°C	55°C	60°C	65°C
Peak viscosity					
WF1	413	396	383	360	367
WF2	264	263	...	241	283
WF3	272	272	247	243	241
WS1	187	185	148	171	250
WS2	258	257	233	262	281
WS3	206	200	159	187	252
MS	249	254	257	257	256
WM	310	311	318	314	319
Holding strength					
WF1	184	178	173	156	135
WF2	140	143	...	126	125
WF3	124	123	118	97	82
WS1	113	117	106	105	125
WS2	183	167	179	166	159
WS3	157	144	123	140	147
MS	106	104	129	110	112
WM	112	111	111	112	110
Final viscosity					
WF1	360	360	361	333	288
WF2	311	315	...	284	277
WF3	242	245	239	201	245
WS1	281	292	266	265	296
WS2	328	307	323	316	285
WS3	308	300	260	276	292
MS	250	250	260	256	260
WM	155	150	147	151	149

^a Measured in RVA units (RVU).

^b WF, wheat flour; WS, wheat starch; MS, regular maize starch; WM, waxy maize starch. Standard deviation range 1.2–5.6, except WM (range 2.5–10.3).

^c Standard time conditions: hold 2 min, heat to 95°C over 6 min, hold at 95°C for 4 min, cool to 50°C over 4 min, hold at 50°C for 4 min.

^d WF2 not tested at an initial temperature of 55°C.

TABLE II

Rapid Visco Analyser (RVA) Peak Viscosities^a of Starch and Flour Samples at Different Initial Holding Times and Temperatures^b

Sample	Initial Temp (°C)	Initial Holding Time			
		0 min	1 min	2 min	3 min
WF1	50	399 (6.4)	398 (3.7)	396 (2.8)	397 (2.9)
	60	425 (8.1)	391 (5.1)	360 (3.8)	358 (2.4)
WF2	50	263 (6.1)	266 (2.9)	262 (1.9)	264 (2.0)
	60	292 (3.6)	263 (2.3)	241 (2.0)	230 (1.4)
WF3	65	333 (9.8)	304 (5.3)	286 (1.2)	282 (2.8)
	50	268 (6.1)	269 (4.7)	272 (3.4)	270 (2.7)
WS1	60	284 (7.4)	264 (3.8)	243 (3.3)	238 (2.7)
	50	186 (6.2)	187 (3.4)	185 (2.1)	183 (2.2)
WS2	60	221 (7.3)	184 (4.1)	171 (3.5)	176 (2.5)
	65	310 (6.6)	271 (5.2)	250 (3.8)	246 (2.1)
WS3	50	254 (5.5)	258 (3.2)	257 (2.8)	255 (1.2)
	60	287 (8.7)	270 (4.5)	262 (3.2)	257 (3.1)
MS	50	197 (6.8)	205 (3.6)	200 (1.8)	202 (2.6)
	60	237 (7.2)	208 (5.9)	187 (3.6)	186 (2.7)
WM	50	251 (5.3)	254 (2.7)	254 (3.3)	251 (2.5)
	60	258 (6.8)	257 (4.8)	257 (3.5)	248 (3.4)
WF1	65	258 (4.6)	260 (3.1)	256 (2.9)	254 (2.5)
	50	314 (7.9)	315 (6.2)	311 (4.6)	314 (3.5)
WF2	60	332 (9.4)	318 (7.6)	314 (5.8)	310 (2.4)
	65	322 (8.8)	317 (5.4)	319 (3.2)	314 (3.4)

^a Measured in RVA units (RVU).

^b WF, wheat flour; WS, wheat starch; MS, regular maize starch; WM, waxy maize starch. Each value represents the mean of 10 measurements with the standard deviation in brackets.

Initial Holding Time

The response of the flours and starches varied according to the initial temperature when initial holding times of 0–3 min were used. At an initial temperature of 50°C, maize starch, wheat starch, and wheat flour all showed little effect on the mean peak viscosity with changing initial times. The most obvious effect was the spread of values obtained with 10 replicate measurements (Table II). For one wheat flour with an initial holding time of zero, the variation in the peak viscosity was 20 RVU, but this was reduced to 4 RVU with a 3-min holding time. An initial time of 1 min showed a reduced variation, while a 2-min hold was very similar to the 3-min hold. Other flours displayed similar effects, but neither maize nor wheat starch showed the same spread of peak viscosity as wheat flour with short initial times. There was little effect on the final viscosity with different initial times with all starch and flour samples.

The effect on wheat flour is probably related to the hydration of the particles. In initial stages, there would be competition between the starch, protein, and pentosans for hydration and, for short initial holding times, some starch granules would be incompletely hydrated when the heating started. It is probable that this would be a random effect and the swelling and interaction of the granules leading to the peak viscosity could be affected, with a consequent effect on the value obtained for the peak viscosity. As the initial time was increased, the hydration would be more complete when the heating started and the viscosity effects would be more uniform.

For starches, the effect of changing the initial holding time at different initial temperatures varied according to the type of starch. Compared with starting at 50°C, the peak viscosity of maize starch

TABLE III
Rapid Visco Analyser (RVA) Peak Viscosities^a of Maize Starches Measured at Different Initial Temperatures and Heating Times^b

Sample	Heating Time	Initial Temperature			
		40°C	50°C	60°C	65°C
MS	2	239	241	241	236
	4	240	246	248	252
	6	249	254	257	256
	8	250	256	256	260
	10	258	255	255	258
WM	2	324	320	316	317
	4	319	323	318	323
	6	308	313	313	322
	8	306	322	321	318
	10	306	328	317	311

^a Measured in RVA units (RVU).

^b MS, regular maize starch; WM, waxy maize starch. Standard deviation range 2.3–3.6.

TABLE IV
Rapid Visco Analyser (RVA) Peak Viscosities^a of Wheat Starches Measured at Different Initial Temperatures and Heating Times^b

Sample	Heating Time	Initial Temperature			
		40°C	50°C	60°C	65°C
WS1	2	215	207	181	233
	4	210	199	178	237
	6	186	173	175	244
	8	173	158	175	260
	10	157	147	177	268
WS2	2	256	265	253	287
	4	256	268	268	270
	6	258	255	263	281
	8	251	240	264	290
	10	248	227	284	288
WS3	2	242	228	201	242
	4	228	215	196	247
	6	206	200	187	252
	8	188	173	196	264
	10	177	161	188	276

^a Measured in RVA units (RVU).

^b WS, wheat starch. Standard deviation range 1.8–4.5.

did not vary much by changing the initial hold time at 60 or 65°C, but wheat starch showed major changes. At these temperatures for each sample, the peak viscosity also showed a wider range of values with zero holding time, compared with longer holding times, but this was by far outweighed by the variation in the values for peak viscosity caused by the different initial temperatures (Table II).

Heating Time

The heating rate was affected by both the heating time and the initial temperature. A heating time of 6 min will require a heating rate of 5°C/min in raising the temperature from 65 to 95°C, but a rate of 9.17°C/min in achieving the same peak temperature from 40°C. In this series of experiments, the same time profile was used with different initial temperatures. Thus, the heating rates were different for each time profile at the different initial temperatures.

There were very obvious differences among the samples in their response to changing the heating time. In regular maize starch, the peak viscosity showed an increase as longer heating times were used and this was apparent for all initial temperatures (Table III). There were some variations in the response at the different initial temperatures. With a 40°C start, the peak viscosity was little changed at 4 min compared with 2 min, but samples with longer heating times showed a continual increase in peak viscosity. Starting at 50 and 60°C, the peak viscosity increased with heating times up to 6 min, and then remained essentially the same. With 65°C as the initial temperature, there was a large increase observed by changing the heating time to 4 min from 2 min, but longer heating times gave only small increases in peak viscosity. This contrasted with waxy maize starch in which the peak viscosity tended to decrease with longer heating times (Table III).

Changing the heating time had no significant effect on the holding strength and final viscosity of both maize starches, except for the 2-min heating time at 40 and 50°C. In these runs, the heating rate

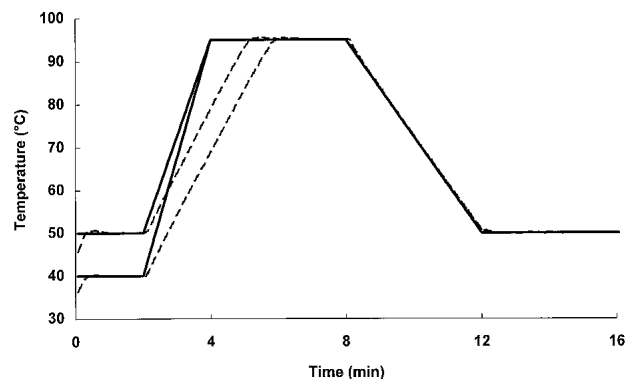


Fig. 1. Comparison of actual (---) and programmed (—) Rapid Visco Analyser (RVA) block temperature for profiles raising the temperature from 40 and 50°C to 95°C.

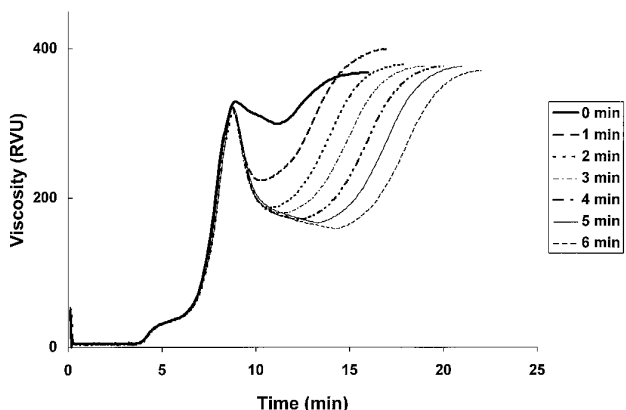


Fig. 2. Rapid Visco Analyser (RVA) viscosgrams of a wheat flour with holding times of 0–6 min at 95°C. Initial temperature was 50°C.

exceeded the maximum for the instrument and 95°C could not be achieved until about 4 min after heating commenced (Fig. 1). Thus, in these examples, the first 2 min of the hold time at 95°C was actually being used for heating, and the differences in holding strength were caused not by an effect of the heating time but by the reduction in the holding time at 95°C. This also explains the similarity between the viscosities observed for 2- and 4-min heating times with a 40°C starting temperature.

Wheat starch and wheat flour showed more significant changes for samples in their response to the different heating times at the various initial temperatures. All three starches showed a decrease in peak viscosity for longer heating times with initial temperatures of 40 and 50°C (Table IV). Starting at 60°C, one starch increased peak viscosity with increasing heating time, one decreased in peak viscosity, and the other showed little change. With a 65°C start, two starches increased in peak viscosity with increasing heating time, and the third remained essentially unchanged. The sample which showed no change at 65°C was the sample which increased with a 60°C starting temperature.

With increasing heating time, the wheat flours showed a decrease in peak viscosity for all samples with a 60°C initial temperature (Table V). Starting at 65°C, one sample showed no change in peak viscosity but the others had an increase in viscosity with longer heating times. Two samples remained almost unchanged with increasing heating time with a 40 or 50°C start, while the third sample showed major decreases in peak viscosity.

TABLE V
Rapid Visco Analyser (RVA) Peak Viscosities^a of Wheat Flours Measured at Different Initial Temperatures and Heating Times^b

Sample	Heating Time	Initial Temperature			
		40°C	50°C	60°C	65°C
WF1	2	451	453	374	370
	4	450	434	364	372
	6	413	396	360	367
	8	399	382	351	368
	10	384	358	348	364
WF2	2	274	271	248	279
	4	273	270	246	284
	6	264	263	241	283
	8	261	265	241	281
	10	259	261	240	283
WF3	2	272	264	244	216
	4	266	267	249	227
	6	272	272	243	241
	8	267	271	243	242
	10	275	265	234	233

^a Measured in RVA units (RVU).

^b WF, wheat flour. Standard deviation range 1.2–3.9.

TABLE VI
Rapid Visco Analyser (RVA) Peak Viscosities^a of Wheat Flour (WF3) and Wheat Starch (WS1) with Two Different Heating Rates and Five Different Initial Temperatures

Initial Temp (°C)	Heating Rate	
	5.83°C/min	7.5°C/min
WF3		
40	262 (3.7) ^b	273 (3.8)
50	261 (2.9)	272 (3.4)
55	249 (2.8)	246 (2.1)
60	243 (3.3)	241 (3.5)
65	240 (3.3)	227 (2.3)
WS1		
40	172 (3.7)	178 (2.5)
50	173 (4.2)	180 (3.7)
55	145 (2.1)	146 (2.8)
60	172 (3.2)	175 (2.7)
65	250 (2.5)	236 (1.7)

^a Measured in RVA units (RVU).

^b Mean of three readings with standard deviations in brackets.

All wheat starches and flours behaved similarly with respect to the holding strength. With one exception, all initial temperatures and heating times showed no change or slight decreases in the trough viscosity. The exception was one of the flours using an initial temperature of 65°C where there was a significant rise in the value observed with increasing heating time. The final viscosity showed similar trends, with all samples, initial temperatures, and heating times causing no change or small decreases in values. One of the starches showed a small but significant increase in final viscosity with increasing heating time.

Constant Heating Rates with Different Initial Temperatures

For these experiments, two constant heating rates were used for the four different starting temperatures. Heating rates of 5.83 and 7.5°C/min were chosen because they represented the heating rates to achieve 95°C from 60 and 50°C, respectively, and for wheat flours these temperatures gave the greatest difference in peak viscosity. These experiments were necessary to show that it was indeed the initial temperature causing the effect, and not just the differences in heating rate required to raise the temperature to 95°C. Heating times varied from 5.14 to 9.43 min for 5.83°C/min, and from 4 to 7.33 min for 7.5°C/min. The results showed that while differences in heating rate did indeed cause variation in the peak viscosity, more significant differences were observed between the viscosities obtained with different starting temperatures (Table VI). Analysis of variance indicated that the differences in peak viscosity arising from initial temperature were significant for both starch ($P < 0.001$) and flour ($P < 0.05$), but those arising from the heating rate were not significant ($P > 0.7$ for both starch and flour).

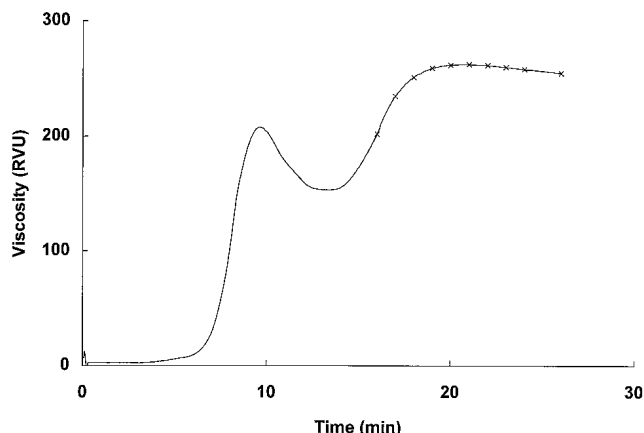


Fig. 3. Rapid Visco Analyser (RVA) viscomogram of a wheat flour showing viscosity (X) after holding in the final stage at 50°C for 0, 1, 2, 3, 4, 5, 6, 7, 8, and 10 min. Viscosities would have been the final viscosity for each of these final holding times had the profile been terminated. Initial temperature was 50°C.

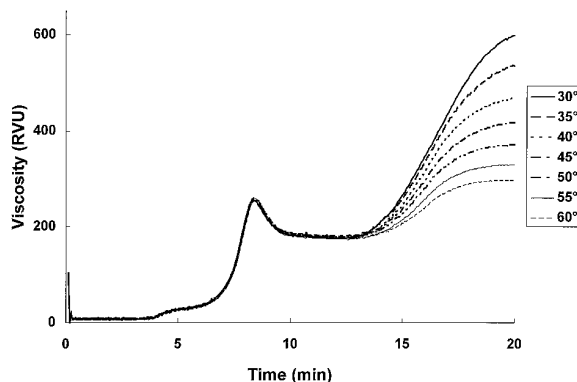


Fig. 4. Rapid Visco Analyser (RVA) viscomograms of a wheat flour with final temperatures of 30, 40, 50, and 60°C. Initial temperature was 50°C.

Holding Time at 95°C

Changing the time that the test material was held at the maximum temperature had similar effects on samples with different initial temperatures. Figure 2 shows the effect on varying the time from 0 to 6 min. With all initial temperatures, only the peak viscosity of the samples was affected with a zero hold time at 95°C. With hold times of 1–6 min, only events after the peak were affected. The wheat starches, all of which reached the peak viscosity well after the maximum temperature was reached, were affected more than the wheat flours or regular maize starch which reached peak viscosity around the time 95°C was achieved. Waxy maize was not tested in this experiment, but as its peak viscosity is reached well before the end of the heating phase, there should have been no effect on the peak viscosity, even with no holding time at 95°C.

The most significant effect of these different holding times was on the holding strength (trough) and, to a lesser extent, on the final viscosity (Fig. 2). Lower values were obtained for the trough with longer holding times at 95°C. While the holding strength continued to decrease up to and beyond 6 min, the decrease after 4 min was much less than the decrease in the first 2 min. Although the viscosity continues to decline, even with very long holding times, the trough reached is not very much less than that at 4 min (Zeng et al 1997). The change in the final viscosity was less marked. The final viscosity in the sample held for 1 min at 95°C was much higher than the final viscosity in either the 0- or 2-min samples. Longer holding times at 95°C reduced the final viscosity by a small amount, with the reduction being approximately the same for each 1 min increment of holding time. The viscosity parameters, breakdown and setback, would also be affected as they are derived from the trough value.

Cooling Times

The main effect of changing the cooling time was on the final viscosity. Short cooling times were difficult to achieve with ambient water cooling the RVA, and it took a minimum of ≈ 3 min for the temperature of the instrument to reach 50°C. This meant that the final holding time was effectively reduced from 4 to 3 min with a 2-min cooling time and the viscosity was still increasing at the end of the test. The effects were similar to reducing the final holding times which are shown in Fig. 3. Cooling times of 4 min or greater could be readily achieved and, in these cases, the final hold at 50°C was for the programmed time (4 min in these experiments). For the materials tested, the final viscosity appeared to have reached a plateau.

Final Holding Time

With final holding times of between 0 and 10 min, there was a steady increase in the final viscosity up to a holding time of 4 min with all flours and starches (Fig. 3). After 4 min, there was a slight reduction in the final viscosity. With waxy maize starch, the final viscosity reached a maximum with a hold time of 2 min, and holding for longer times caused a slight reduction.

Final Temperature

By varying the final temperatures from 30 to 60°C, the viscosity of the gel was increased with lower final temperatures, as might have been expected from qualitative observation of starch gels becoming more firm as they were allowed to stand and cool to room temperature. However, the higher viscosity of the starch gels at 40°C or below reduced the transfer of heat through the gel so that the final viscosity did not reach a plateau (Fig. 4). If viscosity needs to be measured at a lower final temperature, it is possible that this may be achieved without increasing the total test time by reducing the cooling time to 3 min and increasing the final holding time to 5 min. With a subambient temperature coolant, a shorter cooling time could be employed, and an even longer final holding time for lower temperatures may be possible. However, there may not be any need for using lower final temperatures. The

viscosity after 4 min at 30 or 40°C was correlated with the viscosity at 50°C ($r^2 = 0.95$ and 0.97 , respectively), and final viscosity measured at 50°C should be a good guide to strength of the gel at lower temperatures.

α -Amylase Levels of Flours

As all samples of starch and flour were from commercial sources, it was assumed that they had been derived from sound grain. However, to check that there were not unacceptable amounts of α -amylase present, all flours and starches were tested under standard RVA conditions in the presence of silver nitrate (Batey et al 1997). The increases in viscosity for the wheat flours were small, indicating that the amount of α -amylase was low. Variation in the viscosity of the starches was within experimental limits. It is unlikely, therefore, that the variations observed under the different conditions resulted from high α -amylase levels.

DISCUSSION

The different behaviors of maize starch and wheat-based materials may be explained by different gelatinization temperatures. Both normal and waxy maize starches gelatinize at temperatures $>60^\circ\text{C}$ (Inouchi et al 1991), which is $7\text{--}10^\circ\text{C}$ higher than wheat starch (Fujita et al 1992). The temperature measurement in the RVA is actually the temperature of the heating block, and the temperature of the can contents can be several degrees lower than the block, depending on the sample type and viscosity (Hazelton and Walker 1996). For maize starch, this means that even with a starting temperature of 65°C , the test mixture will usually be below the gelatinization temperature. In wheat starch and flour, the range of initial temperatures being examined would mean that actual temperature of the mixture could be above the gelatinization temperature before heating begins for some samples. In others, where the temperature is below gelatinization, different heating rates will bring the starch to gelatinization at different times, thus explaining the varying effects on different wheat flour and starch samples.

Also, note the difference between pasting and gelatinization temperatures. Pasting occurs when the granules absorb water and swell, and start to interact with each other, causing a rise in viscosity. Gelatinization occurs when the internal crystalline structure of the granule is lost by heating. This can be observed as a loss of birefringence in the granules under a microscope illuminated with polarized light. In waxy maize starch, pasting occurs before gelatinization, while for regular maize and wheat starch, gelatinization occurs well before pasting. Wheat starch, although having a lower gelatinization temperature than maize starch, has a higher pasting temperature (Ellis et al 1998). The slight lowering of peak viscosity in waxy maize as heating time is increased could thus be ascribed to shear thinning, the breakdown of the paste structure by the shearing effect of the RVA paddle.

The anomalous behavior of wheat samples with an initial temperature of 65°C goes part of the way toward explaining the observation that higher initial temperatures gave better results for predicting the Japanese udon noodle potential of wheat flours (Konik et al 1992, Batey et al 1997). Although there is no published work to indicate this, it is not unlikely that gelatinization temperature may affect the quality of noodles. It is clear that starting at 60 or 65°C shows a greater differentiation between starch and flour samples, and this could be related to the effect of cooking and cooling on the starch granules and resulting gels. It also explains why the difference between the peak and final viscosity was observed to be the best parameter to use as the predictor of udon noodle quality with higher initial temperatures (Batey et al 1997). With some flours giving high peak and final viscosities, and others giving high peak but low final viscosities, this measure has the potential of better discrimination between samples.

While the heating time and initial temperature had major effects on the peak viscosity, there were also minor effects on the holding

strength and final viscosity. These are most likely related to shear thinning. In samples where pasting occurred sooner and the gels were exposed to the shear effect for longer times, there is greater chance for this to reduce the viscosity. Shear thinning can also be used to explain the reduction in the holding strength as the hold time at 95°C is increased, and in the final viscosity as the sample is held at the final temperature for longer times.

Reducing the final hold time to <4 min meant that there was insufficient time for the gel to reach its final maximum viscosity. Waxy starches, which have a low final viscosity, reach this in <2 min, but for most starches or flours, a holding time of 4 min is required for this to occur. The reason for this is probably that the gel is not being uniformly cooled. As the instrument starts to cool, the viscosity of the gel close to the outside of the RVA can will increase. Initially, the stirring will mix this higher viscosity gel with the lower viscosity, warmer gel toward the center of the can, but as the instrument temperature drops and the viscosity increases, the mixing will become less efficient and the measured viscosity will reflect the viscosity closer to the center. At this stage, the gel will have both a temperature and a viscosity gradient from the wall to the center of the can, and the real viscosity at the final temperature will only be achieved when the entire contents of the can have reached the final temperature. The more viscous the gel, the longer this will take to occur. For this reason, a final holding time should be chosen so as to allow the maximum final viscosity to be reached. The cooling rate can also affect the final viscosity if rapid cooling means that the combined cooling and final time is insufficient for the entire sample to reach the final temperature.

In one standard procedure suggested by the manufacturer of the RVA, a final holding time of 2 min is utilized. For samples with a low final viscosity, such as waxy maize starch, this is not a problem, but this time is not enough for the actual final viscosity to be reached with most starches. At 2 min, lower viscosity starches are close to maximum final viscosity but higher viscosity gels may be well below it, although the measured viscosities may not be very different. This would tend to reduce the discrimination between samples.

The work presented here suggests that there are conflicting needs between choosing conditions for a standard procedure for characterizing pasting properties to be applied across laboratories and choosing conditions for predicting product quality. For a standard procedure, effects arising from conditions internal and external to the instrument should be minimal. The initial hold time should be long enough to overcome differences in temperature of the test materials—water and starch—and to allow hydration of the starch granules. For this, at least 1 min is desirable, and 2 min may be preferable. The initial temperature should be such that small variations in actual block temperature do not affect the viscosity. A temperature of 50°C would be satisfactory for wheat and maize samples, although for starches from other botanical sources a lower temperature may be more appropriate. The heating rate should be easily achievable, so the heating time should be at least 4 min from 50°C or 5–6 min from 40°C. Rapid breakdown of viscosity occurs in the early stages of holding at the peak temperature, so the holding time should be long enough for the rate of breakdown to slow substantially. Waiting for the breakdown to be complete would lead to excessively long test times (Zeng et al 1997). Holding for 4 min is a good compromise even though breakdown is not complete. The cooling and final hold times have the greatest effect on the final viscosity, and it is important to ensure that sufficient time is allowed for the entire sample to cool. Cooling for 3 min and holding at the final temperature for 4 min is probably the shortest practicable length of these stages. A longer final hold time would be necessary if final temperatures <50°C are used, although it is unlikely that lower temperatures would provide additional useful information. Taking into consideration the need to take advantage of the ability of the RVA to have a short test cycle, an appropriate procedure could be hold at 50°C for 1 min, heat to

95°C over 4 min, hold at 95°C for 4 min, cool for 3 min to 50°C, and hold for 4 min at 50°C. This gives a total test time of 16 min, 4 min shorter than the procedure usually used in our laboratory, but 3 min longer than the manufacturer's suggested procedure. Choice of 95°C as the peak temperature may be governed by the altitude at which a laboratory is situated. The depressed boiling temperature of water at higher altitudes can cause foaming in the test can (C. F. Morris, *personal communication*), and a slightly lower peak temperature may be necessary.

For food product quality, such a standard method may not be optimal, as different samples of the same material react differently when the operating conditions are changed. However, the versatility of the RVA will allow variation of temperature profiles to choose the best methods for a particular product. For this, many measurements under different conditions may be required, and the method selected will probably be unique for each product. Consideration of such factors as the methods of preparing the food and the conditions under which it is stored and consumed and relating these to what is happening in a RVA test will help to decide appropriate conditions for conducting the test.

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