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ABSTRACT

The Rapid Visco-Analyser (RVA) and the Micro Visco-Amylograph (MVA) were compared in measuring the viscosity properties of rice flours. A total of 72 rice samples were procured from three cultivars harvested at two locations and three moisture contents and separated into thin, medium, and thick kernel-thickness fractions. A fast and a slow heating rate was used in the procedure for both instruments. Cultivar, kernel thickness, and harvest location affected rice viscosity. The RVA viscosity profiles using a fast heating rate were best correlated with those of the MVA using a slow heating rate. The RVA slow heating rate resulted in lower final viscosities than those using the MVA because of the spindle structure of the RVA. For both the RVA and the MVA, greater rice flour peak viscosities and less trough and final viscosities were obtained with a slow rather than a fast heating rate.

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INTRODUCTION

The processing performance of cereal grains, such as rice, is often estimated by measuring the viscosity of pastes made by adding a specified amount of water to flours produced by grinding the grains. Instruments for measuring paste viscosity are typically equipped with a spindle positioned inside a rotating cup. During a test, the paste in the cup is heated to 95°C at a certain rate, held at 95°C for a specified duration, and then cooled to 50°C. During this temperature regime, the starch in the slurry swells, reaches a peak viscosity, breaks down, and then increases again (Fig. 1).

The viscosity properties of cereal starches and flours have traditionally been measured using the Brabender Viscoamylograph. This instrument requires a large sample, 50 g, and an extended measuring duration of approximately 2 h. In an effort to reduce the sample size and shorten the testing duration, the Rapid Visco-Analyser (RVA) was developed. The RVA uses only 3 g of sample and requires about 12 min to conduct a test (Voisey et al., 1977; Wrigley et al., 1996). Similar starch pasting properties were reported from both instruments (Chang et al., 1998). However, Thiewes and Steeneken (1997a) found that the Brabender Viscoamylograph was better than the RVA in discriminating the pasting properties of native and modified starches. It was reported that these two instruments had similar pasting profiles for starches (the purified carbohydrates from flours), but different profiles for wheat flours (Deffenbaugh and Walker, 1989). The concentration of starch paste also produced differences in the Brabender Viscoamylograph and the RVA measurements (Thiewes and Steeneken, 1997a). Despite these limitations in using the RVA, it has largely replaced the more sensitive Brabender Viscoamylograph due to the smaller sample size and shorter operating duration.

The Micro Visco-Amylograph (MVA) is a recently introduced instrument that operates on the principle of the Brabender Viscoamylograph. It uses about 12 g of rice flour and requires about 15 to 40 min for a complete test. Suh and Jane (2003) compared the MVA to the RVA using corn, potato, wheat, and tapioca starches. They found that the MVA breakdown viscosity was less, but the setback viscosity was greater than that measured by the RVA. The differences were explained by the differences in spindle structures of the two instruments. No studies were found that quantified the performance of the MVA to that of the RVA when using rice flour, the typical medium for conducting rice viscosity tests. As such, this study compared the pasting properties measured by the RVA to those of the MVA using a broad range of rice flour samples.

MEET THE STUDENT-AUTHOR

Nettie K. Mathis

I transferred to the University of Arkansas in fall 2003 to pursue a degree in food science after earning an Associate of Science degree from Northwest Arkansas Community College in May 2003. I was awarded a scholarship from the Mid-South Division of the Institute of Food Technologists, the Ozark Food Processors Association Carolyn S. Q. Sharp scholarship, and the Division of Agriculture Transfer College scholarship. I am a member of the Food Science Club and the Institute of Food Technologists.

Shortly after transferring to the University of Arkansas I began working for Dr. Siebenmorgan in the Rice Processing Program and began work on the research project that led me to write this paper. This project has been a valuable learning experience in both the laboratory and in the process of writing the paper. My plans after graduation are to pursue a career in the field of research and new product development.

MATERIALS AND METHODS

Two long-grain rice cultivars, Francis and Wells, and a long-grain hybrid, 'XL8 Clearfield' ('XL8CF'), were harvested in 2003 from both Lodge Corner, Ark., at harvest moisture contents of 24.3-24.9%, 18.1-18.5%, and 14.5-15.8% and Essex, Mo., at HMCs of 21.8-25.0%, 18.6-20.0%, and 15.5-17.8%. The HMC was measured using an individual kernel moisture meter (Shizuoka Seiki CTR 800E, Japan). The rough rice was transferred from the field to the Rice Processing Laboratory at the University of Arkansas on the same day as harvest. The rough rice was dried on a tarp at room temperature to a moisture content of 12.5% and was fractionated into thin, medium, and thick fractions using a commercial-scale Carter-Day grader (Seedburo Equipment Co., Chicago, Ill.) equipped with two cylindrical screens that had 1.88 and 2.03 mm rectangular slot widths, respectively. Rough rice was first placed inside the rotating 2.03 mm screen; retained rice comprised the 'thick' fraction while rice passing through the slots was fed onto the smaller screen. The same procedure with this screen produced the medium (retained kernels) and thin (passed through kernels) fractions. The separation procedure for each fraction was repeated to ensure a thorough separation. An unfractionated rice sample served as a reference. Thus, a total of 72 lots (three cultivars x two harvest locations x three harvest moisture contents x four thickness fractions) were used for this study. Subsamples of each lot were cleaned using a grain cleaner (MCI Kicker Grain Tester, Mid-Continent Industries, Inc., Newton, Kan.). Rough rice sub-samples (150 g) were hulled with a Satake paddy husker (Satake Engineering Co., Ltd., Tokyo, Japan) to produce brown rice, which was milled for 30 s in a laboratory mill (McGill No. 2, Rapsco, Brookshire, Texas). The resultant milled rice was separated into head rice and brokens using a sizing device (Seedburo, Chicago, Ill.). The head rice was ground into flour using a cyclone mill (UDY Corporation, Fort Collins, Colo.) equipped with a 0.5 mm screen.

Viscosity properties of the rice flour samples were determined using both a Rapid Visco-Analyser (RVA-4 Series, Newport Scientific Pty., Ltd., Warriewood, NSW, Australia) at a rotational speed of 160 rpm following AACC method 61-02 (AACC, 2000) and a Micro Visco-Amylograph (C. W. Brabender Instruments, Inc., South Hachensack, N.J.) at a rotational speed of 250 rpm. For the RVA, a paste was prepared by mixing 3 g of rice flour (12% moisture content basis) with 25 mL of distilled water. Two heating rates were used with the RVA: (1) a fast heating rate in which the flour slurry was heated to 95°C at 11.8°C/min, held at 95°C for 2.5 min, and cooled to 50°C at 11.8°C/min; and (2) a slow heating rate in which the slurry was heated from 50°C to 95°C at a rate of 3.0°C/min, held at 95°C for 10 min, and cooled to 50°C at 3°C/min. For the MVA, 11.7 g of rice flour (12% moisture basis) was mixed with 105.3 mL of distilled water. Two heating rates were used: (1) a fast heating rate in which the flour slurry was heated from 50°C to 95°C at 7.5°C/min, held at 95°C for 2.5 min, and cooled to 50°C at 7.5°C/min (7.5°C/min heating rate was chosen instead of the 11.8°C/min used with the RVA because the MVA could not maintain more than a 7.5°C/min heating rate); and (2) the slow heating rate was the same as used with the RVA. The fast and the slow heating rates were designed for the RVA and the MVA, respectively. To study the effects of the heating rates on rice-flour pasting properties, both fast and slow heating rates and similar test durations were applied to both the RVA and the MVA. A typical pasting profile is shown in Fig. 1. The peak viscosity (PV), trough (TR), breakdown (BD), final viscosity (FV), setback (SB), peak time (PTime), and pasting temperature (PTemp) were recorded for each viscosity determination. Data were analyzed using the Statistical Packages for the Social Sciences (SPSS v10, SPSS Inc., Chicago, Ill.) statistical analysis package to determine correlation coefficients.

RESULTS AND DISCUSSION

Thickness distributions of rough rice samples

The thickness fraction distributions of rough rice samples are shown in Fig. 2. The 'Francis' and the 'XL8CF' medium fractions were dominant, comprising approximately 60 to 80% of the total mass. Wells was generally a thicker-kernel cultivar in that approximately 45% to 72% of the total mass was represented in the thick fraction, compared to only 7.6% to 22.3% in the 'Francis' and 'XL8CF'. The thick fraction mass percentage of 'Wells' from Lodge Corner increased as the HMC increased, however, the changes of the thick fraction mass percentages of 'Wells' from Essex were not as significant as those from Lodge Corner (Fig. 2). The thin fractions of all cultivars were less than 17% of the total rough rice mass. The medium fractions usually increased, while the thick fractions decreased as the HMC decreased, except those of 'XL8CF' from Lodge Corner. The variations in the thin fraction mass of the three cultivars with the HMC did not follow a consistent pattern.

Comparison of peak viscosity by variety

As indicated in Fig. 1, there are many components of a viscosity profile that can be used to characterize the rheological properties of rice flour. The PV is the most common of these and is focused on in this discussion.

Regardless of whether the RVA or the MVA was used, 'Francis' variety had the greatest PV of all cultivars, followed by 'Wells', then 'XL8CF'. The average PVs of unfractionated rice flour samples for 'Francis', 'Wells', and 'XL8CF' were 242, 227, and 207 RVU, respectively, as measured by the RVA. When measured by the MVA, the average PVs of the unfractionated samples for 'Francis', 'Wells', and 'XL8CF' were 627, 592, and 544 BU, respectively. There were greater differences in viscosity as measured by the MVA; however, this could be due in large part to the numerical magnitude differences in the instrument values. Overall, the trend in viscosity differences among cultivars, as seen in the unfractionated samples, was followed in each of the thickness fractions as well for both instruments.

Comparison of peak viscosity by kernel thickness

The PVs of 'Wells' rice flour samples harvested at three MCs from Lodge Corner and Essex measured at two heating rates using the RVA and the MVA are shown in Fig. 3a and 3b, respectively. Overall, PV increased with rice kernel thickness. While there were some deviations, the rate of increase was generally linear; the average increase in PV from the thin to thick kernel fraction was 21 RVU for the RVA and 38 BU for the MVA. The average PVs for the unfractionated, thin, medium, and thick rice kernel fractions of 'Wells' across harvest locations, HMC, and heating rates were 239, 218, 232, and 247 RVU using the RVA and 582, 569, 575, and 600 BU using the MVA, respectively.

'Francis' and 'XL8CF' PV trends were similar to those of 'Wells' in that PVs linearly increased with thickness fraction. 'Francis' thick fractions had the highest average PV, 257 RVU and 646 BU as measured by the RVA and the MVA, respectively. The thin fractions of 'Francis' had the lowest PVs of 230 RVU and 598 BU for the RVA and the MVA, respectively. The average PVs of the 'XL8CF' thin, medium, and thick fractions across harvest location and HMC using the RVA and MVA were 202, 208, and 210 RVU and 528, 538, and 543 BU, respectively.

Peak viscosities of the samples harvested at Lodge Corner were slightly greater than those from Essex; this was true for both viscosity measurement instruments (Fig. 3a and b). However, of perhaps greater significance in PV trends between Lodge Corner and Essex was the variability in PVs across the three harvest MCs. For both instruments, the spread in PV values from high to low HMC was much greater for the Lodge Corner than Essex samples (Fig. 3a and b). The reason for these location effects may be due to kernel thickness distribution differences between Lodge Corner and Essex (Fig. 2). The kernel thickness distributions of 'Wells' at Lodge Corner were much more variable across HMC than at Essex. The 'Wells' medium and thick fractions, which comprised well over 90% of the rough rice sample mass, from Essex changed much less than those from Lodge Corner. These thickness distribution differences could in turn be due to different environmental conditions between the two locations, particularly differences during the grain-filling period (Yoshida and Hara, 1977; Fujita et al., 1984).

Theoretically, the unfractionated PVs should be similar to the weighted average PVs of the thin, medium, and thick fractions. About 70% of the mass fraction-weighted average PVs were similar to the unfractionated PVs, indicating that the variability in PV among cultivar/harvest locations/HMC lots was attributed to kernel thickness. However, the rest of the weighted average PVs were either less than or greater than the unfractionated PVs. This may have been caused by the milling practice in that thin kernels in an unfractionated bulk are often less severely milled than if separated prior to milling (Chen and Siebenmorgen, 1997). As such, the degree of milling may not have been uniform across thickness fractions. This difference in milling produces different degrees of milling, which has been shown to affect PV (Wang et al., 2004).

Effects of heating rates on viscosity properties

The rate at which rice flour paste was heated during viscosity measurement affected PV in both the RVA and the MVA (Fig. 3a and b). For each instrument, the slow heating rate consistently produced a greater PV than the fast rate used for that instrument; this observation held across all thickness fractions. The average difference of the 'Wells' PV between the 3.0 and 11.8°C/min rates used with the RVA was 15 RVU, while the average difference between the 3.0 and 7.5°C/min for the MVA was 46 BU. The average differences in PVs between the slow and fast heating rates of the unfractionated, thin, medium, and thick kernel fractions of 'Wells' using the RVA were 14, 14, 18, and 10 RVUs, respectively. Similar trends were observed with the MVA; the average differences were 75, 61, 101, and 80 BU, respectively, between the slow and fast heating rates. These results did not agree with those of Deffenbaugh and Walker (1989). Their results with the RVA and the Brabender Viscoamylograph showed that wheat flours had greater PVs with faster heating rates.

The PV differences between fast and slow heating rates of samples harvested from Essex were not as large as those harvested from Lodge Corner. This finding definitely indicates a location effect, but the fundamental reason as to why the difference in heating rates was greater at Lodge Corner than at Essex is unknown.

The RVA viscosity profiles (Fig. 4a) showed that for the slow heating rate, the FVs (the viscosity measured when the final paste temperature reached 50°C) were less than the PVs (Fig. 3a), whereas with the fast heating rate, the FVs were equal or exceeded the PVs (Fig. 3a). For the MVA, the FVs exceeded the PVs for both slow and fast heating rates. However, the fast heating rate produced greater FV values than the slow heating rate. 'Wells' unfractionated FVs using the RVA fast and slow heating rates were 232 and 183 RVU, respectively, and those using the MVA fast and slow heating rates were 799 and 650 BU, respectively. The lower FVs obtained using the slow heating rates were due to the additional shearing applied by the spindle to the flour paste during the longer holding duration at 95°C, which related to gelatinized starch shear-thinning behavior (viscosity decreases with shearing) and temperature dependence (Sandhya-Rani and Bhattacharya, 1989). The shear-thinning behavior of the rice samples using the fast and slow heating rates was also observed by the differences in the TR (the lowest viscosity during the 95°C holding period). The average TRs of the rice samples using slow and fast heating rates were 82 and 113 RVU for RVA and 307 and 381 BU for MVA, respectively. The fast heating rate applied less sustained shearing action to the flour paste than the slow heating rate because of the shorter test duration using the fast heating rate and shorter holding period at 95°C. Thiewes and Steenehen (1997b) also pointed out that less shearing would apply to starch paste using the RVA fast heating rate. The less FV than PV observed using the RVA slow heating rate might be due to the spindle design of the RVA. Different starch viscosity profiles were also observed by Thiewes and Steeneken (1997b) and Suh and Jane (2003) using different heating rates, and both explained that the spindle structure could cause viscosity profile changes. The spindle design for the MVA is much different than the RVA; the RVA spindle has a larger surface area than that of the MVA. The severe shearing may affect the gel formation of the flour paste during the cooling period, resulting in lower FVs.

Comparison of the MVA and the RVA performances by using different heating rates

A direct comparison of RVA to MVA viscosity values could not be made since the units for the two instruments are different. In an effort to compare performance of the two instruments, however, a correlation analysis was conducted. For this analysis, 'Wells' was used to compare the PV, TR1, BD, FV, SB, PTime, and PTemp of the two heating rates.

The RVA fast and the MVA slow heating rates had greater correlation coefficients of 0.89, 0.68, 0.70, 0.49, 0.13, 0.47, and 0.68 for PV, TR1, BD, FV, SB, PTime, PTemp, respectively, than other pairs of RVA and MVA heating rates (Table 1). The highest correlation observed was for PV, and the lowest was for SB. Deffenbaugh and Walker (1989) reported that the pasting profiles measured by using the Brabender Viscoamylograph and the RVA were similar; however, the correlation coefficient (r=0.89) was not high enough to interchange the instruments.

Conclusion

Overall, the MVA and the RVA showed similar PV trends. The PVs of the rice flours increased with kernel thickness and were affected by cultivar, harvest MC, and location. The slow heating rate for both RVA and MVA resulted in greater PVs and less TRs and FVs than the fast heating rate for all rice flour samples. The highest correlations between the RVA and the MVA were for PVs, while the lowest correlation was for SBs. Although the rice flour PVs using the RVA and the MVA produced similar trends, the correlations were not high enough for the instruments to be used interchangeably.

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Table 1. Correlation coefficients of rice-flour pasting properties[z] measured by the Rapid Visco-Analyser (RVA) and the Micro Viaco-Amylograph (MVA) using fast (11.8°C/min for RVA and 7.5°C for MVA) and slow (3°C/min) heating rates.

	PV	TR	BD	FV	SB	PTime	PTemp
RVA fast vs. MVA fast heating rate							
PV	0.81***[y]						
TR1		0.32					
BD			0.60**				
FV				0.23			
SB					---		
Ptime						0.34	
PTemp							0.77***
RVA fast vs. MVA slow heating rate							
PV	0.89***						
TR1		0.68***					
BD			0.70***				
FV				0.49**			
SB					0.13		
Ptime						0.47	
PTemp							0.68***
RVA slow vs. MVA fast heating rate							
PV	0.80***						
TR1		0.39					
BD			0.77***				
FV				0.35			
SB					0.19		
Ptime						0.38	
PTemp							0.14
RVA slow vs. MVA slow heating rate							
PV	0.80***						
TR1		0.26					
BD			0.70***				
FV				0.34			
SB					0.16		
Ptime						0.51*	
PTemp							0.12

[z] ***p<0.0001, **p<0.001, *p<0.05;

[y] PV=peak viscosity, TR=trough, BD=breakdown, FV=final viscosity, SB=setback, Ptime=peak time, Ptemp=pasting temperature.

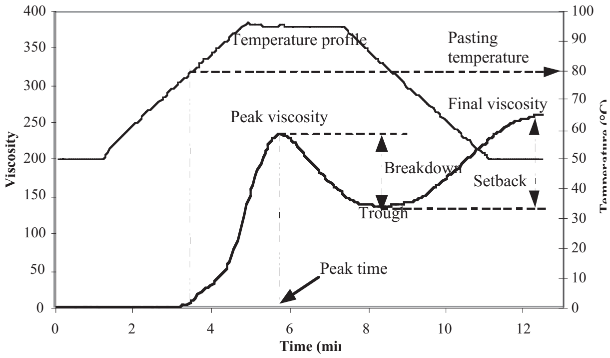

Fig. 1. A typical rice flour viscosity profile.

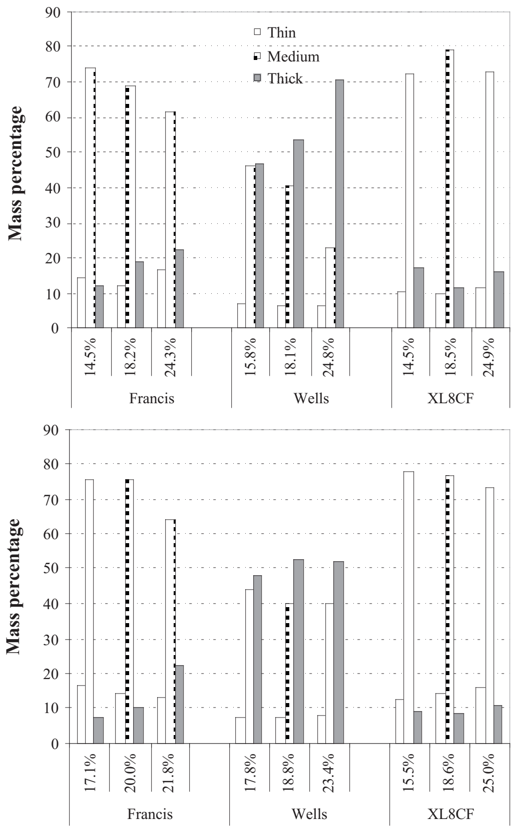

Fig. 2. Thickness fraction distributions of rough rice cultivars harvested at three moisture contents from Lodge Corner, Ark., and Essex, Mo., in 2003.

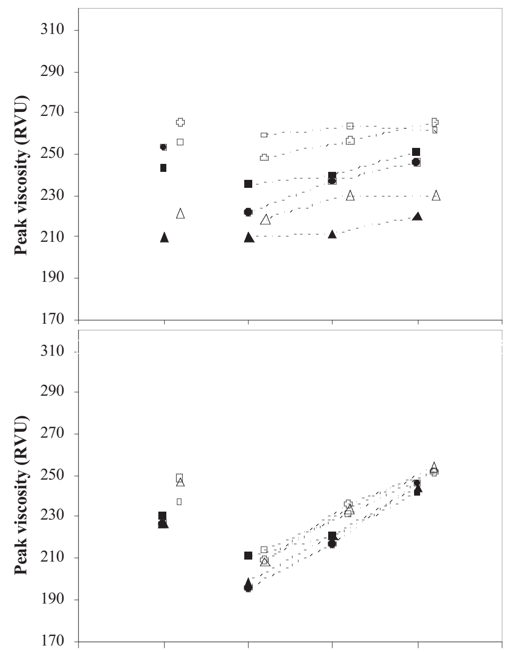

Fig. 3a. Peak viscosities of unfractionated, thin, medium, and thick rice fractions of 'Wells' harvested at the three indicated moisture contents (MC) in 2003 from Lodge Corner, Ark., and Essex, Mo., measured using a Rapid Visco-Analyser with a slow (3.0°C/min) and a fast (11.8°C/min) heating rate.

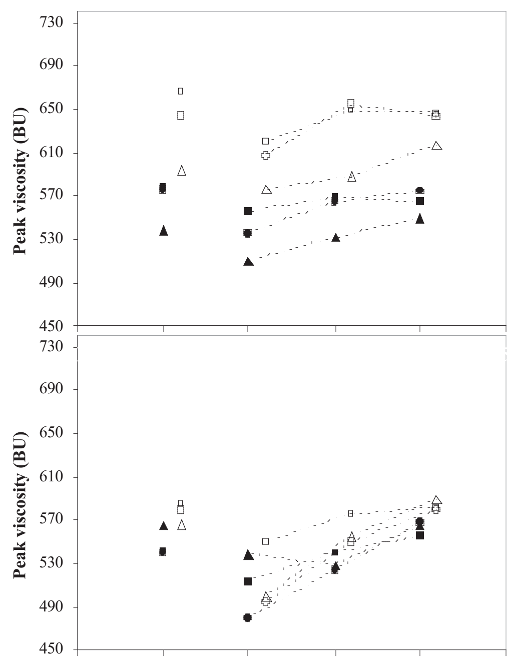

Fig. 3b. Peak viscosities of unfractionated, thin, medium, and thick rice fractions of 'Wells' harvested at the three indicated moisture contents (MC) in 2003 from Lodge Corner, Ark., and Essex, Mo., measured using a Micro Visco-Amylograph with a slow (3.0°C/min) and a fast (7.5°C/min) heating rate.

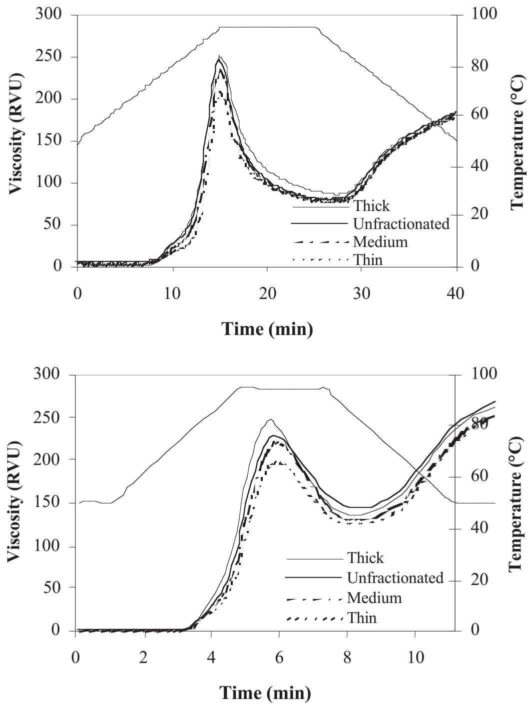

Fig. 4a. Rice-flour pasting profiles of 'Wells' kernel thickness fractions from Essex, Mo., as measured with a Rapid Visco-Analyser using a slow (3.0°C/min) and a fast (11.8°C/min) heating rate.

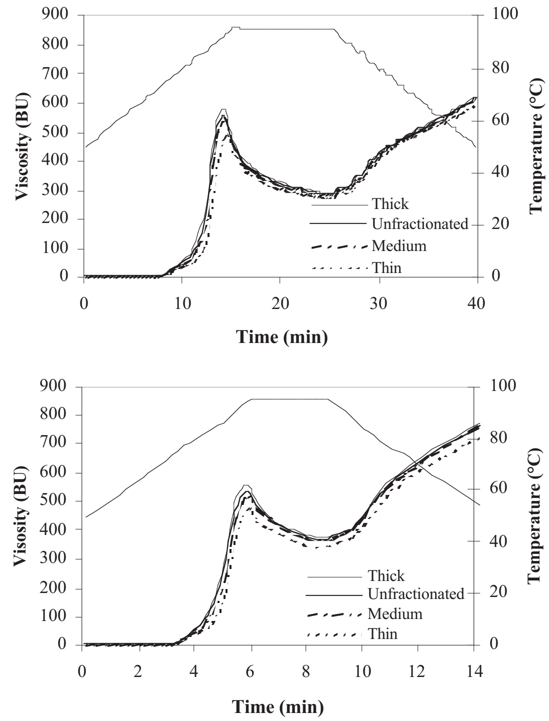

Fig. 4b. Rice-flour pasting profiles of 'Wells' kernel thickness fractions as measured with a Micro Visco-Amylograph using a slow (3.0°C/min) and a fast (7.5°C/min) heating rate.