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Studies on rheological properties of tamarind kernel powder, its derivatives and their blends with maize starch

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Pasting and flow properties of cooked solutions of tamarind kernel powder (TKP), its carboxymethyl and hydroxypropyl derivatives, exhibited shear dependent and pseudoplastic flow behaviour characteristics. Chemical modification decreased the shear dependence of the solution viscosity as the degree of substitution increased. The solutions did not exhibit a yield stress at the concentrations studied.

The effect of TKP and its carboxymethyl and hydroxypropyl derivatives, at different concentrations, on the rheological properties of maize starch dispersions was also studied. The seed gum associated with starch, and the effect was maximum at 10% concentration of the former in the blend. This was evident by the lowering of pasting temperature and the synergistic increase in pseudoplasticity and yield value of the blend pastes. The TKP derivatives also showed maximum association with starch at 10% concentration in the blend but, in comparison to TKP, the degree of association decreased. Thus, the pasting temperature of the blend increased while the pseudoplasticity and yield value decreased as a function of DS/MS. At higher levels of modification, the association was decreased. These results have been explained on the basis of molecular association of the seed gum and its derivatives with starch molecules.

INTRODUCTION

The flow properties of hydrocolloids are very important in several industrial applications such as in food, textiles, paint dispersions, etc., as they have a direct bearing on the quality and consumer acceptability of the finished products (Krumel & Sarkar, 1975; Rao & Anantheswaran, 1982; Patton, 1964; Miles, 1981). Under the influence of an external stress, hydrocolloids, generally polysaccharides and their derivatives, exhibit differences in flow properties owing to their varied structural and macromolecular properties (Morris, 1984). Foods containing hydrocolloids undergo deformations to different extents, when masticated in the mouth, depending on their structural and molecular nature, and subsequently impart different sensory attributes. Szczesnaik and Farkas (1962) have correlated the flow properties of several hydrocolloids to the consumers' organoleptic attributes, i.e. highly shear thinning as non-slimy and less shear thinning as slimy. The latter property in hydrocolloids results in tongue coating and difficulty in swallowing; it is, therefore, unacceptable organoleptically. Furthermore, the flow properties bring about an alteration in thresholds of basic tastes because of the differences in the interaction of hydrocolloids with basic taste compounds and subsequent release of the latter onto the tongue (Stone & Oliver, 1966; Pangborn & Szczesnaik, 1974; Rao, 1977; Sherman, 1982). Hence for specific food application, the flow properties of hydrocolloids are extremely important (Szczesnaik, 1986). The relevance of flow properties pertinent to unit operations in the food industry has been described by Rao and Anantheswaran (1982). In textile processing, several hydrocolloids are used as processing aids and these are subjected to high shear rate. Poor flow properties of a printing thickener are known to cause flushing of the print design and lessen the aesthetic appeal of the printed fabric (Miles, 1981). Hence, the flow properties of thickeners are one of several parameters which are critical for good textile processing (Prabhanjan *et al.*, unpublished data; Muller, 1972; Barth, 1969).

Earlier studies (Rao & Srivastava, 1973) have

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shown that the solutions of TKP (tamarind kernel powder) exhibit non-Newtonian and shear thinning flow properties and some of its inherent drawbacks are of concern for industrial applications. Recent studies on TKP (Prabhanjan *et al.*, 1990; 1991) have shown that chemical modifications such as carboxymethylation and hydroxypropylation, improved the physicochemical properties of the derivatives over the native seed gum. The study also indicated the enhanced prospects of utilizing the derivatives in industrial applications. It was, therefore, of interest to study the rheological properties of these derivatives. This paper is concerned with the studies on the rheological properties of TKP and its carboxymethyl and hydroxypropyl derivatives with respect to their applications in food and textile industries. Further, in such applications, studies on the association of TKP and its derivatives with starch are very important, as the latter form a major component in food and textile applications. As such, it is known that starch and several hydrocolloids associate by molecular associations (Christianson *et al.*, 1981; Sajjan & Raghavendra Rao, 1987). Therefore, the effect of these derivatives on the pasting and flow properties of starch is also reported.

MATERIALS AND METHODS

Defatted TKP (0.85% fat) was obtained as a gift from Natural Chemicals, Hyderabad, India. Studies on the preparation and physicochemical properties of carboxymethyl and hydroxypropyl derivatives, having different modification levels (DS in the case of the former and MS in the latter), have already been reported (Prabhanjan, 1989, 1991; Prabhanjan *et al.*, 1989). In Table 1, relevant data such as the proximate composition, viscosity, solubility and swelling power of TKP and its derivatives are shown. Maize starch was purchased from the local market. A Brabender viscograph type VSK (Disburg, FRG), fitted with a 350 cmg sensitivity catridge was used for determining the pasting behaviour of various slurries. Some modifications to the method of Bhattacharya and Sowbhagya (1981), were employed. Dispersions of individual gum or a blend, were prepared at room temperature (25°C). The lump-free dispersion, after rapid stirring was quickly transferred to the rapid amylogram microbowl attached to the Brabender viscograph, and cooked from 50 to 95°C at a heating rate of 1.5°C/min, held at 95°C for 10 min, cooled rapidly to 70°C followed by controlled cooling (1.5°C/min) to 40°C. The cooked and cooled (30°C) pastes were used for rheological measurements, using a rotatory viscometer Rheotest-2 (GDR). For solutions of up to 4% concentration, spindle S1 and for higher concentrations (5% and above) spindle S3 were used. Shear stress and apparent viscosity were calculated in the shear range of 3–1312 s^{-1} and 0.333–145 s^{-1}, respectively for spindles S1 and S3. The rheometer reading was noted after subjecting the dispersion to shearing action for 40 s at each shear rate. Rheological indices, namely T_0, K and n were calculated by the linear regression method using the power law equation given below.

$$T - T_0 = KD^n \qquad (1)$$

where T = shear stress, dynes/cm^2

Table 1. Proximate composition and physical properties[a] of seed gum and its derivatives

Gum/ derivative	DS/MS	SG (%)	Moisture (%)	Proteins (%)	Fat (%)	Viscosity (cps)	Solubility (%)	Swelling (%)
TKP	—	—	8.8	18.7	0.85	1160	42.5	13.3
CMTKP	0.03	0.9	10.1	16.3	0.53	1440	44.0	16.2
CMTKP	0.08	2.2	10.8	15.2	0.20	1680	47.0	16.2
CMTKP	0.15	4.1	10.0	13.9	0.10	1200	53.8	19.1
CMTKP	0.22	5.9	12.7	12.3	trace	900	54.3	22.6
CMTKP	0.33	8.8	11.9	13.0	trace	600	60.0	22.7
CMTKP	0.48	12.9	12.0	11.9	trace	440	68.3	23.5
CMTKP	0.60	16.1	13.3	5.3	trace	350	80.7	25.9
CMTKP	1.08	29.0	13.3	4.0	trace	300	85.8	33.0
HPTKP	0.06	2.1	9.0	17.7	0.73	1300	48.4	16.0
HPTKP	0.10	3.5	10.6	16.3	0.71	1560	68.5	16.6
HPTKP	0.16	5.5	10.8	16.0	0.68	1000	74.2	18.4
HPTKP	0.23	7.7	10.7	14.6	0.33	800	77.2	19.8
HPTKP	0.28	9.6	11.2	13.6	0.22	640	82.4	20.5
HPTKP	0.36	11.5	11.0	11.9	0.10	520	83.7	22.0
HPTKP	0.44	13.8	11.5	10.3	trace	480	85.7	22.3

TKP, unmodified tamarind kernel powder; CMTKP, carboxymethyl TKP; HPTKP, hydroxypropyl TKP; DS, degree of substitution; MS, molar substitution; SG, substituent groups. The above viscosity data are for 3% solution.

[a] Details on the methods used in determining the proximate composition and physicochemical properties have been reported (Prabhanjan, 1989, 1991)

T_0 = yield value, dynes/cm^2

K = consistency index, dynes/cm^2/s, D = shear rate, s^{-1}

and n = flow behaviour index, unitless.

The value of n is the measure of the flow behaviour of solutions i.e., for Newtonian fluids, $n = 1$; for dilatant fluids $n > 1$; and for pseudoplastic fluids, $n < 1$. In other words, the lower the n value, the higher the pseudoplasticity and vice versa. The values of T_0, K and n presented here are the mean of two determinations.

RESULTS

Pasting properties of TKP and its derivatives

It is known that the pasting behaviour of TKP (seed gum) dispersions is more or less similar to that of starch dispersions and, therefore, the seed gum dispersions need to be cooked to obtain the maximum viscosity (Rao & Srivastava, 1973). Also, the viscosity of TKP dispersion starts rising at a lower temperature and results in very thick pastes having a higher viscosity, when compared to maize starch at the same slurry concentration. In the present study, the pasting properties were studied at different concentrations (2–8%) using a Brabender viscograph. The results shown in Fig. 1 relate to a 5% dispersion. The viscogram indices (Bhattacharya & Sowbhagya, 1979) of TKP and starch dispersions were calculated and are shown in Table 2. It can be seen that the pasting behaviour of TKP conforms to that already reported (Rao & Srivastava, 1973). With increasing concentration, the pasting temperature (onset of initial viscosity rise) decreased as expected, and the breakdown and setback values increased and were higher when compared to those of starch.

Low substituted derivatives (up to 0.10 DS/MS), on the other hand, also showed the onset of initial viscosity but at a lower temperature than that of seed gum (Fig. 1). With a further increase in the degree of chemical modification, the derivatives were soluble in water and formed viscous solutions at room temperature and hence did not show a well defined temperature for the onset of viscosity. The cooked solution had a lower paste viscosity with increasing DS/MS. Also, as cooking did not exert a significant effect on pasting of the derivatives, the characteristic pasting parameters, namely peak viscosity, breakdown and setback were not clearly discernible.

Pasting properties of starch and blends with TKP or its derivatives

The effect of the addition of TKP or its derivatives on the pasting properties of maize starch was studied at different starch–TKP and starch–TKP derivatives blend proportions by maintaining the total slurry concentration at 10%. The results are represented in Figs 2 and 3 by 8 + 2 blends. The viscogram indices for 9:1 and 8:2 blends are listed in Table 3. It can be seen that the addition of TKP hastened the pasting temperature of starch dispersions and resulted in paste having a higher

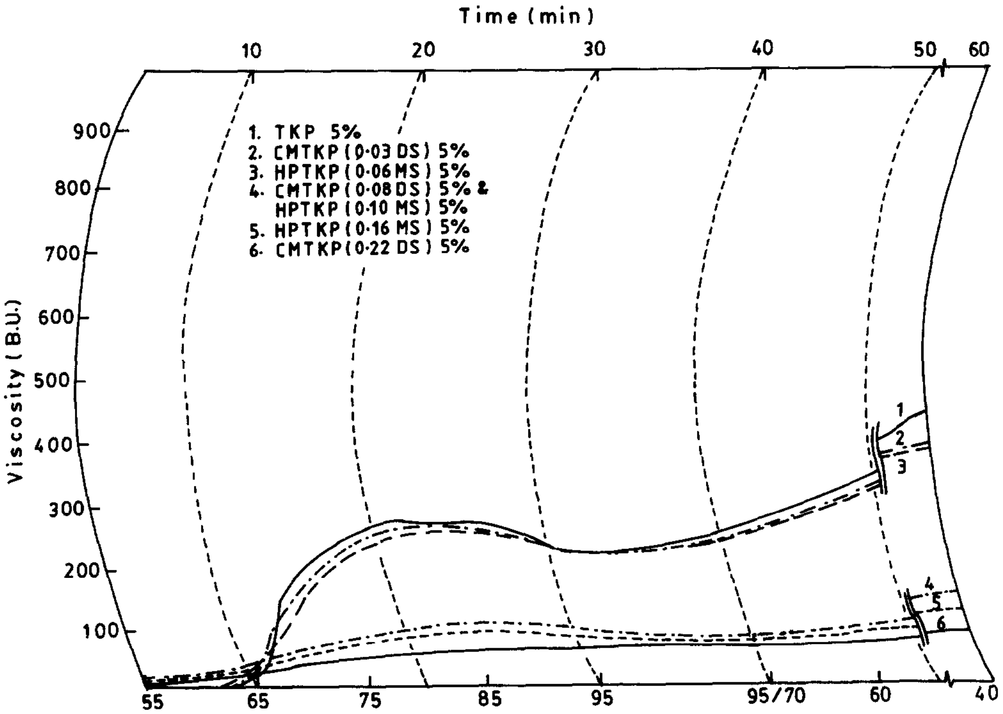

Fig. 1. Pasting behaviour of TKP and its derivatives.

Table 2. Viscogram indices of starch and seed gum (TKP)

Starch (%)	TKP (%)	PT (°C)	P (BU)	H (BU)	C (BU)	P-H (BU)	C–H (BU)	P–H/ C–H
10	—	73.5	385	320	520	65	200	0.33
9	—	76.0	250	230	300	20	70	0.28
8	—	78.5	165	165	180	00	15	0.00
5	—	82.5	120	120	130	00	10	0.00
—	8	49.5	950	650	1240	350	590	0.59
—	5	62.5	270	225	445	45	230	0.83

PT, pasting temperature; P, peak viscosity; H, hot paste viscosity; C, cold paste viscosity;

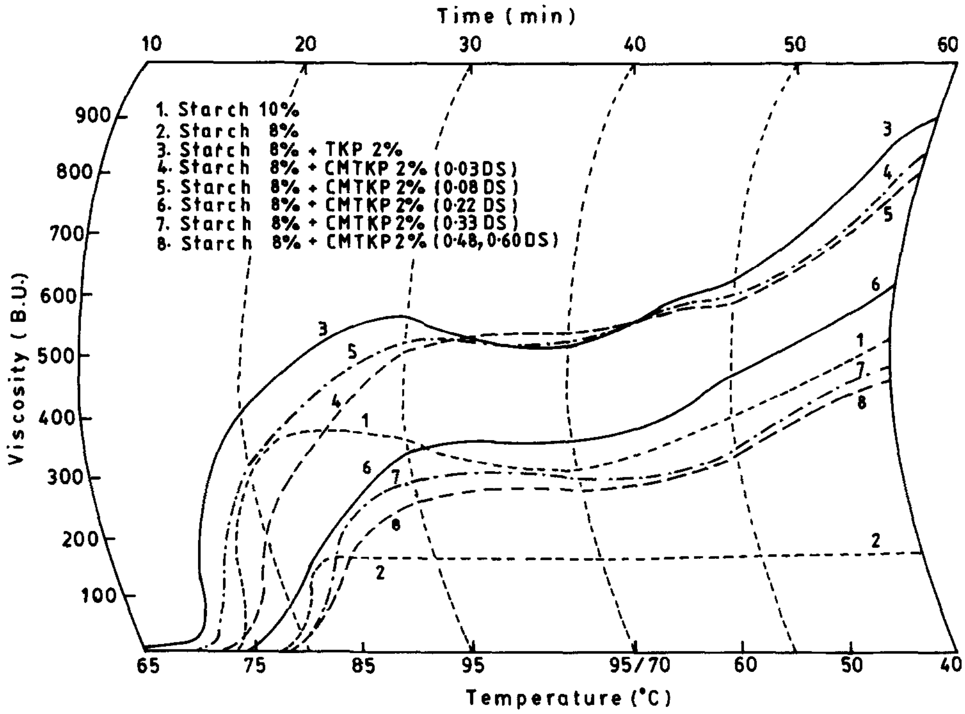

Fig. 2. Pasting behaviour of starch in presence of TKP and its carboxymethyl derivatives.

peak viscosity (*P*) than 10% starch itself. Also, the relative breakdown and cold paste viscosity were higher. With the addition of derivatives in the blend, on the other hand, the onset of the viscosity rise occurred at higher temperatures with increasing DS/MS of the derivative; and with derivatives having 0.3 DS/MS and above, the pasting temperature was higher than that of even 8% starch dispersions alone. Further, the peak occurring during the heating phase gradually decreased and disappeared but viscosity continued to rise until the end of cooking at 95°C ($P = H$). After cooling to 40°C, the cold paste viscosity and the relative breakdown of starch–derivative blends decreased as a function of DS/MS.

Flow properties of TKP and its derivatives

Figures 4 and 5 show the log–log plots of shear rate vs shear stress and Fig. 6 shows the shear rate vs apparent viscosity, respectively, of cooked solutions of TKP and its derivatives. It can be seen that the solutions of TKP and its derivatives are non-Newtonian and shear thinning. The plots obeyed the power law equation. The plots of square root values of shear rate and shear stress values of TKP and its derivatives showed that none of the solutions showed a yield value (T_0) for concentrations up to 5% and thus for these solutions the power law equation reduced to

$$T = KD^n, \text{ since } T_0 = 0 \qquad (2)$$

The rheological indices calculated by using equation (2), are shown in Table 4 for 5% pastes, along with the 'shear factor', *F*, defined as the ratio of viscosities at the highest to the lowest shear rates. It can be seen that the *n* value of TKP is reasonably high. Derivatization of TKP to around 0.1 DS/MS decreased the *n* value slightly, but with further derivatization it increased as a function of carboxymethylation as well as hydroxypropylation. The values of *F* also showed a similar trend with increasing degree of chemical modification.

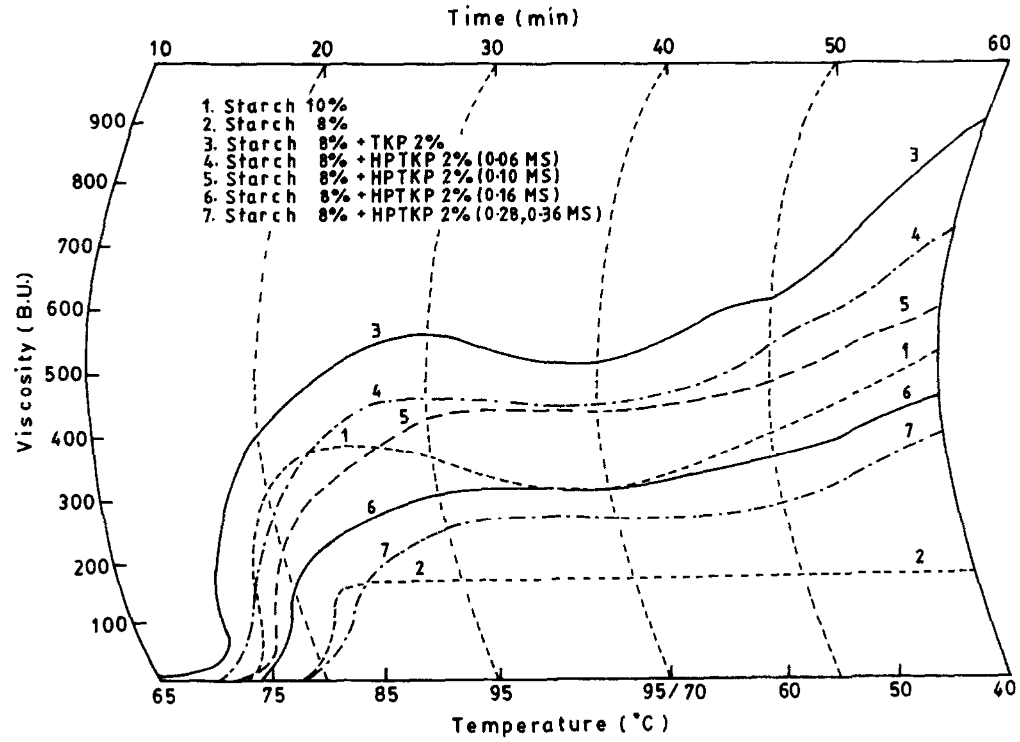

Fig. 3. Pasting behaviour of starch in presence of TKP and its hydroxypropyl derivatives.

Table 3. Viscogram indices of starch in presence of TKP and its derivatives

DS/MS (%)	PT (°C)	P (BU)	H (BU)	C (BU)	P-H (BU)	C-H (BU)	P-H/ C-H
Starch (9%) + TKP or its carboxymethyl derivatives (1%)							
TKP	69.0	460	400	560	60	160	0.38
0.03	68.5	400	370	490	30	120	0.25
0.22	73.5	300	300	380	00	80	0.00
0.33	75.0	270	270	310	00	40	0.00
0.60	76.5	240	240	280	00	40	0.00
Starch (9%) + TKP or its hydroxypropyl derivatives (1%)							
0.06	72.5	365	340	480	25	140	0.18
0.10	74.5	320	320	400	00	80	0.00
0.28	76.5	265	265	320	00	55	0.00
0.36	76.0	250	250	290	00	40	0.00
Starch (8%) + TKP or its carboxymethyl derivatives (2%)							
TKP	64.5	560	520	900	40	380	0.10
0.03	71.5	540	530	840	10	300	0.03
0.08	72.5	530	530	820	00	290	0.00
0.33	79.0	310	310	485	00	175	0.00
0.60	79.5	280	280	420	00	145	0.00
Starch (9%) + TKP or its hydroxypropyl derivatives (1%)							
0.06	72.0	570	515	880	55	365	0.15
0.10	73.0	455	455	720	10	275	0.00
0.28	78.0	310	310	490	00	180	0.00
0.36	79.0	265	265	405	00	140	0.00

For abbreviations see footnote to Table 2.

With increasing concentration, the pseudoplasticity increased as expected (data not presented). A comparison of flow property data (Table 4) does not indicate any appreciable difference in flow properties due to the nature of modification.

Flow properties of starch and blends with TKP and its derivatives

The power law parameters for starch, TKP and their 10% blends in different proportions are shown in

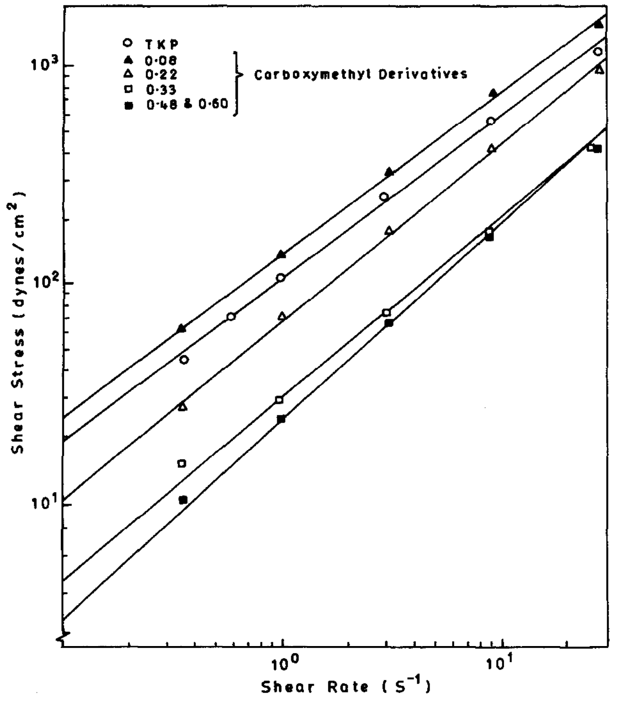

Fig. 4. Log–log plots of shear rate vs shear stress of TKP and its carboxymethyl derivative solutions.

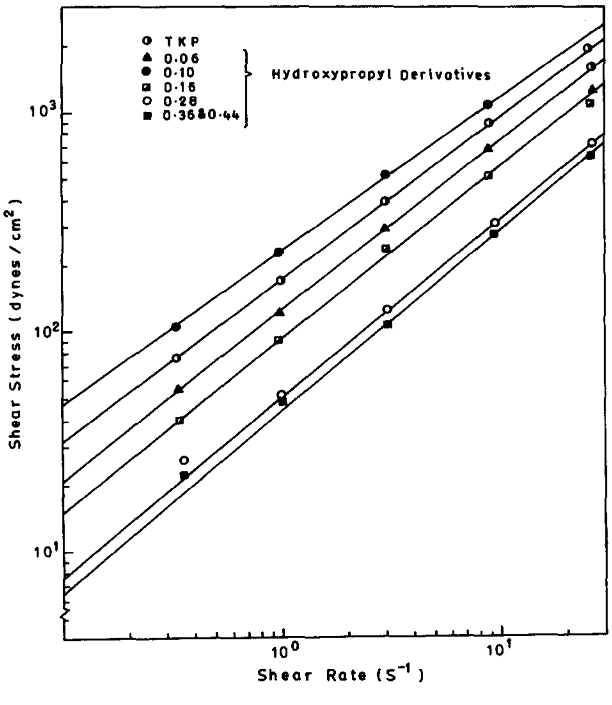

Fig. 5. Log–log plots of shear rate vs shear stress of TKP and its hydroxypropyl derivative solutions.

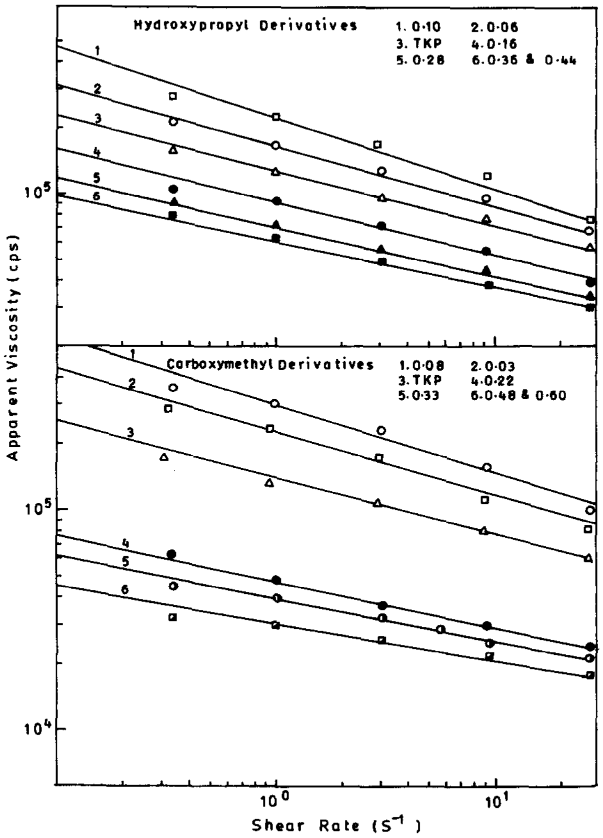

Fig. 6. Log–log plots of shear rate vs apparent viscosity of seed gum and its derivative solutions.

Table 4. Rheological indices of seed gum and its derivative pastes at 5% concentration

Carboxymethyl derivatives				Hydroxypropyl derivatives			
DS	*K*	*n*	*F*	MS	*K*	*n*	*F*
TKP	19.0	0.73	10.3	—	19.0	0.73	10.3
0.03	21.0	0.73	11.0	0.06	21.0	0.73	10.7
0.08	25.0	0.72	11.8	0.10	45.0	0.69	12.1
0.15	16.0	0.75	9.2	0.16	15.0	0.76	9.2
0.22	11.0	0.79	7.9	0.23	11.4	0.78	7.6
0.33	4.6	0.81	7.8	0.28	7.4	0.81	6.8
0.48	3.0	0.88	5.9	0.36	6.2	0.83	6.0
0.60	3.0	0.88	5.9	0.44	6.2	0.83	6.0

K, consistency index, dynes cm^{-2} s^n; *n*, flow behaviour index; *F*, ratio of apparent viscosities at highest and lowest shear rates.

Table 5. In all cases, the pastes showed shear thinning and pseudoplastic behaviour. The log–log plots of shear rate and shear stress were found to fit the power law equation. By plotting the square root values of shear rate and shear stress, yield values were calculated. It can be seen that the *n* value of starch pastes are lower than that of TKP pastes at the same concentration and hence are more pseudoplastic, even though the former had a lower paste viscosity at the corresponding shear rates. Furthermore, starch pastes showed yield values above a 5% concentration while TKP pastes were found to have only small yield values at 8% concentration and above. Upon mixing and cooking starch and TKP from 9.8 + 0.2 down to 9 + 1 blend proportions, the resultant cooked paste showed a synergistic decrease in *n* and increase in T_0 value, when compared to those of the individual components (Table 5). It is noteworthy that *n* and T_0 values were the lowest and highest, respectively

Table 5. Rheological indices of starch, seed gum and their blend pastes

Starch (%)	Seed gum (%)	K	T_0	n
5.0	—	7	—	0.570
8.0	—	52	361	0.547
10.0	—	280	1089	0.528
—	5.0	18	—	0.740
—	8.0	155	25	0.685
—	10.0	400	64	0.600
9.8	0.2	280	1146	0.520
9.5	0.5	285	1260	0.400
9.0	1.0	590	1764	0.223
8.5	1.5	590	1521	0.293
8.0	2.0	550	1369	0.338
7.0	3.0	540	529	0.432
5.0	5.0	225	256	0.496

K, consistency index, dynes cm^{-2} s^n; n, flow behaviour index; T_0, yield value, dynes/cm^2.

for a 9 + 1 blend, indicating the maximum synergism. With a further increase in the proportion of TKP in the blend, from (8 + 2 to 5 + 5), the n value increased while T_0 decreased.

Rheological indices derived as described above, for different proportions of starch–TKP derivative blend pastes, are shown in Table 6. It was found that starch–TKP derivative blends also showed a synergistic decresase in n and an increase in T_0 values although this was less than observed for native TKP. As a function of degree of chemical modification and for a given blend composition, the synergistic effect was observed up to approximately 0.1 DS/MS and then it decreased. With highly substituted derivative blends, the flow behaviour index increased and the pastes showed lower yield values. It is interesting to note that even the starch–TKP derivative blend pastes at 9 + 1 and 8 + 2 blends showed the maximum synergistic effect, but this was again less than starch–TKP blends at the respective blend proportions. At equal derivative proportions in the blend (5 + 5), the n value was as high as 0.7 with a very low yield value.

DISCUSSION

Pasting and flow properties of TKP and its derivatives

Studies on the pasting properties of starch and TKP essentially give a measure of associations in the polysaccharide network. On heating and subsequent cooling of aqueous starch dispersions, paste viscosity rises, retrogradation and formation of a gel are the well established events. These are attributed to the breakdown of the granular structure of starch, hydration of the network and intermolecular associations. On cooking TKP similar events occur, although the seed gum does not have a granular structure. Srivastava and Singh (1967) have proposed the structure of the seed gum polysaccharide and it is further reported (Srivastava & Krishnamurthy, 1972) that the polysaccharide is made up of one insoluble and two soluble fractions, which are probably responsible for the cooking pattern. The seed gum shows a lower pasting temperature, when compared to that of starch, suggesting that the seed gum has an overall weaker molecular organization. Introduction of carboxymethyl or hydroxypropyl groups into the polysaccharide network results in the spanning of molecular chains and, therefore, its molecular organization is further weakened by the nature and extent of chemical modification, as is evidenced by further lowering or absence of paste viscosities for the derivatives. Earlier physicochemical studies on modified TKP (Prabhanjan, 1989; Prabhan-

Table 6. Rheological indices of starch pastes in the presence of carboxymethyl and hydroxypropyl derivatives of TKP

DS/MS	9 + 1 Blend			8 + 2 Blend			5 + 5 Blend		
	K	T_0	n	K	T_0	n	K	T_0	n
Carboxymethyl derivatives									
0.03	456	1722	0.328	370	1482	0.453	415	900	0.540
0.08	400	1892	0.310	285	1764	0.473	435	1225	0.559
0.22	325	1600	0.379	237	1225	0.494	142	900	0.600
0.33	280	1444	0.410	230	961	0.570	82	676	0.689
0.48	250	900	0.449	105	529	0.570	40	256	0.680
0.60	250	841	0.452	95	324	0.580	32	225	0.700
Hydroxypropyl derivatives									
0.06	410	1681	0.332	245	1369	0.460	365	784	0.555
0.10	350	1846	0.340	215	1444	0.469	320	1089	0.590
0.16	315	1722	0.420	160	1225	0.489	125	961	0.625
0.28	280	1225	0.420	130	784	0.550	65	625	0.690
0.36	275	1156	0.439	125	625	0.559	61	400	0.693
0.44	270	961	0.444	125	400	0.564	60	400	0.700

For abbreviations see footnotes to Tables 4 and 5.

jan, 1991) have indicated that the seed gum has a certain degree of structural organization, similar to that of granular starch, which is susceptible to disruption by chemical modification, cooking and alkali treatment. The present data on the pasting behaviour of TKP and its derivatives conform to the earlier studies.

The flow properties could also be explained on the basis of the above concepts. Seed gum solutions can be considered to have a certain degree of molecular entanglement (Graessley, 1965, 1974), resulting in the formation of viscous solution due to the formation of water clusters in the network. When such solutions are sheared, molecular entanglements would be disrupted allowing alignment of molecular chains in the direction of the shearing force and lowering of solution viscosity, resulting in a shear thinning behaviour. Derivatization of the seed polysaccharide would affect the flow properties of the derivatives in two probable ways, depending on the extent of chemical modification. Firstly, the presence of substituent groups would span and reduce the intermolecular associations and entanglements as described earlier (Prabhanjan *et al.*, 1989; Prabhanjan, 1989, 1991) and secondly render hindrance to the alignment of molecular chains to the direction of shearing force during laminar flow. Chemical modification of the polysaccharides would alter the hydrophilic–lipophilic balance (HLB), making the polysaccharide more lipophilic (Sarkar, 1984; Prabhanjan *et al.*, 1990) which may also influence the flow behaviour. Thus, the results in Table 3 demonstrate that the shear dependence of solution viscosity decreased after modification. This is further supported by the dependence of F on DS/MS.

Pasting and flow properties of starch–TKP and starch–TKP derivatives blends

It can be seen from Fig. 2 and Table 2 that molecular associations are operating between starch and the seed gum components, with the derivatives decrease as a function of chemical modification. When an aqueous starch dispersion is cooked, soluble fractions are gradually released into the liquid medium and the granular rigidity is lost, which subsequently forms a mixture of ruptured swollen granules, granular fragments and solubles. Upon cooling, the amylose fraction retrogrades leading to formation of a gel. Christianson *et al.* (1981), in a study on the effect of guar, xanthan and cellulose gums on the pasting property of wheat starch, have found that the added hydrocolloid reduces the temperature of the initial rise in viscosity and increases the paste viscosity of the starch. This was interpreted as the result of molecular associations during gelatinization forming an additional molecular network.

The effect of the addition of TKP on the cooking of maize starch is consistent with the interpretation and observations of Christianson *et al.* (1981). On the other hand, the rationale for the increase in pasting temperature and decrease in viscosity of starch–TKP derivative pastes, with increasing DS/MS of TKP, could be as follows. It is seen from Table 1 that solubility increases with DS/MS. When dispersed in water along with starch, the derivatives hydrate faster and form a coat on the starch granules which delays the gelatinization of starch granules. Thus it is seen that, with highly substituted derivatives ($DS/MS > 0.4$), the pasting temperature is higher than that of starch itself. A careful analysis of pasting temperature and viscogram indices of the blends (Table 3) suggests that TKP associates with starch during gelatinization, but does not affect the process. In contrast, the association of TKP derivatives extends the gelatinization of starch. Thus the peak viscosity gradually decreases and disappears with increasing DS/MS while the viscosity continues to rise. The lowering of viscosity of cooked and cooled starch–derivative paste suggests that the molecular associations are reduced, probably due to factors such as molecular spanning, lipophilic properties and the number of substituent groups.

The flow properties of $9+1$ blends are quite interesting as they show a synergistic decrease in n and an increase in T_0, indicating that at this blend ratio the two polysaccharides engage in maximum associations, and thus the network accommodates more water molecules which subsequently gets depleted to a maximum extent when the solution is sheared. Characterization of flow properties of wheat starch in the presence of guar, locust bean, xanthan and cellulose gums was reported by Sajjan and Raghavendra Rao (1987). The added hydrocolloid, particularly xanthan gum, was found to synergistically increase the pseudoplasticity of starch dispersions. The increased pseudoplasticity of starch in the presence of xanthan gum was attributed to the anionic nature and higher molecular weight of the hydrocolloid which associated and extended the conformation of amylose molecules. In the present study, the seed gum increased the pseudoplasticity probably by a similar mechanism. With both types of derivatives, the pseudoplasticity decreased. Although the carboxymethyl derivatives are anionic, their effect on the rheological properties of starch contrasts with that described for xanthan gum. This could be due to the polydisperse nature of the derivatives brought about during derivatization reactions (Prabhanjan, 1989, 1991). Further, on similar rheological grounds as described for the derivatives, the effective molecular associations of starch–derivatives decreases with increasing DS/MS and thus the synergistic effect is reduced. Molecular incompatibility may also be advocated as an explanation. However, that does not seem probable considering the higher solubility of the derivatives in water and similar results of Sajjan and

Raghavendra Rao (1987). In addition, the incompatible interactions would probably lead to precipitation of one of the components.

CONCLUSIONS

Chemical modification of seed gum polysaccharide chains with substituent groups, disrupted the organization in the molecular network and thus reduced molecular associations. This aspect decreased the pseudoplasticity of the derivative solutions by reducing the alignment of the chains during laminar flow. Cooking of starch in the presence of seed gum reduced the pasting temperature of starch as a result of the formation of molecular associations, yielding very viscous pastes. Chemical modification of the seed gum reduced this effect. The pseudoplasticity of the starch + TKP blend paste increased synergistically. The association seemed to be maximum at a 9+1 blend ratio. Similar associations between starch and the derivatives were not pronounced but reduced due to the molecular spanning, degree of chemical modification and the lipophilic nature of the substituent groups in the seed gum.

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