

# Effect of Oil Content and pH on the Physicochemical Properties of Corn Starch-Soybean Oil Composites

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## ABSTRACT

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Starch-lipid composites are a new category of fat replacers. The physicochemical properties of reconstituted corn starch and soybean oil composites (CSSBOC) were evaluated and compared with the properties of reconstituted jet-cooked corn starch (JCCS). Gel firmness, thermal properties, and hot pasting properties at two pH levels and two oil content levels were studied. Amylose content of CSSBOC was unaffected by processing. Buffer pH significantly affected the firmness of the gels made with JCCS. Gels appeared to have a more ordered structure and were firmer at pH 3.4 than at pH 6.0. The firmness of gels made with CSSBOC was not affected by pH or oil content. Retrogradation enthalpy

of the gels made with JCCS was significantly affected by pH. Differences in the thermal characteristics of gels made with CSSBOC were attributed to pH and oil content. Peak viscosity, cold paste viscosity, and breakdown viscosity changed significantly when CSSBOC pastes were reconstituted in different pH buffers. Only hot paste viscosity and cold paste viscosity changed significantly when JCCS pastes were reconstituted in different pH buffers. Results establish critical parameters for processing decisions and for the understanding of the behavior of CSSBOC in food system models in which pH is an important factor.

Starch-lipid composites have been reported as a new type of fat replacer and flavor carrier (Eskins and Fanta 1996; Felker et al 1998). Processing of such composites includes passing a continuously stirred suspension of unmodified starch and lipid in water through a jet cooker with excess steam. The wet slurry can be used as is or, optionally, dried. Starches from all botanical sources can be utilized. The source of lipids varies from vegetable oils and fats to animal oils and fats. Stable and nonseparable composites with various amylose-amylopectin and lipid-starch ratios can be obtained according to the specific application desired. Electron microscopy showed that the oil present in these composites was encapsulated as droplets of  $\approx 1\text{--}10\ \mu\text{m}$  diameter within the starch-water matrix (Eskins et al 1996) and oil droplets are stabilized by the thin films of starch at the oil-water interface (Fanta et al 1999). Starch-lipid composites can be added to food products either as dispersions collected directly from the jet cooker or as reconstituted dispersions prepared by adding the dried composite to water.

Although the use of starch-lipid composites as fat replacers has been reported (Byars 2003; Warner et al 2001; Garzón et al 2003), only general reviews of preparation and properties of these composites have been published (Fanta and Eskins 1998; Felker et al 1998); no studies on the physicochemical properties of such materials are available. The objectives of this study were to determine the effect of oil content and pH on the chemical composition and physical properties of starch-oil composites. Corn starch and soybean oil composites (CSSBOC) were used as model systems in this study. We utilized soybean oil because it is readily available at low cost in the United States. Amylose content, gel firmness, thermal properties, and pasting properties of CSSBOC gels were studied and compared with gels of jet-cooked corn starch (JCCS). This characterization defines some critical parameters and supplies some necessary information for the application of CSSBOC in food systems.

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## MATERIALS AND METHODS

Normal, unmodified food-grade corn starch was purchased from A.E. Staley Manufacturing (Decatur, IL) and Crisco pure soybean oil was bought at a local market. Citric acid anhydrous was purchased from Archer Daniels Midland (Decatur, IL), sodium citrate was obtained from Sigma (St. Louis, MO), both monopotassium phosphate and sodium hydroxide were purchased from Fisher Scientific (Fair Lawn, NJ).  $\alpha$ -Amylase A-6255 from porcine pancreas was acquired from Sigma (St. Louis, MO).

### Preparation of Jet-Cooked Starch and Starch-Oil Composites

For the preparation of JCCS and CSSBOC, normal corn starch and distilled water were mixed to a solids content of 16% dwb. This dispersion was stirred in a stainless steel Waring blender (model 37BL84, Dynamics Corporation of America, New Hartford, CT) for 2 min and subsequently pumped through a laboratory model steam jet cooker consisting of a progressive cavity pump (model 2M1 SS03 AAA; Robbins and Myers, Springfield, OH) and a manual stainless hydroheater (model M101-030; Hydrothermal, Waukesha, WI). The jet cooker was operated under excess steam conditions (Klem and Brogly 1981); outlet pressure was maintained at 275.8 kPa (140°C), steam line pressure was 448.2 kPa (155°C) and pumping rate was of 1L/min. The resulting dispersion was stirred again in the Waring blender and subsequently fed through the jet cooker under the conditions previously described. The resulting slurry was dried on a double-drum drier (model 20; Drum Drier and Flakes Co., South Bend, IN) heated with steam at 206.8 kPa (135°C). In CSSBOC, soybean oil was added at 20:100 and 40:100 (dwb) before the second mixing in the blender and the second pass through the jet cooker. Dry flakes from the drum drier were milled using a Retsch mill type ZM1 (Brinkmann Instruments, Westbury, NY). The final moisture content of the JCCS powder was  $6.77\% \pm 0.685$  (dwb), while the moisture content of the composites was  $3.05\% \pm 0.837$  (dwb) for the 20:100 CSSBOC and  $2.61 \pm 0.633$  (dwb) for the 40:100 CSSBOC. The powders were packed into polyethylene bags and stored at  $-20^\circ\text{C}$  until analyses were performed. Amounts of those products used in subsequent experiments were corrected for moisture and are reported on a dry weight basis. The process-product for the starch-lipid composites is Fantesk (Eskins and Fanta 1997, 1999).

### Compositional Analysis

Amylose content of JCCS and CSSBOC was determined with the colorimetric procedure of Morrison and Laignelet (1983). To avoid interference of oil with the assays, samples were previously

defatted by extraction with ethanol following the method described by Adkins et al (1970). A standard curve of absorbance vs. % amylose was prepared by analyzing known mixtures of corn amylose and waxy corn starch.

Total oil content of CSSBOC was determined by the method described by Knutson et al (1996). A 1-g sample of CSSBOC was dispersed in 80 mL of boiling water and then cooled to room temperature. For starch hydrolyzation, 200 units of porcine pancreas  $\alpha$ -amylase was added to the sample for 3 hr. The dispersion was then transferred to a separatory funnel and extracted with two 20-mL portions of hexane. After hexane evaporation, the extracted oil was determined gravimetrically. For determination of unbound oil content in JCCS and CSSBOC, extraction with petroleum ether according to an official method (AOCS 1997) was performed. All compositional determinations were performed in triplicate.

### Reconstitution of Starch-Oil Composites

Aqueous suspensions of JCCS or CSSBOC were prepared at a starch concentration of 10.7% (w/w) by mixing the required weight of solid with the required weight of 0.1M citrate buffer (pH 3.4) or 0.2M monopotassium phosphate buffer (pH 6.0).

### Gel Firmness

Suspensions of JCCS or CSSBOC in buffer were transferred to a blender for 5 min. Each suspension was then transferred to the sealed 400-mL stainless steel chamber of an Omni mixer (Ivan Sorvall, Norwall, CT). The suspension was then heated in a boiling water bath for 15 min while stirring at 1,000 rpm. Slurries (25 g) obtained from the mixer were transferred to plastic vials with lids and stored at 4°C for 24 hr. Gels were equilibrated at 23°C for 1 hr before evaluation. Gel firmness (kPa) was determined using a texture analyzer (TA.XT2, Stable Micro Systems, Godalming, UK). A cylindrical flat-ended 5-mm probe compressed the gel at a speed of 1 mm/sec for a distance of 2 mm. Two gels were prepared for each treatment and four repeated measurements per gel were taken.

### Retrogradation of Gels Measured by DSC

Retrogradation transition temperatures and enthalpies of the gels made with JCCS and CSSBOC were determined by DSC analysis. Samples were reconstituted with buffer in the mixer as previously described. Slurry (23 mg) was placed in a hermetically double-sealed, coated aluminum pan (TA Instruments, New Castle, DE) and stored at 4°C. After 24 hr, pans were removed and equilibrated at 23°C for 1 hr before DSC scans. All DSC scans were performed using a DSC model 2920 (TA Instruments) with refrigerated cooling system attached. Samples were heated at 10°C/min from 23 to 180°C and a nitrogen flow rate of 24 cm<sup>3</sup>/min was maintained during the runs. The DSC was calibrated against an indium standard and 0.2  $\mu$ W/sec sensitivity. From the DSC curve, the onset temperature ( $T_o$ ), peak temperature ( $T_p$ ), and transition enthalpy ( $\Delta H$ , J/g) were recorded.

### Pasting Properties

A Rapid Visco Analyser (RVA) (model series 4; Foss North America, Eden Prairie, MN) was used to study the thermal pasting properties of JCCS and CSSBOC. The Approved Method 76-21 (AACC 2000) was used, following the standard 2 profile: heat from 50 to 95°C in 7.5 min, hold for 5.0 min, cool to 50°C in 7.5 min, and hold for 2 min. Quantity analyzed was calculated to provide a final starch concentration of 10.7% (dwb) of the sample in 20 mL of pH 3.4 or pH 6 buffer. Tests were done in duplicate. Peak viscosity of the composite (PV), hot paste viscosity (HPV), cold paste viscosity (CPV), breakdown viscosity (BD = PV - HPV), and setback viscosity (SB = CPV - HPV) were studied.

### Statistical Analysis

The experimental design was a completely random design (CDR) with two replicates. Various statistical analyses were performed,

such as Pearson coefficients for calculating JCCS and CSSBOC correlations at two different pH levels for gel firmness, RVA, and DSC variables. Statistical analysis for JCCS also included *t*-test comparisons of the two pH levels for gel firmness, RVA, and DSC variables. The statistical analysis for CSSBOC was a two-factor (pH and oil content) analysis of variance (ANOVA). A Levene's test for homogeneity of variance was used to check whether data transformations were necessary. Least significant difference (LSD) values at the 0.05 level were used as a multiple comparison test to detect oil content  $\times$  pH interaction significance. Both main effects (oil content and pH) consisted of only two levels, so differences could be discerned directly from the ANOVA *F*-tests. Statistical analysis was performed using PROC GLM (v. 8.0, SAS Institute, Cary, NC)

## RESULTS AND DISCUSSION

### Compositional Analysis

The total amylose content of JCCS was 27.8%  $\pm$  0.314. This result is similar those reported by Germani et al (1983) and Bathnagar and Hanna (1997), who found 29 and 25% amylose in normal corn starch, respectively. The total amylose content was 28.2%  $\pm$  0.477 for 20:100 CSSBOC and 25.4  $\pm$  1.49 for 40:100 CSSBOC. These values were not significantly different from that of the starting material (JCCS) and results are consistent with those reported by Knutson et al (1996), who observed the same amylose content values when comparing normal, unmodified food-grade corn starch and CSSBO. Through quantitative analysis, they concluded that there was no change in the starch composition and no evidence of chemical reaction between the starch and the oil during the cooking and drying process.

The amount of unbound oil ranged from 7.59% (w/w) for 20:100 CSSBOC and 17.9% (w/w) for 40:100 CSSBOC. Those results agreed well with Knutson et al (1996), who reported 6.7% (w/w) for 20:100 CSSBOC and 16.8% (w/w) for 40:100 CSSBOC.

The amount of total oil recovered after hydrolysis of the composites ranged from 14.0% (w/w) for 20:100 CSSBOC to 27.1% (w/w) for 40:100 CSSBOC. The total oil recovered by Knutson et al (1996) was 12.8% (w/w) for 20:100 CSSBOC and 23.9% (w/w) for 40:100 CSSBOC. This indicates that a substantial portion of the oil is lost during jet-cooking due to separation before the mixture reaches the hydroheater, where the final dispersion and cooking take place.

### Gel Firmness

Results from statistical analysis indicated that the firmness of gels made with JCCS were significantly affected by pH level ( $P = 0.0017$ ) (Table I). Lowering the pH of gels from pH 6.0 to pH 3.4 significantly increased resistance to compression. These results suggest degradation of the starch by the citric acid present in the

TABLE I  
Effect of pH on Firmness of Gels Made with Jet-Cooked Corn Starch and Corn Starch and Soybean Oil Composites<sup>a</sup>

Material	Gel Firmness (kPa)		Significance <sup>b</sup>
	pH 3.4	pH 6.0	
Jet-cooked starch <sup>c</sup>	0.195 (2 $\times$ 10 <sup>-2</sup> )	0.100 (1.5 $\times$ 10 <sup>-2</sup> )	0.00170**
Oil-starch composites <sup>d</sup>	0.653 (8.5 $\times$ 10 <sup>-3</sup> )	0.393 (9.8 $\times$ 10 <sup>-2</sup> )	0.0650ns

<sup>a</sup> Values in parentheses represent standard errors of two replicates. 20:100 and 40:100 oil-to-starch ratio composites were combined for overall comparison of pH levels from jet-cooked starch and composites.

<sup>b</sup> \*\*, statistically significant at  $P < 0.01$ ; ns, not significant.

<sup>c</sup> Mean pH differences for jet-cooked corn starch were analyzed with *t*-test statistics.

<sup>d</sup> Main effect mean pH differences for corn starch and soybean oil composites were analyzed with two-way analysis of variance (*F*-test).

pH 3.4 buffer. Partial reduction in the molecular weight of the starch occurs during jet-cooking due to turbulence and high shear (Dintzis and Bagley 1995; Dintzis and Fanta 1996). High shear and heating used to mix and reconstitute JCCS and CSSBOC suspensions might have caused further breakdown of amylose and amylopectin chains, and such effect might have been more pronounced under acidic conditions. Autio and Poutanen (1994) have demonstrated that acid modification and heating of starches cause considerable changes in the microstructure of starch dispersions. According to these authors, there is a specific molecular weight of both amylose and amylopectin that results in a better miscibility of the two moieties and this miscibility leads to a dense network structure. This theory has also been stated by Lansky et al (1949), who reported that starch retrogradation was maximum at a critical chain length. In our experiments, treatment of the samples at pH 3.4 may have favored optimum molecular weight in which molecules had better mobility and could associate by hydrogen bonding, creating stronger gels.

Results from Levene's test for homogeneity of variance indicated that a transformation of the data corresponding to firmness of gels made with CSSBOC was necessary. Therefore, gel firmness values were transformed according to the formula: Gel hardness = arc sin (gel hardness)<sup>1/2</sup>. After data transformation, we found that, unlike systems using only JCCS, changes in pH did not affect the continuity of the gels made with CSSBOC (Table I). Similarly, oil content did not significantly affect gel hardness when CSSBOC slurries were prepared. The mean force needed to compress gels made with 40:100 composites at both pH levels was 0.655 ± 0.093 kPa, while firmness of gels made with 20:100 composites was 0.391 ± 0.065 kPa for both pH levels.

Due to the lack of literature on physical properties of starch-oil composites, it was not possible for us to compare our results to other authors. However, we consulted results from research involving other starch-oil systems (Osman et al 1961; Eliasson et al 1988; Navarro et al 1997). Our observations differ from those obtained by Navarro et al (1997). During trials with pastes made with 7% (w/w) corn starch dispersions and 5% (w/w) sunflower oil, they found that gels containing sunflower oil had higher storage modulus *G'* values (a measurement of rigidity of the gel) than control pastes without lipids. These authors hypothesized that amylose-lipid interactions may have contributed to the reinforcement of the amylose network, but Osman et al (1961) hypothe-

sized that soybean oil does not interact with amylose. On the other hand, Eliasson et al (1988) observed a decrease in *G'* when heating normal maize starch slurries with soybean oil. Although this decrease was not statistically significant, they attributed it to the loss of continuity of the structure of the gels formed in the presence of this oil. They hypothesized some inhibition of granule-to-granule contact, which might contribute to the elasticity due to the formation of a transient network. Results from those reports suggest that the effect of oil addition on the continuity of the starch gel network depends on the starch origin and processing conditions.

The effects of pH and oil content on the firmness of the gels made with JCCS and CSSBOC were supported by the degree of association between the variables. Firmness of gels made with JCCS and pH were negatively correlated ( $r = -0.72, P < 0.05$ ). Firmness of gels made with CSSBOC was also correlated with pH ( $r = -0.38, P < 0.05$ ) and oil content ( $r = 0.39, P < 0.05$ ) but in a lesser degree.

### Retrogradation of Gels Measured by DSC

There was no significant effect of pH on *T<sub>o</sub>* and *T<sub>p</sub>* for JCCS gels. However, the retrogradation enthalpy of gels made with JCCS at pH 3.4 was significantly higher than that of the gels at pH 6.0 ( $P = 0.0142$ ) (Table II). The transitions reported here correspond to melting of the retrograded amylose fraction of the starch. According to Raphaelides and Karkalas (1988), Sievert and Pomeranz (1989), Sievert and Pomeranz (1990), and Czuchajowska et al (1991), endothermic transitions in retrograded samples due to melting of recrystallized amylose take place at 120–177°C. The observed difference in enthalpy for melting amylose crystals suggests that retrograded samples have different stabilizing forces, while lower calculated enthalpies indicate that amylose associations were hindered at pH 6. Because retrogradation describes a return to an ordered crystalline structure from a state of disorder, we conclude that at pH 3.4, gels had a more ordered structure. These observations support our previous hypothesis that acid treatment and shear effect during reconstitution of JCCS at pH 3.4

TABLE II

Effect of pH on Thermal Characteristics of Jet-Cooked Corn Starch<sup>a</sup>

Property <sup>b</sup>	pH		Significance <sup>c</sup>
	3.4	6.0	
<i>T<sub>o</sub></i> (°C)	142 (1.20)	139 (2.95)	0.479ns
<i>T<sub>p</sub></i> (°C)	151 (0.775)	146 (2.10)	0.147ns
• <i>H</i> (J/g)	4.27 (0.395)	0.71 (0.165)	0.0142*

<sup>a</sup> Values in parenthesis represent standard errors of two replicates.

<sup>b</sup> Mean pH differences for thermal properties *T<sub>o</sub>*, *T<sub>p</sub>*, and •*H* were analyzed with *t*-test statistics.

<sup>c</sup> \*, statistically significant at  $P < 0.05$ ; ns, not significant.

TABLE IV  
Effect of pH on Pasting Properties (cps) of Jet-Cooked Corn Starch<sup>a</sup>

Property <sup>b</sup>	pH <sup>c</sup>		Significance <sup>d</sup>
	3.4	6.0	
Peak viscosity (PV)	2,609 (175)	2,428 (81.2)	0.363ns
Hot paste viscosity (HPV)	61.3 (3.12)	115 (9.06)	0.0004**
Cold paste viscosity (CPV)	160 (8.39)	238 (14.9)	0.0005**
Breakdown viscosity (BD)	2,547 (175)	2,312 (83.8)	0.2462ns
Setback viscosity (SB)	99.1 (9.20)	123 (12.3)	0.1505ns

<sup>a</sup> Values in parentheses represent standard errors of two replicates.

<sup>b</sup> BD = PV – HPV, SB = CPV – HPV.

<sup>c</sup> Mean pH differences for pasting properties were analyzed with *t*-test statistics.

<sup>d</sup> \*\*, statistically significant at  $P < 0.01$ ; ns, not significant.

TABLE III

Effect of pH and Oil Concentration on Thermal Characteristics of Corn Starch and Soybean Oil Composites<sup>a</sup>

Property	pH <sup>b</sup>		Significance <sup>c</sup>	Composite Oil-to-Starch Ratio <sup>d</sup>		Significance <sup>c</sup>
	3.4	6.0		20:100	40:100	
<i>T<sub>o</sub></i> (°C)	149 (1.62)	94.4 (2.65)	<0.001**	127 (8.80)	118 (10.5)	0.0436*
<i>T<sub>p</sub></i> (°C)	160 (1.28)	126 (1.40)	<0.001**	145 (5.80)	142 (7.04)	0.531ns
• <i>H</i> (J/g)	5.28 (0.798)	12.5 (1.39)	<0.001**	6.69 (0.971)	11.5 (2.04)	0.0009**

<sup>a</sup> Values in parenthesis represent standard errors of two replicates.

<sup>b</sup> Main effect mean pH differences for *T<sub>o</sub>*, *T<sub>p</sub>*, and •*H* of corn starch and soybean oil composites were analyzed with two-way analysis of variance (*F*-test).

<sup>c</sup> \*\*, statistically significant at  $P < 0.05$  and  $P < 0.01$ , respectively; ns, not significant.

<sup>d</sup> Main effect mean differences between oil-to-starch ratios for *T<sub>o</sub>*, *T<sub>p</sub>*, and •*H* properties of corn starch and soybean oil composites were analyzed with two-way analysis of variance (*F*-test).

leads to an improved molecular association and to a higher degree of hydrogen bonding in the gels. Thus, the higher degree of hydrogen bonding accounts for both higher enthalpy values and higher gel firmness. Correlation analysis of DSC parameters showed that the pH was highly and significantly correlated to the retrogradation enthalpy of the gels ( $r = -0.98$ ,  $P < 0.05$ ).

There were significant ANOVA main effects on thermal characteristics for pH and oil content (Table III). The DSC retrogradation parameters varied with pH; the  $T_o$  and  $T_p$  of CSSBOC gels at pH 6.0 decreased significantly ( $P < 0.001$ ), while the retrogradation enthalpy increased ( $P < 0.001$ ). Increase in  $T_o$  ( $P = 0.0436$ ) and decrease in retrogradation enthalpy ( $P = 0.0004$ ) were observed in retrograded gels made with 20:100 CSSBOC as opposed to 40:100 CSSBOC, but no significant change in  $T_p$  was detected. Those differences suggest that pH treatment and oil content of the gels generated molecules with a different matrix conformation and differences in the degree of amylose association. Lower calculated enthalpies suggest that amylose associations in the gels were hindered at pH 3.4 and at 20:100 oil-to-starch ratio.

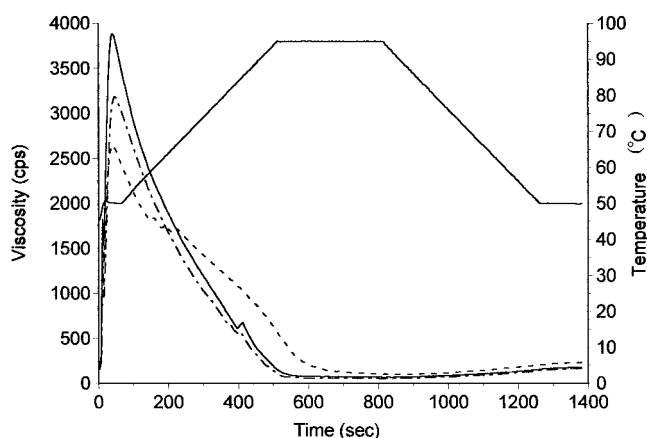
Correlation analysis between DSC parameters of CSSBOC and pH and oil content showed high negative association between  $T_o$  and pH ( $r = -0.9751$ ,  $P < 0.0001$ ) and  $T_p$  and pH ( $r = -0.9746$ ,  $P < 0.0001$ ), and high positive association between  $\Delta H$  and pH ( $r = 0.7465$ ,  $P = 0.0002$ ). Only weak association was found between  $\Delta H$  and oil content of CSSBOC ( $r = 0.4888$ ,  $P = 0.0337$ ).

### Pasting Properties

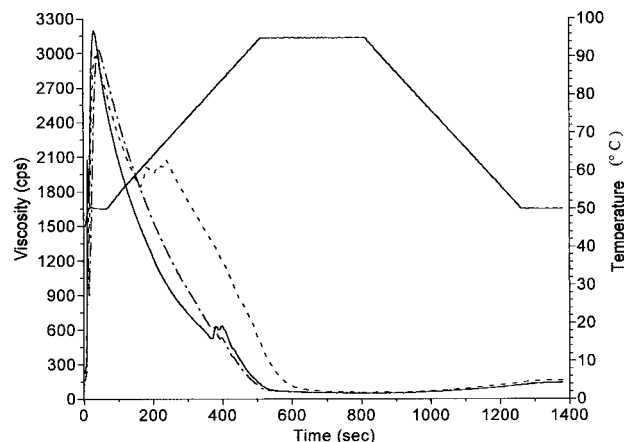
There was a significant change in HPV ( $P = 0.0004$ ) and CPV ( $P = 0.0005$ ) when pastes were made with JCCS in different pH buffers (Table IV). Lowering the pH caused HPV and CPV to decrease from 115 cps to 61.3 cps and from 238 cps to 160 cps,

respectively. For CSSBOC, pH also affected PV ( $P = 0.0105$ ), CPV ( $P = 0.0423$ ), and BD ( $P = 0.0119$ ) of the pastes (Table V). Pastes made in pH 6 buffer solution had higher viscosity values as compared with pastes at pH 3.4. Reduction in paste viscosity as measured by RVA techniques has been observed in cassava starch pastes in pH 4 buffer as compared with pastes in pH 7 buffer (Mestres et al 1997) and acidified cassava and corn starch (Bertolini et al 2000). They attributed the reduction in paste viscosity to starch degradation due to acid, which leads to higher solubilization of amylopectin. The composites in our trials may have undergone a mild form of starch hydrolysis during exposure to heat and shearing in the RVA. However, during studies of the effect of pH on the properties of starch pastes from unmodified, acid-modified, and oxidized corn starches, Bechtel (1947) reported an increase in maximum viscosity and HPV from pH 3.4 to pH 6.0, but a reduction in BD in unmodified and acid modified starches. On the contrary, he observed a decrease in maximum viscosity and BD and an increase in HPV. From these observations, he concluded that the effects of pH on paste characteristics of the starches differ depending on the kind of modification of the starch.

Pasting properties of CSSBOC were not significantly affected by oil concentration (Table V). However, RVA profiles suggested that at pH 6 (Fig. 1) the 20:100 composite hydrated faster than the 40:100 CSSBOC and that CSSBOC hydrated faster than JCCS. In addition, a second peak, or a shoulder, was detected in the profiles corresponding to JCCS and a sharp peak in the profile corresponding to 20:100 CSSBOC. These secondary peaks might be due to variations in the rate of buffer diffusion into the solid particles. Such diffusion seems to be slower in JCCS than in CSSBOC. We consider that the samples were behaving like highly absorbent polymers experiencing a gel-blocking effect. Gel blocking occurs



**Fig. 1.** Rapid Visco Analyser (RVA) profiles of a representative run of corn starch and soybean oil composites at pH 6. Ratios: 20:100 oil to starch (—); 40:100 oil to starch (---). Jet-cooked starch (· · · ·).



**Fig. 2.** Rapid Visco Analyser (RVA) profiles of a representative run of corn starch and soybean oil composites at pH 3.4. Ratios: 20:100 oil to starch (—); 40:100 oil to starch (---). Jet-cooked starch (· · · ·).

**TABLE V**  
Effect of pH and Oil Concentration on Pasting Properties (cps) of Corn Starch and Soybean Oil Composites<sup>a</sup>

Property <sup>b</sup>	pH <sup>c</sup>		Significance <sup>d</sup>	Composite Oil-to-Starch Ratio <sup>e</sup>		Significance <sup>d</sup>
	3.4	6.0		20:100	40:100	
Peak viscosity (PV)	2,717 (128)	3,279 (167)	0.0105*	3,050 (174)	2,946 (155)	0.614ns
Hot paste viscosity (HPV)	49.5 (4.28)	59.8 (4.93)	0.1123ns	60.1 (3.56)	49.1 (5.42)	0.089ns
Cold paste viscosity (CPV)	142 (9.74)	172 (9.24)	0.0423*	161 (7.68)	153 (12.1)	0.5752ns
Breakdown viscosity (BD)	2,667 (129)	3,219 (165)	0.0119*	2,990 (173)	2,897 (155)	0.6523ns
Setback viscosity (SB)	92.8 (6.88)	112 (7.59)	0.0821ns	101 (7.13)	104 (8.10)	0.7652ns

<sup>a</sup> Values in parentheses represent standard errors of two replicates.

<sup>b</sup> BD = PV - HPV, SB = CPV - HPV.

<sup>c</sup> \*, statistically significant at  $P < 0.05$ ; ns, not significant.

<sup>d</sup> Main effect mean pH differences for pasting properties of corn starch and soybean oil composites were analyzed with two-way analysis of variance ( $F$ -test).

<sup>e</sup> Main effect differences between oil-to-starch ratios for pasting properties of corn starch and soybean oil composites were analyzed with two-way analysis of variance ( $F$ -test).

when particles absorb liquid on their surface and swell, preventing passage of liquid into the center of the particle for additional absorption (Chen et al 1985). The difference in diffusion rate in CSSBOC may be due to the amount of oil. Presence of oil droplets in the 20:100 CSSBOC may allow faster hydration of the material because oil droplets break the continuity of the starch matrix, creating channels through which water can diffuse more easily (Eskins et al 1996). Higher amounts of oil appeared to reverse this process. During drum drying we have observed that 40 parts of oil per 100 parts of starch is the upper limit for the starch matrix to hold oil without separation. At this high oil concentration, excess oil tends to coat the particles, resulting in water absorption delay from the composite.

The above trend was also observed in pastes at pH 3.4 (Fig. 2); however, initial hydration was about the same for all samples. We speculate that the ionic strength and particular ions present in the buffers affected the hydration and penetration of buffer and, therefore, the gel blocking effect and viscosity of the pastes. Further research will be needed to prove this hypothesis.

Analysis of RVA parameters of JCCS showed high correlation between pH and HPV ( $r = 0.83$ ,  $P < 0.05$ ) and between pH and CPV ( $r = 0.78$ ,  $P < 0.05$ ). Lower correlation was found between pH and SB ( $r = 0.56$ ,  $P < 0.05$ ). For CSSBOC, there was a low positive association between pH and PV ( $r = 0.44$ ,  $P < 0.05$ ), pH and CPV ( $r = 0.37$ ,  $P < 0.05$ ), and pH and BD ( $r = 0.43$ ,  $P < 0.05$ ).

## CONCLUSIONS

The influence of oil content and pH on pasting properties, gel properties, and retrogradation behavior of gels made of reconstituted starch-oil composites were evaluated. Because the pH of food systems and functional carriers varies with ingredient selection, an important finding was that pH significantly affected some of the physical properties of the CSSBOC; for example, gels appeared to have a more ordered structure at pH 3.4. Those effects were critically different from the effects of pH on JCCS alone (without lipid). Also, because the composites are functional food adjuncts, the amount of oil present in the composites affected both the chemical composition and some of the physical properties.

Most literature data on physical properties of starch slurries and starch-oil systems and the effect of critical factors such as pH and lipid content have been reported on samples processed by methods other than excess-steam jet cooking. Therefore, a direct comparison of our results to published reports is not possible. However, we concluded that the method of preparation of our starch-oil system produces different and variable interactions and, therefore, different effects on the physical properties of the final material. These findings supply basic parameters for processing choices and for understanding the performance of corn starch and soybean oil composites in various food system models where pH is an important factor or variable.

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