Starch–hydrocolloid composites prepared by steam jet cooking

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Abstract

Starch–hydrocolloid composites, containing 1–10% hydrocolloid, have been prepared by a jet cooking and drum drying process that intimately mixes the two components and yields products that have physical properties differing from those obtained by conventional cooking techniques. Dried composites can be readily redispersed in water to yield smooth, viscous dispersions that exhibit considerable lubricity. Viscosities of final products depend upon the particular starch and hydrocolloid used. Composites prepared from cornstarch with either guar gum or konjac gum did not form gels when dispersed in water but remained smooth and free-flowing, even after prolonged standing. Other hydrocolloids, such as xanthan gum, locust bean gum, carrageenan and CMC produced composites that set up to soft gels. The properties of these composites suggest their use in foods as fat replacers, stabilizers, gelling agents and thickeners.

Introduction

Starch is produced annually in the United States in large quantities, much of which is in excess of current market needs. As part of a continuing research program at our Center, we are investigating the preparation and properties of blends, complexes, and copolymers of starch with other materials such as synthetic polymers, natural gums, and lipids. The goal of this research program is to increase utilization of starch in a wide variety of commercial applications.

Starch is isolated from plant sources as discrete granules which are insoluble in water at room temperature due to hydrogen bonding and areas of crystallinity. Although the solubility of starch in water increases as temperatures approach 95–100°C, starch still exists largely as highly swollen but insoluble granules and granule fragments that are easily separable from the aqueous solution. Solutions of starch in water are easily obtained by passing starch–water slurries through a continuous steam jet cooker (1,2). Jet cooking has been used for decades to prepare starch solutions for non-food applications and is carried out by pumping an aqueous starch slurry through a narrow orifice in the cooker where it is mixed with steam at high temperature and pressure. Two methods of steam jet cooking are used: thermal jet cooking (where the amount of steam introduced exceeds the amount required to reach the desired temperature). The intense turbulence caused by the instant heating of starch and the passage of excess steam through the cooker promotes the rupture and dissolution of starch granules and also leads to a lowering of solution viscosity due to mechanical shearing of the starch macromolecule (2). In this study, we describe the preparation and properties of new starch–hydrocolloid composites, in which starch is the major component. Composites are prepared by an excess steam jet cooking process that totally dissolves, partially degrades and intimately mixes the polysaccharide components. Although the viscous properties of various starch–hydrocolloid mixtures (3–6) and their use in food products (7–9) have been described, use of steam jet cooking as a method for preparing composite compositions has apparently not been investigated. As we will show in this report, starch–hydrocolloid composites prepared by jet cooking have unique properties that make them suitable for a number of food-related applications.

Materials and methods

Materials

The following starches were used: cornstarch (Buffalo 3401 from CPC International, Inc., Argo, IL); waxy cornstarch (Amioca from National Starch and Chemical Corp., Bridgewater, NJ); high amylose cornstarch (Amylomaize...
VIS, in lSC/min. The hot viscous solution was then drum dried and then cooled to 94°C, held at 94°C for 15 min, and then cooled at 1.5°C/min to 30°C. Viscosity, in Brabender Units (BU) was continuously recorded as a function of time and temperature.

The cooled dispersion was recovered from the viscoamylograph cup, and the pH was determined at 25°C. The sample was then poured into a beaker, covered with plastic wrap, and allowed to stand for 20 h at room temperature. A second sample was allowed to stand for 20 h in a refrigerator at 5°C. Samples were examined for gel formation; and viscosities of these dispersions were then determined at 30 r.p.m. with a Brookfield model LVT viscometer, using the No. 3 and 4 spindles.

Brabender and Brookfield viscosity data are largely the result of single rather than replicate experiments, and no attempt was made to determine relative standard deviations.

Results

Starch–hydrocolloid composites, containing 1–10% hydrocolloid, were prepared by dispersing the two components in water and then passing the resulting dispersions through an excess steam jet cooker at elevated temperatures and pressures. Mixtures containing <10% hydrocolloid were used because of processing difficulties caused by the high viscosities of most hydrocolloid solutions. Although guar gum was used in most experiments, xanthan gum, locust bean gum, carrageenan, CMC, and konjac gum were also examined as representative examples of the wide range of hydrocolloids available commercially. A variety of starches was also used; however, most composites were prepared from cornstarch because of its availability and low cost. As expected, physical properties of composites depended not only upon the starch:hydrocolloid ratio, but also upon the particular starch and hydrocolloid used in the formulation.

The reduction in polysaccharide molecular weight caused...
Steam jet cooking of starch–hydrocolloids

by the jet cooking process was estimated by passing waxy cornstarch through the jet cooker under the same conditions used for composite preparation and then comparing the intrinsic viscosities of starch samples before and after cooking. In initial experiments, we observed that jet cooking reduced the intrinsic viscosity of waxy cornstarch (in 90:10 by volume, dimethyl sulfoxide:water) from an initial value of 220–115 ml/g. A more complete study of the effect of jet cooking on starch molecular weight is in progress and will be reported separately.

Drum drying proved to be a practical method for isolating these composites from jet cooked solutions. Products were obtained in the form of coarse flakes that could be easily milled into free-flowing powders containing ~5% moisture. Composites could also be isolated by spray drying; however, the spray drying process needs further study because of the high viscosities of jet cooked solutions. Dried composites could be easily redispersed in water with rapid stirring to give smooth, viscous dispersions that also exhibited considerable lubricity.

Brabender viscoamylograph and Brookfield viscosity data for cornstarch–guar gum composites containing 1–10% guar are summarized in Table 1. Figure 1 shows the viscoamylograph curves obtained for the 5% guar composite (Curve A) and the 0% guar product prepared by jet cooking pure cornstarch (Curve B). Comparison of curves A and B shows that viscosity was increased by the presence of 5% guar in the composite, particularly at the beginning of the viscoamylograph experiment, before the sample was heated. The composites in Table 1 all showed a similar relationship between viscosity and temperature, i.e. high initial viscosity, a decrease in viscosity on heating, and only a minor viscosity increase when the dispersion was cooled back to 30°C.

The presence of guar gum in these composites inhibited the formation of gel in aqueous dispersions recovered from the viscoamylograph. Although the cornstarch product

Table 1  Viscous properties of cornstarch–guar gum composites. Dependence upon starch:guar ratio

<table>
<thead>
<tr>
<th>Wt. ratio of cornstarch:guar</th>
<th>Brabender viscoamylograph dataa</th>
<th>Brookfield viscosity (cp) after standing 20 h, 30 r.p.m. (spindle no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BU, initial, 30°C</td>
<td>BU, 94°C</td>
</tr>
<tr>
<td>100:0</td>
<td>300</td>
<td>20</td>
</tr>
<tr>
<td>99:1</td>
<td>330</td>
<td>20</td>
</tr>
<tr>
<td>97:3</td>
<td>700</td>
<td>15</td>
</tr>
<tr>
<td>95:5</td>
<td>690</td>
<td>30</td>
</tr>
<tr>
<td>90:10</td>
<td>900</td>
<td>70</td>
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</tbody>
</table>

Figures 1

Effects of guar gum addition and cooking conditions on paste viscosity. Viscosity versus temperature curves were obtained with a Brabender viscoamylograph at a solids concentration of 30 g in 500 ml. (A) The jet cooked 95:5 cornstarch–guar composite described in Table 1. (B) The jet cooked 100:0 composition described in Table 1. (C) A control composition prepared in a stirred reactor from 95 parts cornstarch and 5 parts guar gum.

Table 1

*Viscosity expressed in Brabender Units (BU).*
containing no guar produced a gel on standing. Composites containing as little as 1% guar yielded smooth dispersions, even after standing for 20 h at 5°C. Brookfield viscosities measured after 20 h were not greatly different for composites containing 1, 3, and 5% guar, but were higher for the 10% guar product. No separation of water occurred when an aqueous dispersion of the 5% guar composite was frozen and thawed.

Figure 1 also shows a viscoamylograph curve for a control composition prepared by heating an aqueous dispersion of cornstarch and guar gum containing 5% guar in a stirred reactor at 90–95°C (Curve C). In contrast to the jet cooked product (Curve A), this control composite exhibited a low initial viscosity, which increased on heating and then increased further as the stirred dispersion was allowed to cool back to 30°C. Moreover, unlike the product prepared by jet cooking, the aqueous dispersion of the control composite set up to a firm gel on standing.

Another control composition was prepared by heating an aqueous dispersion of cornstarch and guar gum containing 5% guar in an autoclave at 132°C (30 p.s.i.g. steam pressure) to dissolve both polysaccharides. The resulting drum dried composite produced viscoamylograph curve A in Figure 2. Curve B of Figure 2 was obtained for a composite having the same composition but prepared by jet cooking at the temperature and steam pressure used for the autoclave preparation. Although initial viscosities of the two composites were similar, the paste viscosity of the autoclaved composite was higher throughout the entire heating and cooling cycle. Also, the sharp viscosity increase on cooling resembled that of the conventionally cooked composite shown in Curve C of Figure 1. Differences between the two composite preparations could also be seen in the dispersions recovered from the viscoamylograph. The autoclaved composite gelled on standing; whereas a smooth dispersion was obtained from the jet cooked preparation.

Table 2 summarizes the viscous properties of composites prepared by jet cooking guar gum with a number of common, commercially available starches. In this series of products, guar gum and starch were combined in a weight ratio of 5 parts per 100. It is evident from both viscoamylograph and Brookfield viscosity data that viscous properties are influenced significantly by the type of starch used in the formulation. Differences are especially apparent when Brookfield viscosities of composites prepared from waxy corn, potato, and tapioca starches are compared with the viscosities of products prepared from normal dent corn starch and wheat starch. The composite prepared from high amylose cornstarch produced a grainy paste when dispersed in water, no doubt due to retrogradation of the amylose component.

Table 3 shows viscous properties of a series of composites prepared by jet cooking cornstarch with a number of commercially available hydrocolloids. The weight ratio of hydrocolloid:starch in these preparations was 5 parts per 100. Although viscoamylograph viscosities depended upon the particular hydrocolloid used in the formulation, the relationship between viscosity and temperature was similar for all of these materials. Each of the composites showed a high initial viscosity, a sharply reduced viscosity at 94°C, and only a relatively small viscosity increase on cooling back to 30°C. Konjac gum was the only hydrocolloid in this series that behaved in a manner similar to guar gum and did not produce a gel when the dispersion was allowed to stand for 20 h.

Discussion

Differences in viscous properties between starch–hydrocolloid composites prepared by jet cooking and those prepared by conventional cooking techniques can be attributed to the high temperature and intense mechanical shear of the excess steam jet cooking process, which totally dissolves, partially degrades, and intimately mixes the two polysaccharide components. Under these conditions, addition of a small amount of hydrocolloid to starch can significantly affect viscosity and gel formation by interfering with the normal hydrogen bonding and retrogradation that occurs in starch solutions.

Although viscous properties of these composites are affected by the particular starch and hydrocolloid used in the formulation, these properties are at present difficult to predict on the basis of polysaccharide structure. For example, despite the fact that guar gum and locust bean gum are both galactomannans and differ only in the frequency of galactose substitution, guar gum alone inhibits the gelling properties of cornstarch. Konjac gum also
### Table 2  Viscous properties of starch–guar gum composites. Dependence upon the starch used for composite preparation

<table>
<thead>
<tr>
<th>Starch</th>
<th>g Guar per 100 g starch</th>
<th>Brabender viscoamylograph data&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Brookfield viscosity (cp) after standing 20 h, 30 r.p.m. (spindle no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BU. initial, 30°C</td>
<td>BU. 94°C</td>
</tr>
<tr>
<td>Corn</td>
<td>5</td>
<td>620</td>
<td>33</td>
</tr>
<tr>
<td>Waxy corn</td>
<td>5</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>Waxy corn (control)</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>High amylose corn</td>
<td>5</td>
<td>50</td>
<td>42</td>
</tr>
<tr>
<td>High amylose corn (control)</td>
<td>0</td>
<td>45</td>
<td>10</td>
</tr>
<tr>
<td>Wheat</td>
<td>5</td>
<td>480</td>
<td>15</td>
</tr>
<tr>
<td>Potato</td>
<td>5</td>
<td>290</td>
<td>45</td>
</tr>
<tr>
<td>Tapioca</td>
<td>5</td>
<td>100</td>
<td>30</td>
</tr>
</tbody>
</table>

<sup>a</sup>Viscosity expressed in Brabender Units (BU).

### Table 3  Viscous properties of cornstarch–hydrocolloid composites. Dependence upon the hydrocolloid used for composite preparation

<table>
<thead>
<tr>
<th>Hydrocolloid&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Brabender viscoamylograph data&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Brookfield viscosity (cp) after standing 20 h, 30 r.p.m. (spindle no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BU. initial, 30°C</td>
<td>BU. 94°C</td>
</tr>
<tr>
<td>Xanthan gum</td>
<td>720</td>
<td>50</td>
</tr>
<tr>
<td>Locust bean gum</td>
<td>560</td>
<td>30</td>
</tr>
<tr>
<td>Carrageenan</td>
<td>260</td>
<td>–</td>
</tr>
<tr>
<td>CMC</td>
<td>470</td>
<td>20</td>
</tr>
<tr>
<td>Konjac gum</td>
<td>690</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Composites were prepared from 5 parts hydrocolloid per 100 parts cornstarch, by weight.

<sup>b</sup>Viscosity expressed in Brabender Units (BU).

<sup>c</sup>Viscosity was too low to measure.
inhibits gel formation, despite the fact that it is a gluco-
mannan. There are also unexplained differences in the
viscous properties of composites prepared from cereal
starches, such as corn and wheat, and those prepared from
tuber and root starches, such as potato and tapioca.
Additional research on structure–property relationships is
needed.

Use of these composites as thickeners, fat replacers, and
stabilizers in food products is suggested by a number of
factors. First, and perhaps most importantly, composites
are prepared by a simple cooking and drying process that
requires no reactions involving potentially toxic chemicals.
Also, composites isolated by drum drying can be easily
redispersed in water to yield smooth aqueous dispersions
that exhibit considerable lubricity. The molecular weight of
starch in these composites is higher than the molecular
weight of most commercial maltodextrins; preliminary
experiments suggest that this higher molecular weight
favors complex formation between the amylose component
of starch and the emulsifiers present in some food formu-
lations. Complexation of this type can improve the prop-
erties of some food products. Finally, viscosities and gelling
properties of these products can be easily tailored for
specific food applications by varying the hydrocolloid and/
or starch used for composite preparation.

Although testing in foods is still preliminary, starch–
hydrocolloid composites have performed favorably when
tested as fat replacers, thickeners, stabilizers, and gelling
agents in sour cream, yogurt, and soft serve dairy product
formulations. We have also observed that emulsions of
vegetable oil and water can be stabilized by the addition of
these composites. For example, when the wheat starch–
guar gum composite described in Table 2 was dispersed in
water at 10% solids and then blended with corn oil, the
resulting product was smooth and spreadable and remained
stable during extended storage. Moreover, substitution of
this preparation for a commercial margarine in a standard
lean cake recipe (American Association of Cereal
Chemists, Method 10-90) yielded a cake having a similar
volume, softness, and crumb texture.

Conclusions
Starch–hydrocolloid composites, containing 1–10% hydro-
colloid, are easily prepared by a steam jet cooking process.
Starch and hydrocolloid are completely dissolved, reduced
in molecular weight and intimately mixed to yield unique
composite compositions having properties different from
those of composites prepared by conventional cooking
techniques. Drum drying yields products in the form of
coarse flakes that can be milled into free-flowing powders
with moisture contents of ~5%. Dried composites disperse
easily in water to yield smooth, viscous dispersions that
exhibit considerable lubricity.

A wide variety of starches and hydrocolloids can be used
to prepare these composites, and viscous properties depend
upon the particular starch and hydrocolloid used in the
formulation. Water dispersions of cornstarch–guar and
cornstarch–konjac do not form gels but remain as smooth
pastes, even after prolonged standing. In contrast to these
two compositions, soft gels are obtained from composites
prepared from xanthan gum, locust bean gum, carrageenan
and CMC.

The smoothness, high viscosity and high lubricity of these
composites in water dispersion suggest their use in a
number of food related applications. The acceptance of
these products as food additives is favored by the fact that
they are prepared by a simple cooking and drying process
that requires no chemical reactions.

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