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Short Communication

Stable starch–lipid compositions prepared by steam jet cooking

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INTRODUCTION

Starch is isolated from plant sources as discrete granules that are insoluble in water at room temperature due to hydrogen bonding and areas of crystallinity within the granule. Although true solutions of starch in water are difficult to prepare using conventional cooking procedures, starch solutions are easily obtained by passing starch–water slurries through a continuous steam jet cooker (Winfrey & Black, 1964; Klein & Brogly, 1981). This technique has been used commercially for decades to prepare starch solutions for non-food applications and involves pumping an aqueous starch slurry through an orifice where it is mixed with steam at high temperature and pressure. The intense turbulence that results from the condensation of high pressure steam and the passage of excess steam through the cooker not only promotes rupture and dissolution of starch granules but also leads to mechanical shearing of starch macromolecules and a lowering of solution viscosity (Klein & Brogly, 1981).

Despite the widespread use of jet cooking to solubilize starch, the co-jet cooking of starch with non-starch materials is a new area of research that has been virtually unexplored. As part of a continuing research program on starch utilization, we are investigating the use of steam jet cooking as a method for preparing blends and complexes of starch with other monomeric and polymeric materials. Our earlier publications in this area describe the co-jet cooking of starch with hydrocolloids, such as guar (Fanta & Christianson, 1995), and with poly(ethylene-co-acrylic acid) (Fanta *et al.*, 1992). In this report, we describe the preparation of starch–lipid compositions by a jet cooking process that utilizes the high temperature and turbulence within the cooker to uniformly disperse the lipid component within the starch–water matrix as small droplets (about 10–50 μm) that will not separate and coalesce, even after prolonged standing and after the product is dried. Although research on these starch–lipid composites is still in a preliminary stage, our initial results are reported in this short communication because of the commercial interest in these compositions as fat replacers and stabilizers in foods and as components in cosmetics, drug delivery systems and adhesives. Detailed studies in each of these research areas will be published separately.

MATERIALS AND METHODS

The following method was used to prepare a cornstarch–soybean oil composition containing 20 parts of oil per 100 parts of starch, and is a representative example of the experimental procedure used.

A mixture of 80 g of refined food grade soybean oil (Wesson Oil, Hunt–Wesson, Inc.) and about 400 ml of water was stirred in a Waring blender at maximum

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speed for about 1 min, and the dispersion was transferred to a 4 l beaker along with sufficient water to give a total water volume of 3 l. Four hundred grams (dry basis) of food grade cornstarch (A. E. Staley Mfg Co.) was then added to the stirred water–oil mixture. An oil phase separated almost immediately from water when stirring was stopped. The rapidly stirred mixture of oil, water and starch was passed through a Penick and Ford laboratory model continuous steam jet cooker operated with 65 psig line pressure steam at a pumping rate of about 1 l per minute. Steam pressure within the cooker was maintained at 40 psig (140°C), resulting in a large excess of steam passing through the cooker along with the cooked dispersion. The cooked dispersion contained about 9.5–10% solids, due to dilution of the mixture with condensed steam.

A small portion of the dispersion was allowed to cool to 25°C without stirring, and viscosity was measured with a Brookfield Model LVT viscometer (No. 3 or 4 spindle). Generally, three repetitive measurements were made, and an average value was calculated. Dispersions were gently mixed with a spatula just prior to viscosity measurement.

The hot starch–oil dispersion was dried on an 18 × 12 inch diameter double drum-drier heated with 30 psig steam and rotated at 4 rpm. The flake-like product was then coarsely ground by passing it through a Retsch centrifugal grinder (Brinkman Instruments, Inc., Des Plains, IL, USA). The final product was a dry, flowable powder with a moisture content of about 5%. This powder could be easily redispersed in water in a Waring blender at 10–20% solids to give a smooth viscous dispersion. Maximum dispersion of the solid particles was achieved by heating the dispersion to about 95°C in a microwave oven.

Small samples of aqueous dispersions were poured onto polyethylene sheets and allowed to air-dry to thin films. Samples of these films were fractured and were then examined and photographed at the fracture faces by scanning electron microscopy. A Hitachi ISI scanning electron microscope was used, and samples were coated with a thin layer of gold–palladium (60–40) alloy. Fractured samples were extracted with ethanol to reveal oil domains as voids in the fracture surface.

To determine the effect of slow stirring on the viscosities of cooked samples, one portion of the hot, jet cooked dispersion was poured into a beaker, covered with plastic wrap and allowed to stand and cool undisturbed. Brookfield viscosity was then measured after the mixture had stood first for 3 h and then overnight (about 22–25 h). Another portion of the hot, jet cooked dispersion (about 650–750 g) was placed in a Readco steam jacketed sigma double arm mixer with 1 quart working capacity (Teledyne Readco, York, PA, USA). Before addition of the sample, the mixer was heated to about 100°C by passing steam at atmospheric pressure through the jacket. The steam line was then disconnected, and the mixer was allowed to stir (75 rpm) and cool to room temperature over a 3 h period. Brookfield viscosity was determined after this 3 h stirring period and again after the mixture was transferred to a beaker and allowed to stand undisturbed overnight (about 22–25 h).

RESULTS AND DISCUSSION

Mixtures prepared for steam jet cooking typically contained 10–20% starch solids and 5–50 parts of lipid per 100 parts of starch, by weight. A wide variety of lipids and lipid-like materials were used, for example, soybean oil, canola oil, olive oil, semi-solid hydrogenated vegetable oil, butter and paraffin oil. Cornstarch was used in most formulations; however, products were also prepared from waxy cornstarch, wheat starch, potato starch and cereal flour. Although the lipid component separated rapidly from these formulations before they were cooked, jet cooked dispersions of starch and lipid were stable and could be stored for weeks without noticeable phase separation, despite the absence of emulsifiers in the system. Brookfield viscosities of jet cooked dispersions varied with the type of lipid and starch used in the formulation and also with the lipid–starch ratio. Some representative viscosity values are shown in Table 1. Although jet cooked dispersions became viscous when cooled and even formed soft gels at high solid concentrations, they became fluid and pourable when reheated, much like a semi-solid fat or shortening.

With certain starch varieties, Bookfield viscosities increased significantly if hot dispersions from the jet cooker were slowly stirred as they were allowed to cool, as opposed to simply letting them stand in covered beakers with no agitation. Results obtained with a series of soybean oil–starch compositions (40:100) are shown in Table 2. Slow stirring dramatically increased the viscosity of the composition prepared from normal cornstarch, and a further sharp increase in viscosity was observed when the stirred dispersion was allowed to stand overnight. The wheat starch composition behaved similarly, although the effect of stirring was not as pronounced. Although the initial viscosity of the stirred potato starch sample was somewhat less than that of the unstirred sample, the stirred dispersion set up to a soft gel on standing overnight. Since the product prepared from waxy maize starch was unchanged by stirring, the amylose component appears to be responsible for the effects of stirring. Stirring effects are apparently unrelated to the presence of lipid, since a jet cooked solution of normal cornstarch, prepared in the absence of soybean oil also became more viscous with stirring. We are investigating these viscosity changes in more detail.

Electron microscopy showed that the lipid was uniformly dispersed within the starch–water phase as

Table 1. Preparation and properties of starch–lipid compositions[a]

Starch variety	Lipid used	Amount (g/100 g starch)	Viscosity of jet cooked dispersion after cooling[a]: Time standing (at 25°C)	Brookfield viscosity, Cp[b]
Corn	None		Overnight	1150
Corn	Soybean oil	5	Overnight	900
Corn	Soybean oil	40	Overnight	820
Corn	Canola oil	20	3–4 h	810
Corn	Olive oil	20	3–4 h	740
Corn	Crisco	20	2–3 h	970
Corn	Butter	5	3–4 h	460
Corn	Butter	20	3–4 h	410
Corn	Butter	50	3–4 h	570
Corn	Paraffin oil	40	Overnight	900
Waxy corn	None		Overnight	360
Waxy corn	Soybean oil	40	3 h	300
			Overnight	320
Wheat	Soybean oil	40	3 h	1000
			Overnight	1100
Potato	Soybean oil	40	3 h	1660
			Overnight	3920

[a] Four hundred grams of starch, 3 l of water and the required amount of lipid were mixed together and jet cooked. The jet cooked dispersion was poured into a beaker and was allowed to stand and cool without stirring.

[b] A Model LVT Brookfield Viscometer was used with No. 3 spindle at 30 rpm. Solids concentration was about 9.5–10% and varied due to dilution of the dispersion with variable amounts of condensed steam.

Table 2. Effect of stirring on Brookfield viscosities of cooled starch–soybean oil composites[a]

Starch variety	Brookfield viscosity of cooled (25°C) dispersion, Cp[b]: Let stand 3 h	Let stand overnight	Stirred 3 h	Stirred 3 h, then let stand overnight
Corn	730	940	3190	6700
Waxy corn	300	320	280	320
Wheat	1000	1100	2480	3180
Potato	1660	3900	1290	Gel

[a] Two hundred grams of starch, 1500 ml of water and 80 g of soybean oil were mixed together and jet cooked.

[b] A Model LVT Brookfield viscometer was used with either No. 3 or 4 spindle. Solids concentration was about 9.5–10% and varied due to dilution of the dispersion with variable amounts of condensed steam.

droplets, about 10–50 μm in size. These droplets did not coalesce and separate, even after drying. Fig. 1 shows a scanning electron micrograph of the fracture surface of a film obtained by air-drying a jet cooked dispersion containing 40 parts of soybean oil per 100 parts of cornstarch. The sample was extracted with ethanol, so that oil domains would appear as voids in the fracture surface.

Drum-drying was a practical and efficient method for isolating these compositions from water dispersions, and yielded products in the form of coarse flakes. Drum-dried products were not oily to the touch and could be easily ground or milled into free-flowing powders with final moisture contents of about 5%. Oil was not released from these products upon grinding. Powdered products could also be obtained by spray drying; however, it was necessary to work at low solids concentrations because of the high viscosities of cooked starch solutions.

Water dispersions were easily prepared from the drum-dried products by adding them slowly to water with rapid stirring (for example, in a Waring blender) and then heating the resulting dispersions to about 95°C in a microwave oven. The appearance of these dispersions was similar to the original jet cooked products that had never been dried. For example, a drum-dried 40:100 soybean oil–starch composition was dispersed in water as described above at a concentration of 20 g in 200 ml of water. Brookfield viscosities (No. 3 spindle, 30 rpm), measured at 80, 48 and 30°C were 40, 88 and 140 cp, respectively. After 18 h at room

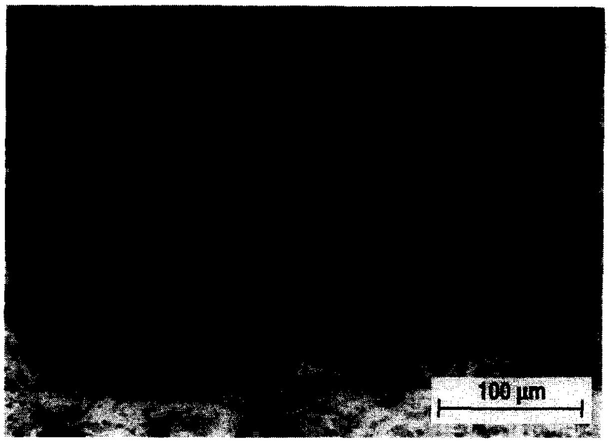

Fig. 1. Fracture surface of a film obtained by air-drying a jet cooked dispersion prepared from 40 parts soybean oil per 100 parts cornstarch. The fractured film was extracted with ethanol to show the oil domains as voids.

temperature, the Brookfield viscosity was 1020 cp. The dispersion was smooth and creamy, and there was no separation of oil from the aqueous phase.

Figure 2 shows the ethanol-extracted fracture surface of a film prepared by air-drying a 10% water dispersion of a 40:100 soybean oil–cornstarch composition that was first drum-dried and then redispersed in water. This composition was isolated from the same jet cooked dispersion used to obtain the micrograph in Fig. 1. Comparision of the two micrographs shows that agglomeration of oil droplets did not occur during the process of drum-drying and then redispersing this product in water. In fact, the average size of oil domains appears smaller in Fig. 2 than in Fig. 1.

A useful property of these starch–lipid compositions is their ability to function as stabilizers for lipid–water mixtures and to inhibit the rapid phase separation that normally occurs when lipid and water are combined. We were able to utilize this property in the preparation of these compositions by adding a portion of the starch–lipid product from a previous experiment to an uncooked mixture of starch, water and oil prepared for jet cooking. This 'add-back' procedure inhibited the normally rapid separation of oil during the time period between mixture preparation and jet cooking and, therefore, greatly facilitated the jet cooking operation. The amount of 'add-back' material needed to stabilize these mixtures ranged from 10 to 25% of the weight of starch used in the formulation.

Fig. 2. Fracture surface of a film prepared by: (1) drum-drying a jet cooked dispersion prepared from 40 parts soybean oil per 100 parts cornstarch; (2) redispersing the drum-dried product in water at 10% solids; and (3) allowing the resulting dispersion to air-dry. The fractured film was extracted with ethanol to show the oil domains as voids.

Although use of volatile oils in the preparation of these compositions was limited by their tendency to escape as vapors during the jet cooking process, volatile or essential oils and flavorings could be added to starch–lipid dispersions after jet cooking but prior to drying, provided that drying was carried out at a sufficiently low temperature. Volatile oils were readily absorbed by starch–lipid dispersions and remained entrapped within the starch matrix after drying. Although volatile materials were stable with respect to loss by evaporation, they were released when the starch matrix was either scratched or broken. We have successfully entrapped both limonene and a dispersion prepared from fresh strawberries by adding these components to 10% dispersions of a cornstarch–soybean oil composition (100:20) and then allowing these mixtures to air-dry. We are investigating further the use of starch–lipid composites as encapsulating agents for volatile oils and flavorings and will report these results at a later date.

Although the formation of a uniform dispersion of lipid within the starch–water matrix can be easily explained by the high temperature and intense turbulence of the jet cooking process, the absence of phase separation after prolonged standing, and especially after drying, was unexpected. The high viscosity of jet cooked starch solution is probably one factor contributing to phase stability. In this regard, we observed that substitution of a low molecule weight maltodextrin for starch in a formulation with soybean oil yielded a dispersion that was not only low in viscosity, but was also unstable with respect to lipid separation.

Another factor might possibly be the formation of helical inclusion complexes between starch and lipid (Hahn & Hood, 1987; Eliasson *et al.*, 1988; Huang & White, 1993). Even in small amounts, starch–lipid complexes formed during the jet cooking process might stabilize dispersions of aqueous starch and lipid, since the complex could distribute itself at the lipid–water interface and thus function as a non-ionic emulsifier. Although triglycerides reportedly do not form complexes of this type because of their sterically hindered structure (Osman *et al.*, 1961), minute amounts of monoglyceride present in naturally occurring lipid materials (or possibly produced from lipid during the jet cooking process) could produce starch–lipid complexes. Also, we should consider a less likely possibility that lipids and lipid-like materials that do not normally complex with starch might do so under the high temperatures and turbulent conditions of steam jet cooking. A preliminary experiment, carried out with a high molecular weight dextran rather than starch, suggests that the question of complex formation in these systems should not be dismissed without further study. Dextran, like starch, is composed of α-D-glucopyranose repeating units; however, these units are joined by 1,6-linkages, thus preventing formation of the helical configuration necessary for complex formation. When a mixture of dextran, soybean oil, and water was jet cooked, we observed that the dispersion was less stable with respect to lipid separation than a comparable dispersion prepared from starch. More research is obviously needed to determine the factors responsible for the stabilization of these starch–lipid compositions. The properties of starch–lipid compositions, in particular the smoothness and lubricity of water dispersions, suggests their use in foods as thickening agents, suspending agents, stabilizers and fat substitutes. Also, the presence of the oil component makes them receptive to the addition of a wide variety of water-immiscible materials, such as additional oil or lipid, volatile and essential oils, food flavoring materials, antioxidants, medicinal agents, agricultural chemicals and adhesive materials. The composites are also useful in seed coating formulations, since the oil component provides compatibility between the dried composition and the waxy coating found on many seed varieties. Research on the many commercial applications of these materials is in progress.

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