Effect of Partial Replacement of Gum Arabic with Carbohydrates on Its Microencapsulation Properties

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Gum arabic solutions (10% w/v) were emulsified with soy oil at oil/gum ratios of 0.25−5.0. At oil/gum ratios <1.0, it was established that gum arabic could be partially replaced with a nonsurfactant carbohydrate. To assess different carbohydrates as replacers for gum arabic, emulsions and spray-dried emulsions of soy oil and mixed solutions (10% w/v) of gum arabic and a range of carbohydrate wall materials (oil/gum = 0.5) were prepared and analyzed. Maize starch and glucose were ineffective as partial replacers of gum arabic, but maltodextrins of various dextrose equivalence values (5.5−38) successfully replaced 50% of the gum arabic. The microencapsulation efficiency of the gum arabic/maltodextrin stabilized powders was further increased by increasing total solids of the feed to the dryer and by increasing the atomizer nozzle diameter.

Keywords: *Gum arabic; maltodextrin; emulsion; microencapsulation; wall material*

INTRODUCTION

Gum arabic is a complex hydrocolloid with excellent solubility and surface-active properties and produces low-viscosity solutions at high concentrations relative to other gums. These solubility and surface-active qualities have facilitated its extensive use as an encapsulation agent for the retention and protection of chemically reactive and volatile oils and flavor compounds in commercial food flavorants. However, gum arabic is an expensive ingredient, and its availability and costs are subject to fluctuations; hence, there is always a need to evaluate alternatives.

It is recognized that the role of an encapsulation wall material is twofold (*1*). First, where the encapsulation of lipid-based ingredients is concerned, the material must have surface-active and film-forming properties. Second, the role of the encapsulation agent is to form a dried matrix around the lipid droplets, which binds them together within the encapsulate and prevents volatile loss and contact with the atmosphere. This latter function requires materials capable of forming low-viscosity concentrates, which dry readily to yield nonhygroscopic and highly soluble powders. Gum arabic is ideally suited to the encapsulation of lipids as it fulfills the roles of both a surface-active agent and the drying matrix. Typically the ratio of oil/wall material used for microencapsulation in gum arabic applications is <0.15 (*2*), which is far in excess of what is required for the emulsification role (*3*). Consequently, a large proportion of the gum arabic is fulfilling the matrix-forming function, which could perhaps be performed as effectively by a less expensive ingredient.

The objective of this study was threefold: first, to establish precisely the minimum amount of gum arabic necessary to maintain a stable emulsion; second, to identify carbohydrates that could be used to replace the gum arabic in the encapsulation matrix which is not fulfilling a surface-active role; and third, to investigate two key processing variables for their effect on the efficiency of the final product.

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EXPERIMENTAL PROCEDURES

Materials. Gum arabic obtained from Sigma Chemical Co. (Poole, Dorset, U.K.) and refined soy oil from Anglia Oils Ltd. (Kingston-upon-Hull, North Humberside, U.K.) were used to prepare the emulsions. Analysis of the gum arabic (10.9% moisture, 0.33% nitrogen, and specific rotation = −31°) confirmed it to be *Acacia senegal* (*4*, *5*). Cornstarch solids and maltodextrins were supplied by Cerestar U.K. Ltd. (Trafford Park, Manchester, U.K.), native maize starch was provided by National Starch and Chemical Co. (Stayal Road, Manchester, U.K.), and lactose, sucrose, and glucose were obtained from Merck Ltd. (Darmstadt, Germany). All other reagents used in the analysis were of GPR grade and were obtained from BDH Laboratories Ltd. (Poole, Dorset, U.K.).

Determination of Gum Arabic Adsorbed at the Oil—Water Interface. An aqueous solution of gum arabic (10% w/v), containing a sodium azide preservative, was prepared and stirred overnight at 20−25 °C. Emulsions with an oil/gum a ratio of 0.25, 0.5, 0.75, 1.0, 2.0, 3.0, 4.0, or 5.0 were prepared as described by McNamee et al. (*3*). The emulsions were individually centrifuged at 6000*g* for 30 min; samples of the resulting subnatant were removed using a long-needled syringe to penetrate the cream layer and passed through a 0.25-μm Millipore filter (Gelman Sciences, Ann Arbor, MI) to avoid contamination with lipid droplets. The protein content of the filtrate was determined according to a modified Lowry method (*6*). The results of this analysis reflected the level of unadsorbed gum arabic protein and were used to calculate the protein load according to the formula

$$\text{protein load} = (P_t - P_u)/(O \times \text{SSA})$$

where P_t = total protein (mg/mL in pre-emulsion gum arabic solution), P_u = unabsorbed protein (mg/mL in filtered subnatant), O = quantity of oil emulsified into gum arabic solution (g/mL), and SSA = specific surface area of emulsified fat droplets (m^2/g of oil).

Preparation of Spray-Dried Powders. Emulsions of soy oil and mixed solutions (10% w/v) of gum arabic/carbohydrate

10.1021/jf001003y CCC: $20.00 © 2001 American Chemical Society
Published on Web 06/27/2001

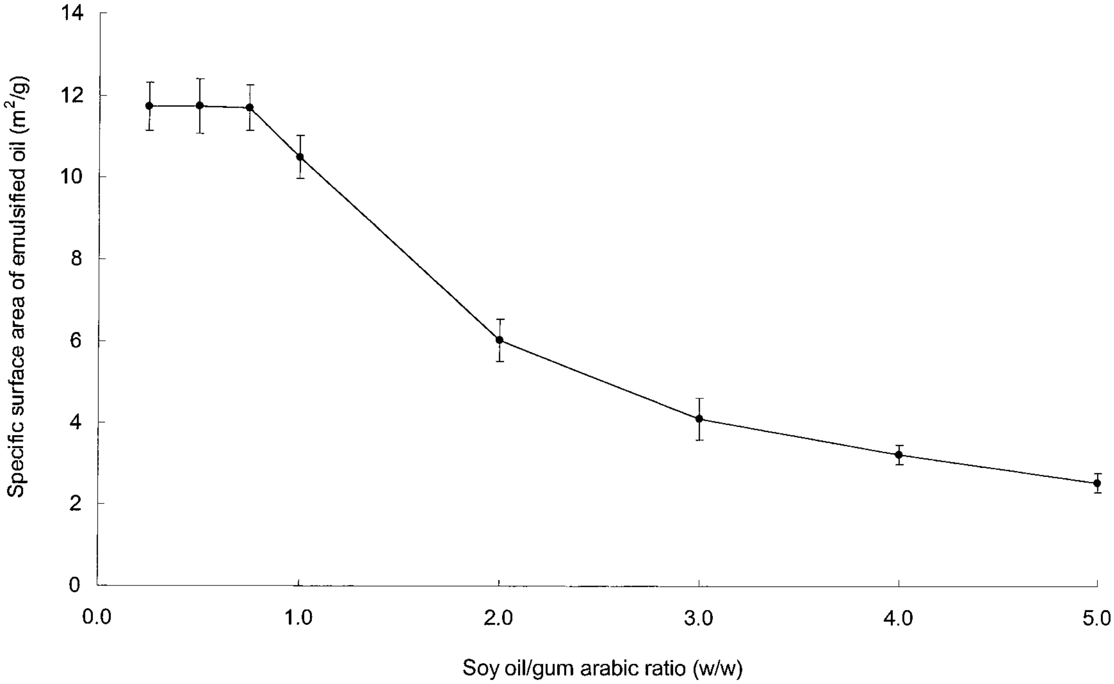

Figure 1. Specific surface area of emulsified oil in soy oil/gum arabic emulsions at various oil/gum arabic ratios (mean ± SE).

Table 1. Composition of the Emulsion Wall Materials

wall material composition (% w/w)	code
100% gum arabic	GA
50% gum arabic, 50% maize starch	GAMS
50% gum arabic, 50% glucose	GAGL
50% gum arabic, 50% cornstarch solids (DE 5.5)	GACA5.5
50% gum arabic, 50% cornstarch solids (DE 14)	GACS14
50% gum arabic, 50% maltodextrin (DE 18.5)	GAMD18
50% gum arabic, 50% maltodextrin (DE 28)	GAMD28
50% gum arabic, 50% maltodextrin (DE 38)	GAMD38
50% gum arabic, 40% maltodextrin (DE 18.5), 10% glucose	GAMD18GL
50% gum arabic, 40% maltodextrin (DE 18.5), 10% sucrose	GAMD18SU
50% gum arabic, 40% maltodextrin (DE 18.5), 10% lactose	GAMD18LA

wall materials (oil/wall ratio = 0.5) were prepared by homogenization at 20 MPa × five recirculations. Details of the various wall materials used are shown in Table 1. The gum arabic and carbohydrate were combined as a dry premix and then solubilized prior to soy oil addition and subsequent homogenization.

The emulsions were spray-dried using a laboratory spray-dryer (LabPlant SD-04, Huddersfield, West Yorkshire, U.K.). The product was fed to the spray-dryer at room temperature at a rate of 30 mL/min, and the inlet and outlet temperatures were maintained at 180 and 100−120 °C, respectively. The dried powders were collected and subsequently stored in opaque containers at 4 °C.

Effect of Emulsion Solids Concentration and Nozzle Size on Encapsulation Efficiency. Gum arabic and maltodextrin DE 18.5 were combined at a 1:1 ratio and dissolved in distilled water at concentrations of 10, 20, 25, 30, or 35% (w/v). These solutions were homogenized with soy oil at an oil/wall ratio of 0.5 resulting in emulsions with total solids concentrations of 14.3, 27.3, 33.3, 39.1, or 44.7% (w/v), respectively. Each emulsion was divided in two lots and spray-dried using either a 0.5- or 1.5-mm nozzle atomizer.

Characterization of Emulsions and Spray-Dried Emulsions. The particle size distribution of the emulsion lipid droplets and the spray-dried microcapsules was determined using a Malvern Mastersizer as described by McNamee et al. (*3*). Microencapsulation efficiency (ME) was assessed by determining the total oil content of the powders and free oil on the powders using the methods described by McNamee et al. (*3*).

Table 2. Mean (± SD) Lipid Globule Size and Protein Load of Gum Arabic (10% w/v) and Soy Oil Emulsions as a Function of Oil/Gum Arabic Ratio

oil/gum ratio	emulsion $D_{4,3}$	protein load[a]
0.25	0.67 (0.02)	0.783 (0.014)
0.50	0.67 (0.01)	0.829 (0.050)
0.75	0.66 (0.02)	0.761 (0.019)
1.00	0.74 (0.03)	0.766 (0.024)
2.00	1.35 (0.11)	0.766 (0.010)
3.00	1.63 (0.15)	0.853 (0.034)
4.00	1.97 (0.15)	0.788 (0.040)
5.00	2.25 (0.16)	0.844 (0.020)

[a] Units = mg of gum arabic protein adsorbed/m^2 of emulsified oil surface.

Statistical Analysis. All results represent the means of three replicates. Statistical analyses were performed using the SAS package. Statistical significance was determined by analysis of variance (ANOVA). *P* values <0.05 were deemed to be statistically significant.

RESULTS AND DISCUSSION

Gum Arabic Adsorbed at the Oil—Water Interface. This part of the study was undertaken to establish the proportion of gum arabic required for emulsion stabilization. The effect of the oil/gum arabic ratio on the average emulsion fat globule size and gum arabic protein load is shown in Table 2. Increasing the oil/gum ratio from 0.25 to 1.0 had no significant effect on the calculated volume average lipid globule size ($D_{4,3}$) for the emulsions, which is in agreement with previous findings in this laboratory (*3*). This observation may be explained by examining the changes in the specific surface area (SSA) of the emulsified oil at the various oil/gum ratios, which, as shown in Figure 1, remained constant at 11.7 m^2/g at oil/gum ratios <1.0. This result, together with $D_{4,3}$ values remaining constant at ∼0.67 μm, suggests that as the oil/gum ratio increased from 0.25 to 1.0, sufficient gum arabic was available to stabilize the increasing quantity of oil and that the size

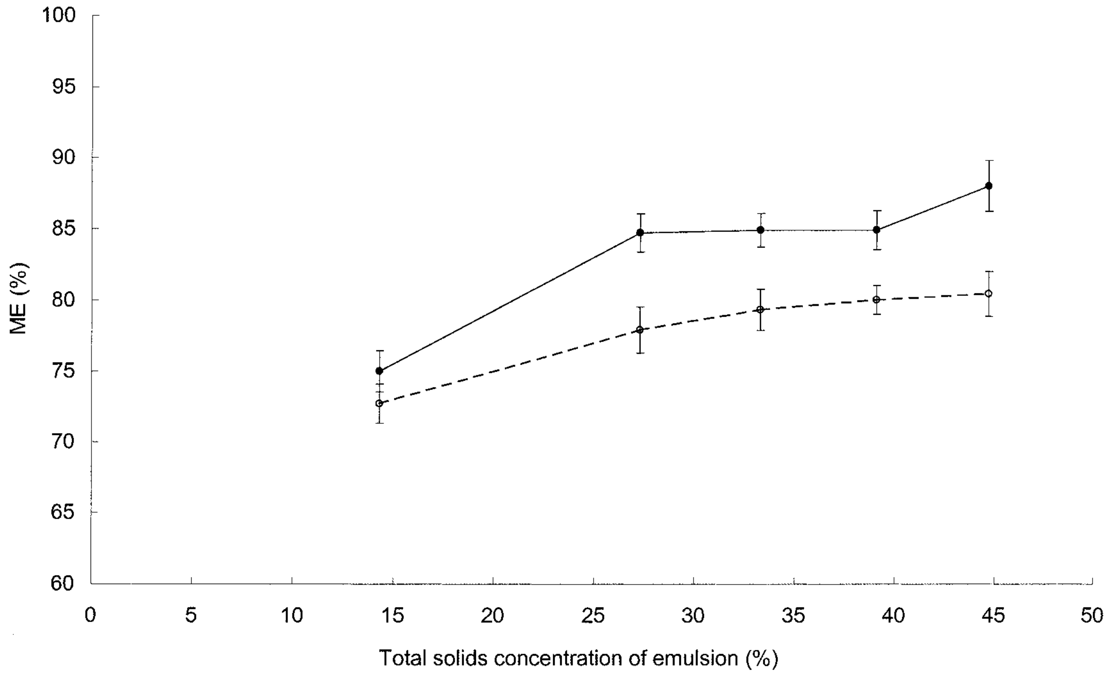

Figure 2. Effect of total solids of soy oil and GAMD18 emulsions (oil/wall = 0.5), spray-dried using a 0.5 mm (dashed line) or 1.5 mm (solid line) nozzle on the microencapsulation efficiency of the resultant powders (mean ± SE).

of the oil droplets was dependent upon homogenization conditions. The increase in $D_{4,3}$ values, and decrease in SSA, when the oil/ratio exceeded 1.0 suggest insufficient availability of gum arabic to adsorb at the oil water interface. It is likely that a maximum oil surface area that could be stabilized by a constant quantity of gum arabic had been reached, so the emulsion oil droplets became larger (Table 2), resulting in a constant total emulsified fat surface area per volume of emulsion but a decreasing specific surface area of emulsified oil (Figure 1).

Gum arabic emulsions with a $D_{4,3}$ of <1 μm are sufficiently stable for the production of spray-dried powders (*1*). This study has shown that in order to produce an emulsion with this lipid globule size using a 10% (w/v) gum arabic solution, the oil/gum ratio must be ≤1.0; that is, the weight of oil used must be at least matched by the weight of gum arabic. This quantity of gum arabic provides sufficient surface-active material to stabilize this emulsion. Increasing the proportion of gum arabic above this ratio will not affect the fat globule size of the emulsion, although it may provide a thicker matrix to bind the oil droplets together in the dried encapsulate. Increasing the proportion of wall material in an encapsulated product results in an increase in the encapsulation efficiency (*3*), but instead of using additional gum arabic to increase the proportion of wall material, the gum arabic may be replaced with a less expensive carbohydrate, for example, providing the oil/gum arabic ratio of 1.0 is maintained. On the basis of this information, a range of carbohydrates were investigated as agents that could be mixed with gum arabic at a 1:1 ratio to encapsulate soy oil at an oil/wall material ratio of 2.0.

Evaluation of Carbohydrate Replacements for Gum Arabic. The replacement of gum arabic with the various carbohydrates had no significant effect on the emulsion $D_{4,3}$ (Table 3). The lipid particle size in the GAMs emulsion, however, could not be determined due to interference by the insoluble maize starch granules. Gum arabic as the sole encapsulation agent resulted in

Table 3. Characteristics of Emulsions of Soy Oil and Solutions (10% w/v) of Mixed Gum Arabic/Carbohydrate Wall Material and Their Resultant Spray-Dried Powders (Mean ± SD)

wall material	emulsion $D_{4,3}$ (μm)	powder $D_{4,3}$ (μm)	ME (%)
GA	0.68 (0.01)	12.9 (0.68)	74.3 (1.98)
GAMs		13.7 (0.30)	29.6 (6.05)
GAGl	0.70 (0.02)	26.4 (2.25)	91.8 (0.51)
GACs5.5	0.69 (0.01)	13.6 (0.31)	73.8 (1.85)
GACs14	0.70 (0.02)	13.1 (0.78)	71.7 (2.41)
GAMd18	0.71 (0.01)	10.8 (1.30)	72.7 (1.30)
GAMd28	0.73 (0.02)	15.5 (2.03)	72.2 (1.70)
GAMd38	0.71 (0.01)	12.1 (0.58)	72.8 (2.05)
GAMd18Gl	0.68 (0.01)	12.1 (0.06)	73.4 (0.45)
GAMd18Su	0.68 (0.01)	11.8 (0.86)	73.3 (1.72)
GAMd18La	0.67 (0.01)	11.5 (0.40)	69.6 (1.53)

a powder with an ME of 74% (Table 3). The use of maize starch as a gum arabic replacement resulted in a powder with a poor ME (30%). This poor ME is representative of the importance of excellent solubility characteristics in a microencapsulation agent and the ability to form a nonporous dried matrix. The powder containing a wall material of 50% glucose and 50% gum arabic had an ME of 92%. This high ME may be attributed to the clumping of powder particles (powder $D_{4,3}$ = 26.4 μm) or the presence of large glassy crystals within the powder (2−3 mm in length), which appeared to have been formed on the inside wall of the drying chamber. This powder also appeared slightly brown in color, and this together with its tendency to cake, its sweetness, and its hygroscopic properties would possibly limit its food application. Replacing half of the gum with cornstarch solids/maltodextrins of various DE values (5.5−38) had little influence on the ME. The maltodextrin DE 18.5 would probably be selected as the most suitable partial replacer for gum arabic as it is easily solubilized and bland in flavor, and as some preliminary work has shown, the dried encapsulates manufactured with this wall material are most rapidly reconstituted in water. When 20% of this maltodextrin was further replaced with sucrose, lactose, or glucose, the ME remained unaffected. It has been proposed that the incorporation

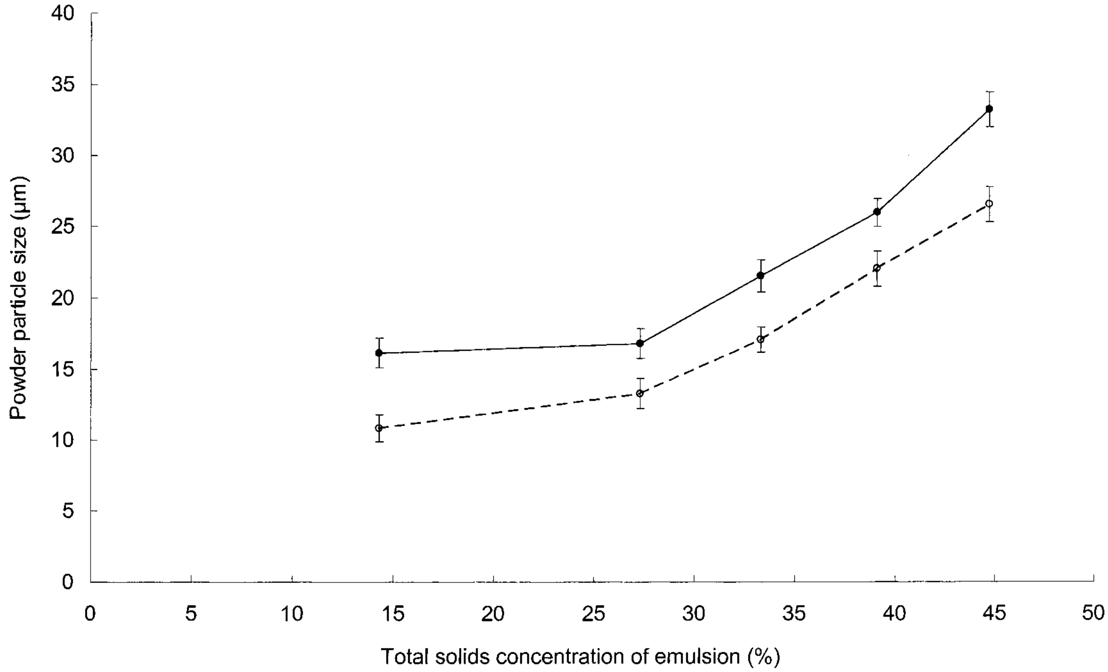

Figure 3. Effect of total solids of soy oil and GAMD18 emulsions (oil/wall = 0.5), spray-dried using a 0.5 mm (dashed line) or 1.5 mm (solid line) nozzle on the particle size of the resultant powders (mean ± SE).

of simple sugars results in the formation of a glassy layer on the microcapsules, preventing the loss of lipid material from cracks and holes on the surface (*7, 8*). It would appear that such a protective effect was not evident in this study, although it may have contributed to the high ME observed for the GAGL powder.

With the exception of the GAGL powder, the average particle sizes of the powders were similar irrespective of the wall material used (10−16 μm).

Effect of Emulsion Solids Concentration and Nozzle Size on Encapsulation Efficiency. Increasing the concentration of the emulsion total solids to the spray-dryer resulted in a significant increase ($P < 0.05$) in ME (Figure 2) and particle size of the powders (Figure 3). These trends were observed irrespective of nozzle diameter. ME is related to the powder particle size (PPS) as the degree of oil extracted from the encapsulates using the described method would be affected by their surface area to volume ratio.

All emulsions were fed to the spray-dryer at the same flow rate, and the air pressure of the atomizer was kept constant irrespective of nozzle diameter. Differences in PPS between powders spray-dried using each of the nozzles must therefore be attributed to a combination of a less efficient atomization of emulsions at high total solids due to their higher viscosity (*9*) or a greater degree of contraction of particles from low total solids emulsions during the drying process (*3*).

Gum arabic may be partially replaced as an encapsulation agent for lipid-based materials with maltodextrins/cornstarch solids (DE 5.5−38) provided a gum arabic/oil ratio of 1.0 (w/w) is maintained. The particular maltodextrin/cornstarch solid chosen for this role will ultimately depend on the particular application, as they may be selected so as to contribute to the products desired characteristics in terms of flavor (sweetness) and solubility.

ABBREVIATIONS USED

$D_{4,3}$, volume average diameter (lipid globule size); DE, dextrose equivalence; ME, microencapsulation efficiency; PPS, powder particle size; SSA, specific surface area.

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Received for review August 9, 2000. Revised manuscript received March 15, 2001. Accepted April 24, 2001.

JF001003Y