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Chemical Modification of Gum Arabic and Its Application in the Encapsulation of *Cymbopogon citratus* Essential Oil

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ABSTRACT: Sodium trimetaphosphate (STMP) is an effective crosslinking agent of starch and can be used in other polysaccharides for promoting changes in their physical and chemical characteristics. In this study, gum arabic was modified with different STMP concentrations and evaluated as the changes in the physical and physicochemical characteristics. Further, modified gum arabic was evaluated by encapsulation efficiency (EE) of *Cymbopogon citratus* essential oil. A lower viscosity was observed with the increase of the STMP concentration. Higher concentrations of STMP decreased the water amount retained in the modified gum arabic. The increasing of the crosslinking degree causes a decrease in particle size. The EE of modified gum arabic with 6% STMP was 97%, whereas for the unmodified gum arabic was 85%. The high efficiency encapsulation of the essential oil is a positive result of physicochemical changes in the gum arabic crosslinking. © 2014 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2015**, *132*, 41519.

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INTRODUCTION

Plant gums are hydrocolloids classified as anionic or nonionic polysaccharides, or salts of polysaccharides produced by higher plants as a protective mechanism to pathogens and mechanical injury. Among those gums, gum arabic has wide application in the food industry as a stabilizer, thickener, and emulsifier (syrups, soft drinks, gums, and sweets) and in the textile, ceramics, cosmetics, and pharmaceutical industries.[1,2] Gum arabic is exuded from trunks and branches of *Acacia senegal* and *Acacia seyal*, it has a light yellow color and is not toxic.[3] The chemical characteristics of gum arabic exhibit some variations depending on location and age of the tree origin. Chemically, gum arabic is highly heterogeneous consisting of a mixture of anionic polysaccharides and minor protein fractions. The sensorial and physicochemical characteristics of gums confer attributes that make it attractive to industry, but in addition to this, these are also limiting factors for different applications that require low water solubility and hydrophobicity.

Natural polysaccharides can be modified using chemicals to alter their properties and give them a wider application. Crosslinking agents such as epichlorohydrin, vinyl sulfone, diepoxides the isothiocyanate, and various diolefins and sodium trimetaphosphate (STMP) can be used in polysaccharides for promoting possible changes in their physical and chemical characteristics. The STMP is a salt that has a low toxicity to humans. It has been used as a crosslinking agent of starch, hyaluronic acid, and guar gum in the preparing of gels for pharmaceutical proposals.[4–6] At basic pH, this salt forms a phosphate ester linkage with two sugar units from polysaccharides.[7,8]

The modified gum arabic with STMP has low water solubility and hydrophilicity. These characteristics are important for applications such as the encapsulation of bioactives where this substance should be retained within the capsules and be released at certain pH conditions, temperature, or slowly under natural conditions. Essential oils are volatile aromatic compounds that have shown to possess antibacterial, antifungal, and insecticidal properties attractive to industries. Lemon grass essential oil (*Cymbopogon citratus*) has major compounds, the stereoisomers (*E*)-citral (geranial), and (*Z*)-citral (neral) (70–85%) accompanied by myrcene (12–20%) that confer antimicrobial and analgesic properties.[9] Encapsulation of essential oils is an attempt to reduce the volatilization of volatile cores, as well as protecting them from radiation, humidity, and the contact with oxygen.[10–12] It is also possible, through the encapsulation, to avoid possible undesirable chemical reactions between the bioactive substance and the wall material due to a physical separation barrier.

The choice for the encapsulation method depends on several factors, such as particle size, physical, and chemical properties of the wall material and the core, and mainly the final application. There are several techniques for encapsulation: spray drying, extrusion, coacervation, fluidized bed, drum drying, molecular inclusion, freeze-drying, being that spray drying is the most used in the food and pharmaceutical industries. Spray-drying is a unit operation by which the liquid product is atomized instantaneously in a hot gas current in order to obtain the powder. Generally, the gas used is air or more rarely an inert gas such as nitrogen. In the initial liquid feeding, the sprayer can be a solution, an emulsion or a suspension. Spray-drying produces a very fine powder size depending on the starting feed materials and the operating conditions.[13–15] Studies involving encapsulation of bioactive substances with gums using the atomization technique have successfully been described in the literature.[16–18] This technique is widely used in the food industry because of its low cost, rapid procedure, and because it provides a small particle size, making the final product very soluble. This study aimed to modify gum arabic with STMP in order to promote change in chemical and physical characteristics and obtain an efficient encapsulation of the *C. citratus* essential oil.

EXPERIMENTAL

Materials

Gum arabic was supplied by JB Química LTDA (Brazil). STMP was supplied by Sigma Aldrich (St Louis, MO). All the chemicals reagents used in the analysis were of analytical grade.

Essential Oil Extraction and Analysis

The essential oil was extracted from *C. citratus* plants grown at Embrapa Tropical Agroindustry's (Fortaleza, Brazil) experimental field. Leaves were cut into small pieces and submitted to hydrodistillation in a Clevenger-type glass apparatus during 3 h, affording a yellow oil. The obtained oil was dried over anhydrous sodium sulfate, filtered, and maintained under refrigeration until the GC–MS and GC–FID analysis.

GC–MS analysis was carried out on a Varian 450-GC/240-MS instrument equipped with a nonpolar VF-5MS fused silica capillary column (30 m × 0.25 mm ID, 0.25 μm film thickness), utilizing helium as a carrier gas and a flow rate of 1.5 mL min^{-1}, with split ratio of 1 : 30. The injector temperature and detector temperature were set at 250°C. The oven temperature was programmed to increase from 70 to 180°C at 4°C min^{-1}, and afterwards to 250°C at 10°C min^{-1}. Mass spectra were recorded in a range of mass-to-charge ratio (m/z) between 30 and 450. GC-FID analysis was accomplished on a Shimadzu GC-2010 Plus Chromatograph under the same chromatographic conditions employed for the GC–MS analysis, except for the carrier gas (hydrogen). The retention indices were determined by the injection of a mixture of C_7-C_{30} homologous *n*-alkanes (Sigma, St. Louis, MO). The identification of the volatile compounds was performed through comparison of the mass spectra recorded with those provided by spectrometer database (NIST 02–147,198 compounds) and with the retention indices and mass spectra of the literature.[19] The relative content of oil constituents was determined by the peak area normalization method and expressed as percentages. All analysis was performed in triplicate.

Chemical Modification of Gum Arabic

Gum arabic solution of 20% (w/v) was prepared and homogenized in ultra-Turrax (IKA, T25 digital) at 20,000 rpm for 1 min. Then the crosslinking agent, STMP, in 1%, 3%, 6%, and 9% concentrations was added and under stirring for 3 h at 40°C (pH 12 with 2*M* NaOH). Once the crosslinking procedure had been completed the solution was calibrated to pH 7. Uncrosslinked material was removed by centrifugation at 10,000 rpm for 10 min and successive washing in ethyl alcohol and acetone (1 : 1) solution. In the last step, the crosslinked material was kept in a desiccator for 48 h.

Characterization of Emulsions of Modified Gum Arabic

The emulsions of modified gum arabic was characterized by particle size distribution analysis, viscosity analysis, and swelling properties. The particle size distribution was determined using a Zetasizer Nano series, Nano Zs (Malvern Instruments, UK). Emulsions were prepared with 0.5% modified and unmodified gum arabic using water as a dispersant. The results were expressed as the mean of five readings. The kinematic viscosity measurements were performed using a Schott AVS model 350 capillary viscometer (52023/300). The viscosity measurement was obtained from the equation $v = k.t$ where t is the time allowed to flow down through the capillary in seconds, and the parameter k represents a viscometer constant ($\text{mm}^2\ \text{s}^{-2}$). Measurements of swelling behavior of the crosslinked materials were evaluated to determine the water content retained in the crosslinked sample (Wf), equilibrium water content (EWC), and the swelling degree (DSW) according to the methodology proposed by Bo.[20] These results were expressed as the means of three readings. In the characterization of modified gum arabic by infrared spectroscopy technique, a small quantity of this material was mixed with 200 mg KBr and compressed to form tablets. These tablets were scanned in the absorbance model in the spectral region of 4000–400 cm^{-1} using a Perkin–Elmer spectrophotometer (model 16 PC).

Statistical analysis was performed using the SPSS program for two-sample (independent groups) *t*-test.

Encapsulation of Essential Oil with Modified Gum Arabic

Emulsion was prepared from gum arabic 20% (w/v) homogenized in Ultra-Turrax (IKA, T25 digital) at 20,000 rpm for 1 min. Then, 6% of the crosslinking agent, STMP, and 5% lemon grass essential oil, *C. citratus*, was added and stirred for 15 min (pH 12 with 2*M* NaOH). At the end of this period, the solution was calibrated to pH 7. Subsequently, the emulsion was diluted with water 1 : 4 (v/v) and submitted to an ultra-turrax homogenization at 20,000 rpm for 5 min.

The emulsions were spray-dried in a Labmaq MSD 1.0 Mini spray dryer (Labmaq, Brazil) under the following parameters:

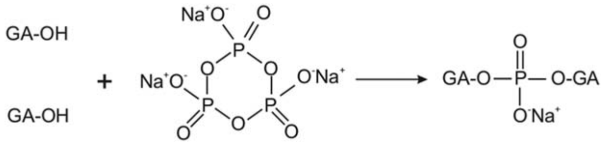

Figure 1. Crosslinking reaction of gum arabic with sodium trimetaphosphate.

nozzle orifice of 1.2 mm diameter, with a hot air flow of 3.5 L h^{-1} and the air flow of 30 L min^{-1}. The feed rate was adjusted to 0.50 L h^{-1}. The inlet air temperature was set at 180 ± 2°C and outlet temperature at 100 ± 10°C.

Analysis of Encapsulation Efficiency (EE)

The efficiency of encapsulation was calculated from the determination of the total oil and surface oil. The total oil content from the spray-dried microencapsulated product was determined by distilling 10 g of the sample for 3 h in a Clevenger type apparatus[21] and was chemically characterized by GC, following the same procedure utilized for the original oil. The total volume of the collected *C. citratus* oil was multiplied by the oil density (0.8793 g cm^{-3}), thereby obtaining the total oil mass of the sample. The surface oil was extracted with petroleum ether for 6 h in a Soxhlet extractor. The EE was calculated as follows:

$$EE=\left[\frac{(total\ \ oil-supercial\ \ oil)}{total\ \ oil}\right]x100 \qquad (1)$$

Morphological Characterization of the Encapsulated Material

Dehydrated samples were mounted on double-sided carbon tabs and coated with platin (200–500 A) using sputter coating (Emitech K 550). The samples were then imaged by scanning electron microscopy (Zeiss, Berlin, Germany, DSM 940 A) at 10 kV, using a working distance of 6 mm and an aperture of 10 μm.

RESULTS AND DISCUSSION

Characterization of Emulsion of Modified Gum Arabic

Chemical modification of gum arabic with crosslinking agents causes physicochemical changes in the polymer chain that can bring advantages in the improvement of undesirable characteristics such as hydrosolubility and hydrophilicity for some industry applications. Changes in osmotic potential, intermolecular interactions with water and other substances, flexibility of the polymer chain, viscosity, particle size distribution, and swelling properties are some characteristics related to the degree of polysaccharides crosslinking. In this study, gum arabic was crosslinked with STMP according to Figure 1. The crosslinking reaction occurred through the hydroxyl groups of the polysaccharide and led to ester linkages.

Different concentrations of STMP were evaluated on the effect in the characteristics of viscosity, particle size distribution, and swelling of emulsion of crosslinked gum arabic. A lower viscosity was observed with the increase of the STMP concentration (Table I). Polymers with low crosslinking degrees are more susceptible to water entry causing the increase in mass and also in its viscosity. According to Gebben et al.[22] if a crosslinking agent is added to a polymer solution, two different modes of crosslinking can be expected. The first one is the crosslinking between different polymer molecules, called intermolecular crosslinking, which will lead to an increase in viscosity and finally to a gelation of the system. The second mode is the internal crosslinking of a single polymer molecule, called intramolecular crosslinking, leading to a decrease in viscosity due to the volume contraction of the polymer.

High viscosities are undesirable for various applications, such as for the encapsulation of bioactives using a spray dryer, because under a practical standpoint, this characteristic is not suitable for the equipment. In the comparative analysis, the viscosity of modified gum arabic with 6 and 9% STMP were not significantly different from gum arabic without modification ($P > 0.05$). The modified gum arabic with 3% STMP showed high viscosity compared to other treatments ($P < 0.05$).

The swelling process of a polymeric material occurs at molecular level and involves the molecules diffusion of a liquid into the polymer. In the presence of proper solvents, crosslinked polymers swell incorporating solvent, while the chain can be rearranged toward a new equilibrium conformation. The swelling property can be expressed in mass, volume, and length units. The swelling process in the polymer structure is divided into three steps: diffusion of water molecules into the polymeric network, relaxation, and expansion of the polymer chains. In this work, swelling degree of polymers was measured by weighing a sample before and after exposure to water (variation of mass) being: (a) the fraction of water retained in the modified gum arabic $Wf=(m-m')/m$ (2), (b) the swelling degree of modified gum Arabic (DSW), which is the relationship between

Table I. Physical and Physical Chemical Characteristics of Modified Gum Arabic with Different Concentrations of Sodium Trimetaphosphate

Treatments/Parameters	Wf	DSW	EWC	Viscosity (mm^2/s)
Modified gum arabic (STMP 1%)	0.88 (±0.01)^a	8.6 (±1.22)^a	88.20 (±1.72)^a	–
Modified gum arabic (STMP 3%)	0.70 (±0.01)^b	3.4 (±0.15)^b	70.20 (±1.10)^b	88.24 (±3.50)^a
Modified gum arabic (STMP 6%)	0.62 (±0.01)^c	2.7 (±0.08)^c	61.70 (±2.19)^c	31.27 (±0.33)^b
Modified gum arabic (STMP 9%)	0.56 (±0.04)^c	2.3 (±0.19)^c	56.20 (±3.64)^c	30.94 (±0.13)^b
Modified gum arabic (STMP 0%)	–	–	–	30.09 (± 0.50)^b

Values with different letters in the same column are significantly different ($P < 0.05$).
(Wf) water content retained in the crosslinked sample, (EWC) equilibrium water content, and (DSW) swelling degree.
The viscosity of crosslinker gum arabic (1%) was very high to be added in capillary viscometer. Because of this physical incompatibility was not possible to measure its viscosity.

Table II. Analysis of the Particle Size Distribution of Modified Gum Arabic with Different Concentrations of Sodium Trimetaphosphate

Treatments	Particle size (nm)
Modified gum arabic (STMP 1%)	427.90 ± 8.00 (77.96%)
	78.98 ± 7.50 (20.34%)
	2780 ± 0.56 (1.70%)
Modified gum arabic (STMP 3%)	315.50 ± 4.90 (51.60%)
	1310 ± 9.90 (30.50%)
	33.20 ± 2.90 (12.53%)
Modified gum arabic (STMP 6%)	256.50 ± 7.60 (87.86%)
	1492.83 ± 3.10 (8.30%)
	770.30 ± 5.30 (3.86%)
Modified gum arabic (STMP 9%)	242.20 ± 24.50 (77.90%)
	183.70 ± 25.30 (19.60%)
	1634 ± 2.40 (2.26%)
Modified gum arabic (STMP 0%)	31.47 ± 0.83 (93.60%)
	1809 ± 0.23 (5.83%)
	1.03 ± 0.92 (0.53%)

Values between parentheses are percentage of particle volume.

the mass of the swelling sample by the dry mass DSW = m/m′ (3), and (c) the water content at the equilibrium of modified gum arabic (EWC) is $Wf \times 100$ (4). In this study, m = mass of swollen crosslinked sample and m' = mass of dry crosslinked sample.

The different concentrations of STMP influenced the gum arabic characteristics related to Wf, DSW, and EWC (Table I). All concentrations of modified gum arabic were significantly different among themselves, except the 6 and 9% concentration that did not show significant difference ($P > 0.05$). The effect of the crosslinking agent on the swelling degree of gum arabic was evaluated and is showed in Table I. Higher concentrations of STMP decreased the water amount retained in the modified gum arabic. This fact is evidenced by the values obtained from EWC, Wf, and DSW. This result is because of the increasing of the crosslinking degree that causes a decrease in the distance among the chains and causes an increase in the resistance strength and tensile strength for chain deformation. Thus, substances with high degree of crosslinking have low water absorption. If the free volume in the polymer is low, the volume of water that will penetrate the polymeric matrix to initiate the swelling process is smaller.

The crosslinking degree of gum arabic with STMP can also be monitored by particle size distribution (Table II). Gum arabic exhibits three main populations (trimodal distribution) with particle of diameter of 31.47 nm (93.60% by volume), 1809 nm (5.83% by volume), and 1.03 nm (0.53% by volume). After chemical modification process with all concentrations of the crosslinking agent, the gum arabic undergoes considerable increase in particle size. However, the increasing of the crosslinking degree causes a decrease in particle size of the modified gum. A likely explanation is that when the crosslinked material is immersed into aqueous medium, the polymer chains interact with the environment. There is an expansion of their chains (swelling), increasing the distance among monomers and their volume. At this point, the osmotic force which assists the displacement of the solvent into the hydrogel is counterbalanced by a retractable elastic force, thereby generating a conformational force (entropy) of the polymer chains. When the two forces are counterbalanced, the material will reach its state of equilibrium swelling.[23] If the concentration of the crosslinking agent is high, internal crosslinking of the polymeric chain is high too, therefore, it is more difficult for water to enter into polymeric structure, causing small changes in the final volume of the molecule. On the other hand, a small amount of the crosslinking agent will cause a small internal crosslinking, thus the polymer molecule expands becoming greater. Other works in literature point out that high emulsion viscosity influences the atomized droplets and therefore, the size of the particles becomes largest.[24,25]

The effect of the concentration of STMP on the crosslinking of gum arabic was also evaluated by infrared spectroscopy. The FTIR spectrum of gum arabic exhibited characteristic absorptions bands of a polysaccharide and are in according to previous reports: a broad band at 3403 cm^{-1} corresponding to OH bond, two strong bands at 1610 and 1428 cm^{-1} related to asymmetric and symmetric stretching vibration of the carboxylic acid salt —COO— as well as bands at 1141, 1073, and 1033 cm^{-1} associated with the alcohol and ether C—O linkages.[26] The incorporation of STMP to gum arabic was characterized by the narrowing of band at 3403 cm^{-1} since sugar hydroxyls were partially replaced by P—O—C bonds (Figure 2). The absorptions of P—O—C bonds are not easily distinguishable because of the overlapping with C—O stretching from the natural gum arabic. However, the STMP was also evidenced by

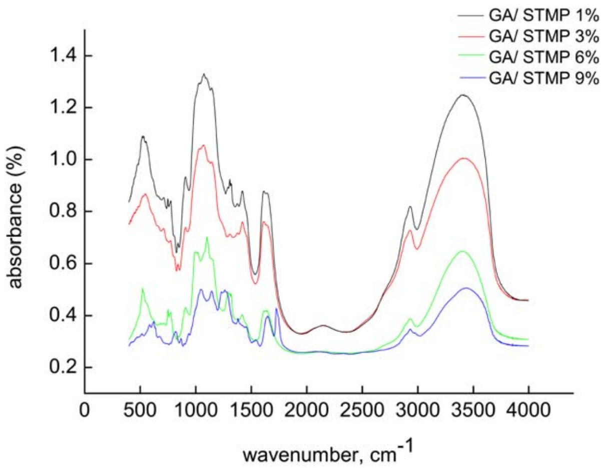

Figure 2. Overlapping of FTIR spectral bands for modified gum arabic with different concentrations of sodium trimetaphosphate: 1, 3, 6, and 9%. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

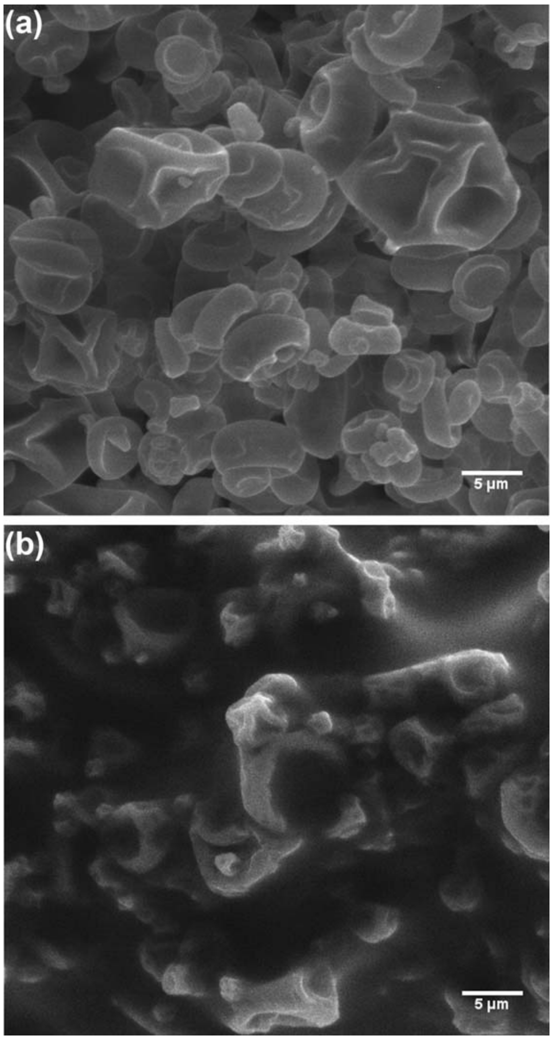

Figure 3. (a) SEM micrographs of microcapsules of gum arabic without and (b) with sodium trimetaphosphate crosslinker.

presence of a band at 1261 cm^{-1}, which is characteristic of P=O stretching. Furthermore, the absence of bands at 780 and 520 cm^{-1}, which are typical of P_3O_3 ring demonstrated that the removal of residual STMP was efficient.[27]

Encapsulation of Essential Oil with Modified Gum Arabic

The characteristics of gum arabic after chemical modification should be evaluated for novel practical use. In this study, we evaluated the potential for encapsulation of the *C. citratus* essential oil with modified gum arabic using the technique of spray drying. The evaluation of the viscosity, particle size distribution, and swelling characteristics were useful for choosing the appropriate concentration of STMP in the process of chemical modification of gum arabic for the bioactive encapsulation. All these characteristics are interrelated and represent the crosslinking degree of the polymer. Polymers with a higher crosslinking degree provide better conditions for the encapsulation of substances of interest. In view of the results obtained from analysis of viscosity related to the particle size distribution and the swelling degree, the concentrations of 6% and 9% STMP could be recommended to modify the gum arabic and to encapsulate the *C. citratus* essential oil. In this work we chosen the lower concentration 6% STMP for encapsulation by represent a lower cost of reagent. The SEM micrographs indicated that the microcapsules of gum arabic without STMP showed to be nearly spherical and round shaped with remarkably shrunks [Figure 3(a)]. This was in agreement with the findings of Tatar et al.[28] for gum arabic microcapsules. The microcapsules of modified gum arabic with 6% STMP had not a definite shaped and they present noticeable agglomeration, probably due to efficiency of STMP in the crosslinking of the polymer [Figure 3(b)]. Further, both SEM micrographs of encapsulated materials indicated no crack in the particle surface. The cracks in the surface of the microcapsules are undesirable, resulting in oil release.

The EE of modified gum arabic with 6% STMP was 97%, whereas for the unmodified gum arabic was 85% (Table III). The high efficiency encapsulation of the essential oil is a positive result of physicochemical changes in the polymer after crosslinking. Other articles in the literature indicate that the efficiency of the encapsulation process with gum arabic is around 80%).[29–31]

Chemical Composition of the Essential Oil from C. *citratus*

The essential oils from *C. citratus* were basically constituted of monoterpenes, with geranial (46.5–51.5%) and neral (ca. 33%) being the most abundant components, in agreement with the results reported in Refs. [9,32. Furthermore, three aliphatic ketones and one phenylpropenoid were identified. Nevertheless, the GC/MS and the GC–FID analysis, revealed slight differences between the composition of the oil obtained directly from the leaves (EO) and the oil recovered from the microcapsules (EOM) (Table IV). The neral content was not altered by microencapsulation, however, the geranial increased from 46.55 to 51.49%. On the flip side, β-myrcene decreased from 11.51 to 3.15%. Some compounds such as estragole and citronellal, were present only in the original oil, while the other ones (unidentified compounds), were exclusively detected in EOM. These variances are due to the spray drying operating conditions applied to the oil during the microencapsulation that leads to a loss or thermal degradations of some constituents.[33] Additionally, Bertolini et al.[34] demonstrated that the retention of volatile monoterpenes in gum arabic capsules depends on their chemical functionality (solubility and diffusion through the forming matrix) and steric factors of the volatile compounds. Considering the subtle alteration in the chemical composition and that

Table III. Properties of Encapsulated *C. citratus* Oil After Spray Drying

Treatment	Cashew gum (%)	Matrix : oil	EE (%)	Surface oil (%)
Modified gum arabic	20	4 : 1	97	3
Gum arabic	20	4 : 1	85	15

Table IV. Chemical Composition of Essential Oil from *C. citratus*: Before (EO) and Oil Recovered from the Microcapsules (EOM)

Components	IK	EO[a]	EOM[a]
6-methyl-hepten-2-one	989	0.40 ± 0.01	0.17 ± 0.04
β-myrcene	994	11.51 ± 1.08	3.15 ± 3.22
cis-*β*-ocimene	1041	0.18 ± 0.03	0.04 ± 0.07
trans-*β*-ocimene	1052	0.12 ± 0.01	0.04 ± 0.06
6,7-epoxy-myrcene	1095	0.21 ± 0.02	0.08 ± 0.07
Linalool	1103	0.74 ± 0.02	0.81 ± 0.16
Unknown 1	1117	0.15 ± 0.01	–
Citronellal	1149	0.18 ± 0.01	–
Z-isocitral	1158	0.25 ± 0.02	0.23 ± 0.02
E-isocitral	1167	0.72 ± 0.05	0.24 ± 0.15
trans−4-caranone	1185	1.12 ± 0.06	0.56 ± 0.15
Estragole	1199	0.11 ± 0.01	–
Citronellol	1231	0.29 ± 0.01	0.38 ± 0.05
Neral	1247	33.03 ± 0.40	32.96 ± 0.48
Geraniol	1256	2.50 ± 0.17	2.58 ± 0.24
Geranial	1277	46.55 ± 0.78	51.49 ± 0.45
2-undecanone	1295	0.18 ± 0.02	0.34 ± 0.06
Not identified	1320	–	0.29 ± 0.26
Not identified	1338	–	0.10 ± 0.09
Not identified	1341	0.28 ± 0.07	1.11 ± 0.80
Not identified	1354	0.46 ± 0.08	2.00 ± 1.58
Not identified	1371	–	0.08 ± 0.14
Not identified	1377	0.45 ± 0.13	1.74 ± 1.24
Geranyl acetate	1381	0.27 ± 0	0.44 ± 0.02
2-tridecanone	1497	0.15 ± 0.01	0.34 ± 0.06
Not identified	1884	–	0.11 ± 0.04
Not identified	1993	–	0.08 ± 0.03
Not identified	2112	0.05 ± 0.01	0.04 ± 0.06
Not identified	2137	0.07 ± 0.02	0.35 ± 0.22
Not identified	2143	–	0.21 ± 0.13
Not identified	2151	–	0.04 ± 0.07

IK-Kovats retention indices calculated from a homologous series of *n*-alkanes (C_7–C_{30}) analyzed on a VF-5MS column.
[a] Mean area percentage determined by GC–FID analyses performed in triplicate.

citral contents have levels higher than 60%, we do not believe that this change is able to affect the biological activities expected for *C. citratus* oil.

CONCLUSIONS

This work shows that crosslinking with STMP is a suitable method for modification of the physical and physicochemical characteristics of gum arabic. Crosslinked gum arabic exhibited an increase in particle size distribution and viscosity in addition to reducing the water amount retained in the polysaccharide matrix. Modified gum arabic with 6% STMP presented desirable characteristics in viscosity, swelling properties, and particle size distribution that resulted in an efficient encapsulation of the *C. citratus* essential oil. Studies of controlled release of the essential oil in different conditions and times are recommended to evaluate the potential of bioactive retention by modified polysaccharide with this method.

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