Encapsulation of liquid smoke flavoring in ca-alginate and ca-alginate-chitosan beads

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Abstract Encapsulation is a technique used in foods that may protect some compounds with sensory impact, in particular flavoring as liquid smoke. We used the dripping method, obtaining two different layers for encapsulation of liquid smoke: calcium alginate and calcium alginate–chitosan. The results show that the load capacity of liquid smoke encapsulation reached values above 96 %. The beads exhibit syneresis at room temperature, but in opposite side, refrigeration temperature stabilizes the hydrogel of beads, allowing the samples loss weight less than 3 % after 72 h. Heated capsules with liquid smoke released several volatile compounds in the headspace and may identify 66 compounds. Among these volatile compounds, phenols derivatives can be considered sensory descriptors to contribute to the specific flavor of smoke. We conclude that the dripping method is highly efficient to encapsulate liquid smoke and released several volatile compounds, although it is necessary to minimize syneresis at room temperature.

Keywords Liquid smoke · Encapsulation · Ca-alginate · Chitosan

Introduction

Smoke flavorings have several advantages compared to traditional smoking techniques: ease of application, speed,

uniformity of the product, reproducibility of the characteristics obtained in the final smoked food, cleanliness of application and a decrease of the content of certain polycyclic aromatic hydrocarbons (Simon et al. 2005).

Flavor, as smoke flavorings, plays an important role in consumer satisfaction and influences further consumption of foods. However, manufacturing and storage processes, packaging materials and ingredients in foods often cause modifications in overall flavor by reducing aroma compound intensity or producing off-flavor components. Therefore, to limit aroma degradation or loss during processing and storage, it is beneficial to encapsulate volatile ingredients prior to use in foods or beverages (Madene et al. 2006).

Encapsulation may be defined as a process to entrap one substance within another substance, thereby producing particles with diameters of a few nm to a few mm. Some benefits of encapsulated ingredients in the food industry could be: superior handling of the active agent, immobility of active agent in food processing systems, improved stability in final product and during processing (i.e., less evaporation of volatile active agent and/or no degradation or reaction with other components in the food product such as oxygen or water), off-taste masking, controlled release (differentiation, release by the right stimulus) (Zuidam and Shimoni 2010). The smoke flavor is a sensory characteristic sought in some foods such as seafood and some meat products, currently achieved with conventional smoking or with the addition of liquid smoke (Montazeri et al. 2013). Liquid smoke encapsulating would give the desired smoke flavor with the advantages already mention that gives a flavor encapsulation.

Flavor encapsulation could be accomplished by a variety of methods. The two majors industrial processes are spray-drying and dripping (Madene et al. 2006). Encapsulation of flavors via dripping in glassy carbohydrate matrices has been used for

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volatile and unstable flavors. The principal advantage of the dripping method is the stability of the flavor against oxidation. Carbohydrate matrices have very good barrier properties and dripping is a convenient process enabling the encapsulation of flavors (Gouin 2004).

In this study, calcium alginate gel was employed as the matrix for flavor encapsulation. Alginate has been approved as a coating material by the US Food and Drug Administration and European Food Safety Authority. One of the major advantages of flavor encapsulation in alginate beads is that the encapsulation does not adversely affect the release of the flavor during consumption of the product. The beads provide a sustained release of the flavor to the product during storage and prior to consumption (De Roos 2006).

An additional encapsulating agent used in this study was chitosan. Chitosan, obtained from crab exoskeletons, has several polar groups such as $-OH$ and $-NH_2$ which can act as electron donors. Whereas alginates have been largely employed in drug delivery systems, there is increased interest in studying chitosan for its biological applications due to its mucous adhesiveness, no toxicity, biocompatibility and biodegradability (Sinha and Kumria 2001). Chitosan and alginate can react together by coacervation due to their opposite charges. The easy solubility of chitosan at low pH is prevented by the alginate network since alginate is insoluble at low pH conditions. The possible dissolution of alginate at higher pH is prevented by the chitosan which is stable at higher pH ranges (George and Abraham 2006). Alginate-chitosan capsules have been proposed to encapsulate natural antioxidants from yerba mate (Deladino et al. 2008) and some micronutrients such as ferrous fumarate, ascorbic acid and β -carotene (Han et al. 2008).

Thus, the objectives of this work were to encapsulate liquid smoke in calcium alginate beads, with and without a chitosan layer; to analyze the loading capacity, the syneresis process at ambient conditions, the stability of samples at refrigeration (4 °C), and the aromatic profiles of beads.

Materials and methods

Encapsulating agents

The encapsulating agents used were 1 % (w/v) sodium alginate (Sigma-Aldrich, USA, mannuronic acid to guluronic acid ratio 1.56, medium viscosity), and chitosan 1 % (w/v) in acetic acid (Sigma-Aldrich, USA, deacetylation degree higher than 75 %, density: 0.15–0.3 g/cm³).

Capsules formation

Capsules formation was carried out according to the dripping method of Deladino et al. (Deladino et al. 2008), with slight modifications. Beads were obtained by mixing mechanically

the active component (commercial water-soluble liquid smoke, 1 % w/v) with the sodium alginate, forming a stable solution. Once homogenized, the alginate-liquid smoke solution was pumped with a peristaltic pump (Masteflex, model 7521–10, Barrington, Illinois, USA) at 0.60 cm³/min to a calcium chloride solution (0.05 M, Merck, Darmstadt, Germany). The beads formed in this process were maintained in the gelling bath to harden for 15 min. Then, they were filtered through a Whatman #1 paper and washed with buffer solution (acetic/acetate, pH 5.5). The beads, once filtered and washed, were allowed to stabilize (remove excess surface moisture) at ambient conditions (approx. 22 °C and 65 % relative humidity) for 15 min. Finally, a portion of the beads was immersed in a chitosan solution for 30 min to analyze the effect of an additional layer formed by complex coacervation alginate-chitosan. As a summary, four types of capsules were prepared: capsules of ca-alginate, ca-alginate beads with liquid smoke, ca-alginate-chitosan capsules and ca-alginate-chitosan beads with liquid smoke.

Beads characterization

Loading capacity of beads with the active component was determined gravimetrically according to the indirect method of Chang and Dobashi (Chang and Dobashi 2003) and Jiamrungraksa and Charuchinda (Jiamrungraksa and Charuchinda 2010), drying the beads in an oven at 120 °C for 2 h. The percentage of loading efficiency was calculated with the following equation:

$$\text{Loading capacity (\%)} = \frac{(W_{m0} - W_0)}{W_{m0}} \times 100$$

Where W_{m0} and W_0 denote the weight of beads measured before, and after complete evaporation of active component, respectively.

The weight loss (by syneresis or drying) of beads was determined at ambient conditions (approx. 22 °C) and at refrigeration (4 °C in a refrigerator) by weight difference (gravimetrically) for 72 h, respectively. All measurements were repeated at least in triplicate on bead samples from the same prepared batch.

Instrumental aromatic profiles of the samples

About 3 g of alginate and alginate-chitosan beads in triplicate, both with liquid smoke, were introduced separately into vials with screw cap and PTFE silicone septum (Supelco, Bellefonte, PA, USA) with 10 ml of physiological saline solution (1 % w/v NaCl). The samples were heated in a thermo block (Equilab 2050-ICE, Paris, France) during 60 min at 30 °C to equilibrate the headspace for to reach equilibrium. Instrumental aromatic profiles of the samples were obtained from the aromas to be

released in the headspaces of the tubes, by the technique of solid phase microextraction (SPME) where the volatiles were adsorbed by the fiber Carboxen/Polydimethylsiloxane (Car/PDMS) and were subsequently released into the injection port of gas chromatograph Shimadzu GC-17 series equipped with a mass selective detector GCMS QP5050A Shimadzu (Tokyo, Japan) for the corresponding separation, identification and analysis (Gianelli et al. 2002, 2003). The fiber was exposed for 5 min in a normal position open purge valve (splitless mode) for complete desorption at 230 °C, after the time required SPME device was removed. Separated compounds using helium gas linear velocity of 28.3 cm s⁻¹ in a capillary column DB-624 of 60 m in length, 0.25 mm inside and 1.4 µm of film (J & W Scientific; 60 m, 0.32 mm ID 1.8 µm, Folsom, USA). For the separation of the compounds was used with onset temperature program of 13 min at 38 °C. It was noted during this time the rise in temperature to 180 °C at 8 °C/min was performed also a second rise of 21.25 min until a maximum temperature of 230 °C at 4 °C/min. The time required for this experimental phase required 52 min (Gianelli et al. 2009).

Statistical analysis

Statistical analysis of data were performed through analysis of variance (ANOVA) using Statgraphics Centurion XVI Software. Differences among mean values were established by the least significant difference (LSD) at 5 %.

Results and discussion

Beads characterization

The diameter of capsules formed with ca-alginate and ca-alginate-chitosan (with and without liquid smoke) was approximately 4 mm (visual observation). Comparing with other studies that encapsulated flavors as vainilline ethyl (Manojlovic et al. 2008) or volatile tea-tree oil (Yeh et al. 2011), the size of ca-alginate capsules obtained was greater, due to the absence of factors as a small diameter syringe and/or high voltage which allows to decrease significantly the diameter of the capsules.

Capsules whit liquid smoke showed a high load capacity, 96.57±0.02 and 98.11±0.0 for ca-alginate and ca-alginate-chitosan, respectively; similarly, Deladino et al. (Deladino et al. 2008) obtained values higher than 85 % in ca-alginate loaded capsules with antioxidant extracts of yerba mate. Similar results were obtained by Bajpai and Tankhiwale (Bajpai and Tankhiwale 2006). However, these authors reported an important loss of active compound during immersion of capsules in chitosan, effect no observed in this study. The high efficiency of liquid smoke encapsulation in

ca-alginate and ca-alginate-chitosan could be attributed to the water-soluble characteristic and low concentration of commercial liquid smoke used.

Syneresis is commonly seen in many biopolymer gel systems as ca-alginate gels and macroscopically is detected as a release of water from the gel (Donati and Paoletti 2009). The gel retains water through hydrogen bonds, but if the gel network contracts, some water will be squeezed out by diffusion (Helgerud et al. 2010). As observed, Fig. 1a

Fig. 1 Syneresis (%) of beads over time at room temperature (a), and Weight loss (%) of beads over time at refrigeration temperature (b). Each observation is a mean ± standard deviation of at least triplicate experiments. Letters represent a least significant difference (LSD) test. Ca-alginate: calcium-alginate; ca-alginate, liquid smoke: calcium-alginate with liquid smoke, ca-alginate-chitosan: calcium-alginate with a chitosan layer; ca-alginate-chitosan, liquid smoke: calcium-alginate with a chitosan layer and liquid smoke

shows the gradual syneresis of samples over time, showing a statistically significant increase of values over time for each treatment, reaching syneresis values at 72 h near of 8 % and 13 % for samples whit and without chitosan, respectively. The high values of syneresis can be attributed to a relative excess of calcium ions (0.05 M) in the gel formation step, tending to give gels with external gelation (Helgerud et al. 2010). On the other hand, Fig. 1a shows a significant reduction in syneresis of the samples by incorporating an additional layer of chitosan, could be associated to a reinforcement of the bead structure; the chitosan could bind to free alginate sites by cooperative ionic bounds.

Figure 1b shows the weight loss over time at refrigeration temperature, observing a reduced weight loss (minor of 3 % at 72 h in all samples), indicates that low temperature stabilizes the hydrogel in samples with, and without chitosan, disappearing syneresis. This behavior could be attributed to the temperature directly influences the rheological properties of materials, in particular experiencing a gradual molecular rearrangement and increasing the strength of calcium alginate gels when subjected to prolong cooling treatments (Papageorgiou et al. 1994).

Aromatic profiles of the samples

Figure 2 shows the chromatograms of volatile compound identified from headspace of capsules with liquid smoke. Table 1 lists the compounds identified, 66 in total, of which 59 were identified from the samples with chitosan (see Fig. 2a) and 60 from the samples without chitosan (see

Fig. 2b). Among the substances identified, compounds arising from liquid smoke and specifically from the thermal degradation of the three main classes of wood components, i.e. carbonyls, furans and pyrans derivatives, as well as some compounds that could mainly arise from cellulose and hemicellulose pyrolysis (Guillén et al. 1995). Among these volatile compounds, phenols derivatives such as eugenol, guaiacol (in this case p-ethylguaiacol), cresol and dimethyl-phenol (see Table 1) can be considered sensory descriptors to contribute to the specific flavor of smoke (according to the review by (Simon et al. 2005)).

On the other hand, Fig. 2 show greater abundance (TIC) of volatile compounds in the samples without chitosan, showing a greater total area than samples with chitosan (see Table 1), which could be attributed to the chitosan can decrease the permeability of the capsules by crosslinking with the calcium alginate gel. Furthermore, it is confirmed that the temperature applied (30 °C for 1 h) was sufficient for the release of volatile compounds from samples, some of which have been recognized as responsible for smoke flavor. Relative to the effect of temperature, Serp et al. (2002), Manojlovic et al. (2008) and Yeh et al. (2011) clearly demonstrated that calcium alginate capsules change their physical properties and in particular significantly increase their permeability, which can explains the release of volatile compounds in the present study. In particular, one can consider that the model by Yeh et al. (2011) can explain the diffusion of volatile compounds from the beads with liquid smoke, where a volatile liquid compound first evaporates inside the capsule and as vapor diffuses outside.

Fig. 2 Chromatogram obtained by SPME-GC-MS after fibre CAR/PDMS exposition for 1 h at 30 °C in the headspace of calcium alginate beads with liquid smoke beads without (a) and with (b) a chitosan layer. The numbers represent compounds identified and listed in Table 1. SPME-GC-MS: Solid Phase Microextraction-Gas Chromatograph- Mass Selective CAR/PDMS: Carboxen/Polydimethylsiloxane

Table 1 Volatile compounds identified in the headspace of ca-alginate with liquid smoke beads with and without a chitosan layer using SPME-GC-MS and CAR/PDMS

N ^o ^a	Compound ^b	Tr ^c	Without chitosan			With chitosan			References
			Area ^d	DS ^e	%Area ^f	Area ^d	DS ^e	%Area ^f	
1	2,3-Dihydro-3-methyl-furan	9.662	11578401	95771	0.22	5831328	466262	0.16	(Guillen et al. 1995)
2	BCH	11.843	23895215	2728274	0.45	7141351	2961590	0.20	
3	5-Methyl-2(5H)-furanone	12.181	6072394	254826	0.11	3497023	438930	0.10	
4	Furfural	12.560	507395584	74669666	9.58	186358024	69785027	5.12	(Guillen et al. 1995; Meier 2009)
5	Pentan-2-one	13.386	9032961	1526339	0.17	—	—	—	(Guillen et al. 1995; Meier 2009)
6	Ethylene	13.410	—	—	—	5038574	1835822	0.14	
7	Heptanal	13.582	—	—	—	6403195	1801316	0.18	
8	2-Methyl-2-cyclopenten-1-one	14.319	32261566	501489	0.61	25129879	3477631	0.69	(Guillen et al. 1995; Meier 2009)
9	1-(2-furanyl)-1-Heptanone	14.426	4617095	2375484	0.09	—	—	0.00	(Guillen et al. 1995; Sung et al. 2007)
10	1-(2-furanyl)-Ethanone,	14.495	33017859	6243563	0.62	23648880	11935306	0.65	
11	5-Methyl-2-furfural	14.629	17656262	7157390	0.33	9919541	7551758	0.27	
12	Benzaldehyde	15.843	83698562	10669095	1.58	40852832	10758537	1.12	(Guillen et al. 1995; Meier 2009; Sung et al. 2007)
13	5-Methyl-2-furfural	15.979	123476336	10184382	2.33	58673022	1661305	1.61	
14	Octanal	16.120	48208638	248513	0.91	22714179	10820335	0.62	
15	2,3-Benzofuran	16.313	31020124	16634694	0.59	17274521	12157214	0.47	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006; Meier 2009)
16	3-Methyl-2-cyclopenten-1-one	16.416	33895301	1158154	0.64	—	—	—	
17	2,3-Dimethyl-2-cyclopenten-1-one	16.574	35854182	5686148	0.68	24072308	9631759	0.66	
18	2-Ethyl-1-hexanol	16.805	29943294	5468244	0.57	18670085	8305772	0.51	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006; Meier 2009; Sung et al. 2007)
19	BCH	17.021	18026609	10764101	0.34	11280184	10904442	0.31	
20	Phenol	17.330	195022011	167897	3.68	130974173	10813942	3.60	
21	BCH	17.465	36536245	11751074	0.69	27390328	1454229	0.75	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006)
22	3-Methyl-1,2-cyclopentanedione	17.649	26392343	23355974	0.50	22580993	8278752	0.62	
23	2-Hydroxy-benzaldehyde	17.955	93256347	26397546	1.76	46533158	111686	1.28	
24	5-Ethyl-2-furaldehyde	18.311	21372376	7123980	0.40	25682110	2390320	0.71	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006; Meier 2009; Sung et al. 2007)
25	Nonanal	18.597	163765051	21789489	3.09	125077875	12155338	3.43	
26	2-Methylphenol(<i>o</i> -Cresol)	18.847	378525870	4848340	7.15	291121987	23755079	7.99	
27	2-Methoxy-phenol	19.102	344884536	29101825	6.51	256166463	30069657	7.03	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006; Meier 2009)

Table 1 (continued)

N ^o ^a	Compound ^b	Tr ^c	Without chitosan			With chitosan			References
			Area ^d	DS ^e	%Area ^f	Area ^d	DS ^e	%Area ^f	
28	BCH	19.267	—	—	—	21329852	2867259	0.59	
29	3-Methylphenol	19.563	309446840	5524007	5.85	—	—	—	(Guillen et al. 1995)
30	4-Methylphenol	19.569	—	—	—	225001676	13529714	6.18	(Guillen et al. 1995; Sung et al. 2007)
31	2,6-Dimethylphenol	19.901	277377673	10105398	5.24	218001136	19938202	5.99	(Meier 2009)
32	2-Hydroxy-4-methylbenzaldehyde	20.169	61258353	14053698	1.16	36284039	2260354	1.00	
33	BCH	20.340	14840447	870018	0.28	12242113	1156621	0.34	
34	BCH	20.522	25329096	5903907	0.48	23534052	27722	0.65	
35	1,3-Dimethoxybenzene	20.698	18729946	6553074	0.35	13022534	470820	0.36	(Sung et al. 2007)
36	2-Ethylphenol	20.908	77990925	11250054	1.47	64163413	11231097	1.76	(Guillen et al. 1995; Meier 2009)
37	Unknown	21.033	26487257	4105222	0.50	14299323	250164	0.39	
38	2,4-Dimethylphenol	21.156	488187860	33929962	9.22	374696935	39143494	10.29	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006; Meier 2009)
39	1-(2-Methylphenyl)-ethanone	21.411	29300453	16698957	0.55	30917915	2763154	0.85	
40	Naphthalene	21.652	106911541	19237935	2.02	91953746	7164535	2.53	(Kostyra and Barylko-Pikielna 2006)
41	2-Methoxy-4-methylphenol (<i>p</i> -Methylguaiacol)	21.852	332958768	20972600	6.29	248265618	25557305	6.82	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006; Meier 2009)
42	2-Ethyl-phenol	21.960	101380482	6338682	1.92	75256746	5123074	2.07	(Guillen et al. 1995)
43	2,4,5-trimethylphenol	22.356	183127976	5517947	3.46	147420825	26582533	4.05	(Meier 2009)
44	3,4-Dimethylphenol	22.755	20387918	5085791	0.39	—	—	—	(Guillen et al. 1995)
45	3-Ethyl-5-methylphenol	23.160	40388048	9374124	0.76	33751630	10040535	0.93	
46	4-Ethyl-2-methoxyphenol	23.372	16468359	6241374	0.31	—	—	—	(Guillen et al. 1995; Meier 2009; Sung et al. 2007)
47	4-(1-Methylethylphenol)phenol	23.564	123829964	—	2.34	—	—	—	
48	1-Ethyl-4-methoxybenzene	23.568	102179530	—	1.93	96892187	13435809	2.66	
49	3,5-Diethylphenol	23.664	38510588	3261678	0.73	27626510	6877429	0.76	(Guillen et al. 1995; Meier 2009)
50	1,4-Bimethoxy-2-methylbenzene	23.891	87451406	10307139	1.65	67681597	9712379	1.86	(Guillen et al. 1995)
51	1-Methoxy-4-propylbenzene	24.084	7180357	—	0.14	6856333	702480	0.19	
52	4-Ethyl-2-methoxyphenol (<i>p</i> -Ethylguaiacol)	24.251	168730013	24704559	3.19	122989676	19412247	3.38	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006; Meier 2009; Sung et al. 2007)
53	2,4,6-trimethyl phenol	24.459	23494068	12087515	0.44	11660976	1331829	0.32	(Meier 2009)
54	2-methyl-5-(1-methylethyl)phenol	24.753	55017812	14085262	1.04	46876225	6262767	1.29	
55	(2-Propynyloxy)benzene	25.188	10214222	711819	0.19	—	—	—	
56	2-Methylnaphthalene	25.354	—	—	—	13604769	916057	0.37	
57	Diethylphenol	25.499	—	—	—	4759703	179286	0.13	
58	3-Methoxy-4,5,6-trimethylphenol	25.950	10267882	1192968	0.19	5526530	834030	0.15	

Table 1 (continued)

N ^a	Compound ^b	Tr ^c	Without chitosan			With chitosan			References
			Area ^d	DS ^e	%Area ^f	Area ^d	DS ^e	%Area ^f	
59	1-Methoxy-4-propylbenzene	26.060	13979375	3753282	0.26	11383581	3584877	0.31	
60	4-(1,1-dimethylethyl)-1,2-Benzenediol	26.211	39580375	3822889	0.75	31898957	3892558	0.88	
61	2-Methoxy-4-(2-propenyl)phenol(<i>Eugenol</i>)	26.546	52247408	5267905	0.99	40852731	6683998	1.12	(Kostyra and Barylko-Pikielna 2006; Meier 2009)
62	2-Methoxy-4-(1-propenyl)phenol(<i>Guaiacylprop-ane</i>)	26.768	52885924	—	1.00	41168817	2334223	1.13	(Guillen et al. 1995; Kostyra and Barylko-Pikielna 2006)
63	2-Methyl-propanoic acid	27.066	23595182	619244	0.45	23614267	3267230	0.65	
64	3-Allyl-6-methoxyphenol	28.131	12904473	2450298	0.24	14205115	231142	0.39	
65	1,2-Dimethoxy-4-(2-propenyl)benzene	28.617	5353596	1016535	0.10	—	—	—	
66	Methylesterdodecanoic acid	29.588	26348661	24449268	0.50	51593732	8264385	1.42	
Total			5293747929		100	3641365257		100	

^a Number of peak (Fig. 2); ^b BCH: Branched Chain Hydrocarbon; ^c Time retention (min) for capillary column (J & W Scientific; 60 m, 0.32 mm ID. 1.8 μ m) installed on a gas chromatograph equipped with detector, chromatographic conditions detailed in [Materials and Methods](#); ^d Results expressed as mean of three replicates of total ion current (TIC); ^e Standard Deviation; ^f Percentage of total TIC area

SPME-GC-MS Solid Phase Microextraction-Gas Chromatograph-Mass Selective; CAR/PDMS Carboxen/Polydimethylsiloxane

Conclusions

Capsules of ca-alginate and ca-alginate-chitosan whit liquid smoke showed a high load capacity (over 96 %). However, the beads exhibit high values of syneresis at room temperature after 72 h, syneresis that is reduced in samples than have the additional layer of chitosan (8 % versus 13 % in samples with and without chitosan, respectively). A factor that allows to stabilize the hydrogel of beads is refrigerated storage (4 °C), allowing the samples loss weight less than 3 % after 72 h. On the other hand, it is confirmed that the temperature applied was sufficient for the release of volatile compounds from samples, and the chromatograms show greater abundance (TIC) of volatile compounds in the samples without chitosan, showing a greater total area than samples with chitosan, which could be attributed to the chitosan can decrease the permeability of the capsules by crosslinking with the calcium alginate gel. Among these volatile compounds, phenols derivatives such as eugenol, p-ethylguaiacol, cresol and dimethyl-phenol can be considered sensory descriptors to contribute to the specific flavor of smoke. In summary, the dripping method is highly efficient to encapsulate liquid smoke and the beads diffuse volatile compounds with sensory impact on the flavor of smoke, although it is necessary to minimize syneresis at room temperature through a better balance calcium/alginate or considered refrigerated storage to increase the stability of the beads.

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