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SHORT COMMUNICATION

Effect of mesoporous silica nanoparticles-based nano-fragrance on the central nervous system

Zhiguo Lu[1,3]* | **Tianlu Zhang**[1,3]* | **Jun Yang**[1] | **Jianze Wang**[1] | **Jie Shen**[1,3] | **Xiangyu Wang**[1] | **Zuobing Xiao**[4,5] | **Yunwei Niu**[4,5] | **Guiying Liu**[2] | **Xin Zhang**[1]

[1]State Key Laboratory of Biochemical Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, P. R. China

[2]Department of Pediatrics, Capital Medical University Affiliated Beijing Anzhen Hospital, Beijing, P. R. China

[3]University of Chinese Academy of Sciences, Beijing, P. R. China

[4]Shanghai Research Institute of Fragrance and Flavor Industry, Shanghai, P. R. China

[5]School of Perfume and Aroma Technology, Shanghai Institute of Technology, Shanghai, P. R. China

Correspondence
Xin Zhang, State Key Laboratory of Biochemical Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, 100190, P. R. China.
Email: xzhang@ipe.ac.cn
Guiying Liu, Department of Pediatrics, Capital Medical University Affiliated Beijing Anzhen Hospital, Beijing, 100029, P. R. China.
Email: liugvying@126.com

*These two authors contributed equally to this work.

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Abstract

Fragrances are widely used in our daily lives and can make us feel happy. However, traditional aromatic products release fragrance quickly and have a strong aroma. This not only worsens our scenting experience, but also severely shortens the useful life of fragrance products. In this study, nano-fragrances based on mesoporous silica nanoparticles with great encapsulation efficiency and slow-release function were designed and prepared. In addition, this nano-fragrances are applied to wallpapers. Open field tests showed that this nano-fragrance had significant stress relief and anti-depressant effects.

KEYWORDS

central nervous system, encapsulation efficiency, fragrance, silica nanoparticles, wallpaper

Abbreviations: citral@RS-MSNs 2, citral is absorbed into the mesopores of RS-MSNs; citral@RS-MSNs-W 3, the wallpaper was treated with citral@RS-MSNs; RS-MSNs 1, rod-shaped mesoporous silica nanoparticles.

1 | INTRODUCTION

Fragrances are widely used in daily life, such as detergents, cosmetics, air fresheners, food, and medicine [1–4]. Fragrances can not only improve our quality of life, but also have biological activity, so they are widely used in aromatherapy [5,6]. However, most fragrance molecules are highly volatile, which not only shortens the use time of the fragrant products, but also results in excessively strong aromas [7,8]. Therefore, the key to improving the effect of fragrances and prolonging the service life of fragrances is to design and prepare materials capable of slow-release perfume.

In recent years, nanoscience and technology have made rapid progress. A variety of nanomaterials are used to load molecules and slow the release of molecules. Micelles and liposomes encapsulate molecules through hydrophilic–hydrophobic interactions [9-11]. Cationic nanoparticles can adsorb anionic molecules, such as nucleic acids or proteins [12,13]. Some carriers can covalently bind molecules through chemical bonds to load molecular [14-16]. However, the above nanotechnologies are not applicable to the encapsulation of fragrance molecules. Micelles and liposomes are dependent on the presence of water. Most fragrance molecules are neutral and therefore cannot be adsorbed by electrostatic interaction. Most fragrance molecules do not have active chemical groups, so it is difficult to be covalently bound to nanomaterials. In other words, the above-mentioned nanotechnologies are not universal for fragrances.

Mesoporous materials have a large specific surface area, pore volume, and tunable pore size, so they have a large surface tension, which can adsorb most fragrance molecules [17-19]. For example, Zhou and his colleagues designed porous metal–organic frameworks to encapsulated fragrances [20,21]. In addition, mesoporous materials, such as mesoporous silica nanoparticles, are easy to prepare and have low production costs. Therefore, mesoporous materials can be applied to large-scale industrial production and reduce the cost of fragrance products with a slow-release property.

In this study, rod-shaped mesoporous silica nanoparticles were prepared and used to adsorb the fragrance molecule citral. Lemon essential oil has antidepressant effects. The main component of lemon essential oil, citral, has an antidepressant effect similar to diazepam, and can increase the secretion of serotonin (5-HT). The citral-encapsulated mesoporous silica nanoparticles were then adhered to the wallpaper. Finally, the effects of citral-containing aromatic wallpapers on central nervous system were evaluated.

PRACTICAL APPLICATION

Many fragrances have been proven to regulate the function of the human central nervous system and are widely used in aromatherapy. However, free fragrances are highly volatile. This not only shortens the service life of the fragrance products, but also lead to a large concentration of fragrance molecules in the air, which makes people uncomfortable. In this study, nano-fragrance based on mesoporous silica was prepared and named citral@RS-MSNs. Citral@RS-MSNs could slow down the release of fragrances. Subsequently, aromatic wallpaper based on free perfume and nano perfume was prepared. Our studies showed that aromatic wallpapers based on nano-fragrance had better anti-depression and relieving stress effects. Furthermore, the preparation cost of mesoporous silica nanoparticles is low, the preparation method is mature, and it can be produced on a large scale by industry. Therefore, Citral@RS-MSNs have broad application prospects.

2 | MATERIALS AND METHODS

2.1 | Materials

Citral was obtained from Aladdin (Shanghai, P. R. China). Superdry tetrahydrofuran (THF) was purchased from J&K Sientific Ltd (Beijing, P. R. China). Hexadecyltrimethylammonium bromide (CTAB), Tetraethyl orthosilicate (TEOS) and ammonium hydroxide (28% solution in water) were obtained from Acros Organics (Beijing, P. R. China). All other chemicals such as ethanol and tetrahydrofuran were analytical grade reagents and were obtained locally.

2.2 | Preparation of the silica nanocolumns loaded with citral and wallpaper loaded with citral

CTAB (5670 mg) was dispersed into deionized water (140 mL). Then 4 mL ammonium hydroxide was added, magnetic stirring for 30 min to make it completely mixed, and 2.44 mL TEOS was added drop by drop under the condition of agitation, take a constant temperature water bath of 40°C, react for 2 h under the condition of agitation, centrifuge, and wash. The particles (RS-MSNs) was collected by filtration and calcined at 550°C for 5 h to remove the CTAB surfactants.

RS-MSNs (100 mg) was dispersed into deionized citral solution (10 mL) under vigorous stirring for 24 h. The organic solvents and unloaded citral were then removed by

vacuum filtration to obtain silica nanocolumns loaded with citral (citral@RS-MSNs). Finally, wallpaper (50 cm^2) were immersed in citral@RS-MSNs aqueous solutions (1 mg/mL). After 12 h, the wallpaper was then dried at 40 °C for 1 h in an oven to obtain wallpaper loaded with citral (citral@RS-MSNs-W).

2.3 | Characterization of RS-MSNs

The morphology of RS-MSNs was observed using scanning electron microscope (SEM, JEOL, Japan) and transmission electron microscopy (TEM, JEOL 2100F).

The dried samples were directly used for the observation without any treatment. Nitrogen adsorption−desorption isotherms were measured at 77 K with a QuadraSorb SI analyzer (USA). Before measurement, the samples were degassed in vacuum at 180 °C for at least 6 h. The Brunauer-Emmett-Teller (BET) method was utilized to calculate the specific surface areas, pore size, and pore volume.

2.4 | Thermogravimetric analysis and determination of encapsulation efficiency

Thermogravimetric analysis (TGA; TGA/DSC 1, Japan) was used to determine the weight (initial weight after water evaporation) loss related to the release of fragrance from the sample. This experiment was performed in the temperature from 25 to 600°C at a heating rate of 10 K/min under a constant nitrogen flow (20 mL/min). Powdered NPs was performed and other samples were carried out in the same weight. The encapsulation efficiency (f) was obtained according to the following formula, five replicates were analyzed for the encapsulation efficiency evaluation:

$$\frac{W1}{100-f} = \frac{W2}{100-W2}$$

where W1 is the weight loss of the citral@RS-MSNs and W2 is the weight loss of the RS-MSNs.

2.5 | The morphology of the wallpaper

The surface morphologies of the untreated wallpaper and the wallpaper finished by citral@RS-MSNs were studied via scanning electron microscope (SEM, JEOL, Japan).

2.6 | The content and release of citral

The content and release of citral was measured by HPLC. For HPLC analysis, we used a mobile phase with water/acetonitrile (v/v = 40%/60%) at a flow rate of 1.0 mL/min and a C18 reversed-phase column ($250 \times 4.6 \times 5$ μm). The concentrations of linalool based on the peak area at the retention time of 5 min at 210 nm. The release rate was calculated via the below formula:

$$\text{Release rate } (\%) = W_1/W_2 \times 100\%$$

where W_1 was the weight of released citral and W_2 was the total weight of citral.

2.7 | Open field tests

Female C57 mice (6 week) were purchased from the Academy of Military Medical Sciences of China. All procedures involving experimental animals were performed in accordance with protocols approved by the Committee for Animal Research of Peking University, China.

Fragrance-treated wallpaper was glued on side wall of mouse cage. After culturing for 7 days, open field tests were performed to test the effects on behavioristics of mice.

2.8 | Statistical analysis

All the data were analyzed in triplicate and presented as a mean value with standard deviation (Mean ± SD).

3 | RESULTS AND DISCUSSION

3.1 | The preparation and characterization of rod-shaped mesoporous silica nanoparticles

Rod-shaped mesoporous silica nanoparticles (RS-MSNs) were prepared via sol–gel method. The morphology and size of RS-MSNs were observed by SEM. As shown in Figure 1A, RS-MSNs were rod-shaped. The length of RS-MSNs was about 150 nm and the diameter of RS-MSNs was about 70 nm. The inner structure of RS-MSNs was detected by TEM. As shown in Figure 1B, there were obvious channels in RS-MSNs.

Pore size, specific surface area, and pore volume were the most important indicators of mesoporous materials. These three indicators were measured by BET method. The N_2 adsorption–desorption isotherm of RS-MSNs was shown in Figure 2A. According to the isotherm, the specific surface area and pore volume of RS-MSNs were calculated as 1.054 m^2/g and 0.896 cm^3/g, respectively. As shown in Figure 2B, the pore width of RS-MSNs was about 4 nm. These results indicate that rod-shaped mesoporous silica nanoparticles were successfully prepared.

3.2 | The preparation and characterization of citral-encapsulated rod-shaped mesoporous silica nanoparticles

Citral is absorbed into the mesopores of RS-MSNs by surface tension and named citral@RS-MSNs. The encapsulation efficiency of citral was detected by TGA. As shown in Figure 3A, RS-MSNs were hardly thermally decomposed within

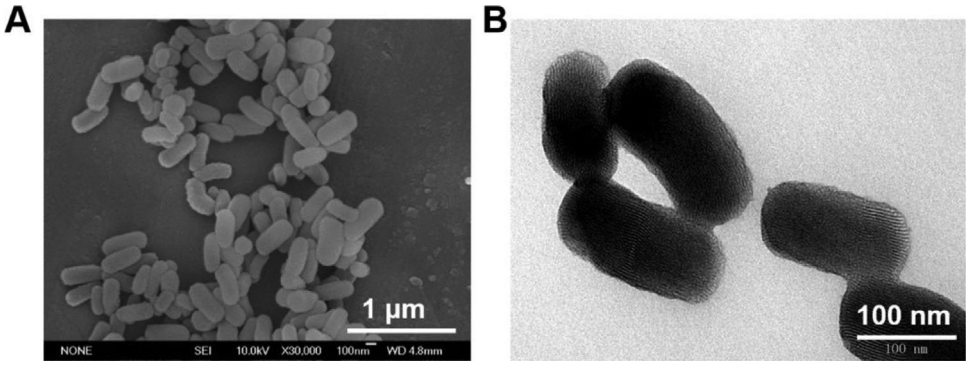

FIGURE 1 The (A) SEM image and (B) TEM image of RS-MSNs

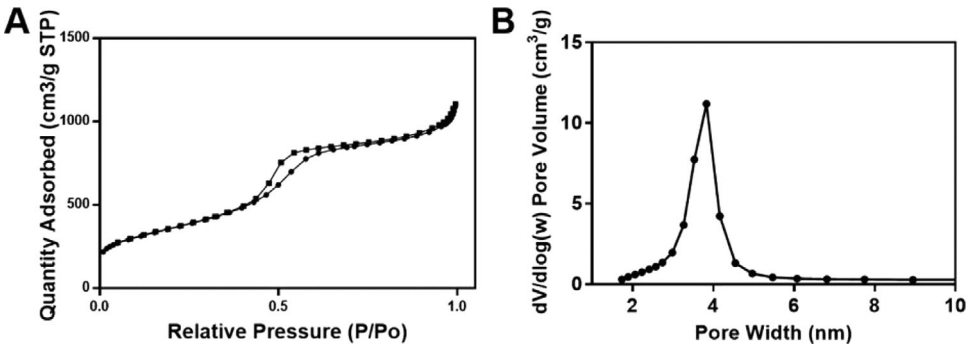

FIGURE 2 (A) The N2 adsorption−desorption isotherm at 77 K for MS-S. (B) The pore diameters of MS-S measured via desorption pore volume distribution

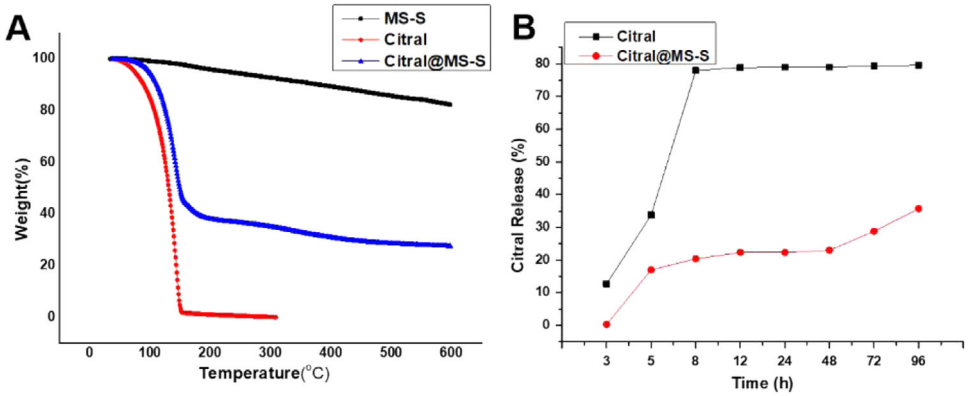

FIGURE 3 (A) The TGA result. (B) The cumulative release profiles of citral in different samples

500°C. In contrast, both citral and citral@RS-MSNs started to be thermally decomposed at 100°C and completely thermally decomposed at 150°C. This result indicated that there was citral in citral@RS-MSNs and the fragrance content of citral was calculated as 52.15% according to the TGA result.

Subsequently, the release of citral was detected. As shown in Figure 3B, nearly 80% of the free citral was released at 8 h. In contrast, only 20% of citral was released from citral@RS-MSNs at 48 h. This result indicated that citral@RS-MSNs has excellent sustained release properties. This is because RS-MSNs had a large specific surface area, which made RS-MSNs have a very strong adsorption capacity, thereby slowing the release of citral.

3.3 | The preparation of citral@RS-MSNs treated wallpaper (citral@RS-MSNs-W) and the effect of citral@RS-MSNs-W on central nervous system

The nanoparticles that encapsulate the fragrance were adhered to the wallpaper by immersion. First, citral@RS-MSNs were dissolved in water to form a suspension. The wallpaper was

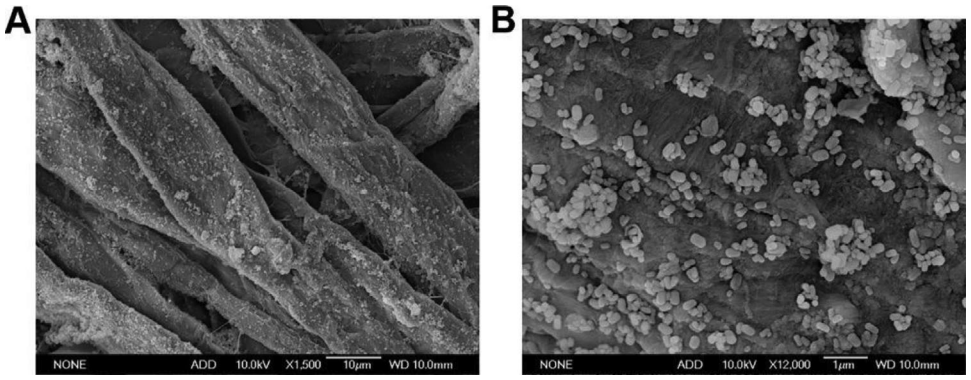

FIGURE 4 The SEM images of (A) citral@RS-MSNs-W and (B) the enlarged image

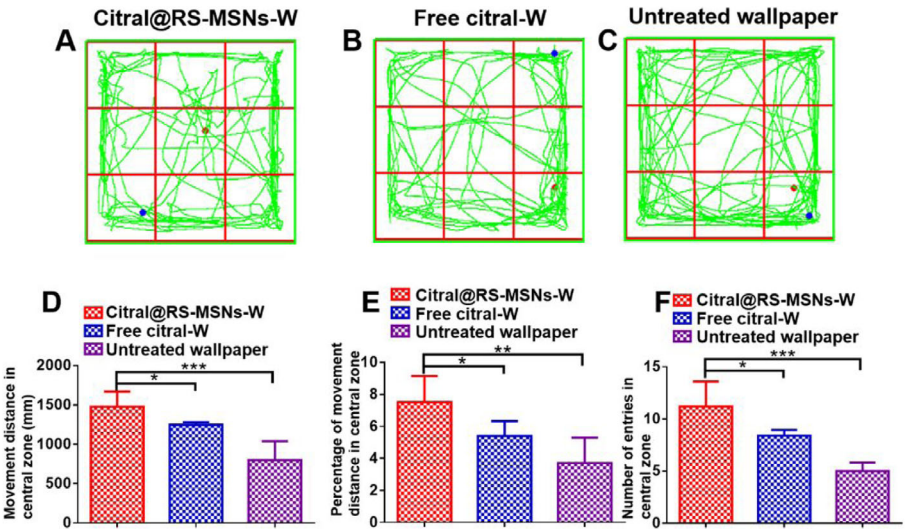

FIGURE 5 (A-C) Representative tracks of movement patterns of different samples in open field. The green curves represented the movement of mice. (D–F) The quantitative results of Figure A–C. The mean ± SD is shown ($n = 3$). $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.005$

then immersed in the suspension. As shown in Figure 4A, the wallpaper was made of fibers. Figure 4B showed that a large number of citral@RS-MSNs adhered to the fibers of the wallpaper. Therefore, fragrance-encapsulated nanoparticles were successfully adhered to the wallpaper.

Open field test is one of the most commonly used methods to evaluate depression and stress [22-25]. When mice are depressed and stressed, they tend to move around the edge of open field. After the wallpaper was pasted on the wall of the mouse cage for 7 days, the neuromodulation effects of the fragrance-treated wallpaper on the mice were evaluated by open field tests. As shown in Figures 5A–C, the distance of citral@RS-MSNs-W treated mice in the central zone was significantly longer than that of free citral-W treated and untreated mice. The movements of the mice were then quantified. Figure 5D showed that the citral@RS-MSNs-W treated mice have significantly increased movement distance in the central region compared to other mice. Figure 5E illustrated that the percentage of movement distance of mice in the central region after treatment of citral@RS-MSNs-W was significantly increased compared to other mice. Figure 5F illustrated that the number of times that mice entered the central region increased after citral@RS-MSNs-W treatment compared with other mice. These parameters together demonstrate that citral@RS-MSNs-W could significantly relieve stress and depression in mice compared to free citral-W and untreated wallpaper.

4 | CONCLUDING REMARKS

Mesoporous silica nanoparticles with a slow-release fragrance function were designed and prepared. These nanoparticles were capable of encapsulating a large number of fragrance molecules. In addition, after the fragrance was encapsulated, these nanoparticles could also significantly slow down the release rate of the fragrance, so that the fragrance was released stably and sustainably. Subsequently, fragrance-encapsulated nanoparticles were applied to the wallpaper. These aromatic wallpapers had significant effects

on relieving stress and depression. Therefore, this nano-fragrance with slow-release function and regulating central nervous system function had great application potential.

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CONFLICT OF INTEREST

The authors have declared no conflict of interest.

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