International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 13 Issue 2 ǁ February 2025 ǁ PP. 117-123

Research progress and application of plant essential oil inclusion complexes

Abstract
Because of its unique aroma and biological activity, plant essential oils are widely used in medicine, food and cosmetics. However, issues such as high volatility, low water solubility, and poor stability of essential oils limit their application. These properties can be effectively improved by forming clathrates with materials such as cyclodextrin. In this paper, the preparation methods, characterisation techniques, application fields and research progress of plant essential oil inclusion complexes are reviewed, aiming to provide reference for further research in this field.
Keywords：*Plant essential oils Cyclodextrin Inclusion complexes*

Date of Submission: 08-02-2025 Date of acceptance: 19-02-2025

I. Introduce

Plant essential oil is a volatile oily liquid extracted from plants, which has a variety of biological activities such as antibacterial, antioxidant, and anti-inflammatory. However, the high volatility and low water solubility of essential oils make them limiting in practical applications[1]. Cyclodextrins are cyclic oligosaccharides composed of glucose units, which have the structural characteristics of internal hydrophobicity and external hydrophilicity, and can form inclusion complexes with essential oils, thereby improving their physical and chemical properties[2].

Cyclodextrin (CD) is a cyclic oligosaccharide compound obtained by enzymatic cyclization of starch, and the main components are 6, 7 and 8 glucose cyclics, which are called α-CD, β-CD and γ-CD, respectively[3]. Among them, β-CD is widely used in the preparation of inclusion complexes due to its good thermal stability, solubility and biocompatibility[4]. The structure of β-CD cannot rotate freely due to the 1,4-glycosidic bond with chair structure, so that β-CD forms a ring-shaped hollow conical cylindrical shape with narrow upper top and wide lower width[5]. As shown in Figure 1-2, the cavity structure of cyclodextrin shows different properties inside and outside due to the different arrangement of hydroxyl groups, with the inner cavity having certain hydrophobic properties and the outer cavity having certain hydrophilic properties[6]. Therefore, cyclodextrin molecules have the characteristics of "internal hydrophobic, external hydrophilic", which can be combined with a large number of hydrophobic substances, so that molecules that meet the size of the cavity can form inclusion complexes with cyclodextrin molecules through hydrophobic force, van der Waals force[7].

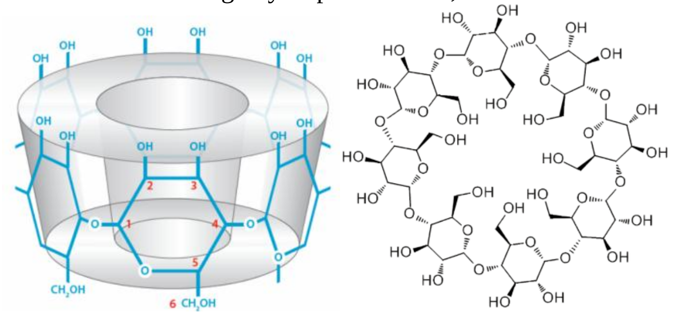


Fig. 1. Molecular structure of β-cyclodextrin

β-cyclodextrin is a typical host molecule, and the simple one can be thought of as a capsule shell that can encapsulate various "drug molecules"[8]. The main factors affecting the stability of the inclusion include the shape and size of the host and guest molecules, the binding force between the host molecule and the hydrophobic cavity of the host molecule, the structure of the guest, the charge and polarity of the host and guest molecules, temperature and solvent effects, etc. Among them, we found that the biggest effect is the size of the molecule, only when the size and shape of the molecule and the cyclodextrin molecule reach an infinite anastomosis can the guest molecule be encapsulated into the cavity of cyclodextrin, the cavity size of the cyclodextrin molecule is large, not all molecules can be encapsulated, in general, aromatic and heterocyclic compounds are easy to enter the cavity of β-cyclodextrin[9]. It is precisely because of this recognition effect on molecules that β-cyclodextrin is able to achieve a certain selectivity for molecules in addition to encapsulating molecules.

In recent years, there have been more and more applications for β-cyclodextrin encapsulation, which is widely used in medical, daily, identification and separation food, industrial production and pharmaceutical encapsulation. In the field of medicine, the release of the drug itself in the human body has certain limitations, and the formation of inclusion complexes with β-cyclodextrin can effectively release the drug in the body to achieve the effect of increasing the degree of release.

II. Preparation method of plant essential oil cyclodextrin inclusion complex

There are various preparation methods for cyclodextrin inclusion complexes of plant essential oils, and common methods include saturated aqueous solution method, grinding method, ultrasonic method, spray drying method, etc[10]. These methods and examples of their applications are described in detail below:

2.1 Traditional preparation methods

- Saturated aqueous solution method: Cyclodextrin is made into a saturated aqueous solution, and the essential oil is stirred or ultrasonicated after adding plant essential oil to form a clath complex with cyclodextrin. This method is simple to operate, but the inclusion rate is low. Mustard essential oil-β-cyclodextrin complex[11]: The optimal inclusion process conditions were a 1:6 ratio of mustard essential oil to β-cyclodextrin, an inclusion time of 1.5 hours, and an inclusion temperature of 50°C. Under these conditions, the inclusion rate was 90.56% and the inclusion yield was 87.22%.
- Grinding method: Cyclodextrins are mixed with essential oils and ground to promote the formation of inclusion complexes by mechanical force. Peppermint oil-β-cyclodextrin complex[12]: The inclusion complex of peppermint oil and β-cyclodextrin was prepared by grinding method, and the optimal preparation conditions were determined by single factor experiments.
- Freeze-drying method: The inclusion complex is prepared by freeze-drying technology, which has the advantages of simple operation and high yield. Inclusion of Aromatic Oil-β-Cyclodextrin[13]: The inclusion of Aromatic Herb Oil and β-cyclodextrin was prepared by freeze-drying method, and the optimal preparation conditions were determined by single factor experiments.
- Spray drying method: the mixed solution of cyclodextrin and plant essential oil is made into a powdered inclusion complex by spray drying, which is suitable for large-scale production. Rose essential oil-β-cyclodextrin complex[14]: the optimal process conditions were as follows: the mass ratio of β-cyclodextrin to essential oil was 6:1, the inclusion time was 2 hours, and the inclusion temperature was 40°C.

2.2 Novel preparation methods

- Ultrasonic-assisted method: use the cavitation effect of ultrasound to accelerate the interaction between cyclodextrin and plant essential oils and improve the inclusion efficiency. Ginger essential oil-β-cyclodextrin complex[15]: The inclusion complex of ginger essential oil and β-cyclodextrin was prepared by ultrasonic, and the results of scanning electron microscopy, differential scanning calorimetry, X-ray diffraction and Fourier transform infrared spectroscopy showed that ginger essential oil was encapsulated in the lumen of β-cyclodextrin. Angelica essential oil-β-cyclodextrin inclusion complex[16]: By heating for 60 minutes, the inclusion rate of Angelica essential oil can be obtained with about 80%.
- Microwave-assisted method: The thermal effect of microwaves and the electromagnetic field are used to promote the formation of inclusion complexes.

In conclusion, there are various preparation methods for cyclodextrin inclusion complexes of plant essential oils, and different methods are suitable for different application scenarios. Methods such as saturated aqueous solution, grinding, ultrasonic, spray drying, and freeze-drying have their own advantages and disadvantages. Selecting the appropriate preparation method and optimising the process conditions are the keys to improving the inclusion rate and stability of the inclusion complex.

2.3 Factors influencing the encapsulation process

Feeding ratio: Most cyclodextrin claths have a master-guest feeding ratio of 1:1-1:6[15].

Selection of inclusion method: Different inclusion methods have a significant impact on the inclusion rate and the properties of the inclusion complex. Ultrasonic methods usually have the highest inclusion rate and grinding methods are the most economical.

Temperature and time: Inclusion temperature and time have an important impact on the inclusion rate. For example, the optimal inclusion temperature for mustard essential oil-β-cyclodextrin inclusion complex is

50°C and the inclusion time is 1.5 hours[11].

In conclusion, there are various preparation methods for cyclodextrin inclusion complexes of plant essential oils, and different methods are suitable for different application scenarios. Methods such as saturated aqueous solution, grinding, ultrasonic, spray drying, and freeze-drying have their own advantages and disadvantages. Selecting the appropriate preparation method and optimising the process conditions are the keys to improving the inclusion rate and stability of the inclusion complex.

III. Characterisation techniques of cyclodextrin inclusion complexes of plant essential oils.

The characterisation technique of cyclodextrin inclusion complexes of plant essential oils is an important means to verify the formation and properties of inclusion complexes. Several commonly used characterisation techniques are detailed below.

3.1 NMR hydrogen spectroscopy (^{1}H-NMR)

^{1}H-NMR is one of the classical methods for the characterisation of cyclodextrin inclusion complexes. By observing the changes in the characteristic peaks before and after the inclusion, the formation of the inclusion complex can be confirmed. For example, in the study of rosemary essential oil and β-cyclodextrin inclusions[17], the low-field peaks of rosemary essential oil disappeared after inclusion, because the signal peaks were shielded after the essential oil entered the cavity of β-cyclodextrin as a core material.

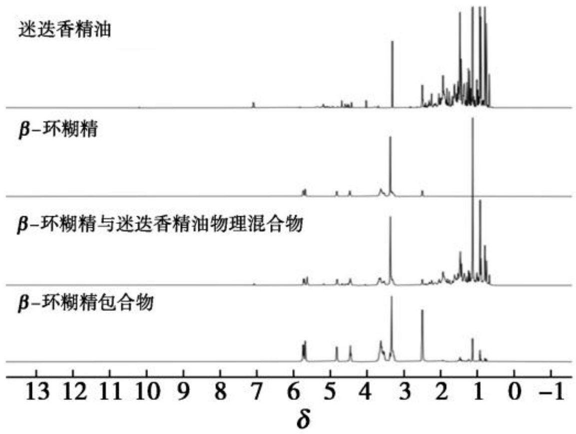
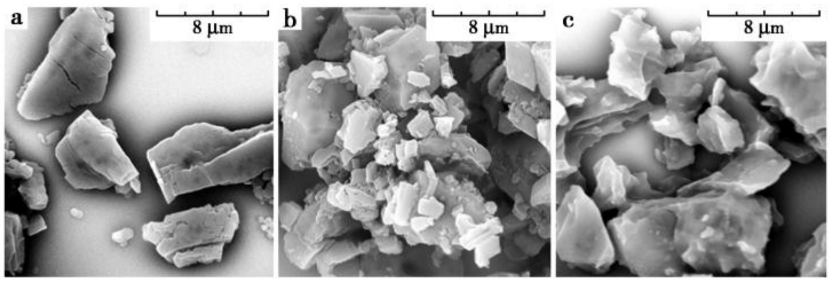


Fig. 2. 1HNMR spectra of β-cyclodextrin and its inclusion complexe

3.2 Scanning electron microscopy (SEM)

SEM is used to observe the morphology and structure of inclusion complexes[17]. In the study of rosemary essential oil and β-cyclodextrin inclusion complex, the surface of the inclusion complex was observed by SEM to be smooth and free of particulate matter, indicating that cyclodextrin had encapsulated rosemary essential oil into the cavity. This morphological change indicates the formation of inclusion complexes.



a. β-cyclodextrin b. Physical mixture c. Molecular inclusion complex

Fig. 3. Scanning electron micrographs of β-cyclodextrin and its inclusion complexe

3.3 X-ray diffraction (XRD)

XRD is a very useful technique for the characterisation of cyclodextrins and their inclusion complexes. When a new solid phase is acquired due to the formation of the inclusion complex, changes in the intensity or position of some characteristic peaks of the cyclodextrin sample are observed. β-CD diffraction patterns show a number of characteristic peaks (4.5, 8.9, 10.6, and 12.4°) indicating their crystal form, as shown in previous studies[27]. The diffraction pattern of PM is very similar to that of β-CD, indicating that there is no complexation between EB and β-CD. On the other hand, there are not many peaks in the inclusion complex to indicate the amorphous state of the sample. These findings strongly suggest the formation of inclusion complexes.

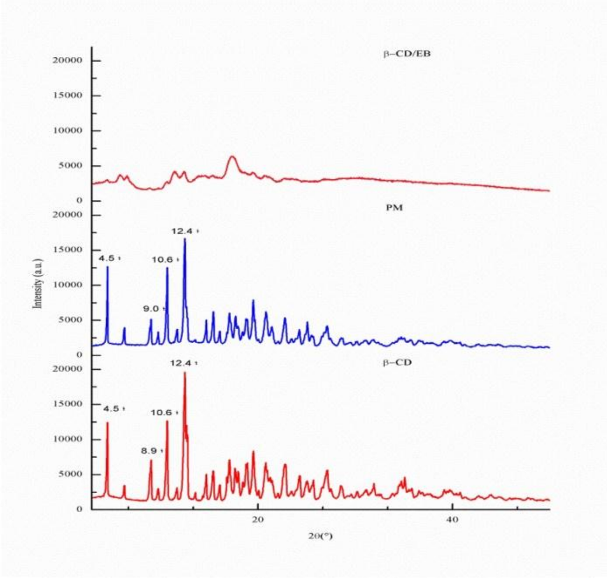


Fig. 4. X-ray pattern of β-cyclodextrin (β-CD), physical mixture (PM) and IC between β-CD and EB (β-CD/EB).

3.4 Differential Scanning Calorimetry (DSC)

DSC is used to analyse the thermal properties of claths. DSC analyses were carried out to measure and compare the thermal stability and the decomposition of the hydrogel beads incorporated with the different Td-EO and GA blend concentrations[14]. As observed in Fig. 5, DSC can be applied for the assessment of complex compounds. By inclusion, a guest molecule in β-CD, the boiling, melting and sublimation points may be changed or indeed disappear. In all curves, the endothermic peak melts were observed. Endothermic signals are in curves related to the softening, lubrication, dehydration, gelatinization, and melting of the material. Therefore, according to the results, it can be said that the amount of Td-EO and GA in the structure of hydrogels has a direct effect on the thermal properties of hydrogels.

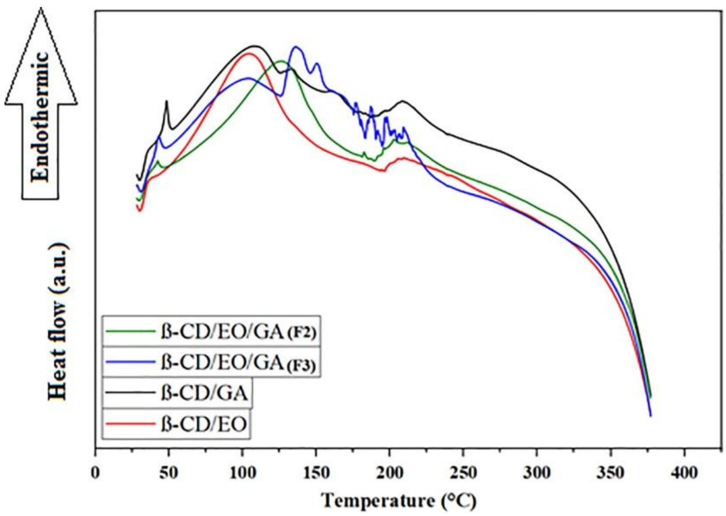


Fig. 5. DSC thermograms of different hydrogel beads

3.5 Infrared Spectroscopy (FT-IR)

FT-IR is used to analyse the chemical structure of claths. As shown in the figure of the study[27], the formation of inclusion complexes was confirmed by FT-IR analysis and it was found that the infrared spectrum of the inclusion complexes was significantly different from that of pure essential oils and physical mixtures. This indicates that the inclusion complex has a unique chemical structure.

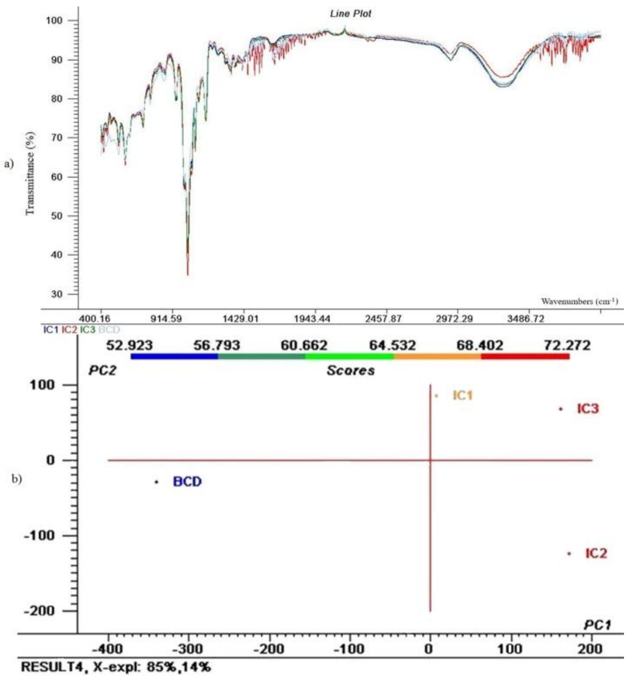


Fig. 6. The aligned FT-IR Spectra (a) and Scores (b) graphical representation of the two principal components (PC1 and PC2) explaining 96% of the total variance, for IC1, IC2, IC3 and control β-CD

IV. Research progress and future trends

In recent years, significant progress has been made in the study of plant essential oil inclusion complexes[18]. By optimising the preparation process and characterisation techniques, the properties of the inclusion complexes can be further improved. Future research directions may include the development of new clad materials, the exploration of the application of clathrates in more fields, and the improvement of the large-scale production capacity of clad complexes[19].

4.1 Domestic research progress

In recent years, remarkable progress has been made in the research of plant essential oil inclusion complexes in China, mainly focusing on the preparation and characterization of inclusion complexes and their applications in medicine, food and other fields[16].

• Preparation technology: Domestic researchers have used a variety of methods to prepare plant essential oil claths, including saturated aqueous solution method, grinding method, ultrasonic-assisted method and spray drying method. For example, Kong Yiming et al. studied the preparation and evaluation of β-cyclodextrin inclusion complexes of volatile oils by herb-patchouli. In addition, Wang Qi et al. used hydroxypropyl-β-cyclodextrin to encapsulate the volatile oil of peppermint-nepeta panicle, which significantly improved the stability of the volatile oil.

• Characterization techniques: Characterize the structure and properties of clathrates by infrared spectroscopy (FT-IR), nuclear magnetic resonance (NMR), differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA).

• Applied research: In the pharmaceutical field, inclusion complexes are used to improve the bioavailability and stability of essential oils[17]. For example, it has been found that the use of cyclodextrin inclusion technology can significantly improve the stability of volatile oils in traditional Chinese medicine. In the food sector, inclusion complexes are used to improve the flavour and preservation of foods.

4.2 Research progress abroad

Important achievements have also been made in the research of plant essential oil inclusion complexes abroad, especially in the in-depth research on the development and application mechanism of new inclusion materials[23].

• New Inclusion Materials: Foreign researchers have explored a variety of modified cyclodextrins as inclusion materials. For example, Kegang Wu et al. studied the effect of β-cyclodextrin with different substituents on the anti-biofilm properties of cinnamon essential oil complexes, and found that maltosyl-β-cyclodextrin is the best wall material to maintain the anti-biofilm activity of cinnamon essential oil[21].

• Application mechanism research: Foreign research not only focuses on the preparation and characterization of inclusion complexes, but also deeply explores their application mechanisms in different fields. For example, molecular docking techniques revealed the reasons for the decline of anti-biofilm effect after inclusion and provided quantitative structure-activity relationship analysis.

• Multi-field applications: In the pharmaceutical field, essential oil complexes are used to develop new antimicrobial and anti-inflammatory drugs[22]. In the food sector, inclusion complexes are used in the development of food additives with sustained-release functions[23].

In short, significant progress has been made in the research of plant essential oil inclusion complexes at home and abroad, but there are some differences in research focus and application direction[24]. Domestic research focuses more on the exploration of preparation technology and application effects, while foreign research focuses more on the in-depth analysis of the development and application mechanism of new materials[25]. In the future, with the deepening of research, plant essential oil complexes are expected to play an important role in more fields, especially in improving drug stability and developing new functional foods[26].

Results and Prospects

The research and application of cyclodextrin inclusion complexes of plant essential oils is of great scientific and practical significance. Through different preparation methods and characterisation techniques, the physicochemical properties and stability of essential oils can be effectively improved, and their application scope can be expanded. In the future, with the deepening of research and technological innovation, plant essential oil cyclodextrin inclusion complexes are expected to play an important role in more fields, especially in improving drug stability and developing new functional foods.

References

[1] JIA W, FANG E, WU Y, et al. Speciation Analysis of Phytosterols in Camellia Seed Oil and Their Dynamic Changes during Refining and Storage [J]. Shipin Kexue/Food Science, 2021, 42(16): 39-45.

[2] BU X, GAO J, NI C, et al. Mechanism of β-cyclodextrin / kerosene Pickering lotion for improving the flotation effect of Aphanitic Graphite [J]. Meitan Xuebao/Journal of the China Coal Society, 2023, 48: 288-95.

[3] CAI J, ZEN W, LI Q, et al. DFT Studies on Electronic Spectrum and Second-order Nonlinear Optical Properties of 8-Quinolinolate Metal Complexes [J]. Acta Chimica Sinica, 2009, 67(20): 2301-8.

[4] CAI J, ZEN W, LI Q, et al. Effect of substituting groups on electronic spectra and second-order nonlinear optical properties of 8-hydroxyquinolinate metal complexes [J]. Acta Physica Sinica, 2009, 58(8): 5259-65.

[5] DU Y, WANG Y, XUE W, et al. Research Progress on Essential Oils from Lauraceae Plants [J]. Shipin Kexue/Food Science, 2023, 44(13): 346-59.

[6] GAO Y, JIN F, ZHU L, et al. Antimicrobial Mechanism of Plant Essential Oils and Its Active Ingredients [J]. Journal of Chinese Institute of Food Science and Technology, 2022, 22(1): 376-88.

[7] KAN Y-H, LI Q. Theoretical Investigation on Electronic Spectra of Fullerene Polypyridyl Ruthenium(II) Complexes by Density Functional Theory [J]. Acta Chimica Sinica, 2008, 66(23): 2585-91.

[8] LI R, HUANG H, TONG G, et al. Hygroscopic properties and corrosion behavior of ammonium salt in a crude oil distillation column [J]. Huagong Jinzhan/Chemical Industry and Engineering Progress, 2023, 42(6): 2809-18.

[9] LI X-J, SUN S-L, LIU Y, et al. DFT Studies on Electronic Spectra and Second-order Nonlinear Optical Properties of Schiff Base Ligands Containing Ferrocene and Their Ni(II) Complexes [J]. Chemical Journal of Chinese Universities-Chinese, 2011, 32(1): 155-60.

[10] LONG M, FENG C, LI Y, et al. Preparation, Characterization and in Vitro Release Characteristics of Sustained-Release Chitosan Microcapsules Containing Tea Tree Oil [J]. Shipin Kexue/Food Science, 2019, 40(16): 242-8.

[11] Li Yixing, Li Fenfang, Chen Jiao, et al. Study on the preparation process, microstructure and sustained release characteristics of mustard essential oil-β-cyclodextrin inclusion complex [J]. Journal of Tropical Crops, 2017, 38(12):6. DOI:10.3969/j.issn.1000-2561.2017.12.028.

[12] Guo Shuyan, Bai Yu, Wang Rui, et al. Study on the preparation process of menthol oil β-cyclodextrin inclusion complex and investigation of its powder properties [J]. Journal of Traditional Chinese Medicine, 2010, 21(8):2. DOI:10.3969/j.issn.1008-0805.2010.08.066.

[13] Wang Jinyu, Tong Yan, Ma Zhenshan, Wang Lin, Yan Jiafu. Chinese Journal β of Experimental Pharmaceutics, 2008, 14(1): 23-26.

[14] SHABKHIZ M A, KHALIL PIROUZIFARD M, PIRSA S, et al. Alginate hydrogel beads containing Thymus daenensis essential oils/Glycyrrhizic acid loaded in β-cyclodextrin. Investigation of structural, antioxidant/antimicrobial properties and release assessment[J]. Journal of Molecular Liquids, 2021, 344: 117738.

[15] Wang Wuxing. Study on preparation process and properties of β-cyclodextrin inclusion complex of ginger essential oil[D]. Tianjin University of Science and Technology, 2017.

[16] LIU Chaoqun. Preparation of Angelica sinensis essential oil/β-cyclodextrin inclusion complex and its inhibitory mechanism on Fusarium oxysporum in stored lily bulbs[D]. Gansu University of Traditional Chinese Medicine, 2024.

[17] Yuan Sihang, Jiang Xuefeng. Study on the sustained release performance of rosemary essential oil and β-cyclodextrin inclusion complex [J]. Chemical Reagents, 2024, 46(11): 36-41. DOI: 10.13822/j.cnki.hxsj.2024.0283.

[18] JI M-H, SHU H-M, GUO F-Y, et al. Study on the preparation process of inclusion complex of volatile oil of Dalbergia odorifera-beta-cyclodextrin [J]. Zhong yao cai Journal of Chinese medicinal materials, 2009, 32(1): 114-7.

[19] LI D, XU J, XIA S, et al. Study on preparation of beta-cyclodextrin inclusion volatile oil from Rhizoma Curcumae [J]. Zhong yao cai Journal of Chinese medicinal materials, 2004, 27(11): 866-9.

[20] LI H, CUI X, TONG Y, et al. Study on two preparation methods for beta-CD inclusion compound of four traditional Chinese medicine volatile oils [J]. Zhongguo Zhong yao za zhi China journal of Chinese materia medica, 2012, 37(7): 908-12.

[21] LIU Y, YIN Z-Q, WEI Q, et al. Study on preparation process and stability of beta-cyclodextrin inclusion compound in volatile oil of Cinnamomum longepaniculatum leaves [J]. Zhongguo Zhong yao za zhi China journal of Chinese materia medica, 2013, 38(13):

2105-8.
[22] NIE Q-X, ZHAO X-M, ZANG C, et al. Studies on preparation technology of Flos Magnoliae essential oil-beta-cyclodextrin inclusion complex [J]. Zhongguo Zhong yao za zhi China journal of Chinese materia medica, 2003, 28(6): 507-8.
[23] SI Q, WU D, CAO Q-R, et al. Preparation and evaluation of valerian oil-beta-cyclodextrin inclusion complex [J]. Zhongguo Zhong yao za zhi China journal of Chinese materia medica, 2013, 38(14): 2309-13.
[24] XU P, SONG L-X. Thermal Decomposition Kinetics of Survived β-Cyclodextrin from an Inclusion Complex of β-Cyclodextrin with Clove Oil [J]. Acta Physico-Chimica Sinica, 2008, 24(12): 2214-20.
[25] XUE F, YIN S-Y. Preparation and authentication of beta-cyclodextrin complex of volatile oil from Ledum palustre [J]. Zhong yao cai Journal of Chinese medicinal materials, 2009, 32(12): 1898-902.
[26] ZHANG A-J, ZHU N, YANG A-D. Studies on the preparation technology of beta-cyclodextrin inclusion compound for chuanxiong volatile oil extracted with CO2 supercritical fluid [J]. Zhongguo Zhong yao za zhi China journal of Chinese materia medica, 2004, 29(1): 39-41.
[27] SANTANA N A D, SILVA R C S D, FOURMENTIN S, et al. Synthesis, characterization and cytotoxicity of the Eugenia brejoensis essential oil inclusion complex with β-cyclodextrin[J]. Journal of Drug Delivery Science and Technology, 2020, 60: 101876.