

Preservation potential of banana fruit of two inclusion complexes between cinnamon and lemongrass essential oil with β -cyclodextrin

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ABSTRACT

Banana is a widely cultivated tropical fruit and one of Vietnam's key export agricultural products. However, this fruit is difficult to preserve and is susceptible to anthracnose, a disease caused by fungi. The inclusion complexes (ICs) of cinnamon essential oil and lemongrass essential oil with β -cyclodextrin are safe and well-researched method for fruit preservation due to their anti-fungi properties. In this study, the cinnamon essential oil/ β -cyclodextrin IC (CEO- β -CD) and lemongrass essential oil/ β -cyclodextrin IC (LEO- β -CD) were used to preserve bananas and increase the physicochemical quality of bananas. The results showed that the CEO- β -CD at a dose of 2.5 mg per g of fruit had a better ability to maintain the physicochemical quality of bananas with the lowest weight loss (7.5%) and the highest firmness (3 N). The L* value, a* value, and b* value also demonstrated good quality bananas with few black spots. Moreover, the total soluble solid (TSS) of 6.5°Brix, the highest reducing sugar content of approximately 2.5 mg/g, and the vitamin C content of about 0.37 mg/100 g flesh exhibited that the CEO- β -CD at a reasonable concentration could be a potential preservative for preserving banana.

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1. Introduction

Banana belongs to the genus *Musa* (family Musaceae), it is a commodity with high economic value and is widely grown in most tropical countries (Phillips et al., 2021). This delicious fruit is a good source of energy, vitamins and minerals; moreover, bananas and their products, like banana flour, contain prebiotic fiber and help in weight loss (Geng et al., 2024). Thus, the bananas is one of the most important fruits produced in more than 120 countries globally, with South America, Asia and Africa. The global banana trade has fast expansion in the past few years and is forecasted to grow at 1.8% per year between 2019 and 2028 and reach a new record high of about USD 14.5 billion (FAO, 2023). Banana is widely grown in most of the provinces in Vietnam and is now a potential export item (CL, 2023). However, this fruit has a short shelf life, resulting in a post-harvest loss in both quantity and quality (FAO, 2023).

Fungal diseases are major causes of post-harvest disease, such as anthracnose with crown rot, they may also cause the production of mycotoxins and off-flavour formation and cause losses in banana-exporting countries (Maqbool et al., 2015). To overcome the problem, synthetic fungicides are the primary means of controlling post-harvest diseases, the most commonly used ones being benomyl, imazalil and thiabendazole (Wang et al., 2023). However, strains resistant to these fungicides, as well as their toxicity to human health and harmful effects on the environment, are also major concerns (Silva et al., 2019). Therefore, there is a growing need to develop a non-chemically for control of post-harvest diseases.

Nowadays, essential oils (EOs), which are the volatiles and fragrant compounds secreted by aromatic plants, have gained great acceptance and scientific interest (Turek & Stintzing, 2013).

They can be achieved by steam distillation of buds, flowers, seeds, fruits, leaves, bark, roots and whole plant. EOs and their separated components have often been used for antifungal potential. Moreover, the multi-component of EOs makes fungi more difficult for pathogens to grow resistant (Sivakumar & Bautista-Banos, 2014). The cinnamon essential oil (CEO) and lemongrass essential oil (LEO) demonstrated high fungicidal activity, thus used to defend fruits against pathogenic attacks (Turek & Stintzing, 2013). However, EOs are volatile, have a strong odor, and are sensitive to the effect of external factors such as temperature, light, oxygen, etc. Thus, inclusion complexes (ICs) of EOs were researched widely to replace EO using in preserve fruits (Marques et al., 2019). Especially, two ICs mentioned above (cinnamon essential oil/ β -cyclodextrin IC, CEO- β -CD and lemongrass essential oil/ β -cyclodextrin IC, LEO- β -CD) have proven to preserve mangoes, which could prevent black spots on fruit skin and enhance the physicochemical properties of post-harvest fruits (Phan et al., 2024).

This study aimed to evaluate the effect of CEO- β -CD and LEO- β -CD on the preservation of banana fruits.

2. Materials and Experiments

2.1. Materials

The smain materials in this study were CEO- β -CD and LEO- β -CD ICs, that were prepared based on the method that was reported (Phan et al., 2024). In brief, β -CD (1.0 mmol, 1.13 g) was dissolved in a 100 mL-round bottom flask at 50oC with stirring, then EO (0.3 mL) was added. After stirring for 2 h, the precipitation was filtered and dried by a vacuum dryer. After prepared, their characterization was examined again using Powder X-Ray Diffraction (PXRD) and Fourier transform-infrared spectroscopy

(FT-IR). Purified water was distilled in the laboratory. All other materials and solvents were of analytical grade.

Plant material: Three hands of mature green Cavendish banana (*Musa acuminata* L.) bought from Co.opmart (Danang, Vietnam) were cut into fingers and washed with tap water, then wiped with ethanol for anti-fungi, and then allowed to air-dry.

2.2. Experiments

Experiment design: The uniform bananas in color, shape, and weight were randomly divided into 20 boxes with dimensions of $20 \times 15 \times 10$ cm³ (three fruits for each box) for five groups, including CEO- β -CD 0.25 mg per gram (CEO- β -CD 2.5), CEO- β -CD 1.0 mg per gram (CEO- β -CD 10), LEO- β -CD 0.25 mg per gram (LEO- β -CD 2.5), LEO- β -CD 1.0 mg per g of fruit (LEO- β -CD 10), and control for comparison. Therefore, inside the treatment boxes, a 5 or 20 g sachet of ICs was hung far from the fruits. Four boxes of the control group did not include the sachet. The fruit storage took place at room temperature. Fruit phyco-chemical quality analysis was conducted on the bananas from each treatment on days 2, 4, 6, and 8 of the storage periods.

Determination of physical quality:

Peel color: To assess the peel color of the bananas, a colorimeter (model CS-210; CHN SPEC, China) was used. The colorimeter recorded values for L* (for perceptual lightness), a* and b* (for the four colors: green, red, blue, and yellow). Each banana was measured in triplicate at three different positions on the fruit (Phan et al., 2024).

Weight loss: The weights of the banana fruits were recorded on each day of analysis using a digital balance (DIGI-DS, Japan). The

weight loss was determined by calculating the percentage loss in relation to the original weight (Ngo et al., 2021).

Firmness: Firmness of the bananas was measured using a fruit hardness test (FR-5120, Lutron, Taiwan). A 6 mm cylindrical probe was pressed into the fruit to a depth of 8 mm. Each banana was measured at three different points on the fruit, and the results were expressed in Newtons (N) (Fekiya et al., 2015).

Determination of chemical quality:

Total soluble solid (TSS): TSS of fruits was measured using a refractometer Atago Master-500 (Atago Co., Ltd., Japan) at room temperature. About 1 mL of extract of the banana flesh was dropped into the meter, after that the result was determined and expressed as % dry matter (Ngo et al., 2021).

Reducing sugars: 10 g of sample was milled with water and diluted to 100 mL, then filtered, and reducing sugar was evaluated using the Luff-Schoorl method. The results were expressed as g glucose equivalent per 100 g fresh weight (Phillips et al., 2021).

Vitamin C content (Ascorbic acid): Vitamin C content was determined by redox titration using I₂ 0.01 N solution. 2 g flesh was milled with 10 mL of HCl 2%, and diluted to 50 mL with HCl 2% solution, then filtered, and titrated with I₂ 0.01 N solution (Phillips et al., 2016).

Statistical Analysis: All data were analyzed by one-way ANOVA. Results are presented as mean $\pm$ SD. Statistical analysis was carried out by using GraphPad Prism 6 software (Version 6.0, GraphPad Software, USA).

3. Results and Discussion

3.1. Physical quality of the banana fruit

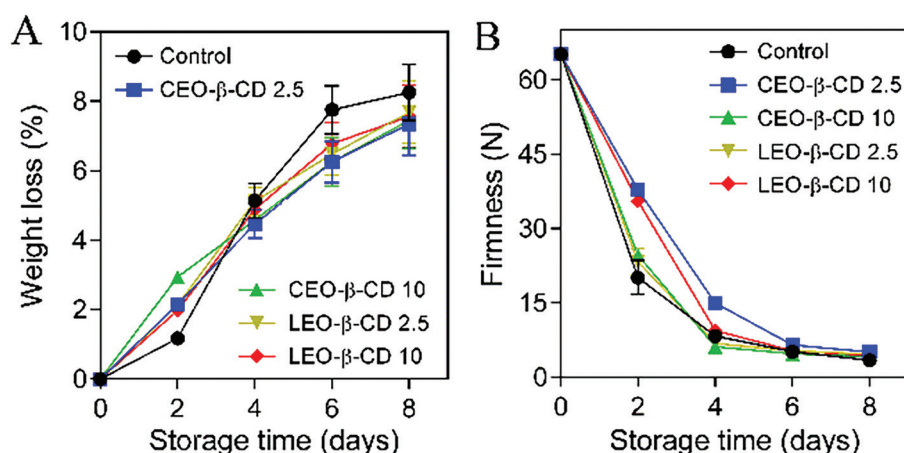


Figure 1. The weight loss and the firmness of the bananas during storage time. CEO-β-CD: Cinnamon essential oil/β-cyclodextrin IC. LEO-β-CD: Lemongrass essential oil/β-cyclodextrin IC.

The weight loss of the banana fruits steadily increased in all treatments during storage, as shown in Figure 1A. The patterns of the curves did not depend on the treatment, indicating that the weight loss of the banana fruits was mostly due to the natural ripening process. By day 6, the average weight loss reached 6.5% of the initial weight, which falls into the category of medium moisture loss according to McGregor's classification (McGregor, 1987). On day 8, the weight loss of the bananas of the control group was over 8%, while the others were about 7.5%. During ripening, the storage temperature influenced the movement of water molecules from the pulp to the peel, and volatile compounds like ethylene and carbon dioxide were released, leading to water molecule evaporation from the peel (Opara et al., 2013). However, as observed in Figure 1A, on days 6 and 8, differences between the five groups were evident. The control group had a higher weight loss than the treated groups, and among the treated groups, the CEO-β-CD 2.5 group exhibited the lowest weight loss compared to the others. The fruits of the control group were spoiled by day 6, which may be caused by fungi.

The bananas of the treatment groups might have an anti-fungal effect from ICs and thus showed a lower spoil level and a lower weight loss compared to those of the control group.

The firmness of the banana fruits significantly decreased starting from two days of storage (Figure 1B). The ICs used did not have a noticeable effect on the firmness of the fruits. After two days of storage, the firmness declined by approximately 40% for the CEO-β-CD 2.5 and LEO-β-CD 10 groups (from about 65 to about 40 N), and by 60% for the other groups. Subsequently, the firmness of the fruits steadily decreased in all five groups throughout the storage period. On day 8, the firmness of the CEO-β-CD 2.5 group (about 3 N) was higher than the other groups. The observed results could be attributed to changes in the levels of certain substances in the banana flesh, such as starch, pectin, or polysaccharides. These changes likely resulted in the reduced firmness of the fruits over time (Opara et al., 2013). The trend of the curves could be found in many researches (Maduwanthi & Marapana, 2021; Mukherjee et al., 2023).

Figure 2 demonstrates the change in peel color of bananas during treatment with ICs. In the initial stage, the L^* values of the fruit peel in all five groups showed insignificant different, and by the end of the storage period, these values decreased (Figure 2B). The L^* values started at almost 57, and ended at 42 of the CEO- β -CD 2.5 group and about 33 for others. This decrease can be attributed to the appearance and spread of brown rots on the peel, as shown in Figure 2A. Interestingly, only the L^* values of the CEO- β -CD 2.5 group exhibited a slow decline after day 6, resulting in the highest L^* value on day 8 compared to the other groups (Figure 2B). The color parameters a^* and b^* , which represent the color of the peel, are depicted in Figures

2C & 2D. Generally, the peel color transitioned from green to yellow during the storage period due to chlorophyll degradation and carotenoid synthesis as the fruit ripened (Ngo et al., 2021). The changes in the a^* values indicate that the ICs had an unnoticeable effect on the ripening process of the bananas with the different increase trends in the five groups. The b^* values of the fruits in the control group increased slowly on day 8, while those in the treated groups exhibited significant increases throughout the storage period. This resulted in the fruits retaining a yellow peel with minimal brown rot. The peel color parameters indicate that the CEO- β -CD 2.5 treatment was most effective in preserving the post-harvest bananas.

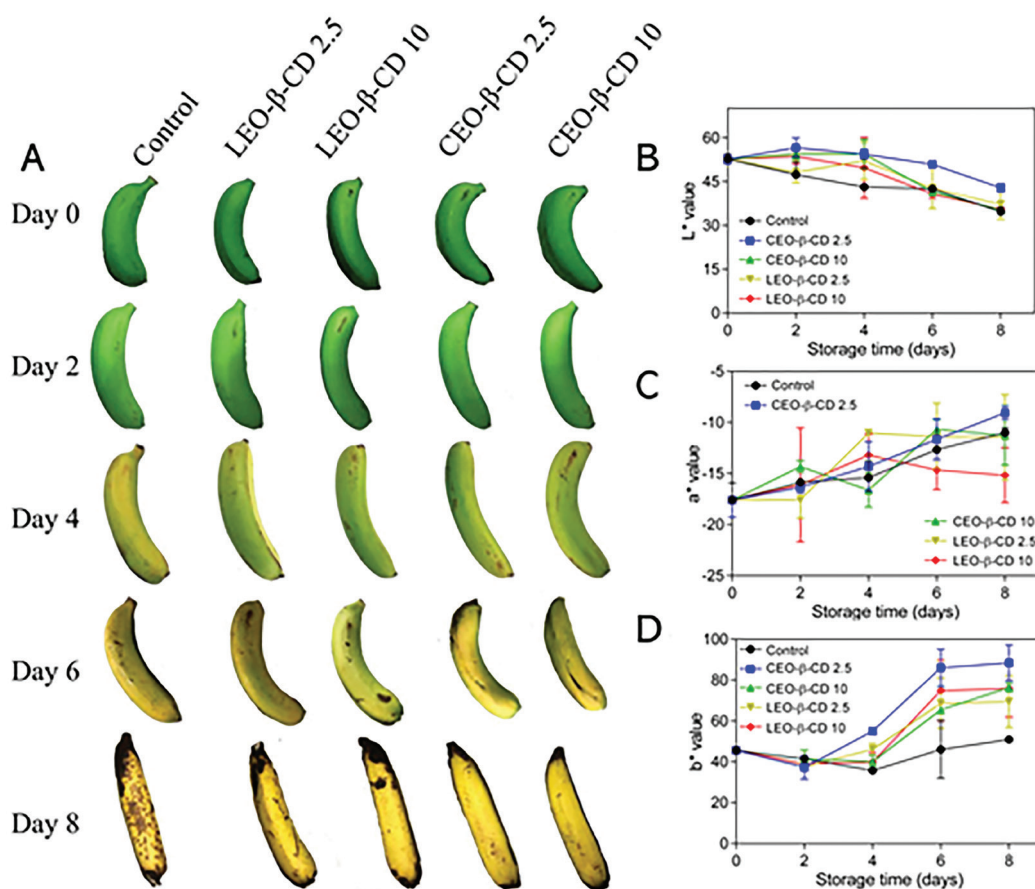


Figure 2. The peel color of the banana fruits during storage time A. Images of bananas, B. L^* value, C. a^* value, and D. b^* value, CEO- β -CD. Cinnamon essential oil/ β -cyclodextrin IC, LEO- β -CD. Lemongrass essential oil/ β -cyclodextrin IC.

Based on the data on peel color, it is evident that the ICs used in storing bananas were more effective in preservation than the control group. This can be attributed to the release of essential oils (EOs) from the ICs during storage, which has been shown to prevent the development of the *Colletotrichum musae* fungus that causes anthracnose disease (Phan et al., 2024). Additionally, CEO has been found to have a higher efficacy in controlling the *Colletotrichum musae* fungus compared to LEO (Fekiya et al., 2015; Suhaizan et al., 2018); thus, the CEO- β -CD IC showed a better preservation ability than the LEO- β -CD IC. However, it is worth noting that CEO has warm properties (Liaqat et al., 2023); thus a higher concentration (10 mg/g) may lead to a higher temperature within the container. This, in turn, could accelerate the ripening and rotting of the fruits in the CEO- β -CD 10 group. Therefore, these results demonstrated that the CEO- β -CD at dose of 2.5 mg/g of fruit had the best preservation ability on bananas.

3.2. Chemical quality of banana fruit

The total soluble solid (TSS) content of banana fruits increased during the ripening process, as shown in Figure 3A. Specifically, the TSS of the control group started at 5.4°Brix, then increased to 6°Brix on day 2, and further rose to 7°Brix by day 8. However, this increase was slower compared to the CEO- β -CD 10 and LEO- β -CD 2.5 groups. The TSS values for the CEO- β -CD 2.5 group were

5.5 and 6.5 on days 2 and 8, respectively. Similarly, the TSS of the fruits in the LEO- β -CD 10 group showed a slower improvement compared to the control group. These were a common trend of TSS during the ripening progress of bananas (Maduwanthi & Marapana, 2021). Moreover, the volatility of EOs from the ICs over time might lead to a higher temperature in the container compared to the control container, thus, the ripening was faster, and there was a quicker increase of TSS of the bananas of the control group.

The reducing sugar content of the fruits in all five groups exhibited similar values for the first six days of storage (Figure 3B). However, on day 8, differences were observed. The reducing sugar content decreased in the control group, while it increased in the treatment groups. The results showed that the reducing sugar of the bananas in five groups had a similar trend with other types of bananas at the stages of maturity (Daniali et al., 2013). Furthermore, on day 6, the bananas of the control group were spoiled, leading to a lower reducing sugar content. Among the four treatment groups, the CEO- β -CD 2.5 group showed the highest reducing sugar content of approximate 2.5 mg/g after 8 days of storage. During ripening, starch is converted into sugars, leading to a softer texture and a sweeter taste associated with ripe bananas. The observed changes in the TSS and reducing sugar content of the banana fruits reflect the ripening process and its impact on the texture and taste of the fruits (Phillips et al., 2021).

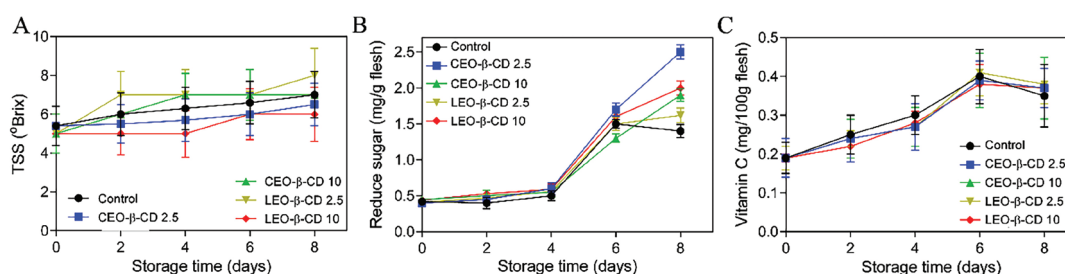


Figure 3. The TSS (A), reducing sugars (B) and vitamin C content (C) of the bananas during storage time. CEO- β -CD: Cinnamon essential oil/ β -cyclodextrin IC. LEO- β -CD: Lemongrass essential oil/ β -cyclodextrin IC.

Figure 3C demonstrates the impact of the ripening process on the vitamin C content in the fruits. Initially, the vitamin C content of the fruits in all five groups increased, followed by a significant decrease. Among the five groups, the control group exhibited the fastest decrease in vitamin C content. At the beginning, the vitamin C content of the banana fruit was 0.19 mg/100 g of fruit flesh. By day 6, this value increased to approximately 0.40 mg/100 g of flesh. By the end of the storage period, the vitamin C content in 100 g of flesh for the four treatment groups was around 0.37 mg. These results align with the natural degradation of vitamin C in fruits over time (Phillips et al., 2016).

The observed changes in the chemical parameters of bananas can be attributed to the ripening and eventual rotting of the fruit after 8 days of storage. In the control group, the fruits began to rot after six days, leading to a decrease in the reducing sugars and vitamin C content. Moreover, the ICs gradually released EOs over time, which helped prevent disease caused by fungi. This resulted in a slower increase in levels of TSS, higher reducing sugars, and a higher vitamin C content in the treatment groups, particularly the CEO- β -CD 2.5 group. The presence of EOs from the ICs likely contributed to the preservation of the fruit and the maintenance of its chemical parameters during storage.

4. Conclusions

In conclusion, both CEO- β -CD and LEO- β -CD ICs demonstrated the ability to enhance the quality and preservation of bananas. However, the CEO- β -CD IC showed significant improvements in preserving bananas, particularly at a dose of 2.5 mg/g. This was evident through a reduction in brown rot, increased firmness, minimal changes in peel color, higher total soluble solids, higher reducing sugar content, and higher vitamin C content compared to the other treatments. Based

on these findings, the CEO- β -CD IC at a dose of 2.5 mg per 1 g of fruit appears to be an effective preservative for post-harvest bananas.

Conflict of interest

The authors declare no conflict of interest.

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