Journal of
Food and Pharmaceutical Sciences

Original Article

Bitter Taste Masking of Sour Lime (*Citrus aurantiifolia*) Peel Extract using B-Cyclodextrin Complex

Yesi Desmiaty[1]*, Ni Made Dwi Sandhiutami[3], Elvira Engita[1,2], Levina Diva Irtan[1,2], Siti Umrah Noor[2]

[1]Department of Biological Pharmacy, Faculty of Pharmacy, Universitas Pancasila, Jakarta, 12630, Indonesia
[2]Department of Pharmaceutical, Faculty of Pharmacy, Universitas Pancasila, Jakarta, 12630, Indonesia
[3]Department of Pharmacology, Faculty of Pharmacy, Universitas Pancasila, Jakarta, 12630, Indonesia
*Corresponding author: Yesi Desmiaty | Email: yesi.desmiaty@univpancasila.ac.id

Received: 6 May 2025; Revised: 23 July 2025; Accepted: 23 July 2025; Published: 30 September 2025

Abstract: Sour lime (*Citrus aurantifolia*) is widely used in Indonesia for beverages and herbal remedies, but the bitterness of its peel limits its application in nutraceuticals. This study aimed to mask the bitter taste of sour lime peel (SLP) extract using β-cyclodextrin (β-CD) to form inclusion complexes. SLP was extracted with 70% ethanol via ultrasonication, then combined with β-CD at different ratios: Ci1 (0.5:2), Ci2 (0.75:2), and Ci3 (1:2), and freeze-dried. The resulting complexes were evaluated for antioxidant activity (DPPH assay) and physicochemical characteristics (bitterness value, FT-IR, SEM, XRD, and DSC). XRD and SEM analyses confirmed all inclusion complexes' amorphous and irregular structures, indicating successful encapsulation. Ci1 and Ci2 showed no detectable bitterness, while Ci3 and the crude extract exhibited bitterness values of 5 and 9 units/g, respectively. FT-IR showed the absence of ester group peaks in Ci1, and DSC indicated a shift in the endothermic peak, supporting complex formation. Among the formulations, Ci2 demonstrated the best performance in masking bitterness while retaining antioxidant activity with IC_{50} 61±1.77 µg/mL. These results suggest that β-CD inclusion complexes, particularly Ci2, effectively improve the palatability of SLP extract and are suitable for further development in functional beverages and nutraceutical products.

Keywords: bitterness reduction; *Citrus aurantifolia* peel, complex inclusion; sour lime by-product; sour lime fruit

1. INTRODUCTION

In citrus processing, the fruit peel is an agroindustrial by-product contributing 40 - 50% of the total fruit weight. Citrus peels are rich in compounds, including volatile oils and flavonoids, compared to the fruit's flesh [1], [2]. The most important essential oil compounds of sour lime (*Citrus x aurantifolia* (Christm.) Swingle) fruit peel are monoterpenes such as limonene, γ-terpinene, β-mirsen, α-pinene, β-pinene, and some sesquiterpenes such as β-bisabolen [3]. Meanwhile, the flavonoids in the sour lime fruit peel are naringin, myristin, quercetin, rutin, tangerine, and hesperidin [3], [4], [5]. Flavonoids have health advantages as antioxidants, maintain cell structure, increase the effectiveness of vitamin C, anti-inflammatory, prevent bone loss, and as an antibiotic, anti-microbial, and anti-cancer. Flavonoids, as antioxidants, block free radicals from attacking other atoms. If free radicals formation and invasion cannot be controlled, they can cause cell damage. It will lead to severe complications in some diseases and produce harmful compounds [6], [7], [8].

Sour lime fruit peel has many advantages that can be added to herbal preparations, nutraceutical beverages, or food supplements so that people can receive the benefits. Sour lime fruit peel has been used to aid digestion and improve respiratory conditions. This peel affects digestion-related symptoms such as reducing food retention, intestinal gas, reducing flatulence, and supporting kidney and liver function. It can also treat ailments characterized by tightness and fullness in the chest and mid-upper abdomen and symptoms such as lack of appetite, vomiting, diarrhea, liver diseases, or coughing up excessive phlegm [9], [10], [11], [12]. It is inevitable, however, that sour lime fruit peel has a bitter taste. The bitterness comes from the naringin compound (4',5,7-trihydroxyflavonone-7-rhamnoglycoside), a flavonoid glycoside with strong anti-inflammatory and antioxidant activities [13], [14]. In the same way as naringin, the bitter taste can be derived from heated limonin[15]. To prevent the bitter taste of limonin, avoid the heating process when preparing pharmaceutical preparations.

Improving the flavor of unpleasant-tasting medications is a significant difficulty in drug formulation development. There are several methods for enhancing the flavor of active medicinal substances, including coating application, sweetener or sugar addition, and complexation with cyclodextrins. Cyclodextrins (CD) are cyclic D-glucose oligomers with a hydrophilic outer surface and a less polar interior cavity. These α-D-glucopyranose units, connected by α-(1,4) bonds, form a lipophilic cavity. They can encapsulate or create inclusion complexes of active pharmacological agents, influencing solubility, medication stability, and taste experience [16], [17], [18]. The most prevalent cyclodextrins are α-CD, β-CD, and γ-CD, which contain six, seven, and eight glucose units, respectively (Figure 1). β-CD has an optimal cavity size of about 6-6.5 Å, suitable for encapsulating intermediate-size molecules such as flavonoids, essential oils, or phenolic compounds. The other study demonstrated that β-CD exhibits the most effective solubilization of flavonoids. In addition, β-CD is the most commonly used type because it is cheaper and readily available than α- or γ-CD [19], [20], [21], [22].

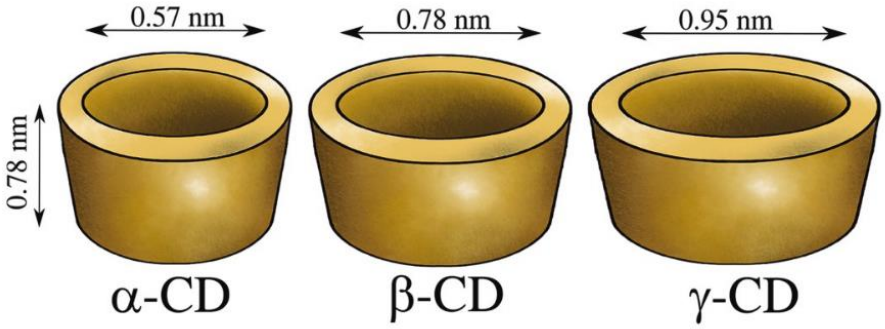

Figure 1. Illustrasion of α-CD, β-CD and γ-CD [23]

Several studies have shown that the bitter taste-causing compounds in orange peel, which are naringin and limonin, can be appropriately encapsulated by β-CD and mask the bitter taste of sour lime peel (SLP) extract [20], [24], [25]. Therefore, we optimized the formulation with the optimal ratio of extract and β-CD in this research. The parameters were antioxidant activity and physicochemical characterization to observe the bitter compounds' effectiveness in β-CD. Antioxidant activity was measured in this study as one of the defined parameters and was related to the biological activity and product quality. Our findings indicate that these inclusion complexes successfully mitigate the bitterness, making lime peel extract a more palatable ingredient for food and beverage applications.

2. MATERIALS AND METHODS

2.1. Materials and Instruments

The fruit of sour lime (*Citrus aurantiifolia* (Christm.) Swingle) was purchased from Cibinong Fresh Market, Bogor, Indonesia. Fruits were determined at the Department of Biology, University of Indonesia. β-cyclodextrin (Mengzhou Huaxing Biochemistry Co. Ltd, China), DPPH/ (2,2-diphenyl-1-picrylhydrazyl) and quinine Hidroklorida (Sigma Aldrich, US), DMSO and Vitamin C (Merck, Germany). Instrument: Freeze Dryer (Coolsafe, Labogene), Scanning Electron Microscope (SEM, SU3500), FT-IR (Shimadzu IRSpirit), X-Ray diffractometer Bruker D8 Advance, and Differential Scanning Calorimetry (Perkin Elmer, DSC 4000).

2.2. *Preparation of SLP extract inclusion complex using β-cyclodextrin*

Sour lime fruits were washed and peeled. The sour lime fruit peel (SLP) was cut into small pieces, dried, and powdered, then extracted with 70% ethanol using ultrasonication (45 min; temperature 30°C; and frequency 40 kHz). The extract was then concentrated with a vacuum rotavapor to obtain SLP extract. Inclusion complexes of SLP extract and β-CD were prepared in the ratio of Ci1 (0.5:2), Ci2 (0.75:2), and Ci3 (1:2). This ratio formulation is based on previous preliminary trials. The mixture was diluted in 2.5 L of water and stirred with a magnetic stirrer for 2 hours. The solution was frozen for one night and lyophilized in a freeze dryer for 72 hours at 47°C, 1 atm, then ground to obtain dry powder [26].

2.3. Antioxidant activity determination

The DPPH antioxidant test procedure aims to assess the ability of the sample to scavenge 0.4 mM DPPH free radicals in methanol, added to a series of SLP extract solution and inclusion complex/Ci1, Ci2, and Ci3 (50-1600 μg/mL). The solution was incubated for 30 minutes before the absorbance was measured at a wavelength of 515 nm. Vitamin C (2.5-12.5 μg/mL) was used as a standard. Free radical scavenging activity was presented as percentage inhibition, and IC_{50} values were calculated by plotting the sample concentration and % inhibition values on a linear graph [27].

2.4. Characterization of SLP-β-CD complex inclusion

Physicochemical characterization tests were conducted on β-CD-SLP complex inclusion (Ci1, Ci2, and Ci3) , and the data were compared with SLP extract and β-CD.

2.4.1. An organoleptic test

This determination was conducted on the shape, color, odor, and taste of SLP extract and β-CD-SLP complex inclusion (Ci1, Ci2, and Ci3).

2.4.2. Bitterness Value of SLP- β-CD complex inclusion

A standard quinine HCl solution is prepared by dissolving 0.1 g in 100 mL of drinking water, then diluted to obtain a 0.01 mg/mL solution (SQ). A sample solution is made by dissolving 20 g of extract in 100 mL of drinking water and further diluting to a 2 mg/mL stock. Serial dilutions are prepared for both (Table 1). The subject rinses their mouth and then tastes 10 mL of the most diluted test solution for 30 seconds. If no bitterness is detected, they expel the solution, rinse it, and wait 10 minutes before trying the next concentration. The lowest concentration that causes a bitter sensation is recorded as the

bitterness threshold. Bitterness value is calculated as:

$$\text{Bitterness value} = \frac{(2000 \times c)}{(a \times b)}$$

Where a = concentration of sample stock solution (mg/mL); b = volume of the stock sample solution that causes bitterness (mL); c = amount of quinine-HCl that causes bitterness (mg) [28].

Table 1. Serial dilution of Quinine HCl and Extract Stock Solution

Tube number	1	2	3	4	5	6	7	8	9	10
S_Q (mL)	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	-
Safe drinking water (mL)	5.8	5.6	5.4	5.2	5.0	4.8	4.6	4.4	4.2	-
Amount of Quinine-HCl in 10 mL solution (=c) (mg)	0.042	0.044	0.046	0.048	0.050	0.052	0.054	0.056	0.058	-
S_T (mL)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Safe drinking water (mL)	9.00	8.00	7.00	6.00	5.00	4.00	3.00	2.00	1.00	-

2.4.3. FT-IR spectrophotometry

A sample of ± 10 mg was mixed with potassium bromide and then put into a cell holder. Subsequently, an infrared spectrophotometer was measured and each sample's compound functional groups were analyzed.

2.4.4. Scanning Electron Microscope (SEM)

The morphology of nanoparticles was observed by Scanning Electron Microscopy (SEM SU3500) with 20 kV tension and 300 V collector bias. The sample was placed on a brass piece (stub). Photographs were taken at 20 kV electron voltage with desired magnification.

2.4.5. Differential Scanning Calorimetry (DSC)

Samples were weighed ±5 mg, placed in an aluminum cell, and then placed in the sample pan in the DSC. The sample was heated at 10°C per minute until it reached 350°C. The melting point shift of the compound was observed.

2.4.6. X-ray Diffraction Examination

The sample diffractogram was obtained using an X-ray diffractometer with a Cu metal X-ray radiation source, Kα filter, 40kV, and 20mA generator. Measurement analysis in the range of theta 5-50^o. Analyzed the diffraction pattern of the sample to obtain the number of crystalline and amorphous phases of the sample.

3. RESULTS AND DISCUSSION

Nowadays, CDs are well-known in processing beverages, foods, and medicinal formulation development communities for their propensity to complex hydrophobic molecules. The ability of CDs to form inclusion complexes with a vast number of compounds leads to improvements such as reducing and even masking bitterness, unpleasant flavors, and tastes, increasing the solubility of hydrophobic active substances, improving drug bioavailability, stabilizing volatile compounds, maintaining physical and chemical stability, increasing shelf life, protecting compounds from heat

treatment, restrict contact between the drug and body tissues to help reduce local irritation or toxicity of certain compound, allow for controlled release of active substances, etc. All these complex advantages make it important in the pharmaceutical, food, and beverage industries [16], [23], [29].

The formation of these encapsulated complexes is mainly affected by the hydrophobic properties of the phytochemical or drug compound interacting with the inside of the CD cavity. The shape and size of the drug compound also influence the interaction. The basic requirement for the formation of an inclusion complex is that the guest compound molecule must fit precisely or partially into the CD cavity [23], [24]. Some published studies show that flavonoids, such as quercetin, rutin, naringin, naringenin, etc., have been demonstrated to be incorporated in these CD cavities [24]. Furthermore, the formation of inclusion complexes of compounds in extracts such as flavonoids with cyclodextrin has also become one of the valuable methods to improve water solubility and antioxidant activity [19], [20], [30], [31]. Freeze-drying was used in this research to produce the inclusion of complex dry powder to avoid the formation of bitter taste due to limonin which is easily damaged by heating.

The selected *C. aurantiifolia* fruit is round to oval in shape, 2.5–5 cm in diameter, smooth-skinned without bumps, green in color, and sour in taste. The sour lime peel (SLP) extract yielded 15.45% as a thick yellowish-brown liquid with a characteristic odor and bitter taste. Among the three β-cyclodextrin inclusion complex formulations (Ci1, Ci2, Ci3), the color deepened with increasing extract concentration, while appearance and odor remained similar. Bitterness tests revealed that Ci1 and Ci2 successfully masked the bitter taste, whereas Ci3 retained some bitterness, though reduced compared to the pure extract (Table 2). This suggests that β-cyclodextrin effectively encapsulated bitter compounds like naringin and limonin, preventing their interaction with taste receptors. Bitterness evaluation followed WHO guidelines [28], using a comparative method against quinine HCl standards, scored on a scale (0–8). Ci1 and Ci2 achieved complete bitterness masking, confirmed through total bitterness calculations, and were selected for further physicochemical characterization.

Table 2. Characteristic examination of sour lime peel (SLP) extract and the inclusion complexes

Evaluation	**SLP Extract**	**Complex inclusion formula**		
		Ci1	**Ci2**	**Ci3**
SLP extract: β-CD		**0.5:2**	**0.75:2**	**1:2**
Appearance	Thick	powder	powder	powder
Odor	citrus odor	citrus odor	citrus odor	citrus odor
Color	Brown	White yellowish +	Light Yellow ++	Yellow +++
Taste	Bitter	Sweet	Slight sweet	Slight bitter
Bitterness Value (unit/g)	9 ± 0.9428	nd	nd	5 ± 0.17

nd = no bitter taste detected

According to the antioxidant activity analysis with DPPH, the results of ANOVA analysis followed by Tukey's multiple comparisons test show that there are significant differences in the mean between groups. All extracts significant to Vitamin C. Ci1 and Ci3 were significantly different ($p<0.05$) compared to SLP extract. Ci2 and Ci3 were significantly different from Ci1. It was also observed that SLP extract (IC_{50} 74.5±2.75 μg/mL) had a lower IC_{50} than Ci1 (IC_{50} 152.9±10.5 μg/mL), but higher than Ci2 (IC_{50} 61±1.77 μg/mL) and Ci3 (IC_{50} 43.7±1.5 μg/mL) (Figure 2). Antioxidant activity increased in line

with the rise in extract concentration. Cyclodextrin has also been reported to be a host that can protect natural antioxidant compounds, such as flavonoids, and can act as a secondary antioxidant [21], [22], [31], [32].

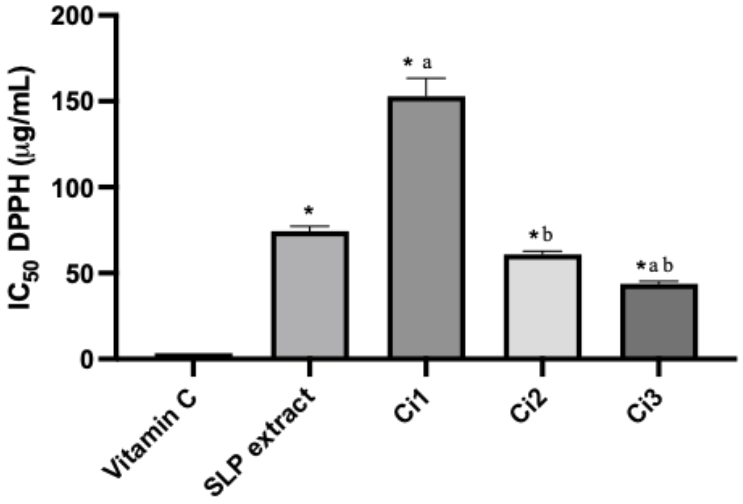

Figure 2. Antioxidant activity test of vitamin C, SLP extract, and inclusion complex

Characterization of the inclusion complex formation using an infrared spectrophotometer can be seen in the infrared spectrum, which is indicated by a shift in the peak of the guest molecular group, where when the inclusion complex is being formed, some of the guest molecular groups will disappear because the host molecule has coated them. Infrared spectrophotometry was used to observe the functional groups in the cyclodextrin and the inclusion of complex powders. Each absorption peak at a specific wave number describes the presence of a particular functional group.

Based on Figure 3 and Table 3, it can be seen that in sour lime peel extract, there was found a peak at 1038.28 cm^{-1} indicating C-O group; 1397.69 cm^{-1} indicating -CH_3 group; 1603.06 cm^{-1} indicating aromatic group, and 3268.85 cm^{-1} indicating -OH. Those peaks are not detected in the β-CD or any inclusion complexes spectra. Meanwhile, the β-cyclodextrin spectrum was found peak at 1021.17 cm^{-1} indicating C-O-C group; 1304.64-1745.68 cm^{-1} indicating C-O group; and 3274.58 cm^{-1} indicating -OH group. The spectra of the three inclusion complexes shown have a similar peak pattern as β-CD. This result suggests that the extract has been successfully encapsulated in β-CD

Table 3. Functional group of FT-IR spectrogram

Wavelength number (cm^{-1})						
	SLP extract	**β-cyclodextrin**	**Ci1**	**Ci2**	**Ci3**	**Functional group [33]**
	-	1021.17	1021.17	1021.17	1021.17	C – O
	1038.28	-	-	-	-	C – O*
	1397.69	-	-	-	-	–CH_3*
	1603.06	-	-	-	-	Aromatic*
	-	1304.64-1745.68	1304.64-1745.68	1304.64-1745.68	1304.64-1745.68	C–O
	-	3274.58	3274.58	3274.58	3280.29	–OH
	3268.88	-	-	-	-	–OH*

*indicates the successful formation of encapsulation in β-CD

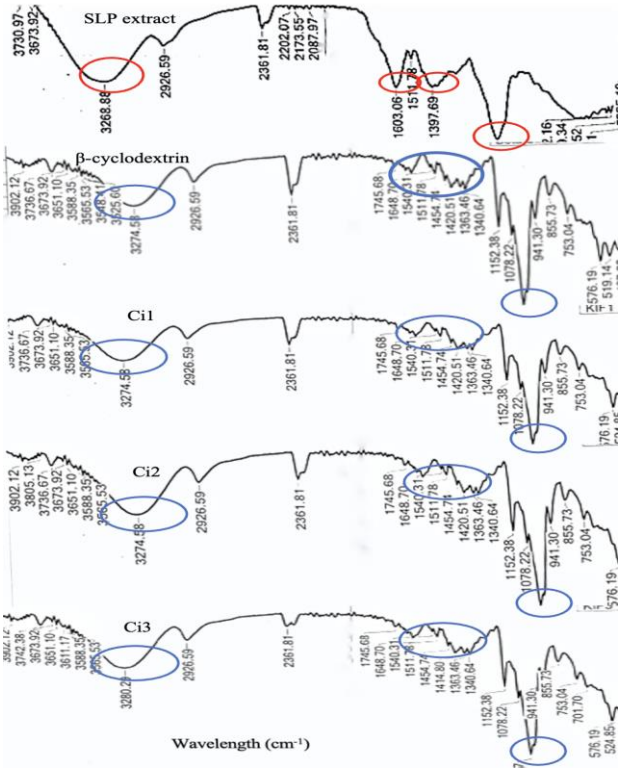

Figure 3. Fourier transform infrared spectroscopy spectra of SLP extract; β-cyclodextrin; Ci1; Ci2; and Ci3.

The SEM morphology of β-CD (Figure 4) is in the form of a crystalline block with a large square shape and a rough surface texture (A), while Ci1 (B) and Ci2 (C) look more amorphous. Figures 4 B and 4C do not show the visible morphology of β-CD, but rather an irregular and uneven shape. This uneven surface is thought to have been an interaction between the SLP extract and β-CD. This suggests that the inclusion complex produces a more amorphous compound as the degree of crystallinity is reduced [34], [35].

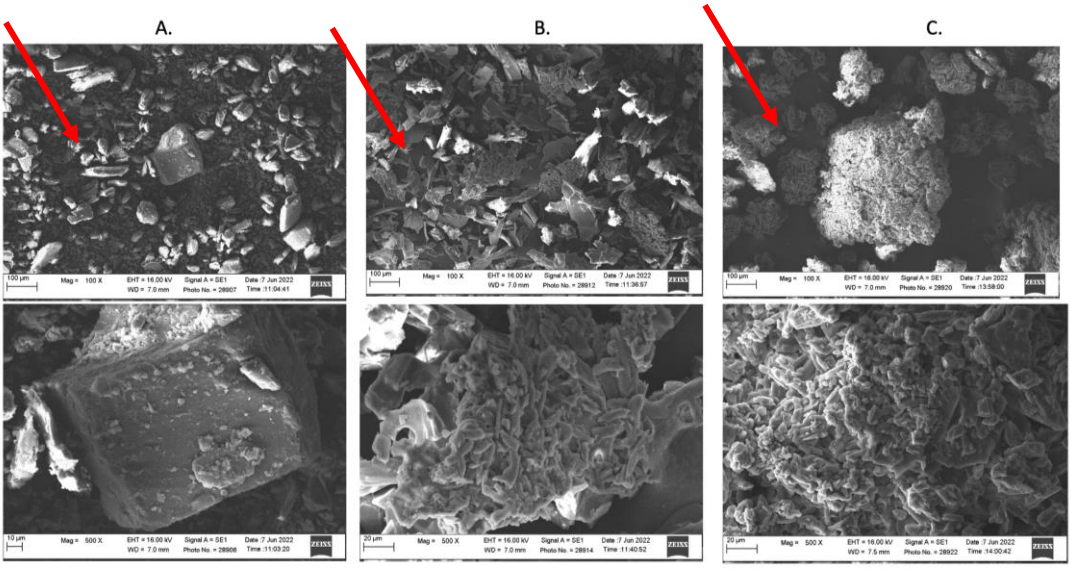

Figure 4. SEM observation (A). β-cyclodextrin magn. 100 and 500x, (B). Ci1 magn. 100 and 500x (C). Ci2 magn. 100 and 500x

DSC is a thermal analysis used to identify the formation of inclusion complexes between active compounds and CDs. The principle of the test is that if guest molecules are embedded in the CD cavity, then generally, the melting point, boiling point, or sublimation point may shift to a different temperature or disappear within the temperature range when the CD decomposes. DSC examinations are performed to characterize the inclusion complex by comparing the thermal behavior of the individual components. It is performed by measuring the peak temperatures that occur when the material absorbs or releases energy or heat when it is heated, cooled, or held at a fixed pressure. Endothermic peaks indicate a melting process, and exothermic peaks indicate a degradation process [36]. Figure 5 shows that β-CD has endothermic peak values of 150.86 and 300.31°C, while Ci1 has endothermic peak values of 156.70 and 330.75°C, and Ci2 has endothermic peak values of 152.48 and 345.17°C. The DSC analysis results show that the endothermic peak of the inclusion complex is shifted when compared to the endothermic peak of β-CD. This provides evidence that the formation of the inclusion complex may cause an abnormality. In accordance with the literature, the shifting of the β-CD endothermic peak could be due to the formation of amorphous solids as a result of the inclusion complex [37], [38], [39].

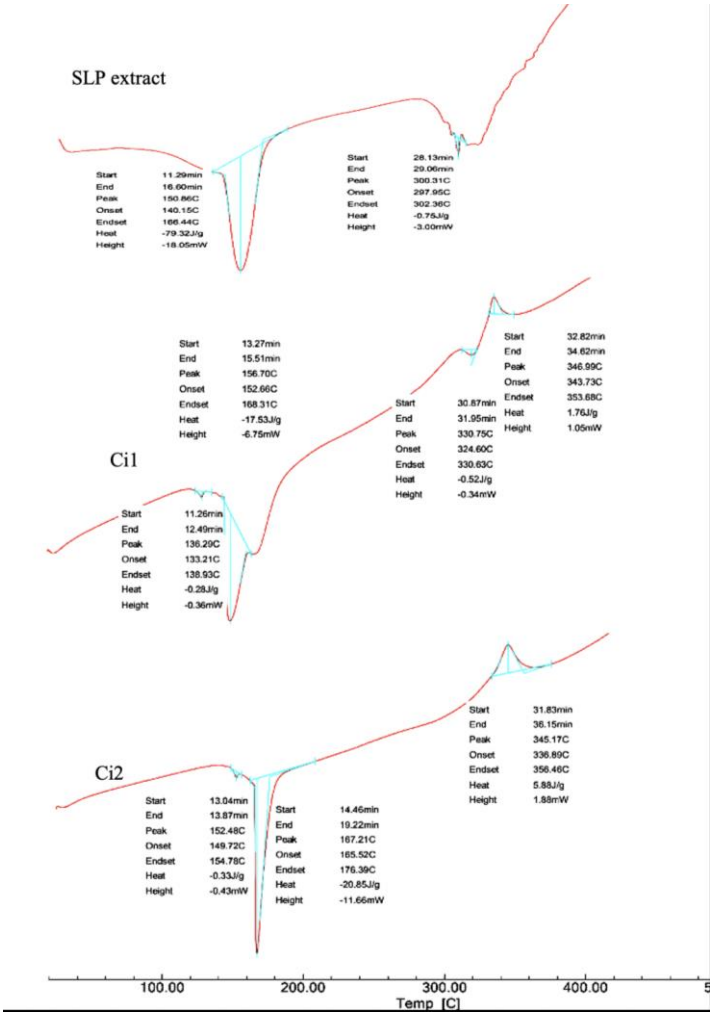

Figure 5. Differential scanning calorimetry thermograms of β-cyclodextrin, Ci1, and Ci2

X-ray diffraction examination is for the degree of change in crystallinity of a single CD and after inclusion complex formed with SLP extract. Each crystalline solid has a unique pattern of X-ray

powder character that can be used as a fingerprint for identification, X-ray crystallography can be used to determine its structure through X-ray diffraction so that it can be known how many crystalline phases are contained in a material. The reduction of crystalline form is evidence of the formation of inclusion complexes [37], [40]. Figure 6 illustrates that β-cyclodextrin had the highest crystallinity (76.2%) with a sharp peak pattern reflecting a highly organized structure, while Ci1 (55.5%) and Ci2 (56.3%) showed lower crystallinity with more scattered diffraction patterns, indicating increased amorphosity (44.5% and 43.7%, respectively). The decrease in crystallinity of Ci1 and Ci2 compared to β-cyclodextrin indicates a change in physical structure and the successful formation of inclusion complexes.

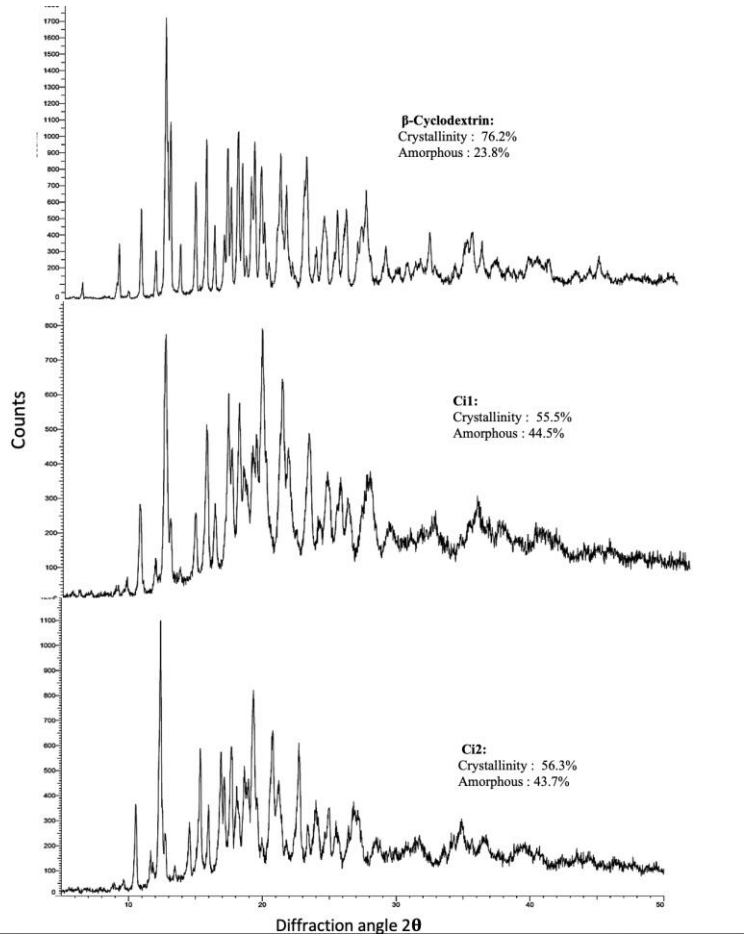

Figure 6. X-ray diffraction patterns of β-cyclodextrin, Ci1, and Ci2

SEM, DSC, and XRD characterization of SLP-β-CD complex inclusion results indicate a higher amorphous form in the inclusion complexes (i.e. in C1 and C2), this is also associated with increased solubility and bioavailability of the active compounds. The optimal ratio of extract and β-cyclodextrin makes an effective inclusion complex that enhances pharmaceutical applicability by masking bitterness and stabilizing bioactive compounds. These findings support the enhancement and utilization of lime peel in nutraceutical and herbal industries.

4. CONCLUSION

Citrus peel extract, rich in flavonoids, polyphenols, and antioxidants, has potential for herbal and beverage applications. Encapsulation with β-cyclodextrin can effectively reduce its bitterness, and

optimizing the extract-to-CD ratio is key to preserving its benefits. Analytical results showed amorphous structures with stable physicochemical properties and improved taste. The Ci2 formulation (0.75:2 ratio) using freeze-drying was most effective in masking bitterness while maintaining antioxidant activity, with IC_{50} 61±1.77 μg/mL making it suitable for nutraceutical and beverage products.

Funding: This research received no external funding

Acknowledgments: The authors and researchers would like to thank all parties involved in the research and to the academic community Faculty of Pharmacy, Universitas Pancasila

Conflicts of interest: The authors declare no conflict of interest

References

[1] [1] N. Liu *et al.*, "A review of chemical constituents and health-promoting effects of citrus peels," *Food Chem*, 365(130585), 2021, doi: 10.1016/j.foodchem.2021.130585.

[2] Y. Desmiaty *et al.*, "Antioxidant and anti-inflammatory activity through inhibition of NF-κB and sEH of some citrus peel and phytoconstituent characteristics," *Saudi Pharmaceutical Journal*, 32(2), 2024, doi: 10.1016/j.jsps.2024.101959.

[3] M. R. Loizzo *et al.*, "Evaluation of Citrus aurantifolia peel and leaves extracts for their chemical composition, antioxidant and anti-cholinesterase activities," *J Sci Food Agric*, 92(15), 2012, doi: https://doi.org/10.1002/jsfa.5708.

[4] A. Bahmanzadagan, H. Tavallali, V. Tavallali, and M. A. Karimi, "Bioactive Compounds of Citrus aurantifolia Wastes by High-Performance Liquid Chromatography Analysis," *Chem Nat Compd*, 59(1), 2023, doi: 10.1007/s10600-023-03942-8.

[5] N. N. Indriyani, J. Al Anshori, N. Permadi, S. Nurjanah, and E. Julaeha, "Bioactive Components and Their Activities from Different Parts of Citrus aurantifolia (Christm.) Swingle for Food Development," *Foods*, 2(10), 2023, doi: 10.3390/foods12102036.

[6] S. Y. Choi *et al.*, "Correlation between flavonoid content and the NO production inhibitory activity of peel extracts from various citrus fruits," *Biol Pharm Bull*, 30(4), 2007, doi: 10.1248/bpb.30.772.

[7] J. Londoño-Londoño *et al.*, "Clean recovery of antioxidant flavonoids from citrus peel: Optimizing an aqueous ultrasound-assisted extraction method," *Food Chem*, 119(1), 2010, doi: 10.1016/j.foodchem.2009.05.075.

[8] N. Koolaji, B. Shammugasamy, A. Schindeler, Q. Dong, F. Dehghani, and P. Valtchev, "Citrus Peel Flavonoids as Potential Cancer Prevention Agents," *Curr Dev Nutr*, 4(5), 2020, doi: https://doi.org/10.1093/cdn/nzaa025.

[9] E. O. Oyinloye *et al.*, "Citrus aurantifolia (Chrism.) Swingle peel extract attenuate nephrotoxicity induced by doxorubicin," *Pharmacological Research - Modern Chinese Medicine*, 11(March), 2024, doi: 10.1016/j.prmcm.2024.100412.

[10] M. Srividhya, K. Ramanathan, and N. Krishnanand, "Efficacy of citrus fruit peel extracts against pathogens causing gastrointestinal disorders," *Int J Pharm Pharm Sci*, 5(4), 2013.

[11] J. Wu, G. Huang, Y. Li, and X. Li, "Flavonoids from Aurantii Fructus Immaturus and Aurantii Fructus: Promising phytomedicines for the treatment of liver diseases," *Chinese Medicine (United Kingdom)*, 15(1), 2020, doi: 10.1186/s13020-020-00371-5.

[12] Y. Desmiaty, F. Xavier, N. M. Dwi Sandhiutami, Y. Noviani, F. Alatas, and R. Agustin, "Unlocking the Potential of Citrus aurantiifolia Bioactive Compounds, Functional Benefits, and Food Applications: A Comprehensive Review," *Food Biosci*, 106259(Feb), 2025, doi: 10.1016/j.fbio.2025.106259.

[13] G. Oshadie De Silva, R. Manawaduge, C. G. Oshadie De Silva, and R. Marapana, "Effect of naringinase enzymatic treatment on the bitter compound naringin in fresh juice of 'Bibila sweet' oranges," *~ 174 ~ Journal of Pharmacognosy and Phytochemistry*, 6(4), 2017.

[14] R. Shukla, V. Pandey, G. P. Vadnere, and S. Lodhi, "Role of Flavonoids in Management of Inflammatory Disorders," in *Bioactive Food as Dietary Interventions for Arthritis and Related Inflammatory Diseases*, Elsevier, 2019. doi: 10.1016/b978-0-12-813820-5.00018-0.

[15] J. Zhang *et al.*, "Effects of postharvest time, heat treatment, pH and filtration on the limonin content in Newhall navel orange (Citrus sinensis Osbeck cv. Newhall) juice," *Molecules*, 23(10), 2018, doi: 10.3390/molecules23102691.

[16] M. Preis, C. Eckert, O. Häusler, and J. Breitkreutz, "A comparative study on solubilizing and taste-masking capacities of hydroxypropyl-β-cyclodextrin and maltodextrins with high amylose content," *Sens Actuators B Chem*, 193(Mar), 2014, doi: 10.1016/j.snb.2013.12.005.

[17] J. Szejtli and L. Szente, "Elimination of bitter, disgusting tastes of drugs and foods by cyclodextrins," Oct. 2005. doi: 10.1016/j.ejpb.2005.05.006.

[18] X.-S. Chen *et al.*, "Debittering of Peanut Protein Hydrolysate Using 2-Butanol in Combination with β-cyclodextrin: Impact on Some Physicochemical Characteristics and Antioxidant Activities," *Food Biophys*, 20(1), 2024, doi: 10.1007/s11483-024-09916-9.

[19] G.-J. You *et al.*, "Comprehensive evaluation of solubilization of flavonoids by various cyclodextrins using high performance liquid chromatography and chemometry," *LWT*, 94, 2018, doi: https://doi.org/10.1016/j.lwt.2018.04.035.

[20] B. dos Santos Lima, S. Shanmugam, J. de Souza Siqueira Quintans, L. J. Quintans-Júnior, and A. A. de Souza Araújo, "Inclusion complex with cyclodextrins enhances the bioavailability of flavonoid compounds: a systematic review," *Phytochemistry Reviews*, 18(5), 2019, doi: 10.1007/s11101-019-09650-y.

[21] S. Alshehri *et al.*, "Host-guest complex of β-cyclodextrin and pluronic F127 with Luteolin: Physicochemical characterization, anti-oxidant activity and molecular modeling studies," *J Drug Deliv Sci Technol*, 55, 2020, doi: https://doi.org/10.1016/j.jddst.2019.101356.

[22] G. Astray, C. Gonzalez-Barreiro, J. C. Mejuto, R. Rial-Otero, and J. Simal-Gándara, "A review on the use of cyclodextrins in foods," *Food Hydrocoll*, 23(7), 2009, doi: https://doi.org/10.1016/j.foodhyd.2009.01.001.

[23] G. Astray, J. C. Mejuto, and J. Simal-Gandara, "Latest developments in the application of cyclodextrin host-guest complexes in beverage technology processes," *Food Hydrocoll*, 106(December), 2020, doi: 10.1016/j.foodhyd.2020.105882.

[24] A. Papaioannou, E. Christoforides, and K. Bethanis, "Inclusion complexes of naringenin in dimethylated and permethylated β-cyclodextrins: Crystal structures and molecular dynamics studies," *Crystals (Basel)*, 10,(1), 2020, doi: 10.3390/CRYST10010010.

[25] L.-J. Yang *et al.*, "Preparation and characterization of inclusion complexes of naringenin with β-cyclodextrin or its derivative," *Carbohydr Polym*, 98(1), 2013, doi: 10].1016/j.carbpol.2013.07.010.

[26] T. Pralhad and K. Rajendrakumar, "Study of freeze-dried quercetin-cyclodextrin binary systems by DSC, FT-IR, X-ray diffraction and SEM analysis," *J Pharm Biomed Anal*, 34(2), 2004, doi: 10.1016/S0731-7085(03)00529-6.

[27] G. Bobo-García, G. Davidov-Pardo, C. Arroqui, P. Vírseda, M. R. Marín-Arroyo, and M. Navarro, "Intra-laboratory validation of microplate methods for total phenolic content and antioxidant activity on polyphenolic extracts, and comparison with conventional spectrophotometric methods," *J Sci Food Agric*, 95(1), 2015, doi: 10.1002/jsfa.6706.

[28] WHO, *Quality control methods for medicinal plant materials*. Geneva, Switzerland: World Health Organization, 1998. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/41986/9241545100.pdf?sequence=1&isAllowed=y

[29] C. T. H. Tran, H.-M. D. Wang, L. T. H. Anh, C. Lin, C.-Y. Huang, and C.-H. Kuo, "Evaluate the effect of β-cyclodextrin on the sensory and physicochemical properties of bitter gourd extract during thermal processing," *Food Chem*, 433, 2024, doi: https://doi.org/10.1016/j.foodchem.2023.137394.

[30] V. Pittol *et al.*, "The challenge of flavonoid/cyclodextrin complexation in a complex matrix of the quercetin, luteolin, and 3- O -methylquercetin," *Pharm Dev Technol*, 27(6), 2022, doi: 10.1080/10837450.2022.2098326.

[31] J. M. López-Nicolás, P. Rodríguez-Bonilla, and F. García-Carmona, "Cyclodextrins and Antioxidants," *Crit Rev Food Sci Nutr*, 54(2), 2014, doi: 10.1080/10408398.2011.582544.

[32] F. da R. Ferreira *et al.*, "Antioxidant activity of the mangiferin inclusion complex with β-cyclodextrin," *LWT - Food Science and Technology*, 51(1), 2013, doi: 10.1016/j.lwt.2012.09.032.

[33] J. Wang, Y. Cao, B. Sun, and C. Wang, "Physicochemical and release characterisation of garlic oil-β-cyclodextrin inclusion complexes," *Food Chem*, 127(4), 2011, doi: 10.1016/j.foodchem.2011.02.036.

[34] L. Frieler, T. M. Ho, A. Anthony, Y. Hidefumi, A. J. E. Yago, and B. R. Bhandari, "Crystallisation properties of amorphous cyclodextrin powders and their complexation with fish oil.," *J Food Sci Technol*, 56(3), 2019, doi: 10.1007/s13197-019-03643-7.

[35] T. M. Ho, T. Howes, and B. R. Bhandari, "Characterization of crystalline and spray-dried amorphous α-cyclodextrin powders," *Powder Technol*, 284, 2015, doi: https://doi.org/10.1016/j.powtec.2015.06.027.

[36] J.-S. Kim, "Study of Flavonoid/Hydroxypropyl-β-Cyclodextrin Inclusion Complexes by UV-Vis, FT-IR, DSC, and X-Ray Diffraction Analysis," *Prev Nutr Food Sci*, 25(4), 2020, doi: 10.3746/pnf.2020.25.4.449.

[37] L. Jiang, J. Yang, Q. Wang, L. Ren, and J. Zhou, "Physicochemical properties of catechin/β-cyclodextrin inclusion complex obtained via co-precipitation," *CYTA - Journal of Food*, 17(1), 2019, doi: 10.1080/19476337.2019.1612948.

[38] L. Cui, Z. H. Zhang, E. Sun, and X. bin Jia, "Effect of β-cyclodextrin complexation on solubility and enzymatic conversion of naringin," *Int J Mol Sci*, 13(11), 2012, doi: 10.3390/ijms131114251.

[39] J. Chen, X. Qin, S. Zhong, S. Chen, W. Su, and Y. Liu, "Characterization of curcumin/cyclodextrin polymer inclusion complex and investigation on its antioxidant and antiproliferative activities," *Molecules*, 23(5), 2018, doi: 10.3390/molecules23051179.

[40] K. Srinivasan and T. Stalin, "Study of inclusion complex between 2,6-dinitrobenzoic acid and β-cyclodextrin by 1H NMR, 2D 1H NMR (ROESY), FT-IR, XRD, SEM and photophysical methods," *Spectrochim Acta A Mol Biomol Spectrosc*, 130(Sep), 2014, doi: 10.1016/j.saa.2014.03.106.