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Phytochemical characterization and bioactivity of *Chamaecrista nomame* (Siebold) H. Ohashi: bridging Korean ethnic food tradition and modern functional science

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Abstract

Chamaecrista nomame (Siebold) H. Ohashi (*C. nomame*) has a long-standing history of consumption in East Asia, particularly in Korea and Japan, as a traditional functional tea. Traditionally, the aerial parts are dried, roasted, and prepared as a hot-water infusion, serving as a conventional daily beverage valued for its health-promoting properties. This study aimed to scientifically evaluate the potential anti-obesity, anti-diabetic, and anti-inflammatory activities of *C. nomame* extracts, bridging its ethnobotanical use with modern functional science. Hot water and 40% ethanol extracts were prepared, and their bioactivities were assessed through pancreatic lipase, α -glucosidase, and nitrite scavenging assays. Although both extracts exhibited bioactivities, the 40% ethanol extract consistently demonstrated significantly higher potency than the hot-water extract across all assays. Notably, within the in vitro enzyme inhibition model, the 40% ethanol extract (200 μ g/mL) exhibited over 90% inhibition of α -glucosidase, demonstrating a substantial inhibitory capacity. The extract also demonstrated substantial lipase inhibitory and nitrite scavenging activities, suggesting its potential role in regulating lipid digestion and inflammatory responses. Molecular docking analysis further supported these findings, revealing that luteolin, a major constituent, possessed favorable binding affinities toward α -glucosidase, lipase, and inducible nitric oxide synthase, with the strongest interaction observed for α -glucosidase (−8.4 kcal/mol). These results provide scientific evidence supporting the traditional use of *C. nomame* as a Korean ethnic food resource and highlight its potential as a natural functional ingredient for the management of metabolic and inflammatory disorders.

Keywords *Chamaecrista nomame* (Siebold) H. Ohashi extract, Phytochemical characteristics, Nitrite scavenging activity, Pancreatic lipase inhibition, α -glucosidase inhibition

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Introduction

Chamaecrista nomame (Siebold) H. Ohashi (*C. nomame*) is an annual herb belonging to the Fabaceae family that is widely distributed in East Asia, including Korea, Japan, and China (Fig. 1). The entire aerial part of the plant is edible and has traditionally been used as a food resource [1, 2]. In Korea, *C. nomame* has been recognized for its ethnobotanical significance and has been designated as a “Traditional Knowledge Target Species” by the National Institute of Biological Resources (NIBR) [3]. Traditional knowledge refers to the collective wisdom, practices, and skills developed by local communities through long-term interactions with nature, including the use of plants for food, medicine, and health maintenance. Reflecting this cultural importance, the Korea Forest Service has also identified *C. nomame* as a promising bio-industrial resource, with potential applications in functional foods, pharmaceuticals, and healthcare products. These recognitions highlight the dual significance of *C. nomame* as both a traditional cultural heritage and a modern functional biomaterial. It has also been traditionally consumed as a substitute tea using the whole aerial parts of the plant [4].

In Japan, the aerial parts of *C. nomame* have traditionally been dried, cut, and lightly roasted, and then decocted to prepare a tea consumed as a substitute for regular tea, particularly in the San-in district, where it is known as “Hama-cha” [5]. This plant is also referred to by various local names such as “Nemu-cha” and

“Mame-cha,” and has been traditionally associated with diuretic, tonic, and laxative effects in folk medicine [6].

In China, the whole plant has long been utilized in folk medicine to treat edema, nephritis, chronic constipation, and respiratory symptoms such as cough and phlegm [7, 8].

Building on this traditional use, recent studies have reported various biological activities of *C. nomame*, including enhanced gastrointestinal motility, diuretic activity, anti-inflammatory effects, protective effects against renal damage, and attenuation of brain damage [9–11]. These activities are believed to be associated with the phytochemical constituents of the plant, particularly phenolic compounds and flavonoids [12]. Luteolin, a flavonoid present in *C. nomame*, is widely recognized for its antioxidant, anti-inflammatory, and metabolic regulatory activities [13–15].

In recent years, the global prevalence of obesity and metabolic disorders has increased markedly [16, 17]. Consequently, there has been growing interest in natural bioactive compounds derived from plant resources as safer alternatives to synthetic pharmaceuticals [18]. However, despite its long-standing traditional use, comprehensive scientific investigations that directly connect its ethnobotanical background with phytochemical composition and functional bioactivities remain limited.

Therefore, the present study aimed to evaluate the phytochemical characteristics and biological activities of *C. nomame* collected from Gangwon-do, Korea. Specifically,

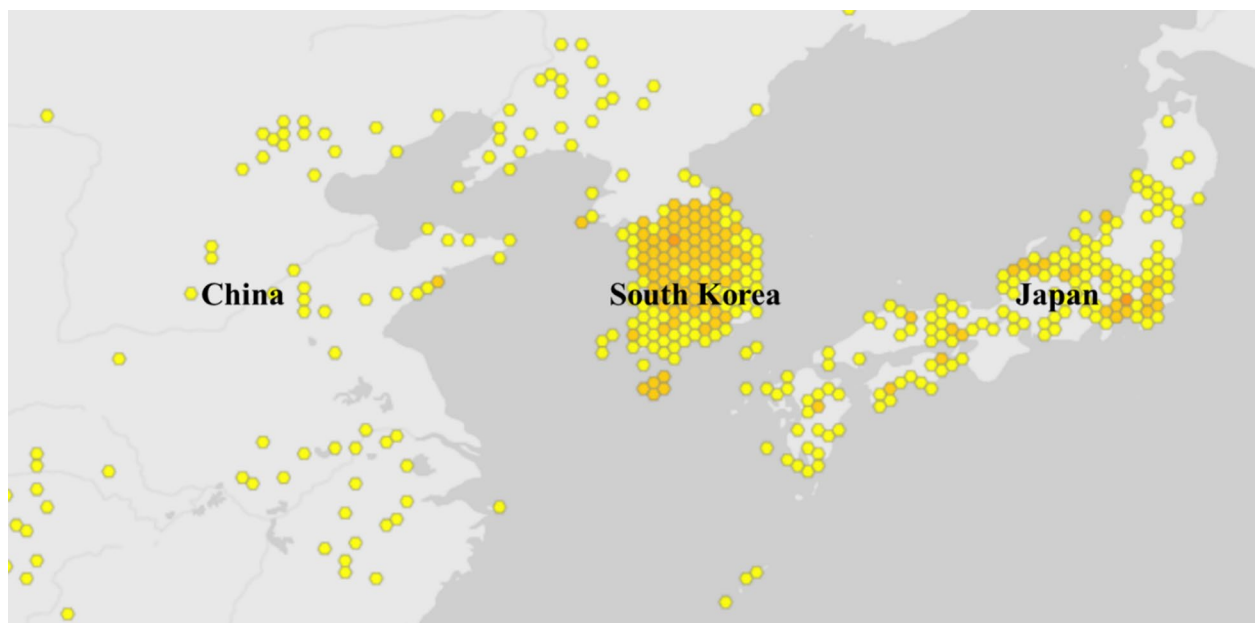


Fig. 1 Distribution map of *C. nomame* in East Asia (Korea, China, and Japan) (retrieved: GBIF.org, <https://www.gbif.org/species/8541694>, accessed 09 April 2026)

this study compares traditional hot-water extraction with ethanol-based extraction commonly used in industrial applications, in order to bridge the gap between traditional consumption practices and modern functional food development. By integrating traditional knowledge with modern scientific analysis, this study seeks to provide scientific evidence supporting the use of *C. nomame* as a functional bioresource for future food and health applications.

Methods

Preparation of plant extracts

C. nomame samples were obtained from Gangwon Medicinal Herbs (Wonju, Korea). The plant materials were cultivated under natural conditions and harvested in June 2024 in Gangwon Province, Korea. The aerial parts of the plant, which are commonly used for traditional consumption, were collected for extraction. The samples were ground to pass through a 40-mesh sieve and stored at 4 °C until extraction. The extracts were prepared according to a previously reported method [13]. Briefly, 50 g of powdered *C. nomame* was extracted with 500 mL of distilled water or 40% ethanol under reflux at 80 °C for 2 h. The extracts were filtered through Whatman No. 2 filter paper and concentrated under reduced pressure at 40 °C using a rotary vacuum evaporator.

Determination of total flavonoid content

The total flavonoid content was determined according to the method described by Moreno et al. [19]. A 1 mL aliquot of the extracts was added to 1.5 mL of 95% ethanol, 0.1 mL of 1 M potassium acetate, 0.1 mL of 10% aluminum chloride, and 2.8 mL of distilled water. The mixtures were incubated at room temperature for 30 min. The absorbance was measured at 415 nm. Quercetin was used as the standard, and results were expressed as milligrams of quercetin equivalents (QE) per gram of extract (mg QE/g).

Determination of total proanthocyanidin content

The total proanthocyanidin content was determined using the vanillin–HCl method [20]. A 0.1 mL aliquot of the extracts was mixed with 0.5 mL of 0.5% (w/v) vanillin–HCl reagent and incubated in the dark at room temperature for 25 min. The absorbance was measured at 500 nm. Catechin was used as the standard, and results were expressed as milligrams of catechin equivalents (CE) per gram of extract (mg CE/g).

Determination of nitrite scavenging activity

The nitrite scavenging activity was evaluated using a modified method of Kato et al. [21]. A 1 mL aliquot of the extracts was mixed with 1 mL of 1 mM sodium nitrite

(NaNO₂, and the pH was adjusted to 1.2 using 0.1 M HCl. The mixture was diluted to 10 mL and incubated at 37 °C for 1 h. Then, 1 mL of the mixture was reacted with 5 mL of 2% (v/v) acetic acid and 0.4 mL of Griess reagent for 15 min. The absorbance was measured at 520 nm. The activity was calculated as follows:

$$\text{Nitrite scavenging activity(\%)} = [1 - (\frac{A_{\text{Experiment}}}{A_{\text{control}}})] \times 100$$

Determination of pancreatic lipase inhibitory activity

The pancreatic lipase inhibitory activity was determined using a modified method [22]. A reaction mixture containing 150 µL of lipase (0.5 mg/mL), 10 µL of extracts, and 30 µL of Tris–HCl buffer was incubated at 37 °C for 10 min. Then, 10 µL of 20 mM p-nitrophenyl butyrate (pNPB) was added and incubated for 15 min. The absorbance was measured at 405 nm. The inhibitory activity was calculated as follows:

$$\text{Inhibitory activity(\%)} = [1 - \frac{A_s - A_b}{A_t - A_c}] \times 100$$

where A_s is the absorbance of the sample group in the presence of the extract, lipase, and pNPB; A_b is the absorbance of the sample blank in the presence of the extract and pNPB in the absence of lipase; A_t is the absorbance of the control group in the presence of lipase and pNPB in the absence of the extract; and A_c is the absorbance of the blank in the presence of pNPB in the absence of both the extract and lipase.

α-Glucosidase inhibitory activity assay

The α-glucosidase inhibitory activity was determined as described by Wang et al. [23]. Briefly, 50 µL of extracts was mixed with 100 µL of α-glucosidase (0.1 U/mL) and incubated at 37 °C for 25 min. Then, 50 µL of 5 mM p-nitrophenyl-α-D-glucopyranoside (pNPG) was added and incubated for 15 min. The absorbance was measured at 405 nm. Acarbose was used as a positive control. The inhibitory activity was calculated as follows:

$$\text{Inhibitory activity(\%)} = [1 - \frac{A_1 - A_2}{A_0 - A_2}] \times 100$$

where A_1 is the absorbance of the sample group in the presence of the extract, enzyme, and pNPG; A_0 is the absorbance of the control group in the presence of the enzyme and pNPG in the absence of the extract; and A_2 is the absorbance of the sample blank in the presence of the extract and pNPG in the absence of the enzyme. The sample blank A_2 was included to correct for intrinsic absorbance and background interference derived from

the plant extract at 405 nm, thereby preventing overestimation of the α -glucosidase inhibitory activity.

Molecular docking analysis

Previous studies have reported that luteolin is one of the major bioactive compounds present in *C. nomame* extracts [13]. Therefore, molecular docking simulations were performed to predict the potential binding interactions between luteolin and the target proteins. The three-dimensional (3D) crystal structures of α -glucosidase (PDB ID: 3A4A), pancreatic lipase (PDB ID: 1ETH), and inducible nitric oxide synthase (iNOS; PDB ID: 3E7G) were retrieved from the Protein Data Bank (PDB). The 3D structure of luteolin was obtained from the PubChem database. Prior to docking, water molecules and co-crystallized ligands were removed, and polar hydrogen atoms were added using AutoDockTools 1.5.7 (The Scripps Research Institute, La Jolla, CA, USA) to prepare the receptor and ligand structures. Molecular docking was executed using AMDock software utilizing the AutoDock Vina docking algorithm. The docking results were evaluated based on binding affinity values (kcal/mol), and the poses with the lowest binding energies were selected for further analysis. The interactions between luteolin and the amino acid residues within the binding pockets were visualized and analyzed using the PyMOL Molecular Graphics System (Schrödinger, LLC, New York, NY, USA).

Statistical analysis

All experiments were performed in at least three independent replicates. Data are expressed as the mean $\pm$ standard deviation (SD). Statistical analyses were conducted using SPSS software (v.24.0; IBM Corp., Armonk, NY, USA). Differences among multiple groups were analyzed using one-way analysis of variance (ANOVA), followed by Duncan’s multiple range test. Comparisons between two groups were performed using Student’s t test. A *p* value < 0.05 was considered statistically significant.

Results

Contents of total flavonoids and proanthocyanidins

Distinct differences in the levels of polyphenolic compounds were observed between ECNE and HCNE. As shown in Table 1, ECNE exhibited markedly higher concentrations of bioactive constituents compared to HCNE. Specifically, the total flavonoid content and total proanthocyanidin content of ECNE were 16.72 ± 0.15 mg QE/g and 25.17 ± 0.98 mg CE/g, respectively, representing significant increases of 90.6% and 80.4% compared to the HCNE group (*p* < 0.001).

Table 1 Total flavonoid and proanthocyanidin contents of *C. nomame* extracts

	Total flavonoid content (mg QE ¹ /g)	Total proanthocyanidin content (mg CE ² /g)
HCNE	8.77 $\pm$ 0.15	13.95 $\pm$ 0.72
ECNE	16.72 $\pm$ 0.15***	25.17 $\pm$ 0.98***

HCNE: hot-water extract of *C. nomame*; ECNE: 40% ethanol extract of *C. nomame*
Each value represents the mean $\pm$ SD (n = 3). Statistically significant differences were determined by Student’s t test (****p* < 0.001)

Nitrite scavenging activity

The nitrite scavenging activities of *C. nomame* extracts were investigated at various concentrations (50, 100, and 200 μ g/mL) to evaluate their potential involvement in reactive nitrogen species (RNS)-related processes. As shown in Fig. 2, both extracts exhibited dose-dependent scavenging activities against nitrite. ECNE demonstrated significantly higher nitrite scavenging activity compared to HCNE across all tested concentrations (*p* < 0.05). Specifically, at the highest concentration of 200 μ g/mL, ECNE showed $40.62 \pm 0.38\%$ scavenging activity, which was approximately 2.3-fold higher than that of HCNE ($17.85 \pm 0.21\%$). Ascorbic acid, used as a positive control, exhibited a scavenging activity of $75.64 \pm 0.28\%$ at the same concentration. These results indicate that ECNE possesses a greater capacity to scavenge nitrite than HCNE.

Pancreatic lipase inhibitory activity

The ability to inhibit pancreatic lipase, a key enzyme for fat digestion, was investigated to assess the potential anti-obesity activity of *C. nomame* extracts. Orlistat, a widely used anti-obesity drug, was employed as a positive control and showed robust inhibitory activity across all tested concentrations. Both HCNE and ECNE displayed inhibitory effects that increased in a concentration-dependent manner within the tested range of 50–200 μ g/mL (Fig. 3). Throughout this range, ECNE consistently exhibited superior inhibitory potency compared to HCNE (*p* < 0.05). At the maximum concentration of 200 μ g/mL, ECNE achieved $24.03 \pm 2.33\%$ inhibition of the enzyme’s activity, which was approximately 1.4-fold higher than that of HCNE ($17.09 \pm 0.19\%$). The positive control, Orlistat, exhibited the most potent inhibitory effect at 200 μ g/mL ($61.94 \pm 0.81\%$). These results suggest that the extraction with 40% ethanol effectively enriched the bioactive constituents responsible for suppressing lipase activity in ECNE.

α -Glucosidase inhibitory activity

Regarding the potential anti-diabetic activity, the inhibitory effects of *C. nomame* extracts on α -glucosidase, an

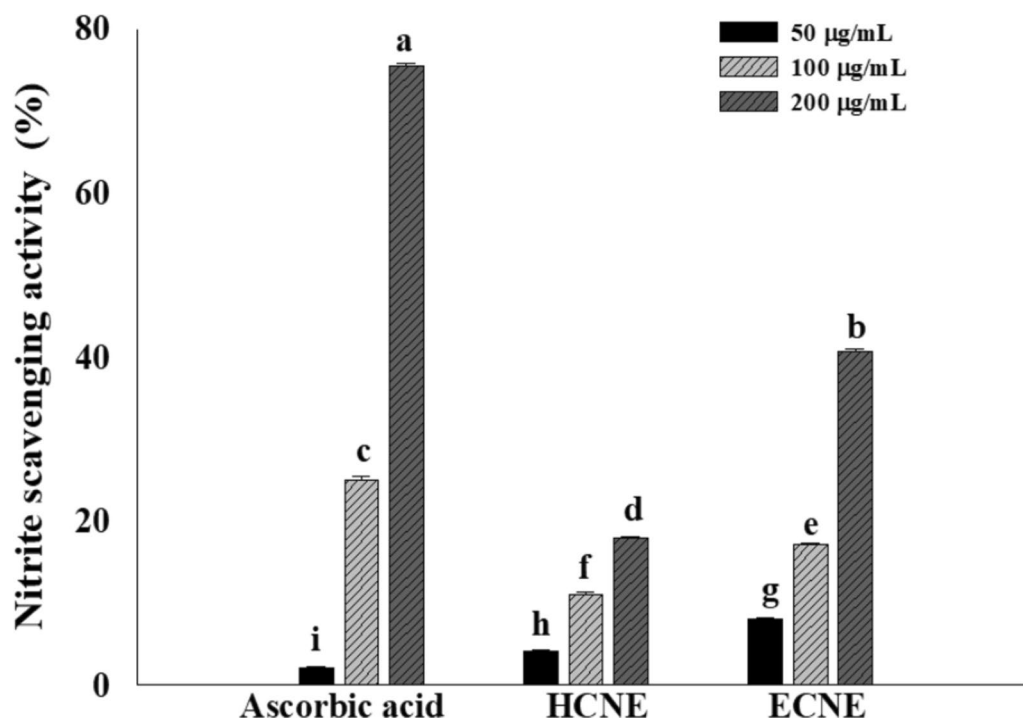


Fig. 2 Nitrite scavenging activity of *C. nomame* extracts. Nitrite scavenging activity of ascorbic acid, HCNE, and ECNE at concentrations of 50–200 µg/mL. Each value is expressed as mean $\pm$ SD deviation ($n=3$). Bars with different letters indicate significant differences according to Duncan's multiple range test ($p < 0.05$). HCNE: hot-water extract of *C. nomame*; ECNE: 40% ethanol extract of *C. nomame*

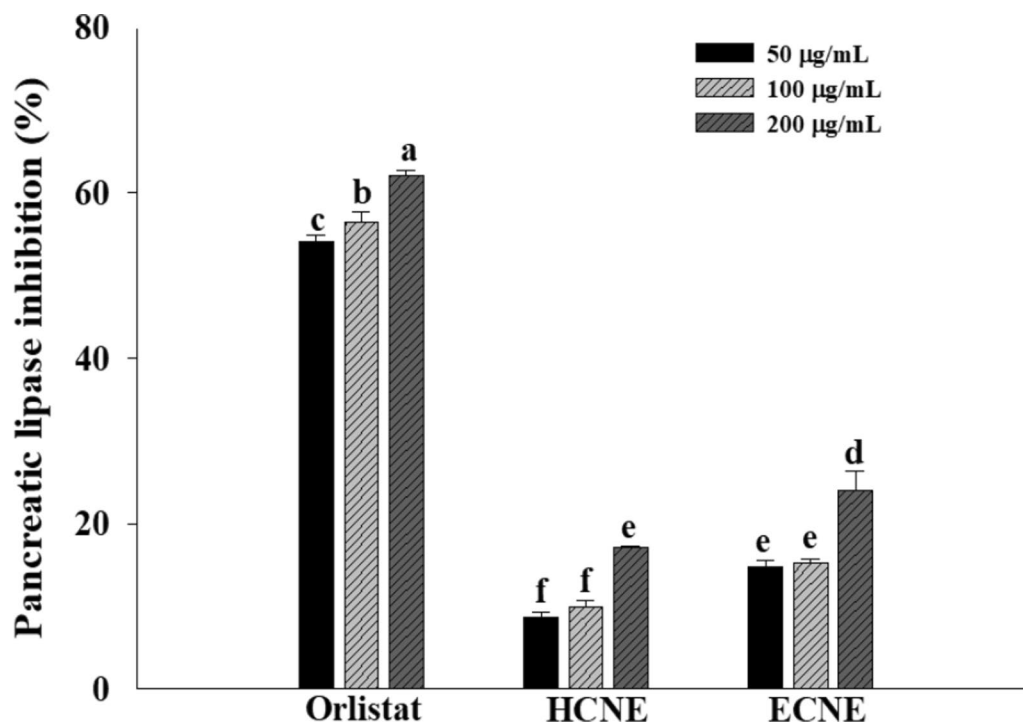


Fig. 3 Pancreatic lipase inhibitory activity of *C. nomame* extracts. Pancreatic lipase inhibitory activity of orlistat, HCNE and ECNE at concentrations of 50–200 µg/mL. Orlistat was used as a positive control. Each value is expressed as mean $\pm$ SD deviation ($n=3$). Bars with different letters indicate significant differences according to Duncan's multiple range test ($p < 0.05$). HCNE: hot-water extract of *C. nomame*; ECNE: 40% ethanol extract of *C. nomame*

enzyme critical for carbohydrate digestion and postprandial blood glucose control, were investigated. Acarbose, a clinically widely used anti-diabetic drug, was employed as a positive control. As shown in Fig. 4, ECNE exhibited a clear dose-dependent inhibitory activity against α -glucosidase within the tested concentration range (50–200 $\mu\text{g/mL}$), whereas HCNE displayed only marginal inhibitory activity without a discernible dose-dependent trend. Notably, the inhibitory potency of ECNE markedly exceeded that of HCNE at all tested concentrations. At 200 $\mu\text{g/mL}$, ECNE exhibited inhibitory activity exceeding 90%, whereas acarbose showed approximately 40–50% inhibition under the same conditions.

Molecular docking simulation of luteolin with target proteins

To elucidate the binding interactions of luteolin with the target proteins, molecular docking simulations were performed against α -glucosidase, pancreatic lipase, and iNOS. While α -glucosidase and lipase were selected based on the direct enzyme inhibition assays, iNOS was included as an additional *in silico* target because it catalyzes the production of NO, which can be further oxidized to nitrite—the chemical species targeted in the

present nitrite scavenging assay [24]. While nitrite scavenging and iNOS inhibition represent two mechanistically distinct effects, both may contribute to mitigating the negative impact of nitrogen-containing reactive species (RNS) derived from NO [25]. Therefore, docking analysis with iNOS may provide preliminary insights into the potential interaction of luteolin with NO/RNS-related targets. Luteolin exhibited binding affinities of -8.4 , -7.0 , and -7.7 kcal/mol toward α -glucosidase, lipase, and iNOS, respectively, suggesting favorable interactions with these proteins. As illustrated in Fig. 5, luteolin interacted with key amino acid residues within the binding pockets of the target proteins. Within the α -glucosidase binding pocket, luteolin interacted with residues including Tyr72, Phe159, Arg315, and Asp352 (Fig. 5C). In lipase, the ligand was stabilized through interactions with Gln307, Trp339, Tyr341, and Asp425 (Fig. 5B). Similarly, luteolin was accommodated within the binding pocket of iNOS through interactions with Arg130, Asp131, Asp256, and Arg258 (Fig. 5A). These findings suggest that luteolin can stably bind within the active sites of these target proteins, indicating its potential to modulate their biological activities through enzyme–ligand interactions.

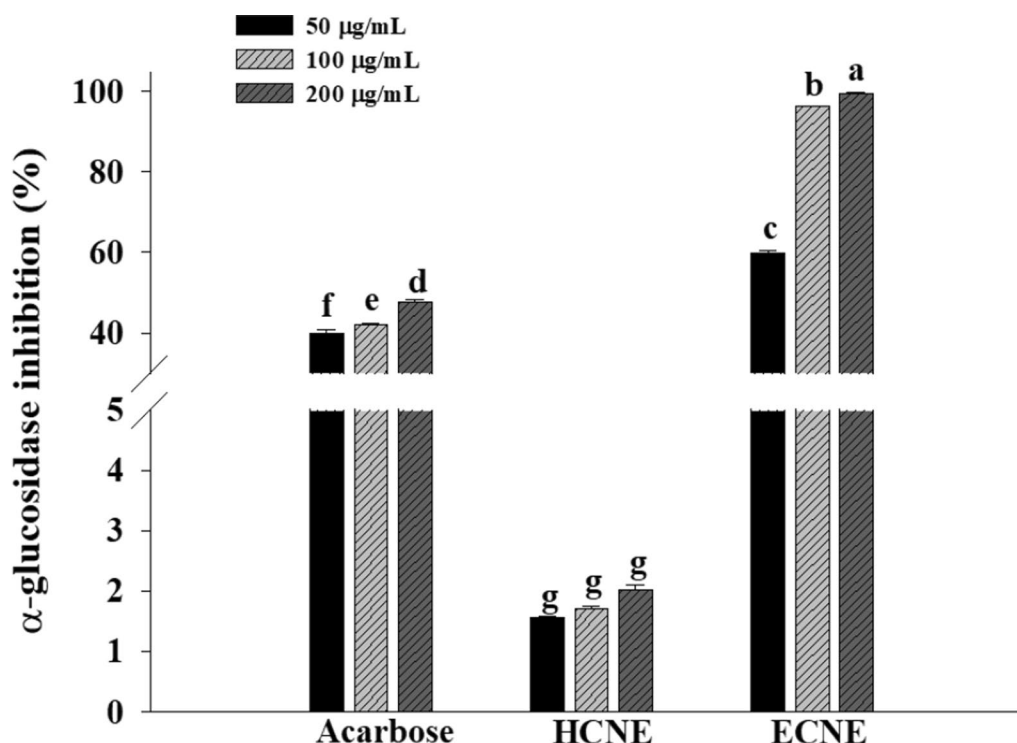


Fig. 4 α -Glucosidase inhibitory activity of *C. nomame* extracts. Inhibitory activity of acarbose, HCNE and ECNE against α -glucosidase at concentrations of 50–200 $\mu\text{g/mL}$. Acarbose was used as a positive control. Each value is expressed as mean $\pm$ SD deviation ($n = 3$). Bars with different letters indicate significant differences according to Duncan's multiple range test ($p < 0.05$). HCNE: hot-water extract of *C. nomame*; ECNE: 40% ethanol extract of *C. nomame*

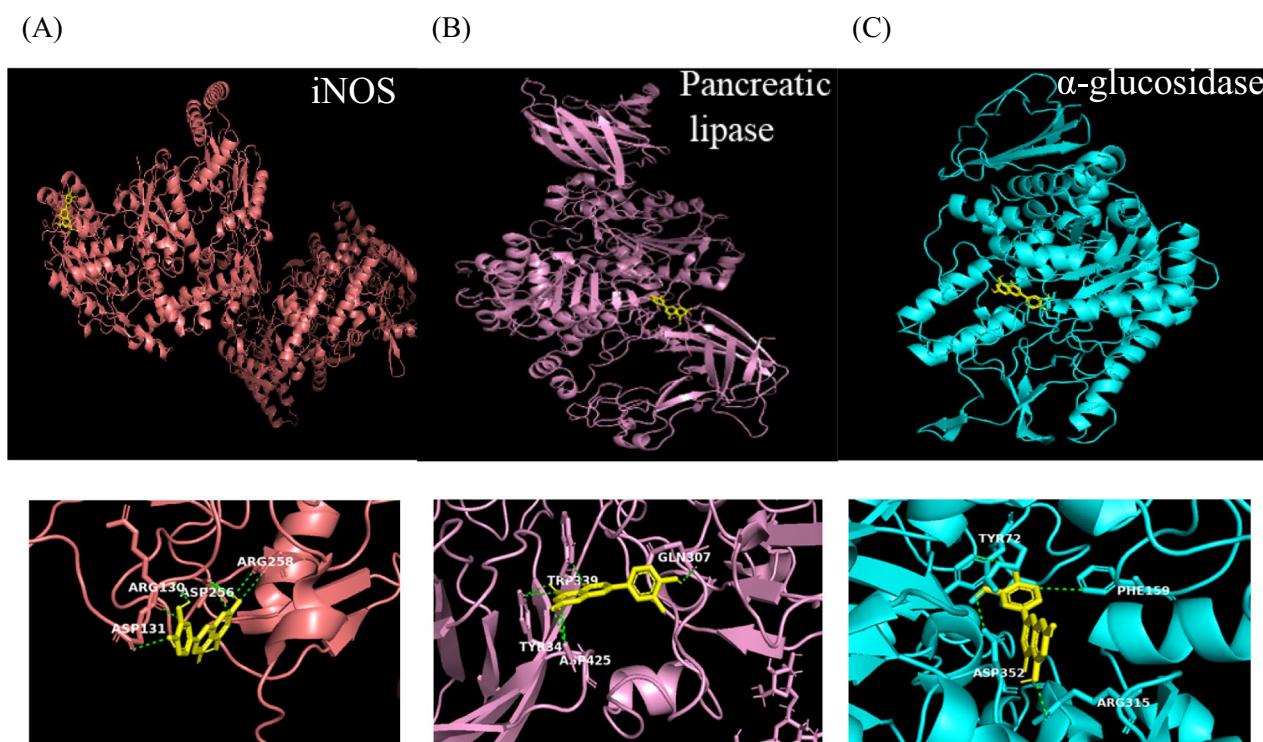


Fig. 5 Molecular docking simulation of luteolin with selected target proteins. **A** Interaction of luteolin with inducible nitric oxide synthase (PDB ID: 3E7G). **B** Interaction of luteolin with pancreatic lipase (PDB ID: 1ETH). **C** Interaction of luteolin with α -glucosidase (PDB ID: 3A4A). The docking poses illustrate the predicted binding modes of luteolin within the active sites of the target proteins

Discussion

Phytochemicals as key contributors to the bioactivities of *C. nomame*

In the present study, the 40% ethanol extract exhibited stronger biological activities across all assays compared with the hot-water extract. This enhanced activity may be attributed to the more efficient extraction of flavonoids and proanthocyanidins by aqueous ethanol, as certain bioactive compounds are not effectively recovered through conventional boiling [26].

The strong inhibitory activities observed in the 40% ethanol extract of *C. nomame* may be closely associated with its high content of flavonoids and proanthocyanidins. These phytochemicals are widely recognized for their diverse biological activities, particularly their roles in regulating oxidative stress and metabolic enzyme activity [27]. In this study, the ethanol extract showed stronger inhibitory effects on pancreatic lipase and α -glucosidase than the hot-water extract, indicating that ethanol extraction more efficiently recovered these bioactive constituents. Inhibition of pancreatic lipase and α -glucosidase, key enzymes in lipid and carbohydrate digestion, is a well-established strategy for managing obesity and postprandial hyperglycemia [28]. Pancreatic lipase hydrolyzes dietary triglycerides into

absorbable free fatty acids and monoacylglycerols, while α -glucosidase catalyzes the final step of carbohydrate digestion by converting oligosaccharides into glucose [29, 30]. Suppressing these enzymes reduces fat absorption, delays glucose uptake, and contributes to improved metabolic control [31]. Thus, simultaneous inhibition of both enzymes may provide a dual approach to regulating lipid and carbohydrate metabolism in metabolic disorders. Beyond enzyme inhibition, the extract also demonstrated notable nitrite scavenging activity, suggesting its potential involvement in oxidative and inflammation-related processes [32]. Together, these findings indicate that *C. nomame* extracts rich in flavonoids and proanthocyanidins may modulate multiple biological pathways relevant to metabolic and inflammatory conditions.

To further support the potential role of polyphenolic constituents in the observed bioactivities, molecular docking analysis was performed using luteolin, a major bioactive compound present in *C. nomame*. Notably, luteolin has previously been isolated as a lipase inhibitor from *C. nomame* by Shimura et al. [33], who reported that luteolin and several flavonols (kaempferol, myricetin, and quercetin) exhibited comparable lipase inhibitory activities, whereas their glycosides, flavanones, and flavan-3-ols showed negligible activity. These findings suggest

that the lipase inhibitory activity of ECNE observed in the present study may be partly associated with its luteolin and related aglycone-type flavonoid contents. In addition, Zhu et al. [34] comprehensively summarized that various flavonoids exhibit α -glucosidase inhibitory activity, with several flavonoids reported to be more effective than acarbose. These findings are consistent with the strong α -glucosidase inhibitory activity of ECNE observed in the present study. Luteolin exhibited favorable binding affinities toward α -glucosidase and pancreatic lipase, providing mechanistic insight into its potential contribution to the inhibitory activities observed in the present study through interactions with key residues within the binding pockets of these enzymes. The binding affinity observed for iNOS provides additional in silico support for the potential interaction of luteolin with NO/RNS-related targets.

Based on these findings, the in chemico assay results demonstrate that *C. nomame* extracts exhibit nitrite scavenging, pancreatic lipase inhibitory, and α -glucosidase inhibitory activities, suggesting their potential to modulate metabolic and inflammation-related pathways. However, these comparisons were conducted between a complex extract and single reference compounds, and thus should be interpreted with caution. Further studies are required to enable more direct comparisons through standardization of active constituents and evaluation based on defined molecular concentrations. In addition, as the present study is primarily based on in chemico assays and molecular docking analysis, further validation through in vivo and clinical studies is necessary to confirm the physiological relevance and therapeutic potential of these findings.

Traditional use and functional potential of *C. nomame*

C. nomame has long been consumed in East Asia as a traditional herbal tea and is commonly associated with digestive and diuretic benefits. The hot-water extraction method reflects this traditional mode of consumption and provides an important context for understanding its baseline functional properties. However, due to the lack of clear records regarding its traditional intake, direct comparison with the concentrations used in the present study is limited. Nevertheless, this study is meaningful in that it compares the traditional hot-water extraction method with the modern ethanol extraction approach, providing insight into the influence of extraction methods on bioactivity. In addition, several in vivo studies using ethanol extracts of *C. nomame* or related plant materials have reported no significant toxicity and have suggested potential biological activities [35, 36]. While these findings suggest the potential applicability

of ethanol extracts in functional formulations, caution is required when extrapolating these results directly to *C. nomame*. Furthermore, information compiled in the European Food Safety Authority (EFSA) Article 13 Consolidated List of Health Claims indicates that proposed conditions of use of approximately 50–200 mg per day have been submitted for *C. nomame* in the context of health claim evaluation, typically in capsule form [37]. This does not represent a recommended or validated intake level, but rather reflects intake conditions considered in functional product formulations.

Collectively, these findings suggest the potential of *C. nomame* as a functional food ingredient. However, further toxicological evaluation and validation through in vivo and clinical studies are required to confirm its safety, metabolic fate, and therapeutic efficacy under practical consumption conditions.

Conclusion

C. nomame, a traditional herbal tea and food resource widely used across East Asia, including Korea, demonstrates biological activities that are strongly influenced by extraction conditions. In the present study, the 40% ethanol extract exhibited superior inhibitory effects on digestive enzymes and higher nitrite scavenging capacity compared with the traditional hot-water extract. These findings indicate that bioactive polyphenols, particularly flavonoids such as luteolin, play a central role in modulating metabolic enzyme activity and inflammation-related pathways. Importantly, by comparing traditional hot-water extraction with modern ethanol-based extraction, this study demonstrates that plant resources rooted in traditional knowledge can be effectively extended to the development of functional foods and health-related materials. Collectively, these results provide robust scientific evidence for the functional value of *C. nomame* and highlight its potential as a natural resource for developing functional ingredients to support metabolic and inflammatory health. Furthermore, future studies are required to evaluate its efficacy and safety under in vivo and clinical conditions, particularly by considering traditional consumption patterns and conducting dose–response assessments.

Abbreviations

<i>C. nomame</i>	<i>Chamaecrista nomame</i> (Siebold) H. Ohashi
HCNE	Hot-water extract of <i>Chamaecrista nomame</i> (Siebold) H. Ohashi
ECNE	40% Ethanol extract of <i>Chamaecrista nomame</i> (Siebold) H. Ohashi
QE	Quercetin equivalents
CE	Catechin equivalents
NO	Nitric oxide
iNOS	Inducible nitric oxide synthase
PDB	Protein Data Bank
SD	Standard deviation
ANOVA	Analysis of variance

RNS Reactive nitrogen species

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Author contributions

Min-Hye Kim was involved in data curation, formal analysis, methodology, validation, and writing—original draft. Ji-Hyun Im contributed to methodology and investigation. Xiaolu Fu, Jewon Park, and June-Seok Lim was involved in investigation and formal analysis. Shuai Wei contributed to visualization and resources. Xing Fu was involved in data curation and methodology. Minwoo Baek contributed to writing—review and editing and conceptualization. Ok-Hwan Lee was involved in writing—review and editing, conceptualization, funding acquisition, and supervision. All authors reviewed the manuscript.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing Interests

The authors declare that they have no competing financial interests or personal relationships that may have influenced the work reported in this study.

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