Chimica Techno Acta
published by Ural Federal University
eISSN 2411-1414; chimicatechnoacta.ru

ARTICLE
2021, vol. 8(2), № 20218202
DOI: 10.15826/chimtech.2021.8.2.02

Synthesis and study of complexes of the novel Russian antiviral drug Camphecene with Plant's Flavonoids

S.S. Khizrieva*, E.V. Vetrova, S.N. Borisenko, E.V. Maksimenko, N.I. Borisenko

Research Institute of Physical and Organic Chemistry, Southern Federal University, Stachki Ave., 194/2, Rostov-on-Don, 344090, Russia
* Corresponding author: hizrieva@sfedu.ru

This article belongs to the regular issue.

Abstract

Traditionally, glycyrrhizic acid has been used to form polydentate complexes. For the first time in the presented paper, the complexation of the Plant's Flavonoids (Quercetin (Qu) and its glycoside - Rutin (Rut)) with the novel Russian antiviral drug Camphecene (Camph) was investigated. The complexes obtained at different molar ratios were studied using UV/Vis spectroscopy. Formation of the host: guest complexes were registered: Qu and Rut molecular complexes (*Camph+2Qu*; *Camph+2Rut*) with a stability constant $K = 3.3 \cdot 10^8$ M^{-2}. Comparison of the binding constants of the obtained complexes shows that the efficiency of Camphecene complexation with the participation of flavonoids is more efficient than with the participation of triterpenoids. Besides, it was found that the complexes of Camphecene with the quercetin and rutin are soluble in water, in contrast to the complexes with triterpenoids, which makes it possible to increase the bioavailability of both Camphecene and flavonoids. The obtained results demonstrate the high potential of flavonoids Qu and Rut to the development of novel pharmaceutical forms using the example of Camphecene in the form of molecular complexes, as the novel forms of delivery.

Keywords

Camphecene
Quercetin
Rutin
antiviral activity
supramolecular complexes

Received: 01.03.2021
Revised: 22.04.2021
Accepted: 27.04.2021
Available online: 28.04.2021

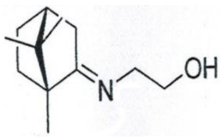
1. Introduction

It is known that a decrease in therapeutic doses of medicinal substances and prolongation of action is possible when they are clathrate with plant glycosides. This property was used in the approach of Academician G. A. Tolstikov to reduce therapeutic doses of drugs and prolong the action [1-3]. In this regard, the presented work considers the possibilities of synthesizing new supramolecular complexes of Qu and Rut using the new antiviral drug Camphecene for the development of low-dose pharmaceutical substances on their basis. The authors consider that these pharmaceutical substances can be used to suppress the multiplication of viruses in the early stages. It is known that Camphecene **1** (Fig. 1), has a broad spectrum of antiviral activity. It is proved to be active against the influenza virus strains type A and type B [4].

The purpose of this work is to synthesize and study supramolecular complexes based on the scaffold monoterpenoid Camphecene and plant flavonoids to develop, in the future, previously unknown low-dose pharmaceutical substances with antiviral activity. Influenza is known to be the most common and dangerous respiratory viral infection. It causes annual epidemics and pandemics, leading to significant increases in morbidity and mortality in all regions of the world. In connection with the growing number of cases of viral infections and especially resistant viral strains, it is necessary to improve the available therapeutic methods, complementing them with the discovery of new antiviral agents. On the other fist, it is widely recognized that the medical heritage of plants is a valuable resource for the treatment of infectious disorders. This indicates a growing interest in antiviral products based on secondary plant metabolites [5, 6].

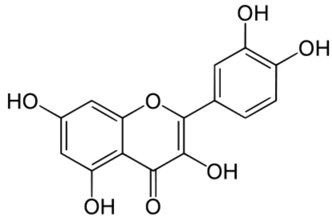
One of the unique plant components used in traditional medicine is bioflavonoids quercetin and rutin (Fig. 1).

Plant flavonoids **2** and **3** are attracting more and more attention of chemists and pharmacologists due to the wide spectrum of their biological activity. Flavonoids have long attracted scientific interest as antiviral agents - in a few



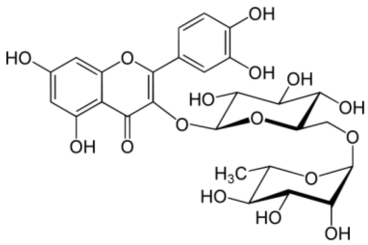
$C_{12}H_{21}NO$

a) Camph(1)



$C_{15}H_{10}O_7$

b) Qu (2)



$C_{27}H_{30}O_{16}$

c) Rut (3)

Fig. 1 Structures of a) Camphecene (**1**), $C_{12}H_{21}NO$; b) Quercetin (**2**), $C_{15}H_{10}O_7$; c) Rutin (**3**), $C_{27}H_{30}O_{16}$

studies, they have shown an inhibitory effect on proteases of various types of coronaviruses [7].

Quercetin (Qu) is one of the most important plant molecules, showing pharmacological activity such as antiviral and anti-inflammatory effects. It has also been demonstrated to have a wide range of anti-cancer properties, and several reports indicate its efficacy as a cancer-preventing agent [8]. Quercetin **2** (Fig. 1), chemical name 2-(3,4-dihydroxy phenyl)-3,5,7-trihydroxychromen-4-one or 3,3′,4′,5,7-pentahydroxyflavone, is classified as a flavonol, one of the six subcategories of flavonoid compounds, and is the major polyphenolic flavonoid found in various vegetables and fruits, such as berries, dill, apples, and onions [9].

According to research results [10], Qu and other several substances exhibited better potential inhibition than Hydroxy-Chloroquine against COVID-19 main protease active site and ACE2. Based on the results obtained by computational methods on molecular docking, it is anticipated that Qu could affect SARS-CoV-2 by interacting with 3CLpro, PLpro, and/or S protein [8, 11].

Thus, Qu is currently promising as a biologically active substance of natural origin, capable of exerting a nonspecific complex effect on inflammatory and destructive processes in the body, and Qu be considered promising in the treatment of allergic pathology, inflammatory and non-inflammatory diseases (Alzheimer's). One of the special effects of quercetin is its protective effect on the vascular endothelium, which is important in COVID-19 since endothelial dysfunction inevitably develops in this pathology [7].

2. Experimental

The following reagents were used in this study: Quercetin (purity 98.2%) from DIA-M (Russia) and Rutin (99.4% purity) from Sichuan Xieli Pharmaceutical Co., Ltd. (China), and locally produced chemicals of the chemically pure grade.

Camphecene – 2-(E)-((1R,4R)-1,7,7-trimethylbicyclo [2.2.1] heptan-2-ylidene-aminoethanol was synthesized at the Novosibirsk Institute of Organic Chemistry (NIOCH SB RAS) (Fig. 2): a mixture of (1R)-(+)-camphor (1.0 equiv.), the appropriate amine (2.5 equiv.), and anhydrous $ZnCl_2$ (0.1% mol on camphor) was reflux for 5–12 h. Diethyl ether was added to the reaction mixture, after completion of the reaction. The organic layer was washed with brine, dried (Na_2SO_4), and evaporated. The crude product was subjected to vacuum distillation [12].

The complex of Camph and Qu and Rut was formed by mixing 96% alcohol solution. The process of complex formation between Qu and Rut and Camph was analyzed using electron-optical UV-Vis spectroscopy (a SPEKS SSP 705-PC spectrometer (CJSC Spectroscopic Systems, Russia).

The complexes of Qu/Rut and Camph were formed by mixing an alcohol solution of Qu/Rut and Camph at the molar ratio of 1:1 and 2:1 (using ethanol as alcohol). The stoichiometry of the complex was evaluated by the dependence of optical density of a Camph solution (measured at 201 nm) on Qu/Rut concentration. A contribution of Qu/Rut to absorbance was corrected by subtracting the absorbance spectrum of Qu/Rut from the total absorbance spectrum. Measurements were carried out in a quartz cell.

3. Results and Discussion

Following the objectives of the work, sets of complexes of bioflavonoids Qu and Rut with an antiviral drug Camphecene at different molar ratios "guest: host" were synthesized.

For a detailed study of the processes of complexation of Qu and Camph, the absorption spectra of Camph in a mixture with different concentrations of Qu were investigated. In the first step, complexes of Qu with Camph were obtained at molar ratios: 1:1 and 2:1 and studied by UV/Vis spectroscopy. The binding of Camph and Qu after mixing of their solutions was accompanied by changes in the

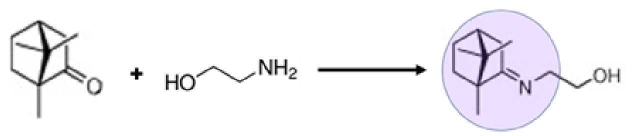


Fig. 2 Scheme of obtaining the scaffold monoterpenoid – Camphecene [12]

absorbance spectrum of Camph indicating the complex formation of these compounds (Fig. 3). The UV-VIS spectrophotometric analysis of the mixture of Camph and Qu has shown that the increase in Qu concentration is accompanied by the change in the shape of the Camph spectrum due to complex formation (its maximum of absorbance becomes lower). As demonstrated in Fig. 3, with an increase in the concentration of Qu from 0 to 0.125 mM, a bathochromic shift of the absorption maximum of Camph (201 → 215 nm) is recorded in the UV/Vis spectra, and a decrease in optical density is observed.

Fig. 3 shows the Camph spectra, which are the difference absorption spectra of the mixture of Camph and Qu and the spectrum of Qu at a given concentration.

An increase in the concentration of Qu (from 0.25 mM and higher) leads to the disappearance of the maximum absorption of Camph, which indicates the complete binding of Camph molecules in the presence of Qu (Fig. 4).

Fig. 4 demonstrates from the dependence of the optical density on the concentration of Qu at the value of the maximum absorption band of Camph λ_{max1}= 201 nm: the optical density sharply decreases its values depending on the concentration of Qu in the mixture.

The study of Rut (Fig. 5) demonstrated similar changes in the UV/Vis spectra of the obtained complexes. When the

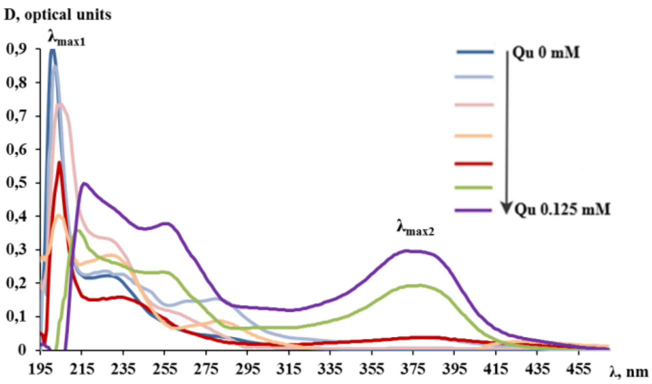


Fig. 3 Absorption spectrum of Camphecene (C_{Camph} = 0.5 mM) at different concentrations of Qu* (in 96% alcohol solution). The upper spectrum line corresponds to the absorbance spectrum of Camph in the absence of Qu (C= 0.0 mM).

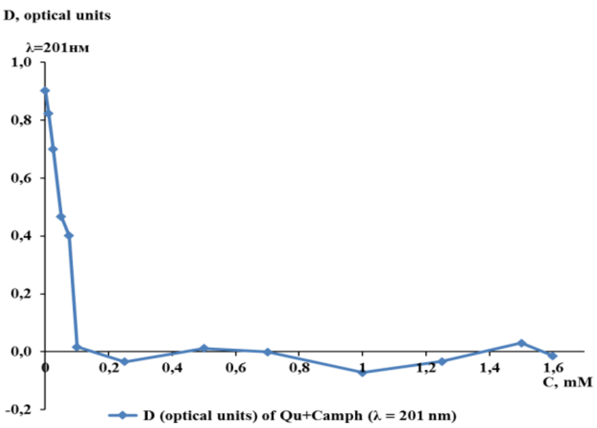


Fig. 4 Dependence of optical density on the concentration of quercetin

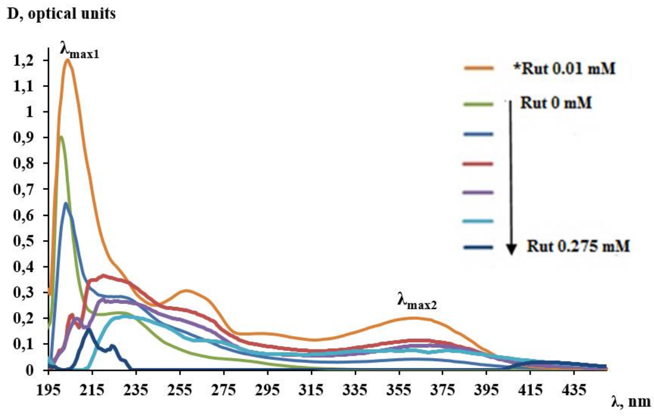


Fig. 5 Absorption spectrum of Camphecene (C_{Camph} = 0.5 mM) at different concentrations of Rut (*Rut 0.01 mM – standard solution of rutin)

Rut concentration changes in the range from 0.05 to 0.275 mM, a bathochromic shift of the absorption maximum of Camph is recorded (201 → 213 nm).

In this study, the stability constants for the complex of Camph and Qu/Rut were analyzed by changes of optical density of Camph solutions (with its constant concentration, C_{Camph} = 0.5 mM) with variable concentrations of Qu/Rut. To calculate the stability constant of the complexes, we used the Benesi-Hildebrand plot (1) [13]. Eq. (1) is applicable for certain experimental conditions (Camph concentration < Qu/Rut concentration).

The stability constant of the *nQu-Camph* complex was estimated from the change in the optical density of Camph (λ_{max1} = 201 nm) at its fixed concentration in solutions in which the Qu (or Rut) concentration was varied. Eq. (1) allows, within the framework of one experiment, not only to estimate the stability constant of the complex (K) but also to determine the stoichiometry ratio "host: guest" (n) in the complex:

$$\Delta D/D - 1 = 1/[\mathrm{Qu}]^n \cdot 1/K \quad (1)$$

where $\Delta D = \Delta\varepsilon \cdot [\mathrm{Camph}]$ – change in the optical density of the solution, K – the constant of stability of the complex, determined for the reaction Camph + nQu ⇄ Camph-nQu:

$$K = \frac{[\mathrm{Camph} - \mathrm{nQu}]}{[\mathrm{Camph}] \cdot [\mathrm{nQu}]} \quad (2)$$

The absorption spectrum of Camph was recorded at a wavelength of 201 nm, while the Camph concentration

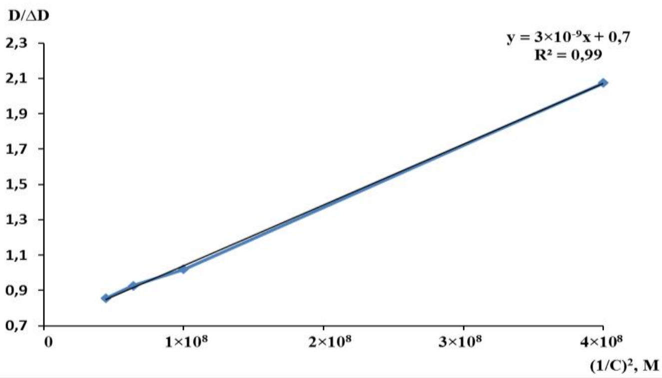


Fig. 6 Dependence of the slope of the straight line $D/\Delta D$ on $1/[\mathrm{Qu}]^2$

was constant and amounted to 0.5 mM. The obtained dependence of the absorption intensity of Camphecene (λ = 201 nm) on the concentration of Qu is shown in Fig. 6.

From the slope of the straight line $\Delta D/D$ depending on $1/[Qu]^2$ (Fig. 6), the stability constant of the complex was calculated using Eq. (1). The stability constant for the *Camph+Qu* complex is $1/K = 3\ 10^{-9}$ M^2 or $K = 3.3\ 10^8$ M^{-2}.

Recognizing the value of the binding constant, the change in the Gibbs energy was calculated. Obtained from the binding constant, the change in Gibbs's energy ΔG = -47.8 kJ. Based on the obtained negative value, it can be concluded that the reaction proceeds spontaneously during the formation of Qu and Camph complexes. Similarly, according to Eq. (1), the stability constant of the complex *Camph+Rut* was calculated, $1/K = 3\ 10^{-9}$ M^2 or $K = 3.3\ 10^8$ M^{-2}. Using the value of the binding constant, the change in Gibbs's energy was calculated. The change in the Gibbs energy ΔG =-47.8 kJ, which allows us to conclude that the reaction proceeds spontaneously during the formation of a complex of Rut with Camph.

Thus, the values of the binding constant Camph for Qu and Rut are comparable, and the same conclusion can be drawn about the change in the Gibbs energy ΔG = -47.8 kJ.

Comparison of the binding constants of the obtained complexes shows that the efficiency of Camphecene's complexation with the participation of flavonoids is more efficient ($K = 3.3\ 10^8$ M^{-2} for the *Camph+2Qu*; *Camph+2Rut* complexes) than with the participation of triterpenoids ($K = 6.94\ 10^6$ M^{-2} for *Camph+2GA*) [14]. Also, it was found that the complexes of Camphecene with the quercetin and rutin are soluble in water, in contrast to the complexes with triterpenoids, which makes it possible to increase the bioavailability of both Camphecene and flavonoids.

4. Conclusions

For the first time, the complexation of the Plant's Flavonoids (Quercetin (Qu) and its glycoside - Rutin (Rut)) with the novel Russian antiviral drug Camphecene (Camph) was investigated.

The complexes obtained at different molar ratios "host: guest" - 1:1 and 2:1 were studied using UV/Vis spectroscopy.

Formation of the "host: guest" complexes were registered: Qu and Rut molecular complexes (*Camph+2Qu; Camph+2Rut*) with a stability constant $K = 3.3\ 10^8$ M^{-2}.

The obtained results demonstrate the high potential of flavonoids Qu and Rut to the development of novel pharmaceutical forms using the Camphecene in the form of molecular complexes, as the novel forms of delivery.

Acknowledgements

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (*State assignment in the field of scientific activity, project No 0852-2020-0031*) and the Russian Foundation for Basic Research *(RFBR, grant no. 19-33-90211-Aspiranty).*

The authors are grateful to the Corresponding Member of the RAS, Doctor of Chemical Sciences, Professor of NIOCH SB RAS Salakhutdinov N.F. for the kindly provided scaffold monoterpenoid Camphecene.

References

1. Tolstikova TG, Tolstikov AG, Tolstikov GA. On the way to low-dose medicines. Herald of the Russian Academy of Sciences. 2007;77(10):447–53. doi:10.1134/S1019331607050012
2. Vetrova EV, Lekar AV, Filonova OV, Borisenko SN, Maksimenko EV, Borisenko NI. Study of molecular complexation of glycyrrhizic acid with chloramphenicol by electrospray ionization mass spectrometry. Journal of natural science, biology, and medicine. 2015;6(Suppl 1):40–3. doi:10.4103/0976-9668.166070
3. Yakovishin LA, Grishkovets VI. Intermolecular Interaction of Glycyrrhizin with Cholesterol. Chimica Techno Acta. 2020;7(4):180–5. doi:10.15826/chimtech.2020.7.4.08
4. Zarubaev VV, Garshinina AV, Tretiak TS, Fedorova VA, Shtro AA, Sokolova AS, Yarovaya OI, Salakhutdinov NF. Broad range of inhibiting action of novel Camphor-based compound with anti-hemagglutinin activity against influenza viruses in vitro and in vivo. Antiviral Res. 2015;120:126–33. doi:10.1016/j.antiviral.2015.06.004
5. Akram M, Tahir IM, Shah SMA, Mahmood Z, Altaf A, Ahmad K, Munir N, Daniyal M, Nasir S, Mehboob H. Antiviral potential of medicinal plants against HIV, HSV, influenza, hepatitis, and coxsackievirus: A systematic review. Phytother Res. 2018;32(5):811–22. doi:10.1002/ptr.6024
6. Dhama K, Karthik K, Khandia R, Munjal A, Tiwari R, Rana R, Khurana SK, Sana U, Khan RU, Alagawany M, Farag MR, Dadar M, Joshi SK. Medicinal and Therapeutic Potential of Herbs and Plant Metabolites / Extracts Countering Viral Pathogens - Current Knowledge and Future Prospects. Curr Drug Metab. 2018;19(3):236–63. doi:10.2174/1389200219666180129145252
7. Zupanets IA, Shebeko SK, Bezugla NP, Otrishko IA. Pathophysiological substantiation of the effectiveness of quercetine use in coronavirus disease (COVID-19) therapy. Pathologia. 2020;17(1):93–101. doi:10.14739/2310-1237.2020.1.203844
8. Derosa G, Maffioli P, D'Angelo A, Di Pierro F. A role for quercetin in coronavirus disease 2019 (COVID-19). Phytotherapy Research. 2020;1–7. doi:10.1002/ptr.6887
9. David AVA, Arulmoli R, Parasuraman S. Overviews of biological importance of quercetin: a bioactive flavonoid. Pharmacognosy reviews. 2016;10(20):84–9. doi:10.4103/0973-7847.194044
10. Omar S, Bouziane I, Bouslama Z, Djemel A. In-Silico Identification of Potent Inhibitors of COVID-19 Main Protease (Mpro) and Angiotensin Converting Enzyme 2 (ACE2) from Natural Products: Quercetin, Hispidulin, and Cirsimaritin Exhibited Better Potential Inhibition than Hydroxy-Chloroquine Against COVID-19 Main Protease Active Site and ACE2. V1 Cross Ref. 2020;1–24. doi:10.26434/chemrxiv.12181404.v1
11. Pan B, Fang S, Zhang J, Pan Y, Liu H, Wang Y, Li M, Liu L. Chinese herbal compounds against SARS-CoV-2: puerarin and quercetin impair the binding of viral S-protein to ACE2 receptor. Computational and structural biotechnology journal. 2020;18:3518–27. doi:10.1016/j.csbj.2020.11.010

12. Sokolova AS, Yarovaya OI, Shernyukov AV, Gatilov YV, Razumova YV, Zarubaev VV, Tretiak TS, Pokrovsky AG, Kiselev OI, Salakhutdinov NF. Discovery of a new class of antiviral compounds: Camphor imine derivatives. European journal of medicinal chemistry. 2015;105:263–73. doi:10.1016/j.ejmech.2015.10.010
13. Vavilin VA, Salakhutdinov NF, Ragino YuI, Polyakov NE, Taraban MB, Leshina TV, Stakhneva EM, Lyakhovich VV, Nikitin YuP, Tolstikov GA. The Cholesterol Lowering Properties of the Complex Compound Simvastatin with Glycyrrhizic Acid (Simvaglyzin) in Experimental Models. Biochem (Moscow) Suppl Series B: Biomed Chem. 2008;2(4):373–80. doi:10.1134/S1990750808040070
14. Khizrieva SS, Vetrova EV, Borisenko SN, Maksimenko EV, Borisenko NI. Synthesis and study of complexes of the novel Russian antiviral drug Camphecene with pentacyclic triterpenes of licorice. Chimica Techno Acta. 2020;7(4):192–8. doi:10.15826/chimtech.2020.7.4.10