



# Expansion of the antifungal activities through in silico docking study of compounds from *Albizia lebeck* fruits

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## Abstract

The development of new computational and experimental techniques that are efficient, fast, and accurate has become a priority for researchers in all domains around the world. The present manuscript deals with the computational investigation of quercitrin (**1**), lebeckisoetin A (**2**), quercetin-3-O- $\beta$ -D-glucopyranoside (**3**), (*E*)-*p*-coumaric acid (**4**), eugenol (**5**), eugenol, 1-acetate (**6**), chiakine (**7**), hexacosan-1',26'-dioate of bis[(2*S*), 2,3-dihydroxypropyl] (**8**), oleanolic acid (**9**), betulin (**10**), hopan-29-ol (**11**), hopan-30-ol (**12**), 22-hydroxyhopan-3-ol (**13**), and lupeol (**14**). These compounds were all isolated from the fruit of *Albizia lebeck*. Only lebeckisoetin A (**2**) and chiakine (**7**) were previously evaluated for their experimental antimicrobial activities, which both revealed potent antifungal activities. This theoretical study was undertaken in the framework of better understanding the experimental results at the atomic level and to expand the antimicrobial assays of the other non-tested compounds. The virtual screening of the antimicrobial activity was performed on Maestro Schrödinger 4.2.1 software using the crystal structures of sterol 14- $\alpha$  demethylase (CYP51) from *Candida albicans* in complex with the tetrazole-based antifungal drug candidate VT1161 (VT1) (PDB Id: **5TZ1**) and the crystal structure of sterol 14- $\alpha$  demethylase (CYP51) from the pathogenic yeast *Candida albicans* in complex with the antifungal drug posaconazole (PDB Id: **5FSA**). This is the first docking study of natural compounds

using these **5TZ1** and **5FSA** as proteins. Compounds (**1-10**) reveal interesting binding strength with both **5TZ1** and **5FSA** proteins, with a docking score ranging from -7.892 to -5.256, supporting the experimental results. In addition, compounds (**1-9**) were mostly active due to the formation of  $\pi$ - $\pi$  interactions, H-bonds, and hydrophobic interactions, as well as  $\pi$ -cation and salt bridge interactions, with both **5TZ1** and **5FSA**.

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## 1. Introduction

The development of new computational and experimental techniques, which are efficient, fast, and accurate, has become a priority for researchers in all domains around the world. The development of high-performance computers with great capacities has led computers to be used in both experimental and theoretical research. Nowadays, almost all research areas have both experimental and theoretical parts. This has shifted the paradigms in drug discovery. Most often, theoretical research is faster than experimental research and is used to either predict or support the experimental results (**Santamouris et al. 20012; Chen et al. 2015; Afshari and Muratçobanoğlu, 2023; Muhammed and Aki-Yalcin, 2024**). Nowadays, the modelization/production of new drugs is an easy task. However, the challenge incurred for this development is not long and tedious like two decades ago because the targeted drug is firstly designed in a computer and then suggested for molecular docking in order to better predict the ligand-receptor interactions. The term for the computational schemes that attempt to search for the “best” atomic coordinates/connectivity or bound association between two complex molecules is known as “docking” (**Ghasemi et al. 2017**). Docking study is a multidisciplinary science that is applied in a wide range of areas, particularly in drug discovery (**Sultana et al. 2024**). The prediction with a reasonable accuracy of the binding affinity between the ligand(s) and the protein is crucial in drug discovery and helpful in the optimization of the compound to establish a perfect connectivity with the targeted protein (**Rezaei et al. 2020; Sultana et al. 2024**). Molecular docking or computational simulation drug design calls upon the calculation of the binding strength between ligand and the protein which are two biological homologs. This manuscript deals with the computational

investigation of some naturally isolated compounds against *C. albicans*. Therefore, the most prevalent human yeast pathogen is *C. albicans* because it is always present in the entire mammalian life cycle (Hargrove et al. 2017). The cytochrome P450 enzyme [Sterol 14 $\alpha$ -demethylase (CYP51)] is the required enzyme used by eukaryotic cells in steroidal biosynthesis and is mostly targeted by antifungal clinical drugs (Hargrove et al. 2017). CYP51 is an interesting subject for fundamental studies of P450. CYP51 is a great practical importance as a drug target. Sterol 14 $\alpha$ -demethylase activity blocks sterol biosynthesis, influencing endogenous cholesterol production processes in animals. CYP51 inhibitors are being studied as potential cholesterol-lowering drugs and herbicides, it is noted that they are largely used as fungicides (Lepesheva and Waterman, 2007; Lepesheva and Waterman, 2011; Scalese et al. 2024). Quercitrin (1), lebbeckisoetin A (2), quercetin-3-O- $\beta$ -D-glucopyranoside (3), (*E*)-*p*-coumaric acid (4), eugenol (5), eugenol, 1-acetate (6), chiakine (7), hexacosan-1',26'-dioate of bis[(2*S*), 2,3-dihydroxypropyl] (8), oleanolic acid (9), betulin (10), hopan-29-ol (11), hopan-30-ol (12), 22-hydroxyhopan-3-ol (13), and lupeol (14) (Figure 1) were all isolated from the fruit of *Albizia lebeck*. Unfortunately, only lebbeckisoetin A (2) and chiakine (7) were evaluated for their experimental antimicrobial activities. The antimicrobial activities of lebbeckisoetin A (2) and chiakine (7) were assayed against five microbial strains (fungal: *Candida albicans*, and bacteria: *Pseudomonas aeruginosa*, *Enterococcus faecalis*, *Escherichia coli*, and *Staphylococcus aureus*) (Leutcha et al. 2022). This theoretical study was undertaken in the framework to support and better understand the experimental results at the atomic level, and to expand the antimicrobial assays of the other compounds reported from *Albizia lebeck* that were not tested experimentally. The virtual screening of the antimicrobial activity performed on the crystal structure of sterol 14-alpha demethylase (CYP51) from *Candida albicans* in complex with the tetrazole-based antifungal drug candidate VT1161 (VT1) (PDB Id: 5TZ1) and the crystal structure of sterol 14-alpha demethylase (CYP51) from a pathogenic yeast *Candida albicans* in complex with the antifungal drug posaconazole (PDB Id: 5FSA) with natural compounds isolated from the fruit of *Albizia lebeck* have shown promising antimicrobial results. This is the first docking study using natural compounds as ligands with the 5TZ1 and 5FSA proteins. In addition, this survey has exhibited promising antifungal activities most of the docked compounds against *Candida albicans*.

## 2. Materials and Methods

### 2.1. General Experimental Procedures

The technical characteristics of the spectroscopic and spectrometric machines, as well as the experimental antifungal assays of the studied compounds, were already reported by Leutcha et al. (2022). ChemDraw 16.0 software was used for the firstly used to draw the study compounds and secondly in the preparation of the docked ligands, while Schrödinger 4.2.1 software (Maestro 4.2.1) was used for the second preparation of the ligands and for the final docking.

### 2.2. Plant Material, Extraction and Isolation, and Experimental Characterization

*A. lebeck* dry fruits were sampled in 2018 in Maroua city and identified by comparison with voucher specimen 58964/NHC in the Cameroon herbarium. The secondary metabolites theoretically studied here were all obtained from the

fruits of *Albizia lebeck*, a plant species of the Fabaceae family. The experimental antifungal assays, as well as all the reported compounds in this study, were obtained as previously reported by **Leutcha et al. (2022)**.

### 2.3. Docking Material

The *in silico* docking investigation was performed in order to have a better view and understanding of the binding interaction strength between the natural ligands and the proteins at the atomic level. So, the 3D crystal complex structures of the two proteins were directly downloaded from the Protein Data Bank (PDB) website. The crystal structure of sterol 14-alpha demethylase (CYP51) from *Candida albicans* in complex with the tetrazole-based antifungal drug candidate VT1161 (VT1) (PDB Id: **5TZ1**) and the crystal structure of sterol 14-alpha demethylase (CYP51) from the pathogenic yeast *Candida albicans* in complex with the antifungal drug posaconazole (PDB Id:**5FSA**) were used as proteins. The structures of the isolated compounds were firstly drawn and prepared in the "MDL SDFfile V3000 (\*.sdf)" format using ChemDraw 16.0. Secondly, the software Maestro Schrödinger 4.2.1 *Ligprep* module was used for the preparation of ligands. A receptor grid was generated around the co-crystallized ligands for both proteins, and the ligands were docked using the glide XP module. In addition, the protein preparation wizard was used for the protein preparation and minimization as reported by Zafar et al. (2023). Finally, to visualize and better understand the ligand-protein binding effects, the 3D and 2D docked poses were captured and examined.

### 2.4. Experimental Antimicrobial Assay

The experimental antimicrobial activities of lebeckisoetin A (**2**) and chiakine (**7**) were performed as reported by **Leutcha et al. (2022)** (Table S1). The microbial strains were collected from the American Type Culture Collection (ATCC): one yeast, *Candida albicans* ATCC 9028, and four bacteria: *Escherichia coli* (ATCC 25922), *Staphylococcus aureus* (ATCC 1026), *Enterococcus faecalis* (ATCC 29212), and *Pseudomonas aeruginosa* (ATCC 74117) (Table S1).

## 3. Results and Discussion

Computational or molecular docking drug design calls upon the calculation of the binding strength between two biological homologs, which are ligands and proteins. This manuscript deals with the computational investigation of some naturally isolated compounds. Therefore, quercitrin (**1**), lebeckisoetin A (**2**), quercetin-3-O- $\beta$ -D-glucopyranoside (**3**), (*E*)-*p*-coumaric acid (**4**), eugenol (**5**), eugenol, 1-acetate (**6**), chiakine (**7**), hexacosan-1',26'-dioate of bis[(2*S*), 2,3-dihydroxypropanone) (**8**), oleanolic acid (**9**), betulin (**10**), hopan-29-ol (**11**), hopan-30-ol (**12**), 22-hydroxyhopan-3-ol (**13**), and lupeol (**14**) (Fig. 1; Table 1) were all isolated from the fruit of *Albizia lebeck*. From all the above-listed compounds, only lebeckisoetin A (**2**) and chiakine (**7**) were experimentally assayed for their antimicrobial activities against five microbial strains (one fungal: *Candida albicans* and four bacterial: *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Enterococcus faecalis*) (Table S1) (**Leutcha et al. 2022**); the reason being the least quantities of most of the isolated compounds. This theoretical study was undertaken in the framework to support and better understand the experimental results at the atomic level, and to expand the antimicrobial assays of the other compounds reported from

*Albizia lebbek* that were not tested experimentally.

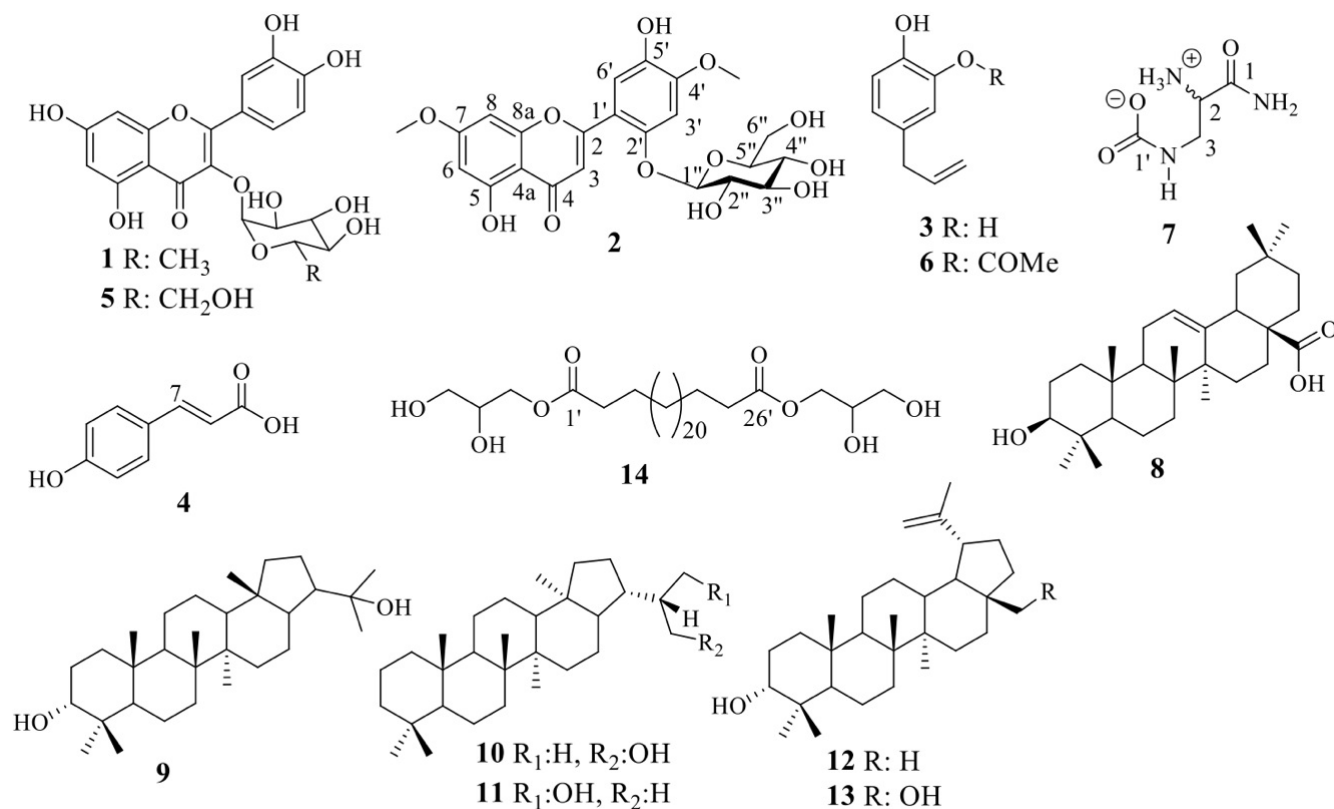
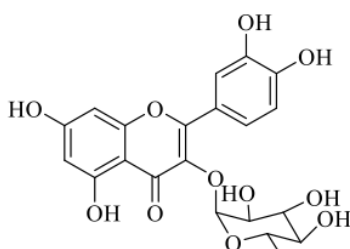
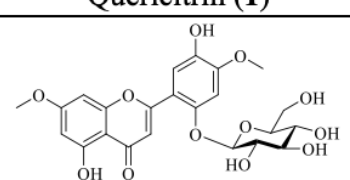
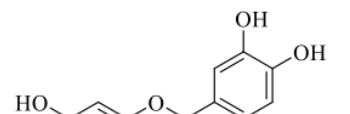
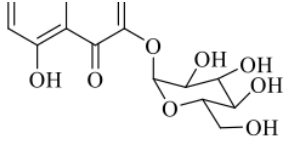
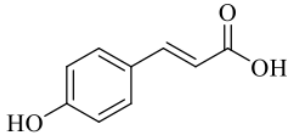
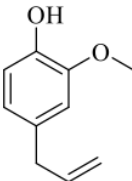
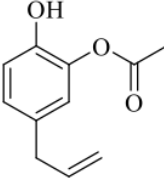
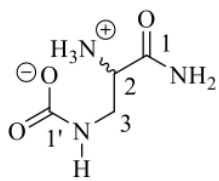
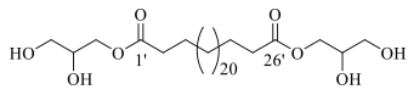
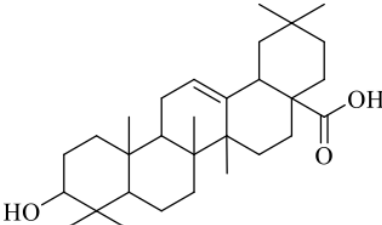
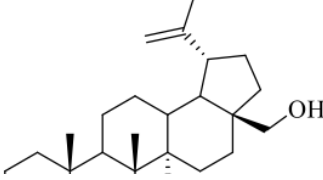
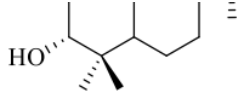
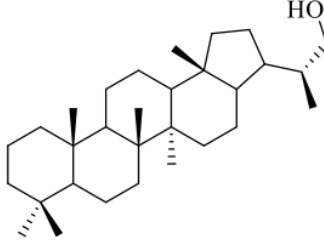
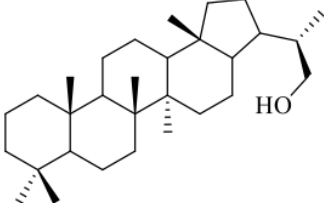


Figure 1. Structures of the docked compounds 1-14

Docked compounds and name	Docking score for <b>5TZ1</b>	Docking score for <b>5FSA</b>	Experimental result against <i>Candida albicans</i> ATCC 9028
 <b>Quercitrin (1)</b>	-7.892	-7.923	Not tested
 <b>Lebeckisoetin A (2)</b>	-7.815	-7.756	Tested with MIC value of 32 μg/mL
			

 <p>Quercetin-3-O-<math>\beta</math>-D-glucopyranoside (3)</p>	-5.528	-7.717	Not tested
 <p>(<i>E</i>)-<i>p</i>-coumaric acid (4)</p>	-5.786	-5.635	Not tested
 <p>Eugenol (5)</p>	-5.947	-5.717	Not tested
 <p>Eugenol, 1-acetate (6)</p>	-5.056	-5.256	Not tested
 <p>Chiakine (7)</p>	-3.516	-5.273	Tested with MIC value of 32 $\mu$ g/mL
 <p>Hexacosan-1',26'-dioate of bis[(2s), 2,3-dihydroxhpronane) (8)</p>	Docking score less than -2	-7.425	Not tested
 <p>Oleanolic acid (9)</p>	Docking score less than -2	-5.923	Not tested
	Docking score less than -2	-5.906	Not tested

 <p><b>Betulin (10)</b></p>	less than -2		
 <p><b>Hopan-29-ol (11)</b></p>	Docking score less than -2	Docking score less than -2	Not tested
 <p><b>Hopan-30-ol (12)</b></p>	Docking score less than -2	Docking score less than -2	Not tested

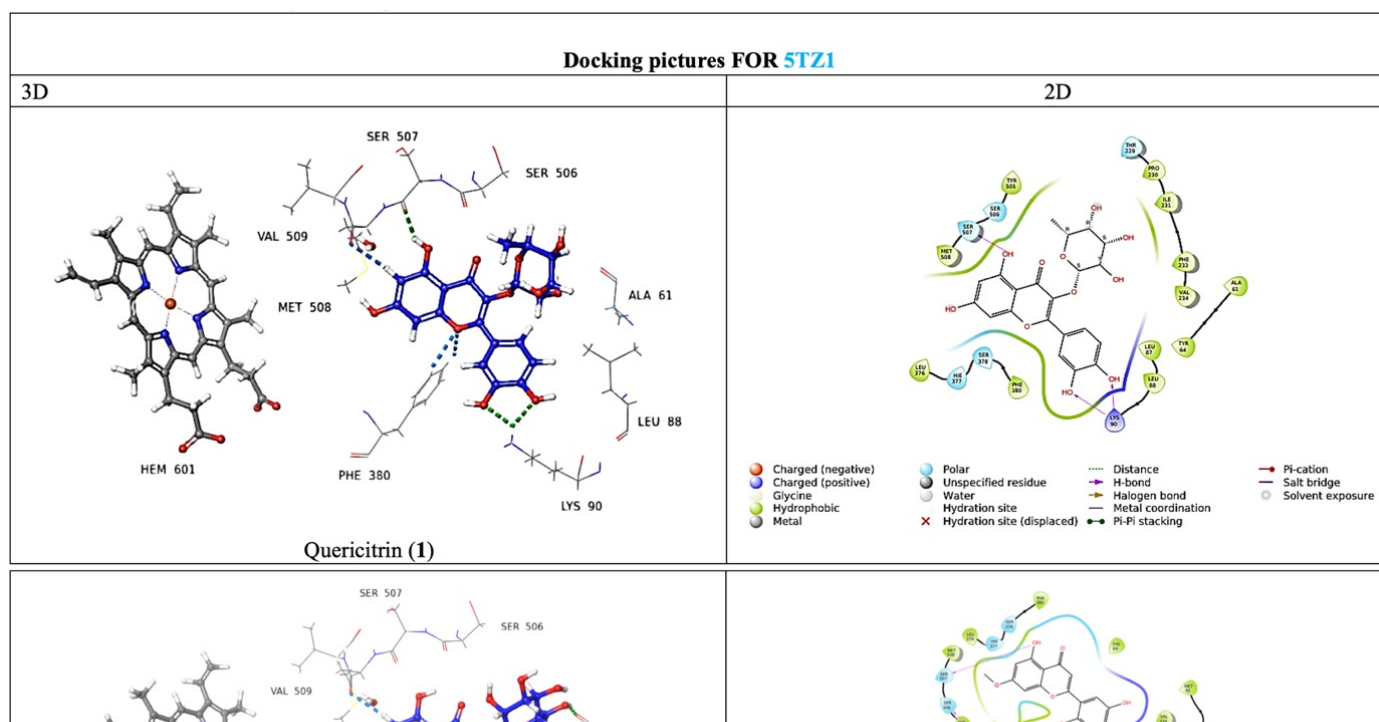
**Table 1.** Docking scores of 5TZ1 and 5FSA.

Tested yeast: *Candida albicans* ATCC 9028; Minimum Inhibitory Concentration (MIC); PDB ID: **5TZ1** (Title: Crystal structure of sterol 14-alpha demethylase (CYP51) from *Candida albicans* in complex with the tetrazole-based antifungal drug candidate VT1161 (VT1)); PDB ID: **5FSA** (Title: Crystal structure of sterol 14-alpha demethylase (CYP51) from a pathogenic yeast *Candida albicans* in complex with the antifungal drug posaconazole).

This experimental survey has exhibited promising antifungal activities of the two naturally isolated compounds against *Candida albicans* with an MIC value of 32 µg/mL (Leutcha et al. 2022). On the other hand, the most prevalent human yeast pathogen is *C. albicans* because it is always present throughout the entire mammalian life cycle (Hargrove et al. 2017). The cytochrome P450 enzyme [Sterol 14 $\alpha$ -demethylase (CYP51)] is the required enzyme used by eukaryotic cells in steroidal biosynthesis and is mostly targeted by antifungal clinical drugs (Hargrove et al. 2017). The X-ray crystal structure of *Candida albicans* CYP51 as a suitable complex agent for a docking study was previously reported by Hargrove et al. (2017). This is the first docking study performed on the 5TZ1 and 5FSA proteins using natural compounds as ligands. However, these two proteins were targeted for their *in silico* and *in vitro* antifungal activities against *C. albicans* (CYP51) (Gandham et al. 2024; Emami et al. 2023; Prakash & Kabir, 2022; Silva et al. 2022; Sari Kart, 2020; Lebouvier et al. 2020).

Before docking, the most stable conformation of the docked compounds was firstly searched, and after docking, some poses were also captured to better explain the ligand-protein interactions. Compounds (1-14) were docked for their antifungal potencies against the sterol 14-alpha demethylase (CYP51) from *Candida albicans* in complex with the tetrazole-based antifungal drug candidate VT1161 (VT1) (PDB Id: 5TZ1) and sterol 14-alpha demethylase (CYP51) from the pathogenic yeast *Candida albicans* in complex with the antifungal drug posaconazole (PDB Id: 5FSA). Compounds

(1-10) reveal interesting docking scores ranging from -7.923 to -3.516, while compounds (11-14) reveal docking scores less than -2 on the two proteins (5TZ1 and 5FSA) (Table 2 and S2). Generally, phenolic compounds were more potent, which may be due to their capacity to form H-bonds, aromatic interactions,  $\pi$ - $\pi$  interactions, and hydrophobic interactions, while other compounds were forming H-bonds, salt bridges, and hydrophobic interactions. In addition, quercitrin (1) (-7.892 and -7.923), lebbeckisoetin A (2) (-7.815 and -7.756), and quercetin-3-O- $\beta$ -D-glucopyranoside (3) (-5.528 and -7.717), which are all flavonoids, were the most active compounds against 5TZ1 and 5FSA, respectively (Table 1, 2, and S2). Compound (1) reveals at the atomic level the formation of H-bonds with Lys 90 and Ser 507, aromatic interactions with H<sub>2</sub>O 2045, Hie 377, Phe 380, and Val 509 and  $\pi$ - $\pi$  interactions with Phe 380, while compound (2) have established H-bonds with Lys 90, Ala 61, Ser 506, Ser 507, and Pro 230; aromatic interaction with Phe 233, Phe 380, and Met 508; and a  $\pi$ - $\pi$  interaction with Phe 233, and compound (3) was establishing H-bonds with Lys 90, Ser 507, Pro 210, and Leu; aromatic interactions with Phe 380 and Tyr 132, and  $\pi$ - $\pi$  interactions with Hie 377, Tyr 132, and Phe 126, and a metallic connection with HEM 601 (heme group), which supports their high docking scores. These results are in agreement with the experimental results assayed on the *C. albican* fungal strain. The interesting *in silico* and *in vitro* potencies of flavonoids against *C. albican* are not amazing. According to Silva et al. (2022), flavonoids are reported to have potent antifungal activities against *C. albican* with interesting docking scores. The moderate activities of eugenol derivatives (compounds 5 and 6) against the sterol 14-alpha demethylase (CYP51) of *C. albican* were in agreement with the reported data of Lima et al. (2020). Among all the non-phenolic compounds, hexacosan-1',26'-dioate of bis[(2S), 2,3-dihydroxypropyl] (8) has revealed the most interesting docking score of -7.425 on 5FSA; this might be due to its capacity to form a large number of H-bonds (H-bonds with Hie 120, ALA 117, Asp 225, Asp 502, Ser 507, Gly 303, and Pro 503). On the other hand, chiakine (7) was the only compound that established the salt bridge with Leu 124, Tyr 183, H<sub>2</sub>O 803, and HEM 601 at the atomic level, with a docking score of -5.273 on 5FSA. This might be due to its amphoteric structure. From the above mentions, it appears that 5FSA was more interactive with all the docked ligands as compared to 5TZ1.

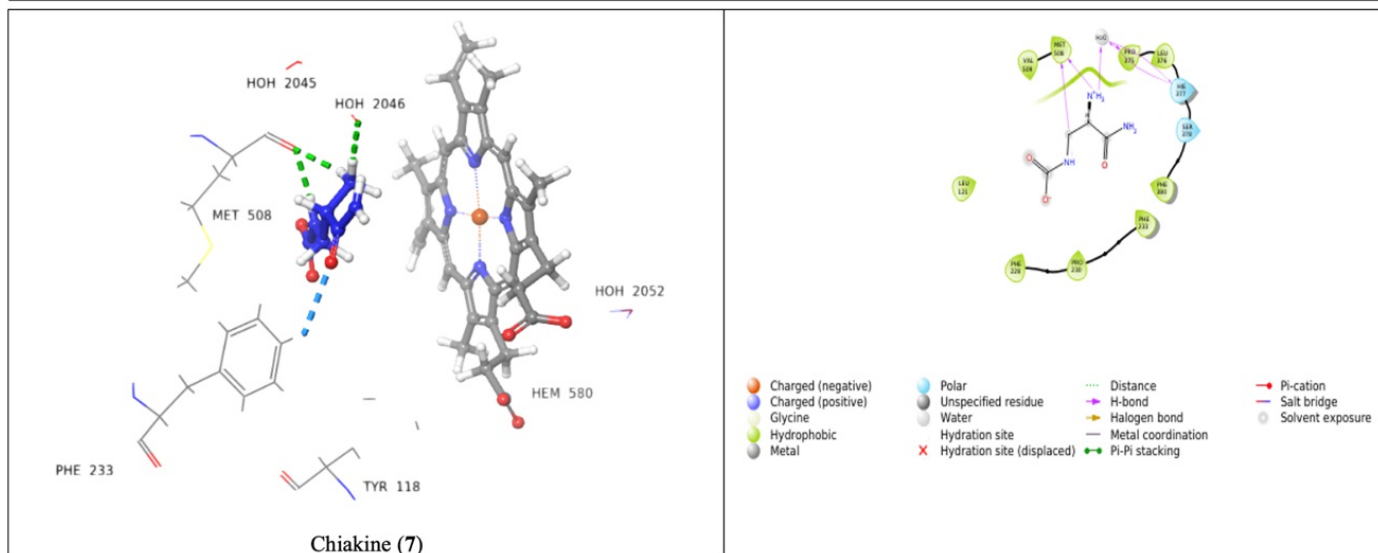
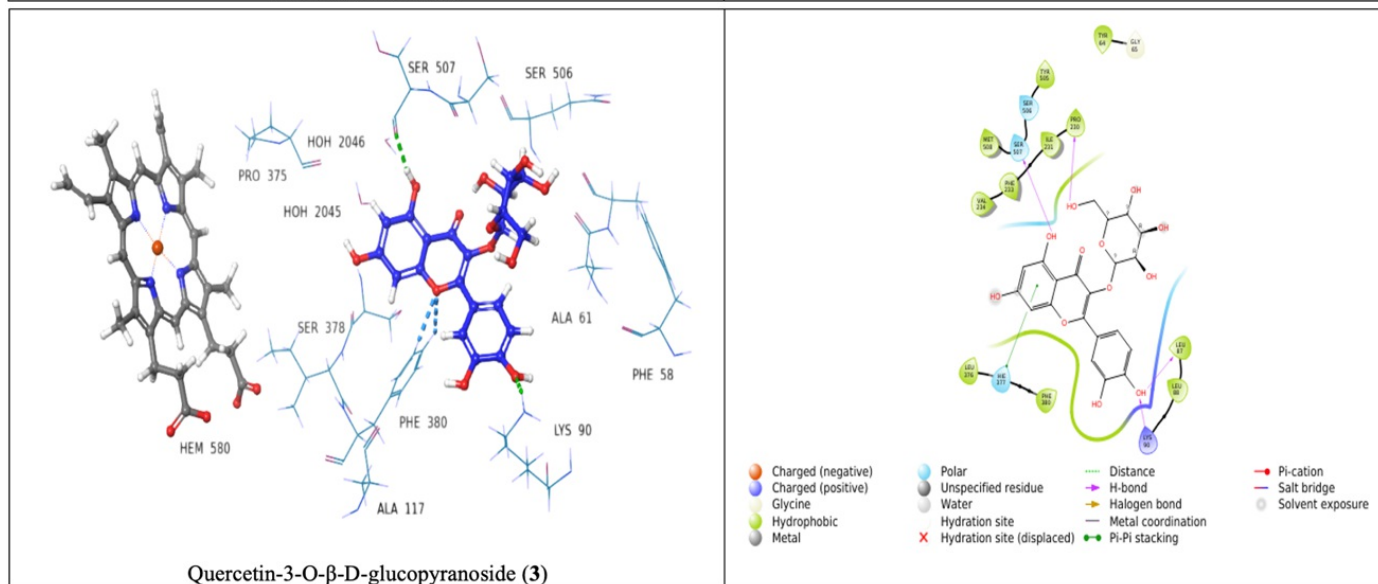
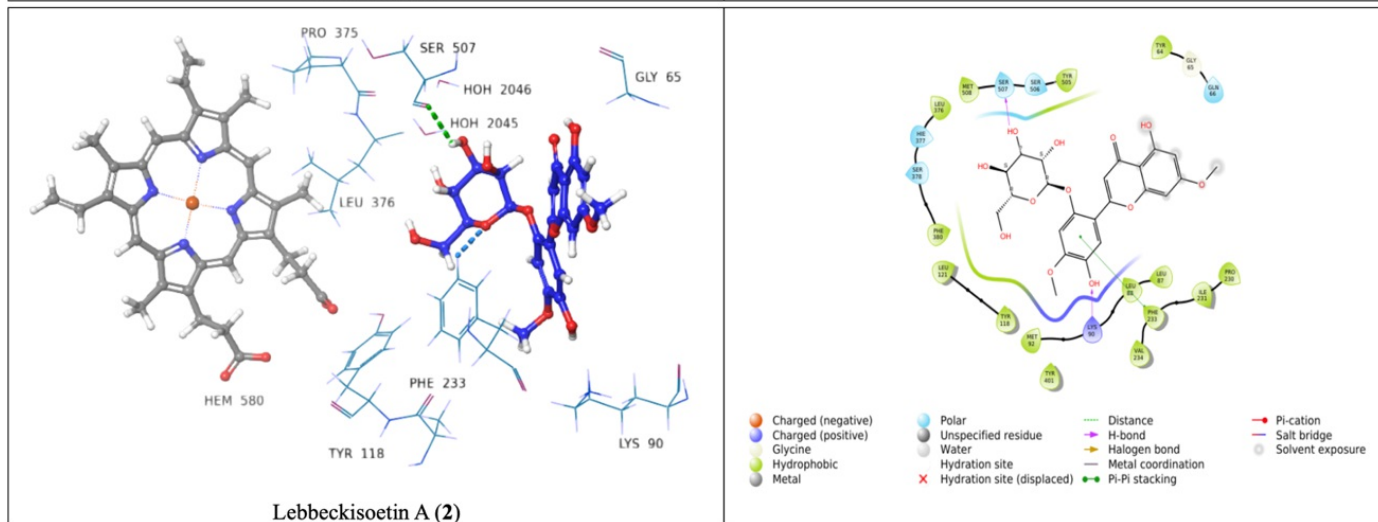
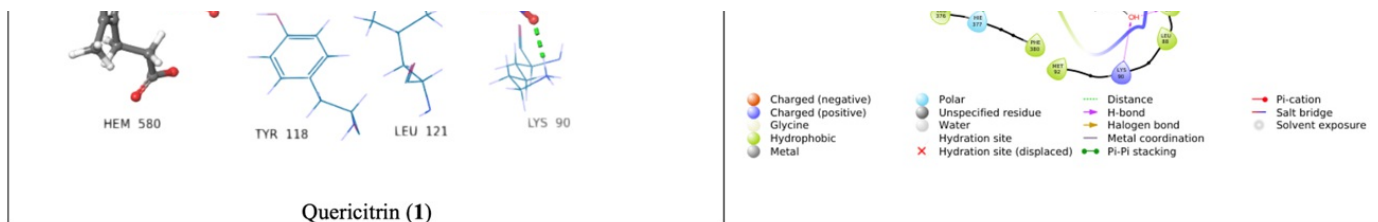




<p style="text-align: center;"><b>Lebeckisoetin A (2)</b></p>	
<p style="text-align: center;"><b>Quercetin-3-O-<math>\beta</math>-D-glucopyranoside (3)</b></p>	
<p style="text-align: center;"><b>Chiakine (7)</b></p>	

**Table 2a.** Interaction between ligands and proteins (5TZ1 and 5FSA)

<b>Docking pictures FOR 5FSA</b>	
3D	2D



**Table 2b.** Interaction between ligands and proteins (**5TZ1** and **5FSA**)

Like previous theoretical investigations undertaken on the above-listed compounds, we can report, to the best of our knowledge, that Quercitrin (**1**) was previously suggested for a docking study of its antioxidant capacity (Peng et al. 2023), while quercetin-3-O- $\beta$ -D-glucoopyranoside (**3**) was docked for its acetylcholinesterase activity (Hamdani et al. 2020) and for its inhibitory effects on human UDP-glucuronosyltransferase 1A isoforms (Zhang et al. 2021). Eugenol derivatives (**5** and **6**) were studied for their *in silico* potencies against breast cancer (Rasul et al. 2022), dynamic molecular simulation of antioxidant and antimicrobial activities (Abdou et al. 2022), and antifungal activity against *C. albicans* (Lima et al. 2020). Additionally, (*E*)-*p*-coumaric acid (**4**) was evaluated for its *in silico* and *in vitro* antibacterial and anticancer activities against lung cancer cell lines (Sathish et al. 2017), murine leukemia cell lines (Soekanto et al. 2021), antiparasitic activities against *Plasmodium falciparum* and *Leishmania braziliensis* (Lopes et al. 2020), type 2 diabetes, inflammatory, and  $\alpha$ -amylase activities (Huang et al. 2023). Oleanolic acid (**9**) was theoretically assayed for its inhibitory effect on N-myristoyl transferase towards antifungal agents (Guerrero-Perilla et al. 2015) and protein-Tyrosine phosphatase 1B (Ghosh et al. 2018), and for its potential to alleviate osteoporosis (Wu et al. 2021). While lupeol (**14**) was docked for its inhibitory antifungal potential on the CYP51 enzyme (Hassan et al. 2022), on cancer (such as Topoisomerase, Caspase-3, PTK, BCL-2, mTOR, PI3K, H-Ras, and AKT) (Gunasekaran et al. 2022), on its Alzheimer potency (Koirala et al. 2017), on mouse skin fibrosarcoma (WEHI-164) and human gastric carcinoma (AGS) cell lines (Ghoran et al. 2020), and on breast cancer (ER- $\alpha$  and HER2) (Pratama, 2018). And, betulin (**10**) was *in vitro* and *in silico* investigated for its antiproliferative effect against lung carcinoma (A549), human leukemia (CCRF/CEM and MV-4-11), melanoma (Hs 294T), prostate cancer (DU 145), and murine leukemia P388 cell lines (Chrobak et al. 2019) and also evaluated for its *in vitro* cytotoxic activity against human cancer cell lines (glioblastoma (SNB-19), amelanotic melanoma (C-32), and two breast cancers (MDA-MB-231 and T47D) (Chrobak et al. 2021)), on a series of monkeypox and SARS-CoV-2 proteins (Burkhanova et al. 2022), and for its alpha-glucosidase and alpha-amylase inhibitory activities (Gurupriya and Cathrine, 2021). To the best of our knowledge, this is the first docking investigation undertaken on lebeckisoetin A (**2**), chiakine (**7**), hexacosan-1',26'-dioate of bis[(2*S*), 2,3-dihydroxypropyl] (**8**), hopan-29-ol (**11**), hopan-30-ol (**12**), and 22-hydroxyhopan-3-ol (**30**).

Indeed, the virtual screening of the antimicrobial activity performed on the crystal structure of sterol 14-alpha demethylase (CYP51) from *Candida albicans* in complex with the tetrazole-based antifungal drug candidate VT1161 (VT1) (PDB Id: **5TZ1**) and the crystal structure of sterol 14-alpha demethylase (CYP51) from a pathogenic yeast *Candida albicans* in complex with the antifungal drug posaconazole (PDB Id: **5FSA**) or natural compounds isolated from the fruit of *Albizia lebeck* has shown promising antimicrobial results. In addition, this is the first docking of natural compounds used as ligands with the **5TZ1** and **5FSA** proteins.

## 4. Conclusion

The aim of this research was the computational investigation of the naturally isolated compounds against *C. albicans*, which is the most prevalent human yeast pathogen. This theoretical study was undertaken in the framework to better

understand the previous experimental results. So, the antifungal performed using **5TZ1** and **5FSA** as protein with fourteen natural compounds (**1-14**) reported from *Albizia lebbek* was in agreement with the experimental results.

## Statements and Declarations

### Conflicts of Interest

No financial or conflict of interests are declared by the authors.

### Authors' Contributions

Peron Bosco Leutcha conceptualized the study; Peron Bosco Leutcha and Humaira Zafar, methodology; Peron Bosco Leutcha, original draft preparation; Peron Bosco Leutcha, Serges Honoré Ediah Ngalaha, Humaira Zafar, Muhammad Iqbal Choudhry, Alain Meli Lannang, supervision, editing, and review.

### Data Availability

In the supplementary material, 2D and 3D poses of docking are available.

### Supplementary Materials

In the supplementary material, 2D and 3D poses of docking are available.

### Acknowledgments

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## References

- Abdou, A., Idouaaram, S., Salah, M., Nor, N., Zahm, S., El Makssoudi, A., & Dakir, M. (2022). Phytochemical study: molecular docking of eugenol derivatives as antioxidant and antimicrobial agents. *Letters in Organic Chemistry*, 19(9), 774-783.
- Afshari, F., & Muratçobanoğlu, B. (2023). Thermal analysis of Fe<sub>3</sub>O<sub>4</sub>/water nanofluid in spiral and serpentine mini channels by using experimental and theoretical models. *International Journal of Environmental Science and Technology*, 20(2), 2037-2052.
- Burkhanova, T. M., Krysanatieva, A. I., Babashkina, M. G., Konyaeva, I. A., Monina, L. N., Goncharenko, A. N., & Safin, D. A. (2022). In silico analyses of betulin: DFT studies, corrosion inhibition properties, ADMET prediction, and molecular docking with a series of SARS-CoV-2 and monkeypox proteins. *Structural Chemistry*, 1-12.

- Chen, Y., Xiao, H., Zheng, J., & Liang, G. (2015). Structure-thermodynamics-antioxidant activity relationships of selected natural phenolic acids and derivatives: An experimental and theoretical evaluation. *PLoS One*, *10*(3), e0121276.
- Chrobak, E., Jastrzębska, M., Bębenek, E., Kadela-Tomanek, M., Marciniak, K., Latocha, M., & Boryczka, S. (2021). Molecular structure, in vitro anticancer study and molecular docking of new phosphate derivatives of betulin. *Molecules*, *26*(3), 737.
- Chrobak, E., Kadela-Tomanek, M., Bębenek, E., Marciniak, K., Wietrzyk, J., Trynda, J., & Boryczka, S. (2019). New phosphate derivatives of betulin as anticancer agents: Synthesis, crystal structure, and molecular docking study. *Bioorganic Chemistry*, *87*, 613-628.
- Debbab, A., Aly, A. H., & Proksch, P. (2011). Bioactive secondary metabolites from endophytes and associated marine derived fungi. *Fungal Diversity*, *49*(1), 1-12.
- Emami, L., Zare, F., Zomorodian, K., Agha, M. S. N., & Sabet, R. (2023). Evaluation of Antimicrobial Activity of Some Hybrids of Pyrimidine-Azole Derivatives along with Molecular Docking Study. *Trends in Pharmaceutical Sciences*, *9*(3).
- Gandham, S. K., Kudale, A. A., Allaka, T. R., Chepuri, K., & Jha, A. (2024). New indazole-1, 2, 3-triazoles as potent antimicrobial agents: Design, synthesis, molecular modeling and in silico ADME profiles. *Journal of Molecular Structure*, *1295*, 136714.
- Ghasemi, J. B., Abdolmaleki, A., & Shiri, F. (2017). Molecular docking challenges and limitations. In *Pharmaceutical sciences: breakthroughs in research and practice* (pp. 770-794). IGI Global.
- Ghoran, S. H., Babaei, E., Seresht, H. R., & Karimzadeh, Z. (2020). Cytotoxic constituents and molecular docking study of the active triterpenoids from *Tripleurospermum disciforme* (CA Mey.) Schultz-Bip. *Jundishapur Journal of Natural Pharmaceutical Products*, *15*(2):e65760.
- Ghosh, P., Bagchi, B., & Bothra, A. K. (2018). Molecular docking and DFT based QSAR study on oleanolic acid derivatives as protein-tyrosine phosphatase 1B inhibitors. *J. Silico In Vitro*.
- Guerrero-Perilla, C., Bernal, F. A., & Coy-Barrera, E. D. (2015). Molecular docking study of naturally occurring compounds as inhibitors of N-myristoyl transferase towards antifungal agents discovery. *Revista Colombiana de Ciencias Químico-Farmacéuticas*, *44*(2), 162-178.
- Gunasekaran, M., Ravi, R., & Subramanian, K. (2022). Molecular docking analysis of lupeol with different cancer targets. *Bioinformation*, *18*(3), 134.
- Gurupriya, S., & Cathrine, L. (2021). Molecular docking studies of isolated compounds andrographolide and betulin from methanolic leaves extract of *Andrographis echinoides* as alpha-amylase and alpha-glucosidase activators. *International Journal of Applied Pharmaceutics*, 121-129.
- Hamdani, S., Ghomri, A., & Allali, H. (2020). Theoretical investigation of the inhibition activity of Some ginkgo biloba flavonoids derivatives toward acetylcholinesterase enzymes: Molecular Docking and DFT approach. *Journal of Fundamental and Applied Sciences*, *12*(1), 347-362.
- Hargrove, T. Y., Friggeri, L., Wawrzak, Z., Qi, A., Hoekstra, W. J., Schotzinger, R. J., & Lepesheva, G. I. (2017). Structural analyses of *Candida albicans* sterol 14 $\alpha$ -demethylase complexed with azole drugs address the molecular basis of azole-mediated inhibition of fungal sterol biosynthesis. *Journal of Biological Chemistry*, *292*(16), 6728-6743.

- Hassan, N. H., El-Hawary, S. S., Emam, M., Rabeh, M. A., Abdelmohsen, U. R., & Selim, N. M. (2022). Potential inhibitors of CYP51 enzyme in dermatophytes by red sea soft coral *Nephthea* sp.: In silico and molecular networking studies. *ACS omega*, 7(16), 13808-13817.
- Huang, Y., Condict, L., Richardson, S. J., Brennan, C. S., & Kasapis, S. (2023). Exploring the inhibitory mechanism of p-coumaric acid on  $\alpha$ -amylase via multi-spectroscopic analysis, enzymatic inhibition assay and molecular docking. *Food Hydrocolloids*, 139, 108524.
- Kaur, J., Katopo, L., Hung, A., Ashton, J., & Kasapis, S. (2018). Combined spectroscopic, molecular docking and quantum mechanics study of  $\beta$ -casein and p-coumaric acid interactions following thermal treatment. *Food Chemistry*, 252, 163-170.
- Koirala, P., Seong, S. H., Jung, H. A., & Choi, J. S. (2017). Comparative molecular docking studies of lupeol and lupenone isolated from *Pueraria lobata* that inhibits BACE1: Probable remedies for Alzheimer's disease. *Asian Pacific journal of tropical medicine*, 10(12), 1117-1122.
- Lebouvier, N., Pagniez, F., Na, Y. M., Shi, D., Pinson, P., Marchivie, M., & Le Borgne, M. (2020). Synthesis, optimization, antifungal activity, selectivity, and CYP51 binding of new 2-Aryl-3-azolyl-1-indolyl-propan-2-ols. *Pharmaceuticals*, 13(8), 186.
- Lepesheva, G. I., & Waterman, M. R. (2007). Sterol 14 $\alpha$ -demethylase cytochrome P450 (CYP51), a P450 in all biological kingdoms. *Biochimica et biophysica acta (BBA)-General subjects*, 1770(3), 467-477.
- Lepesheva, G., & R Waterman, M. (2011). Sterol 14 $\alpha$ -demethylase (CYP51) as a therapeutic target for human trypanosomiasis and leishmaniasis. *Current topics in medicinal chemistry*, 11(16), 2060-2071.
- Leutcha, B. P., Dzoyem, J. P., Jouda, J. B., Sema, D. K., Tsague Tankeu, V. F., Bitchagno, G. T. M.,... & Sewald, N. (2022). Antimicrobial and Cytotoxic Activities of Constituents from the Fruit of *Albizia lebbek* L. Benth (Fabaceae). *Molecules*, 27(15), 4823.
- Lima, J. A. C., Silva, J. F., Freitas, J. C. R., Caiana, R. R. A., Silva Júnior, J. P., & Oliveira, W. A. (2020). Synthesis, antifungal activity and molecular docking of eugenol derivatives. *Scientia Plena*, 16(5).
- Lopes, S. P., Yepes, L. M., Pérez-Castillo, Y., Robledo, S. M., & de Sousa, D. P. (2020). Alkyl and aryl derivatives based on p-coumaric acid modification and inhibitory action against *Leishmania braziliensis* and *Plasmodium falciparum*. *Molecules*, 25(14), 3178.
- Muhammed, M. T., & Aki-Yalcin, E. (2024). Molecular docking: principles, advances, and its applications in drug discovery. *Letters in Drug Design & Discovery*, 21(3), 480-495.
- Peng, W., Wang, N., Wang, S., Wang, J., & Bian, Z. (2023). Effects of microwave and exogenous l-phenylalanine treatment on phenolic constituents, antioxidant capacity and enzyme inhibitory activity of Tartary buckwheat sprouts. *Food Science and Biotechnology*, 32(1), 11-19.
- Prakash, S. M. U., & Kabir, M. A. (2022). Repurposing vilanterol as a novel potential antifungal for *Candida albicans*: In-silico & in-vitro approach. *Medicine in Drug Discovery*, 15, 100137.
- Pratama, M. R. F. (2018). Chemical structure optimization of lupeol as ER-A and HER2 inhibitor. *Asian J Pharm Clin Res*, 11(6), 298-303.
- Rasul, H. O., Aziz, B. K., Ghafour, D. D., & Kivrak, A. (2022). *In silico* molecular docking and dynamic simulation of

- eugenol compounds against breast cancer. *Journal of molecular modeling*, 28(1), 17.
- Rezaei, M. A., Li, Y., Wu, D., Li, X., & Li, C. (2020). Deep learning in drug design: protein-ligand binding affinity prediction. *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, 19(1), 407-417.
  - Santamouris, M., Xirafi, F., Gaitani, N., Spanou, A., Saliari, M., & Vassilakopoulou, K. (2012). Improving the microclimate in a dense urban area using experimental and theoretical techniques-The case of Marousi, Athens. *International Journal of Ventilation*, 11(1), 1-16.
  - Sari, S., & Kart, D. (2020). Design, synthesis, antifungal activity, and QM/MM docking study of twoazole derivatives with indole ring. *J. Res. Pharm*, 24(5), 1-12.
  - Sathish, M., Meenakshi, G., Xavier, S., & Sebastian, S. (2017). Conformational stability, TGA, and molecular docking investigations of p-coumaric acid with special relevance to anti-cancer and antibacterial activity. *Acta Physica Polonica A*, 131(6), 1512-1518.
  - Scalese, G., Mosquillo, M. F., Pérez-Díaz, L., & Gambino, D. (2024). Biosynthesis of ergosterol as a relevant molecular target of metal-based antiparasitic and antifungal compounds. *Coordination Chemistry Reviews*, 503, 215608.
  - Silva, A. F. D., Farias, J. R., Franco, D. C. G., Galiza, A. A., Motta, E. P., Oliveira, A. D. S., & Guerra, R. N. M. (2022). Anti-Candida albicans activity of ononin and other secondary metabolites from *Platonia insignis* MART. *Metabolites*, 12(11), 1014.
  - Soekamto, N. H., Firdausiah, S., Rasyid, H., Asmi, N., & Waelulu, M. (2021). Novel hydroxycinnamamide from morpholine and pyrrolidine: Synthesis, characterization, docking study, and anticancer activity against P388 leukemia murine cells. *Journal of Applied Pharmaceutical Science*, 11(1), 040-048.
  - Sultana, S., Hossain, M., Islam, M., & Kawsar, S. (2024). Antifungal potential of mannopyranoside derivatives through computational and molecular docking studies against *Candida albicans* 1IYL and 1AI9 proteins. *Current Chemistry Letters*, 13(1), 1-14.
  - Wu, Y., Gao, L. J., Fan, Y. S., Chen, Y., & Li, Q. (2021). Network pharmacology-based analysis on the action mechanism of oleanolic acid to alleviate osteoporosis. *ACS omega*, 6(42), 28410-28420.
  - Zafar, H., Anis, R., Hafeez, S., Aqeel Khan, M., Zehra Basha, F., Maslennikov, I., & Choudhary, M. I. (2023). Identification of Non-steroidal Aromatase Inhibitors via *In silico* and *In vitro* Studies. *Medicinal Chemistry*, 19(10), 986-1001.
  - Zhang, R., Wei, Y., Yang, T., Huang, X., Zhou, J., Yang, C., & Shi, S. (2021). Inhibitory effects of quercetin and its major metabolite quercetin-3-O- $\beta$ -D-glucoside on human UDP-glucuronosyltransferase 1A isoforms by liquid chromatography-tandem mass spectrometry. *Experimental and Therapeutic Medicine*, 22(2), 1-8.