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# The Inhibition of 15-Lipoxygenase by *Blechnum orientale* Leaves and its Glycoside-flavonoid Isolates: *In Vitro* and *In Silico* Studies

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**ABSTRACT**

**Fern is one of the groups of primitive plants rich in secondary metabolites that are commonly used to treat various diseases, including antioxidant, anti-hyaluronidase, anti-inflammation, and respiratory disease but less investigated. Flavonoid is one of the secondary metabolites abundantly present in ferns. This study aims to isolate major compounds found in *Blechnum orientale* act as 15-lipoxygenase (15-LOX) inhibitors. Inhibition of lipoxygenase decrease the production of leukotriene that induces bronchoconstriction in asthma. Isoquercitrin (Quercetin-3-O-β-glucopyranoside) and trifolin (kaempferol-3-O-β-D-galactoside) have been successfully isolated from *Blechnum orientale*. Further *in silico* study was performed to explain the binding mode between flavonoid pyranoside or galactoside and flavonoid aglycone in the 15-LOX cavity and their amino acid residues interaction. Isoquercitrin binds with Ile663, Ile400, Leu408, Leu597, Ala404, and Arg403 in the 15-LOX cavity as a lipoxygenase inhibitor. Trifolin binds the same amino acids as isoquercetin with addition His366, Gln596, and Phe175. Both isoquercitrin and trifolin act as competitive inhibitors against lipoxygenase enzymes.**

## 1. Introduction

Pteridophytes of ferns have been used for several purposes, particularly as an agent to cure diseases in folk medicines. *Blechnum occidentale* L., one of the ferns in Brazil, was used to cure inflammation, urinary infection, liver disease, and pulmonary disease (Nonato *et al.* 2009). Adiantum genus was used to cure respiratory problems such as dyspnea, cough, asthma, tuberculosis, and cleansing respiratory (Dehdari and Hajimehdipoor 2018; Hendawy 2021). *Dicranopteris linearis* is used for laxative and antibacterial in asthma in Kumaun Himalaya, while *Davallia solida* and *Microsorum scolopendria* were applied to relieve sore throat and asthma in Polynesia (Ho *et al.* 2010).

Asthma is one of the airway inflammatory diseases that commonly attack many people. The imbalance of enzymes induced over secretion of mediator inflammation such as leukotrienes. Leukotriene is a product of the lipoxygenase (LOX) pathway that functions as a proinflammatory mediator of bronchoconstriction in hypersensitivity diseases like asthma (Hallstrand and Henderson 2010). This leukotriene can be reduced by inhibiting the activity of lipoxygenase. In mammals, LOX is classified into 5, 8, 12, and 15. Enzyme 15-LOX is present in epithelial and non-epithelial cells and contributes to human airways injury (Mabalirajan *et al.* 2013; Elefteriadis and Dekker 2016). Since 15-LOX has a major role in airway inflammation regulation, novel 15-LOX inhibitors are pursued.

This study examines the extract and fraction of *Blechnum orientale* found in Indonesia as a 15-LOX inhibitor. The active fraction was further purified to isolate the major compounds of *Blechnum orientale*. In silico study was performed to get insight into the mechanism of isolate compound against 15-LOX.

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## 2. Materials and Methods

### 2.1. Materials

Dry leaves of *Blechnum orietale* were collected from Lembang, West Java, Indonesia. The specimens were authenticated at the Herbarium of School of Life Science and Technology, Bandung Institute of Technology, with identification number 3127/II.CO3/PP/2017.

Silica gel 60 (0.063-0.200 mm) was used as a stationary phase for column chromatography and silica gel 60 GF254 as a stationary phase for radial chromatography. TLC plates 60 F254 (0.25 mm), and all organic solvents were purchased from Merck. Quercetin marker, lipoxygenase lyophilized from soybean (Product number: L7395-15MU), and linoleic acid (Product number: L1376) as substrate were obtained from Sigma-Aldrich. The absorbance was recorded using Infinite® M200 Pro.

### 2.2. Extraction, Fractionation, and Purification

Two kilograms of dried powdered *Blechnum orientale* folium were extracted by maceration with ethanol 96% for three days. The liquid extract was evaporated under reduced pressure using rotavapor®. The ethanolic extract was partitioned by liquid-liquid extraction with *n*-hexane, ethyl acetate, ethanol, and water, respectively. The hexane fraction (35.88 g), ethyl acetate fraction (42.9 g), ethanol fraction (203.30 g), and water fraction (114.5 g) were examined to lipoxygenase inhibitory assay. The ethyl acetate fraction showed the highest activity as lipoxygenase inhibitor among other fractions and was further purified to isolate the major compounds present therein.

The ethyl acetate fraction (40 g) was fractionated by column chromatography with *n*-hexane and ethyl acetate (0→100%) followed by ethyl acetate and methanol (0→100%). Collected subfractions were monitored by TLC and combined based on the similarity spots profile on TLC and by spraying with 10% sulfuric acid in methanol solution followed by heating. TLC plates were developed in *n*-hexane-ethyl acetate (8:2). One hundred milligrams of subfraction were purified using radial chromatography with 1 mm thickness of silica gel and eluted with ethyl acetate and methanol (0→100%), leading to two subfractions, A and B. Further purification was done by recrystallization with cosolvent ethyl acetate and methanol, yielding isolate 1 (12.1 mg) and isolate 2 (11.9 mg) from each subfraction.

The 1D dan 2D data of NMR spectra $^{1}H$ (500 MHz) and $^{13}C$-NMR (125 MHz) were measured with Agilent® VNMR D2 using methanol-D4. The isolate was also identified on Liquid Chromatography-Mass Spectrometry (LC-MS) equipped with C-18 column (15 x 1 mm) and methanol as the solvent. Volume injection of the sample was five µl, and the flow rate was 0.1 ml/minute with ESI positive ionization.

### 2.3. Inhibition of 15-Lipoxygenase Assay

Enzyme inhibitory assay was measured as described previously by Lyckander and Malterud (1992). Every well contain 2.5 µl of sample mixture with borate buffer pH 9 (0.2 M), 15-LO enzyme (200 U/ml), and 100 µl of linoleic acid (134 µM) as substrate. The absorbance was analyzed at λ 234 nm with quercetin as reference and DMSO as the blank. The $IC_{50}$ values were determined by nonlinear regression from the GraphPad version 9 free trial. The $IC_{50}$ of inhibition lipoxygenase was presented as mean ± SD (n = 3), and the $IC_{50}$ values were calculated as follow:

% inhibition = [(Absorbance control - absorbance sample) / Absorbance control] x 100%

### 2.4. Molecular Docking Study

Isolate A and B from *Blechnum orientale* were examined for lipoxygenase inhibitor activity using in silico with the parameters binding energy and binding pose. Crystallography of 15-lipoxygenase from rabbit (PDB: 1LOX) was downloaded from the Protein Data Bank while the isolated structures were obtained from ZINC database (Isoquercitrin ZINC4096845 and Trifolin ZINC4654800). Chimera was used to prepare the protein and the ligands by adding the hydrogens atoms and standard charges before running the DOCK6. Particularly in the protein, the spheres within a radius of 10 Å from every atoms of the native ligand was defined as the active site and the box for docking simulation was set to 5 Å. Meanwhile, the other paramaters were kept as default values. At the end, flexible docking was executed to obtain binding mode and grid score of the ligands against the protein. To determine the accuracy of the binding mode of this docking protocol, native ligand redocking was performed to calculate its RMSD value.

## 3. Results

### 3.1. Isolation

Isolate 1 was yellowish amorf powder; $C_{21}H_{20}O_{12}$, LCMS–ESI *m/z*:487 [M+Na]$^+$, $^1$H-NMR (δ in ppm and J in Hz) 6.19 (1H, *d*, J = 1.7, H-6), 6.39 (1H, *d*, J = 1.7, H-8), 7.84 (1H, *d*, J = 1.6, H-2'), 6.86 (1H, *d*, J =8.5, H-5'), 7.63 (1H, *dd*, J =8.5, 1.6, H-6'), 5.17 (1H, *d*, J = 7.6, H-1"), 3.42 (1H, *m*, H-2"), 3.48 (1H, *m*, H3"), 3.35 (1H, *m*, H-4"), 3.22 (1H, *m*, H5"), 3.53 (1H, *m*, Ha-6"), 3.64 (1H, *m*, Hb-6"); $^{13}$C-NMR:158.9 (C-2), 135.9 (C-3), 179.6 (C-4), 163.2 (C-5), 100.0 (C-6), 166.3 (C-7), 94.8 (C-8), 158.6 (C-9), 105.8 (C-10), 123.2 (C-1'), 116.2 (C-2'), 145.9 (C-3'), 150.1 (C-4'), 117.6 (C-5'), 123.3 (C-6'), 105.5 (C-1"), 75.8 (C-2"), 78.5 (C-3"), 71.3 (C-4"), 78.2 (C-5"), 62.6 (C-6"). Identification $^1$H-NMR and $^{13}$C-NMR with previous NMR data resulting that isolate 1 was isoquercitrin (Quercetin-3-O-β-glucopyranoside).

Isolate 2 was also yellowish amorf powder; $C_{21}H_{20}O11$, LCMS–ESI *m/z*:447 [M-H]-, $^1$H NMR (δ in ppm and J in Hz) 6.21 (1H, *d*, J = 1.9, H-6), 6.44 (1H, *d*, J = 1.9, H-8), 8.07 (2H, *d*, J =8.8, H-2' and H-6'), 6.87 (2H, *d*, J = 8.8, H-3' and H-5'), 5.40 (1H, *d*, J = 7.5, H-1"), 3.53 (1H, *m*, H-2"), 3.34 (1H, *m*, H3"), 3.61 (1H, *m*, H-4"), 3.22 (1H, *m*, H5"), 3.60 (1H, *m*, Ha-6"), 3.71 (1H, *m*, Hb-6"); $^{13}$C NMR:156.8 (C-2), 133.7 (C-3), 178.0 (C-4), 161.7 (C-5), 98.6 (C-6), 164.6 (C-7), 94.1 (C-8), 156.8 (C-9), 103.6 (C-10), 121.3 (C-1'), 131.0 (C-2' and C-5'), 114.8 (C-3' and C-5'), 160.4 (C-4'), 103.5 (C-1"), 71.7 (C-2"), 73.7 (C-3"), 68.7 (C-4"), 75.8 (C-5"), 60.6 (C-6"). According to $^1$H-NMR and $^{13}$C-NMR our result similar with trifolin (kaempferol-3-O-β-D-galactoside). The structures of isolated compounds were displayed in Figure 1.

### 3.2. Molecular Docking Study

The value of root means square deviation (RMSD) between the native ligand and re-docking ligand was 0.75 Å, indicating that the docking protocol was accurate (Figure 2). Based on the docking pose, the native ligand and quercetin as aglycone were on the right side of cofactor Fe while the addition of glycosides of isoquercitrin and trifolin caused them to move to the left side of Fe. We assumed from the docking pose that quercetin has a binding mode similar to that of the native ligand but quite different with isoquercitrin and trifolin, although they also have flavonoid rings.

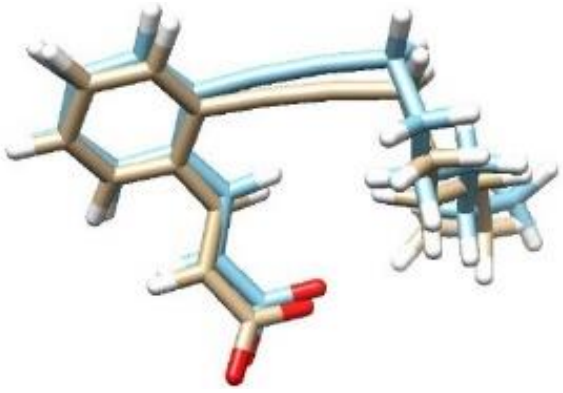
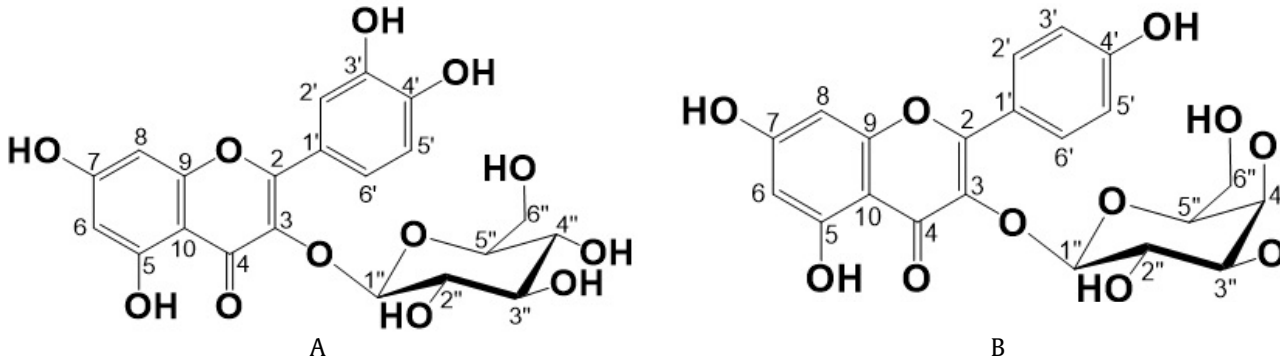


Figure 2. Superimposed native ligand and re-docking ligand in 15-LOX (PDB:1LOX)




A B

Figure 1. The structure of (A) isoquercitrin (Quercetin-3-O-β-glucopyranoside) and (B) trifolin (Kaempferol-3-O-β-D-galactoside)

## 4. Discussion

Arachidonic acid (AA) is a fatty acid in the phospholipids membrane cell and metabolized by two enzymes, cyclooxygenase producing prostaglandins and 5-lipoxygenase producing leukotrienes. Two of these are mediators of inflammation in asthma bronchial. Lipoxygenase is categorized into three types such as 5, 12, and 15-lipoxygenase. Amino acid sequences and biochemical characteristics of 15-LOX in reticulocyte of rabbit and LOX found in plant are similar thus can be applied to search compounds acting as anti-inflammation such as rheumatoid arthritis and asthma (Litalien and Beaulieu 2011; Sroka *et al.* 2017).

Lipoxygenase inhibitor from *Blechnum orientale* in this study revealed that the ethanol extract and ethyl acetate fraction were 196.30 ppm and 129.40 ppm, respectively. The $IC_{50}$ of quercetin as reference was 31.94 ppm. Higher activity of ethyl acetate fraction compared to the other fractions led us to isolate two similar major flavonoids compounds that act as lipoxygenase inhibitor which were identified as isoquercitrin and trifolin.

The $IC_{50}$ value of quercetin isolated from the waste of leaves and shoots of garlic as lipoxygenase inhibitor was 16.9 µM while reynautrin and isoquercitrin, the quercetin pyranoside, were 32.9 and 40.1 µM. The $IC_{50}$ of kaempferol aglycone was 54.4 µM and astragalin, the kaempferol glucoside, was 78.3 µM (Kim *et al.* 2005). The $IC_{50}$ value profile of flavonoid isolated by Kim *et al.* (2005) revealed that flavonoids aglycones have lower $IC_{50}$ value compared to their pyranosides or galactoside, thus higher activity of inhibitor lipoxygenase.

Since our two isolates were also flavonoid pyranoside and galactoside similar to that of flavonoids isolated by Kim *et al.* (2005) it is interesting to study the position of interaction between flavonoid glycosides and the amino acids in 15-LOX compared to the aglycone. The interaction profile of isoquercitrin and trifolin in 15-LOX were performed using DOCK6. According to docking visualization it was revealed that the binding mode between two isolates, isoquercitrin and trifolin showed differences with the aglycone quercetin which was reported as lipoxygenase inhibitor by Kim *et al.* (2005). Quercetin has binding mode similar with native ligand surrounded cofactor Fe (Figure 3).

Naturally, Fe in lipoxygenase enzyme in mammals was surrounded by 6 ligands which consisted of 4 residues histidine (His361, His366, His 541, His545), carboxylic group of the C-terminus of Ile663, and water that form octahedral geometry (Gillmor *et al.* 1997; Kuban *et al.* 1998). Lipoxygenase inhibitors can prevent catalytic process by binding or blocking one or two ligands surrounded Fe. According to our in-silico prediction, quercetin works as inhibitor lipoxygenase by replacing water and interacting His366. From Figure 4, it also revealed that quercetin form hydrogen bond with Gln548 residues. Guo *et al.* (2019) reported that the most active indole derivates to inhibit lipoxygenase enzyme has hydrogen bond with Gln548.

Two isolates, isoquercitrin and trifolin, have the basic structure of flavonoid but the addition of pyranoside or galactoside induce these structures more polar. The increasing of this polarity followed by the changing position of those two isolates in order to align with Fe. Therefore, isoquercitrin and trifolin is no longer in the same quadran as well as native ligand and quercetin which was dominated with hydrophobic area (Guo *et al.* 2019). In ethyl acetate fraction the $IC_{50}$ value higher than quercetin as the consequences there are many compounds medium polarity extracted with ethyl acetate. In order to align with Fe as the axis, isoquercitrin and trifolin lost their ability to form hydrogen bond with Gln548. Although isoquercitrin and trifolin have lost their ability to bind with Gln548, they still can form

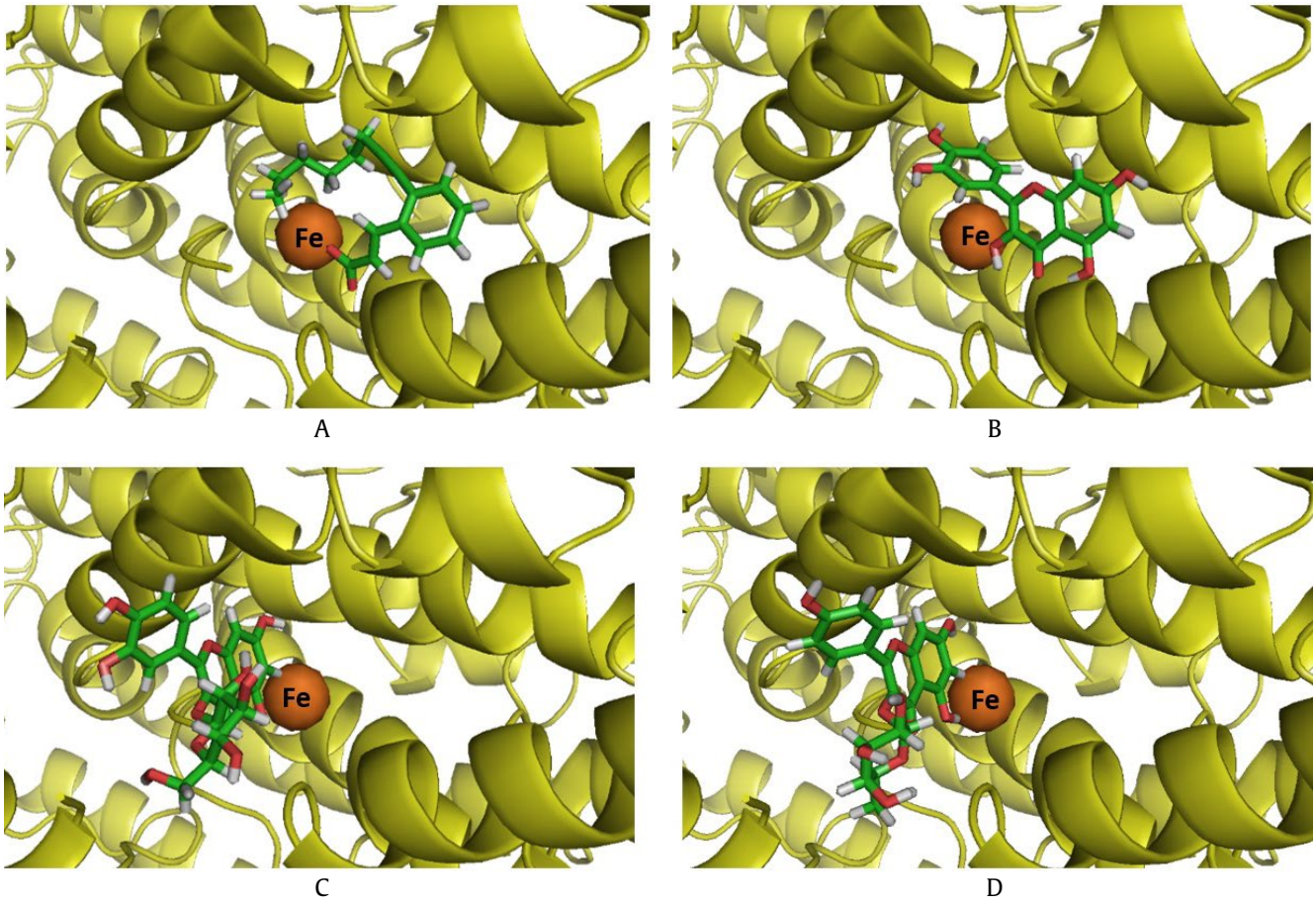



Figure 3. Docking pose of (A) native ligand (B) quercetin (C) isoquercitrin (D) trifolin

hydrogen bond with C-terminal Ile663 residue. In addition, isoquercitrin can form hydrogen bond with Arg403 while trifolin with Gln596. The comparison similarity of amino acid residues for native ligand, quercetin, isoquercetin, and trifolin are summarized in Table 1 and the percentage was calculated based on the native ligand.

Our prediction in-silico results in line with Kim *et al.* (2005) that the addition of sugar moiety in flavonoid especially isoquercitrin and trifolin change the binding mode thus lower their potency to inhibit lipoxygenase enzyme. The future study will be focused on other flavonoid isolates since our study only apply to two isolates. It is also interesting to look insight the pattern of other active compounds such as steroid and terpenes derivates, anthraquinones, coumarin, and more in their aglycone or glycone structure.

In conclusion, in this study, ethyl acetate fraction has higher activity to inhibit lipoxygenase compared to the ethanol extract. From the ethyl acetate fraction, isoquercitrin and trifolin were successfully isolated. According to our in-silico prediction the addition of pyranoside or glucoside not only interfere the binding position but also reduce their ability as lipoxygenase inhibitor.

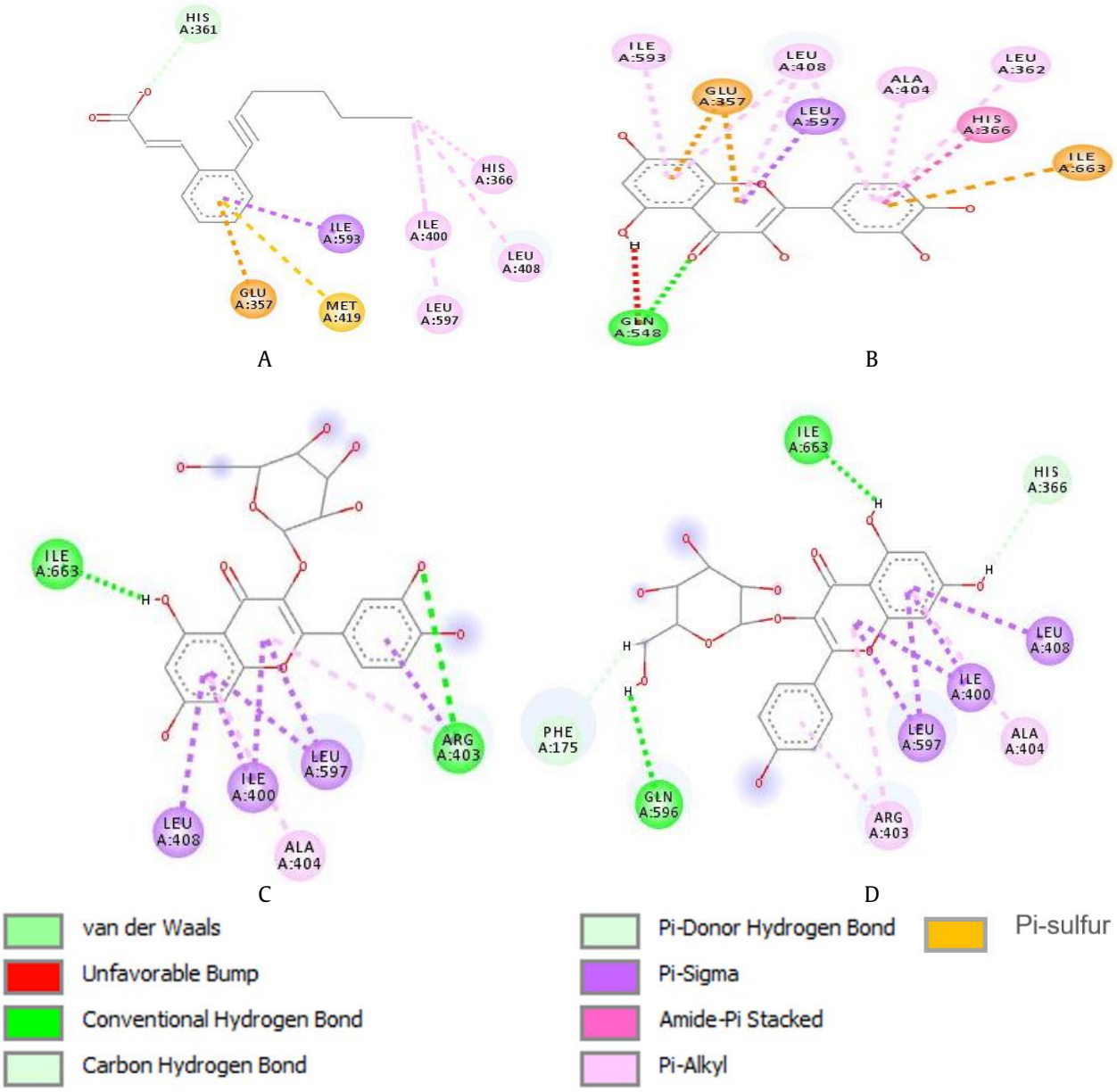



Figure 4. Amino acid interaction of (A) native ligand (B) quercetin (C) isoquercitrin (D) trifolin in 15-LOX cavity

Table 1. Amino acids residues of native ligands, quercetin, isoquercitrin, and trifolin in 15-LOX

| Ligands | Amino acid residues | | | | | | | | | | | | | | Similarity % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Glu 357 | Met 419 | Ile 663 | Ile 400 | Ile 593 | Leu 362 | Leu 408 | Leu 597 | His 366 | Ala 404 | Gln 548 | Arg 403 | Gln 596 | Phe 175 | |
| Native ligand | + | + | | + | + | | + | + | + | | | | | | 100.00 |
| Quercetin | + | | + | | + | + | + | + | + | + | + | + | | | 71.43 |
| Isoquercitrin | | | + | + | | | + | + | | + | | + | | | 42.86 |
| Trifolin | | | + | + | | | + | + | + | + | | + | + | + | 57.14 |

## Conflict of Interest

There are no conflict of interest.

## Acknowledgements

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