A CONCISE OVERVIEW ON HETEROCYCLIC COMPOUNDS EXHIBITING PESTICIDAL ACTIVITIES

Shailendra Yadav¹, Sushma Singh¹ and Chitrasen Gupta²

1. Department of Chemistry, Faculty of Basic Science, AKS University, Satna(M.P.) 485001, India.
2. Department of Chemistry, Kutir P.G.College Chakkey, Jaunpur(U.P.) 222146, India.

Manuscript Info

Manuscript History
Received: 30 June 2021
Final Accepted: 31 July 2021
Published: August 2021

Key words:- Antimicrobial, Biological activities, Heterocyclic compounds, Pesticide

Abstract

Heterocyclic compounds are numerous and diverse group of organic compounds. Heterocycles are abundantly found in nature and express various physiological properties. Heterocycles are intricately linked to all aspects of life. There are many heterocyclic compounds currently known, and the number is constantly rising owing to extensive synthetic development and their applications. Heterocyclic compounds are used significantly in a number of areas, including biochemistry and medicinal chemistry, and some others. They are predominantly synthesized in agrochemical and pharmaceutical industries due to their potential biological activities. This review article focuses on recently synthesized heterocyclic compounds and their different pesticidal activities such as antifungal, antibacterial, antiviral, nematocidal, insecticidal, acaricidal, and herbicidal.

Introduction:

Heterocyclic compounds, especially the 5 & 6 membered compounds of one, two or three heteroatoms in their nucleus, play an important role in the metabolism of all living organisms. However, the compounds existing with 7 or more membered heterocyclic compounds are equally effective. Heterocyclic compounds may be fused or independent heterocyclic structures, as they exist in genetic material like purine and pyrimidine. Most drugs fall under the category of heterocyclics and possess physiological role in living organism.

Pesticides are effective resources in agriculture for protecting crops, increasing yield, and improving efficiency. Chemical pesticides have shown their value by boosting worldwide agricultural production, decreasing endemic illnesses, insect-borne, and protecting forests, plantations, houses, harvested wood products, and fibre. The necessity to boost global food production in order to feed the world's rapidly increasing population is widely understood. Effective pest management is one of the methods for increasing agricultural output since pest infestation accounts for more than 45 percent of yearly food production. Crop loss is much worse in tropical nations because the high temperatures and humidity encourage pests to multiply quickly. In order to fight pests and vector-borne illnesses, a broad range of pesticides must be applied to agricultural plants in the tropics.

According to many review of the literature, a variety of heterocyclic compounds with a condensed ring structure exhibit a wide range of physiological activities in different ways. Several antifungal [1,2], antibacterial [3,4], and herbicidal [5,6]
properties have been shown for condensed N-benzylidene and triazolo-pyrimidines derivatives. The different pesticidal activities are shown in figure 1.

Types of heterocyclic compounds: It is hard to mention all heterocyclic compounds due to their very large number, however a general classification of heterocyclic compounds on the basis of types of hetero atom present in the ring is given in Table: 1.

Table-1: - A general classification of heterocyclic compounds.

| Sn. | Heterocyclic compounds | Types | Pesticidal activity |
|-----|------------------------|-------|---------------------|
| 1.  | Nitrogen Heterocyclics |       | They show specially insecticidal, herbicidal, fungicidal activity. Most of drugs belongs to these types. |
| 2.  | Oxygen Heterocyclics   |       | Shows potential herbicidal, antifungal, antibacterial activity |
|   |     |                                                                 |
|---|-----|-----------------------------------------------------------------|
| 3. | Sulphur Heterocycles | Shows herbicidal, insecticidal, fungicidal and other pesticidal activity given in Fig.1 |
| 4. | Nitrogen and oxygen heterocycles | Shows herbicidal, insecticidal and other biological activity |
| 5. | Sulphur and nitrogen heterocycles | They are good insecticides, herbicides and most of agrochemical belongs to this category. |
| 6. | Miscellaneous | Shows all the pesticidal activity. |
and derivatives of these and other heterocyclics containing 3, 4, 5, 6, 7, 8-member ring with one hetero atom or more than one heteroatom

Figure 1: Types of pesticidal property.

Antifungal activity
Lukowska-Chojnacka et al. (2016) [7] utilized phenylsulfonyl moiety and prepared new derivatives of 2,5-disubstituted tetrazole (Figure 2). The synthesized derivatives showed excellent in-vitro antifungal activity towards A. niger, F. oxysporum, F. sambucinum, and C. coccodes, according to bioassay findings. Only C. coccodes did not showed much inhibition against all the target derivatives tested. However, all the target derivatives worked against C. albicans at the same level and showed significant cell development inhibition (97–99 percent) at doses oscillating between 0.03 to 15 g/mL, which remained less as compared to amphotericin B.

Figure 2: Compound 1.
Xu et al. (2017) [8] used “[1,2,4] triazolo[4,3-a] pyridine” moiety to synthesize a variety of new sulfone compounds and tested them towards H. maydis, R. cerealis, R. solani, and F. graminearum. The bioassay findings showed that “8-chloro-3-((2,6-difluorobenzyl)sulfonyl)-[1,2,4]triazolo[4,3-a]pyridine” (compound 2) had excellent in-vitro antifungal activity towards H. maydis and R. cerealis at (50 g/ml), with reserverates of 76.4 and 78.6 percent, respectively.

Molnar et al. (2017) [9] created a variety of derivatives of dipicolinic acid (Figure 4), some of which exhibited antifungal property towards Aspergillus ochraceus, Aspergillus flavus, Fusarium verticillioides, and Fusarium graminearum fungal species.

Chitra et al. (2017) [10] produced biopolymeric hydrogels (Compound 4) with indole 3-acetic acid, which showed antifungal efficacy towards Rhizopus oryzae, Aspergillus fumigates, and Candida albicans at various doses utilizing Dimethyl Sulfoxide as a negative control and ketoconazole as a positive control.

Muslim RF et al. (2018) [11] created novel disubstituted 1,3-oxazepine-5-one heterocyclic compounds (Figure 6). Azomethine compounds (N1-N5) were created by reacting aromatic aldehydes with primary aromatic amines in 100% ethanol using glacial acetic acid as a catalyst. In general, N9 is the best derivative, with a substantially (p<0.01) greater effect on Candida sp. growth inhibition.
Hua et al. (2020) [12] produced a variety of new aromatic amide derivatives with a sulfone substructure. The target compounds have lower antifungal activity than fluopyram towards \textit{A. kikuchiana \textit{Tanaka}, B. \textit{cinerea}, C. \textit{capsica}, C. \textit{circumscissa}\textit{Sacc.}, G. \textit{zeae}, P. \textit{piricola}, P. \textit{vexans} and \textit{R. solani}}, according to bioassay findings.

Sol Ballari et al. (2019) [13] synthesized many new derivatives of 2-(benzylsulfonyl)benzothiazole (Figure 8). The derivatives obtained were subjected to bioassays and the findings revealed that several derivatives had good antifungal activity towards \textit{A. niger}, \textit{A. ustus}, \textit{A. terreus}, \textit{A. fumigatus}, \textit{B. cinerea}, and \textit{F. oxysporum}. Compound (7a) demonstrated the best antifungal activities towards \textit{A. terreus} and \textit{B. cinerea}, with EC50 values of 0.3 and 4 M, respectively, when compared to captan, whereas compound (k) demonstrated healthy antifungal activities towards \textit{A ustus A. niger}, and \textit{A. fumigatus}, in EC50 standards of 14, 6.3, and 2.3 μM.

YandD et al. (2021) [14] synthesized the \"(E)-3-acyl-5-(methoxyimino)-1,5- dihydrobenzo[e][1,2]oxazepin-4(3H)-one\" (compound 8) analogues and thoroughly investigated the antifungal activities. 5r was shown to be very effective towards \textit{B. \textit{cinerea}} and \textit{S. sclerotiorum}. \"(E)-3-(4-(dimethylamino)benzoyl)-5- (methoxyimino)-1,5- dihydrobenzo[e][1,2]oxazepin4(3H)-one\" showed excellent antifungal activity towards \textit{S. sclerotiorum} and \textit{B. \textit{cinerea}}.
Antibacterial Activity
Li et al. (2014) [15] produced a variety of derivatives “2,5-disubstituted-1,3,4-thiadiazole/oxadiazole” (Figure 10). “2-(Methyl sulfonyl)-5-(4-fluorobenzyl)-1,3,4-oxadiazole” had the greatest in-vitro antibacterial activity towards Xoo, Xac, & Xoc, with EC-50 standards of 1.23, 7.14, and 1.07 g/mL, respectively. The EC50 values were found to be better than bismerthiazol, thiodiazole and kocide 3000. However, in-vivo antibacterial activity testing in greenhouse settings revealed that “2-(Methyl sulfonyl)-5-(4-fluorobenzyl)-1,3,4-oxadiazole” had superior control of rice bacterial leaf blight of rice bismerthiazol and thiodiazole copper. Furthermore, “2-(Methyl sulfonyl)-5-(4-fluorobenzyl)-1,3,4-oxadiazole” showed best potential to decrease the illness of “citrus canker” in fruits and leaves in a field trial towards citrus canker in 2 different locations when compared to a control and the profitable bactericidethiodiazole copper and kocide 3000.

Figure-10:- Compound 9

Wu et al. (2016) [16] utilized 1,3,4-thiadiazole/oxadiazole moiety to synthesize variouspurine derivatives (figure 11) and used the turbidimeter test to assess their in-vitro antibacterial activity towards Xoo and R. solanacearum. The derivatives showed excellent inhibitory activities towards R. solanacearum and Xoo in antibacterial bioassays. These results were improved as related with bismerthiazol and thiodiazole copper.

Figure-11:- Compound 10.

Pyridinium-tailored “2,5-disubstituted-1,3,4-oxadiazole” sulfoxide/thioether/sulfone derivatives (Figure 12) were reproduced by Wang et al. (2016) [17]. Most of the derivatives had greater inhibitory activities towards R. solanacearum Xac, Xoo as compared with bismerthiazole and thiodiazole copper, according to bioassays.

Figure-12:- Compound 11.

Zheng et al. (2017) [18] produced a variety of new derivatives of “2-sulfone-5-pyrazolyl-1,3,4-oxadiazole” (Figure 13). The findings of bioassays designated that several areas of chemicals have significant anti-Xoo action. Compound (12 c) has the greatest antibacterial action towards Xoo (EC50 = 16.6 g/mL) among the test compounds, outperforming bismerthazol and thiodiazole copper.
Similarly, Su et al. [19] created a variety of original sulfone derivative by inserting the aryloxymethyl moiety into the “1,3,4-oxadiazole/thiadiazole” sulfone scaffold.

The findings of antimicrobial activity showed that several of the derivatives had much greater antibacterial activity than thiadiazole copper and bismerthiazol towards *R. solanacearum*, Xac, and Xoo.

Abbass and Zimam [20] developed novel pyrimidine and “1,2,3,4-tetrazole” derivatives based on sulfadiazine (Figure 15) and tested them on 2 kinds of bacteria: *Porphyromonas gingivalis* (Gram-negative) or *Streptococcus* spp. (Gram-positive).

Iqbal et al. (2017) [21] produced derivatives of “N-substituted acetamide of azinane-bearing 1,3,4-oxadiazole” and tested their anti-bacterial efficacy towards 5 bacterial species (*Salmonella typhi*, *Bacillus subtilis*, *S. aureus*, *Salmonella typhi*, *Pseudomonas aeruginosa* and *Escherichia coli*).

All the produced compounds were mild inhibitors, although Gram-negative bacterial strains were more active except for *S. aureus*, 1,3,4-oxadiazole was the most effective inhibitor of growth of bacteria.
Li et al. (2018) [22] synthesized several novel sulfone compounds with a “1,3,4-oxadiazole moiety” and tested their antibacterial activity in-vitro towards Xac & Xoo. When compared to thiodiazole copper and bismethiazol, the antibacterial bioassay findings indicated that “2-(methylsulfonyl)-5-((4-fluorophenyl)sulfonyl)methyl)-1,3,4-oxadiazole” had outstanding bioactivities against Xac & Xoo, values of EC50 1.98 and 0.17 g/mL, singly. Meanwhile, greenhouse experiments revealed that “2-(methylsulfonyl)-5-((4-fluorophenyl)sulfonyl)methyl)-1,3,4-oxadiazole” reduced bacterial leaf blight of rice extracompentently than bismethiazol and thidiazole copper.

Deng et al. (2017) [23] have created variety in novel tetracycline offshoots. "1,7-trifluoromethyl-8-pyrrolidinyltetracyclines", a wide-range antibacterial with improved P. aeruginosa action.

Zhang et al. (2019) [24] utilized 1,3,4-thiadiazole moiety and published a series of sulfone derivatives. When compared to bismethiazol and thidiazole copper, bioassay findings presented that several of the complex presented decent antibacterial activity towards Xac, R. solanacearum and Xoo. Compound (18 a) in particular had high efficacy towards Xoo in vitro, surpassing bismethiazole and thidiazole copper. However, in vivo antibacterial activity findings revealed that compound (18 a) showed almost comparable protective and curative effect towards bacterial leaf blight of rice compared to bismethiazol and thidiazole copper.

Chen et al. (2019) [25] produced a variety of novel sulfone derivatives combining amide and “1,3,4-thiadiazole”. Antibacterial activity tests indicated that compound (18 c) had better antibacterial activity against Xac, R. solanacearum, and Xoo, compared to thidiazole copper, bismethiazol, and fluopyram. The control effectiveness of compound (18 c) towards bacterial leaf blight of rice at 200 mg/L in greenhouse circumstances showed that, when compared to thidiazole copper, bismethiazol, and fluopyram, compound (18 c) was more efficient in falling bacterial leaf blight of rice.

Wang et al. (2019) [26] also utilized 1,3,4-oxadiazole moiety to synthesize a variety of new sulfone derivatives and found that compound (18 b) had higher antibacterial activity towards Xoc & Xoo in vitro and in vivo than bismethiazol and thidiazole copper.
Chen et al. (2020) [27] used “1,3,4-oxadiazole” moiety and developed a series of new sulfone compounds and performed antibacterial assay. The bioassay findings exposed that all of the derivatives had good in-vitro antibacterial activity towards Xoo. Compound (19 a) had superior antibacterial activity towards Xoo as compared to bismerthiazole and thiozole copper.

Xiang et al. [28] used 1,3,4-dichloroisothiazolamide moiety and created a series of “1,3,4-oxadiazole sulfone” offshoots. Compound (19 c) had outstanding in-vitro antibacterial activity towards “Xoo and Xoc”, values of EC50 with 2.21 and 0.79 g/mL, which were found to be better than bismerthiazol, isotianil, and thiozole copper according to bioassay findings. Compound (c) had a higher control efficiency toward rice bacterial leaf blight in green-house circumstances at 200 mg/l than thiozole copper, isotianil, and bismerthiazol, with protection and curative activities of 41.06 percent and 43.99 percent, respectively, compared to isotianil, bismerthiazol and thiozole copper.

Li et al. (2020) [29] established novel class of sulfone compounds with a sulfonohydrazide moiety. The antibacterial activities of compound (19 b) against Xac & Xoo were the best, with EC50 values of 36 and 25 g/mL, which were found to be better compared with bismerthiazol and thiozole copper.

**Antiviral Activity**

Viral diseases, such as the hepatitis, herpes, influenza, common cold, HIV, gastroenteritis, chickenpox, and the Ebola virus, are among the most prevalent infections throughout the world. Antiviral treatment is crucial in preventing viral infections from spreading.
Xu et al. (2013) [30] used “1,3,4- oxadiazole/thiadiazole” piec e to produce an original class of sulfone compounds (Figure 21). When compared to ningnanmycin, antiviral activity findings indicated that several of the derivatives had moderate to excellent antiviral efficacy towards TMV.

\[
\begin{align*}
\text{a: } X &= O, \ R = \text{CH}_3 \\
\text{b: } X &= O, \ R = \text{C}_6\text{H}_5\text{CH}_2 \\
\text{c: } X &= O, \ R = 4-\text{Cl-C}_6\text{H}_5\text{CH}_2 \\
\text{d: } X &= O, \ R = \text{CH}_2\text{CH}_3 \\
\text{e: } X &= S, \ R = \text{CH}_3 \\
\text{f: } X &= S, \ R = \text{C}_6\text{H}_5\text{CH}_2 \\
\end{align*}
\]

Figure 21: Compound 20.

Wu et al. (2015) [31] synthesized a variety of 1,3,4-thiadiazole and pyrazol containing sulfone derivatives (Figure 22). When compared to ningnanmycin, antiviral action findings presented that the synthesized compounds showed excellent antiviral efficacy compared to TMV.

\[
\begin{align*}
\text{a: } R &= \text{CH}_3 \\
\text{b: } R &= \text{C}_6\text{H}_5 \\
\text{c: } R &= (\text{CH}_3)_2\text{CH} \\
\text{d: } R &= \text{CH}_2\text{CH} = \text{CH}_2 \\
\text{e: } R &= \text{C}_8\text{H}_5\text{CH}_2 \\
\text{f: } R &= 4-\text{CH}_3\text{-C}_6\text{H}_4\text{CH}_2 \\
\text{g: } R &= 4-\text{F-C}_6\text{H}_4\text{CH}_2 \\
\text{h: } R &= 4-\text{CF}_3\text{-C}_6\text{H}_4\text{CH}_2 \\
\text{i: } R &= 3-\text{F-C}_6\text{H}_4\text{CH}_2 \\
\text{j: } R &= 2-\text{F-C}_6\text{H}_4\text{CH}_2 \\
\text{k: } R &= 4-\text{NO}_2\text{-C}_6\text{H}_4\text{CH}_2 \\
\text{l: } R &= 4-\text{CH}_3\text{O-C}_6\text{H}_4\text{CH}_2 \\
\end{align*}
\]

Figure 22: Compound 21.

**Nematocidal activity / Insecticidal activity / Acaricidal activity**

Wang et al. (2014) [32] produced four new pyrazole containing moiety sulfone derivatives (Figure 23). The target compounds have lesser larvicidal efficacy towards *M. separata* than chlorantraniliprole, according to bioassay findings.

\[
\begin{align*}
\text{37a: } R_1 &= 3-\text{CH}_3, \ R_2 = 4-\text{Cl} \\
\text{37b: } R_1 &= 4-\text{Cl}, \ R_2 = 4-\text{Cl} \\
\text{37c: } R_1 &= 2,4-2\text{Cl}, \ R_2 = \text{H} \\
\text{37d: } R_1 &= 4-\text{Cl}, \ R_2 = 2,4-2\text{C} \\
\end{align*}
\]

Figure 23: Compound 22.

Yu et al. (2016) [33] used “2,4-diphenyl-1,3-oxazolines” fraction to synthesize a variety of new sulfone derivatives for insecticidal and acaricidal activity in 2016. The bioassay findings revealed that compound (23 a) had even greater acaricidal action towards *T. cinnabarinus* eggs as compared to.toxadazole. Song's group [34] used 1,3,4-oxadiazole/thiadiazole fraction to synthesize a sequence of sulfone offshoots. The bioassay findings indicated that compound (23 b) had outstanding action of nematicidal (100 percent) towards *C. elegans* at 48 & 72 hours.
Xu et al. (2017) [8] discovered that compound 24 (Figure 25) had excellent insecticidal activity towards *H. armigera* (> 90%) and *P. xylostella* (> 95%) at (500 μg/ml).

Li et al. (2019) [35] used anthranilic diamide moiety to synthesize and test a sequence of new sulfone offshoots for insecticidal activity towards *P. xylostella* and *M. separata*. Bioassay findings revealed that compound 25 (Figure 26) had higher insecticidal effects towards *P. xylostella* (100%) and *M. separata* (100%) than chlorantraniliprole at 1-200 mg/L.

Hua et al. (2020) [36] discovered that compound 26 (Figure 27) had admirable nematocidal activity towards *M. incognita*, with a death amount greater than 80% when compared to fluopyram.
Herbicidal activity
Min et al. (2014) [37] used 1,2,4-triazole and announced a novel sulfone derivative (Figure 25). The bioassay findings indicated that compound 27 inhibited root more effectively (73%) and had less action towards KARI (35%) and E. crusgalli (28%) as compared to the “cyclopropane-1,1-dicarboxylic acid” at 100 g/ml.

![Figure 28: Compound 27](image)

Wang et al. [38] produced fluorin-containing “2-(substituted phenoxybutryloxy)alkyl-5,5-dimethyl-1,3,2-dioxaphosphinan-2-one” and “a-[(substituted phenoxybutryloxy or valeryoxy)alkylphosphonates”. In a greenhouse, these chemicals demonstrated herbicidal activity towards a variety of weed species.

![Figure 29: Compound 28](image)

Yang and Tian (2019) [39] used aryl carboxylamide moiety and created 4 sulfone derivatives. At 1000 g/ha, herbicidal activity findings revealed that compound 28 (Figure 29) exhibited in high inhibitory action (77.74 percent) towards “E. crusgalli”. Similarly, Min et al. [37] demonstrated, at 100 or 10 g/ml, compound 29 has excellent action towards B. campestris, but has poor activity towards KARI and E. crusgalli.

![Figure 30: Compound 29](image)

Conclusion:
Heterocyclic compounds are the complex group in organic chemistry. These compounds are essential in a number of ways. Pharmacology and biochemistry are the two main fields that collectively contribute to the holistic efficacious vitality of the compounds having activity against pests. Synthetic organic chemistry finds huge application that requisitely meet the needs of modern society and mankind by synthesizing new biologically active heterocyclic compounds. Most importantly they safeguard crop health by killing the harmful pest and plants that restrict its growth. Besides, heterocyclics are also useful in treatment of animals and human as a therapeutical agent. Heterocyclic compounds show good herbicidal, insecticidal, antifungal, nematocidal, antibacterial and antimicrobial activities. The present review is an attempt to briefly compile the heterocyclic compounds for their pesticidal properties.
Table-2:- Pesticidal properties of different compounds.

| Sn. | Compounds                                      | Pesticidal property                  | References |
|-----|-----------------------------------------------|--------------------------------------|------------|
| 1   | 2,5-disubstituted tetrazole derivatives       | Antifungal activity                  | [7]        |
| 2   | 8-chloro-3-((2,6-difluorobenzyl)sulfonyl)-[1,2,4]triazolo[4,3-a]pyridine | Antifungal activity                  | [8]        |
| 3   | disubstituted 1,3-oxazepine-5-one derivatives | Antifungal activity                  | [11]       |
| 4   | Aromatic amide derivatives                    | Antifungal activity                  | [12]       |
| 5   | 2-((benzylsulfonyl)benzothiazole              | Antifungal activity                  | [13]       |
| 6   | (E)-3-acyl-(methoxyimino)-1,5-dihydrobenzo[e][1,2]oxazepin-4(3H)-one | Antifungal activity                  | [14]       |
| 7   | 2,5-disubstituted-1,3,4-thiadiazole/oxadiazole | Antibacterial activity              | [15]       |
| 8   | 4-(9-((5-substituted-1,3,4-oxadiazole/ thiadiazole-2-yl)methyl)-9H-purin-6-yl)- morpholine | Antibacterial activity              | [16]       |
| 9   | 2,5-substituted-1,3,4-oxadiazole sulfoxide/thioether/sulfone derivatives | Antibacterial activity              | [17]       |
| 10  | 2-sulfone-5-pyrazoyl-1,3,4-oxadiazole derivatives | Antibacterial activity              | [18]       |
| 11  | 1,3,4-oxadiazole/thiadiazole sulfones         | Antibacterial activity              | [19]       |
| 12  | 1,2,3,4-tetrazole derivatives                 | Antibacterial activity              | [20]       |
| 13  | N-substituted acetamide of azinane-bearing 1,3,4-oxadiazole derivatives | Antibacterial activity              | [21]       |
| 14  | 2-(methylsulfonyl)-5-((4-fluorophenyl)sulfonylmethyl)-1,3,4-oxadiazole | Antibacterial activity              | [22]       |
| 15  | 1,7-trifluoroethyl-8-pyrrolidinyltetracyclines | Antimicrobial activity              | [23]       |
| 16  | 1,3,4-oxadiazole sulfone derivatives          | Antibacterial activity              | [28]       |
| 17  | thioether/sulfone compounds containing 1,3,4-oxadiazole/1,3,4-thiadiazole | Antiviral activity                 | [30]       |
| 18  | N-phenylpyrazoyl aryl methanones derivatives  | Larvicidal activity                 | [32]       |

References:-
1. Chen C.J., Song B.A., Yang S., Xu G.F., Bhadury P.S., Jin L.H., Hu D.Y., Li Q.Z., Liu F., Xue W., Lu P., Synthesis and antifungal activities of 5-(3, 4, 5-trimethoxyphenyl)-2-sulfonyl-1, 3, 4-thiadiazole and 5-(3, 4, 5-trimethoxyphenyl)-2-sulfonyl-1, 3, 4-oxadiazole derivatives. Bioorganic & medicinal chemistry,(2007) 15(12):3981-9. https://doi.org/10.1016/j.bmc.2007.04.014
2. Dham S., Kour P., Synthesis of some 2, 6-disubstituted imidazo [2, 1-b]-1, 3, 4-thiadiazoles and their biological activities. Proceedings-National Academy of Sciences India Section A,(1993)63:589-.
3. Srinivas K., Srinivas U., Bhanuprakash K., Harakishore K., Murthy U.S., Rao V.J., Synthesis and antibacterial activity of various substituted s-triazines, European journal of medicinal chemistry,(2006) 41(11):1240-6.https://doi.org/10.1016/j.ejmech.2006.05.013
4. Banday M.R., Matteo R.H., Rauf A., Synthesis, characterization and anti-bacterial activity of 5-(alkenyl)-2-amino-and 2-(alkenyl)-5-phenyl-1, 3, 4-oxadiazoles, Journal of chemical sciences,(2010) 122(2):177-82.https://doi.org/10.1007/s12039-010-0019-6
5. Chen H.S., Li Z.M., Li J.F., Synthesis of 2-pyrazoyl-5-substituted-1, 3, 4-oxadiazoles and their biological activities. Chemical Journal of Chinese Universities-Chinese. (2000) 1;21(10):1520-3.
6. Zhang K.S., Mu L.J., Long Y.X., Synthesis and preliminary bio-activity studies of alpha-pyrazyl-N-phenyl-alpha-aminophosphonates. Chemical Journal of Chinese Universities-Chinese,(1999) 1;20(5):741-3.
7. Łukowska-Chojnacka E., Mierzejewska J., Milner-Krawczyk M., Bondaryk M., Staniszewska M., Synthesis of novel tetrazole derivatives and evaluation of their antifungal activity, Bioorganic & medicinal chemistry,(2016) 24(22):6058-65.https://doi.org/10.1016/j.bmc.2016.09.066
8. Xu F.Z., Wang Y.Y., Zhu Y.Y., Shao J.H., Yu G., Xue W., Wu J., Wu H.B., Shi J., Synthesis and biological activity of novel sulfone derivatives containing a [1, 2, 4] triazolo [4, 3-a] pyridine moiety, Phosphorus, Sulfur, and Silicon and the Related Elements, (2017) 192(7):850-5. https://doi.org/10.1080/10426507.2017.1288626
9. Molnar M., Pavić V., Šarkanj B., Ćaćić M., Vuković D., Klenkar J., Mono-and bis-dipicolinic acid heterocyclic derivatives—thiosemicarbazides, triazoles, oxadiazoles and thiazolidinones as antifungal and antioxidant agents, Heterocyclic Communications,(2017) 23(1):35-42. https://doi.org/10.1515/hc-2016-0078

10. Chitra G., Franklin D.S., Sudarasan S., Sakhivel M., Guhanathan S., Indole-3-acetic acid/diol based pH-sensitive biological macromolecule for antibacterial, antifungal and antioxidant applications. International journal of biological macromolecules. (2017) 95:363-75. https://doi.org/10.1016/j.ijbiomac.2016.11.068

11. Muslim R.F., Majeed I.Y., Saleh S.E., Saleh M.M., Owaad M.N., Abbas J.A., Preparation, characterization and antibacterial activity of the 5-membered ring via Schiff’s bases.

12. Hua X., Liu N., Zhou S., Zhang L., Yin H., Wang G., Fan Z., Ma Y., Design, synthesis, and biological activity of novel aromatic amide derivatives containing sulfide and sulfone substructures, Engineering, (2020) 6(5):553-9. https://doi.org/10.1016/j.eng.2019.09.011

13. Ballari M.S., Cano N.H., Wunderlin D.A., Fereresin G.E., Santiago A.N., One-pot sequential synthesis and antifungal activity of 2-(benzylsulfonyl) benzothiazole derivatives, RSC advances,(2019) 9(50):29405-13. https://doi.org/10.1039/C9RA04488D

14. Yang D., Wang H., Fan Z., Li Z., Zhou S., Hoo Z., Lv Y, Kalinina TA, Glukhareva TV. Design, synthesis and antifungal activity of (E)-3-acyl-5-(methoxyimino)-1, 5-dihydrobenzo [e][1, 2] oxazepin-4 (3 H)-one analogues. Molecular diversity. (2021) 25(1):159-69.https://doi.org/10.1007%2Fs11030-020-10035-z

15. Li P., Shi L., Yang X., Yang L., Chen X.W., Wu F., Shi Q.C., Xu W.M., He M., Hu D.Y., Song B.A., Design, synthesis, and antibacterial activity against rice bacterial leaf blight and leaf streak of 2, 5-substituted-1, 3, 4-oxadiazole/thiadiazole sulfone derivative. Bioorganic & medicinal chemistry letters,(2014) 24(7):1677-80. https://doi.org/10.1016/j.bmcl.2014.02.060

16. Wu W.N., Gao M.N., Tu H., Ouyang G.P., Synthesis and antibacterial activity of novel substituted purine derivatives. Journal of Heterocyclic Chemistry. (2016) 53(6):2042-8. https://doi.org/10.1010/jhet.2527

17. Wang P.Y., Zhou L., Zhou J., Wu Z.B., Xue W., Song B.A., Yang S.,Synthesis and antibacterial activity of pyrimidine-tailored 2, 5-substituted-1, 3, 4-oxadiazole thioether/sulfoxide/sulfone derivatives. Bioorganic & medicinal chemistry letters. (2016) 26(4):1214-7. https://doi.org/10.1016/j.bmcl.2016.01.029

18. Zheng Y.T., Zhang T.T., Wang P.Y., Wu Z.B., Zhou L., Ye Y.Q., Zhou X., He M., Yang S.,Synthesis and bioactivities of novel 2-thioether/sulfone)-5-pyrazolyl-1, 3, 4-oxadiazole derivatives. Chinese Chemical Letters. (2017) 28(2):253-6. https://doi.org/10.1016/j.cclet.2016.06.055

19. Su S., Zhou X., Liao G., Qi P., Jin L.,Synthesis and antibacterial evaluation of new sulfone derivatives containing 2-aryloxyethyl-1, 3, 4-oxadiazole/thiadiazole moiety, Molecules,(2017) 22(1):64. https://doi.org/10.3390/molecules22010064

20. Abbass A.F., Zimam E.H., Synthesis, characterization and study biological activity of some new pyrimidine and 1, 2, 3, 4-tetrazole derivatives based on sulfadiazine, International Journal of ChemTech Research,(2016) 9(11):206-17.

21. Iqbal K., Jamal Q., Iqbal J., Afreen M.S., Sandhu M.Z., Dar E., Farooq U., Mushtaq M.F., Arshad N, Iqbal MM. Synthesis of N-substituted acetamide derivatives of azimine-bearing 1, 3, 4-oxadiazole nucleus and screening for antibacterial activity. Tropical Journal of Pharmaceutical Research. 2017 Mar 7;16(2):429-37.

22. Li P., Hu D., Xie D., Chen J., Jin L., Song B., Design, and evaluation of new sulfone derivatives containing a 1, 3, 4-oxadiazole moiety as active antibacterial agents., Journal of agricultural and food chemistry.,(2018) 66(12):3093-100. https://doi.org/10.1021/acs.jafc.7b06061

23. Deng Y., Sun C., Hunt D.K., Fyfe C., Chen C.L., Grossman T.H., Sutcliffe J.A., Xiao X.Y.,Heterocyclic tetracyclines. 1. 7-Trifluoromethyl-8-pyridinyltetraacyclines: potent, broad spectrum antibacterial agents with enhanced activity against Pseudomonas aeruginosa, Journal of medicinal chemistry,(2017) 60(6):2498-512. https://doi.org/10.1021/acs.jmedchem.6b01903

24. Zhang M., Xu W., Wei K., Liu H., Yang Q., Liu Q., Yang L., Luo Y., Xue W.,Synthesis and evaluation of 1, 3, 4-thiadiazole derivatives containing cyclopentylpropionamide as potential antibacterial agent, Journal of Heterocyclic Chemistry,(2019) 56(7):1966-77. https://doi.org/10.1002/jhet.3576

25. Chen J., Yi C, Wang S, Wu S, Li S, Hu D, Song B. Novel amide derivatives containing 1, 3, 4-thiadiazole moiety: design, synthesis, nematocidal and antibacterial activities. Bioorganic & medicinal chemistry letters. (2019) 29(10):1203-10.https://doi.org/10.1016/j.bmcl.2019.03.017

26. Wang S., Gan X., Wang Y., Li S., Yi C, Chen J., He F., Yang Y., Hu D., Song B., Novel 1, 3, 4-oxadiazole derivatives containing a cinnamic acid moiety as potential bactericide for rice bacterial diseases,International journal of molecular sciences,(2019) 20(5):1020. https://doi.org/10.3390/ijms20051020
27. Chen J., Luo Y., Wei C., Wu S., Wu R., Wang S., Hu D., Song B., Novel sulfone derivatives containing a 1, 3, 4-oxadiazole moiety: design and synthesis based on the 3D-QSAR model as potential antibacterial agent, Pest management science. (2020) 76(9):3188-98.https://doi.org/10.1002/jhet.4173

28. Xiang J., Liu D., Chen J., Hu D., Song B., Design and synthesis of novel 1, 3, 4-oxadiazole sulfone compounds containing 3, 4-dichloroisothiazolylamide moiety and evaluation of rice bacterial activity. Pesticide Biochemistry and Physiology. (2020) 170:104695. https://doi.org/10.1016/j.pestbp.2020.104695

29. Li P., Wang L., Wang X., Recent advances on the pesticidal activity evaluations of sulfone derivatives: A 2010 to 2020 decade in mini-review, Journal of Heterocyclic Chemistry, (2021) 58(1):28-39. https://doi.org/10.1002/jhet.4173

30. Xu W.M., Li S.Z., He M., Yang S., Li X.Y., Li P., Synthesis and bioactivities of novel thioether/sulfone derivatives containing 1, 2, 3-thiadiazole and 1, 3, 4-oxadiazole/thiadiazole moiety, Bioorganic & medicinal chemistry letters. (2013) 23(21):5821-4.https://doi.org/10.1016/j.bmcl.2013.08.107

31. Z.B. Wu, J.Q. Kuang, S. Yang, T.T. Zhang, S.X. Wu, D.Y. Zhang, D.Y. Hu, Y.Q. Ye, Chinese patent CN 103880836 A, (2015).

32. Wang B.L., Wu J., Liu Q.X., Li Y.H., Song H.B., Li Z.M., Synthesis, Structure, and Biological Activities of [5-(Arylthio/sulfinyl/sulfonyl)-3-methyl-1-phenyl-1 H-pyrazol-4-yl]-arylmethanones, Phosphorus, Sulfur, and Silicon and the Related Elements. (2015) 190(1):66-78.https://doi.org/10.1080/10426507.2014.919503

33. Yu X., Liu Y., Li Y., Wang Q., Design, synthesis, acaricidal/insecticidal activity, and structure–activity relationship studies of novel oxazolines containing sulfone/sulfoxide groups based on the sulfonyleurea receptor protein-binding site, Journal of agricultural and food chemistry.(2016) 64(15):3034-40. https://doi.org/10.1021/acs.jafc.6b00645

34. B.A. Song, X.W. Chen, Y.Z. Chen, D.Y. Hu, W. Xue, J.X. Chen, Y.J. Wang, Z.Z. Wang, Chinese patent CN 105646393 A, 2016.

35. Li F.Y., Wang Y.H., Liu J.B., Li Y.X., Li Z.M., Synthesis, insecticidal evaluation and mode of action of novel antranilic diamide derivatives containing sulfur moiety as potential ryanodine receptor activators, Bioorganic & medicinal chemistry, (2019) 27(5):769-76. https://doi.org/10.1016/j.bmcl.2019.01.009

36. Hua X., Liu N., Zhou S., Zhang L., Yin H., Wang G., Fan Z., Ma Y., Design, synthesis, and biological activity of novel aromatic amide derivatives containing sulfide and sulfone substructures, Engineering. (2020) 6(5):553-9. https://doi.org/10.1016/j.eng.2019.09.011

37. Min LJ, Tan CX, Weng JQ, Liu XH. Synthesis, crystal structure, and biological activity of a novel 1, 2, 3-thiadiazole compound containing 1, 2, 4-triazole moiety, Phosphorus, Sulfur, and Silicon and the Related Elements. (2014) 189(3):379-86.https://doi.org/10.1080/10426507.2013.820186

38. Wang W., Zhou Y., Peng H., He H.W., Lu X.T., Synthesis and herbicidal activity of α-[(substituted phenoxybutyroloxy or valeroyoxy)] alklyphosphonates and 2-(substituted phenoxybutyroxy) alkyl-5, 5-dimethyl-1-3, 2-dioxaphosphinan-2-one containing fluorine. Journal of Fluorine Chemistry. (2017) 193:8-16.https://doi.org/10.1016/j.jfluchem.2016.11.008

39. Z.H. Yang, H. Tian, Plant Doc. (2019) 32, 36.