Rec. Pharm. Biomed. Sci. 7 (1), 145-153, 2023

REVIEW ARTICLE

RECORDS OF PHARMACEUTICAL AND BIOMEDICAL SCIENCES

Naphthalene: An Overview

Hasnaa Abdelfatah, Ranza Elrayess*, Mohamed M. Said, Hosam A. Elshihawy

Pharmaceutical Organic Chemistry Department, Faculty of Pharmacy, Suez Canal University, Ismailia 41522, Egypt

Received on: 13. 05. 2023

Revised on: 23. 05. 2023

Accepted on: 25. 05. 2023

* Correspondence Author:

Tel: +201025488849

E-mail address:

Ranza.el-rayes@pharm.suez.edu.eg

Abstract

In recent years, the discovery, identification, and development of biologically active compounds have gained a lot of importance. Numerous scaffolds have been synthesized using naphthalene, which has also been shown to have a wide range of therapeutic properties, including antimicrobial, antiviral, antiprotozoal, antidiabetic, anticancer, anti-inflammatory, antihypertensive, antipsychotic, antidepressant, anticonvulsant, and anti-neurodegenerative effects. The naphthalene-based compounds Naphyrone, tolnaftate, naftifine, nafcillin, terbinafine, propranolol, nabumetone, nafimidone, naproxen, duloxetine, lasofoxifene, and bedaquiline, among others, have also been approved by the FDA and are being marketed as medicines. Thus, the naphthalene scaffold emerges as an essential building block in drug development due to its wide range of biological activities due to its structural modifications. This review examines the pharmacological properties of various chemically modified naphthalene-based compounds.

Keywords: Naphthalene, Antimicrobial, Antidiabetic, Anticancer, Anticonvulsant.

1. Introduction:

Naphthalenes are a class of arenas in which two benzene rings are fused in an ortho position(Ibrahim and Mohamed 2016). Naphthalene is a white substance with a strong, pungent odour that is traditionally generated from coal tar(Makar, Saha et al. 2019). Alexander Garden, a Scottish scientist, made the initial discovery of naphthalene in 1819. Michael Faraday first reported its chemical formula ($C_{10}H_8$) in 1826(Thomas and Science 1992). Conventionally, naphthalene is synthesized using a Diels-Alder reaction between maleic anhydride and 1,1 diaryl ethylene, followed by aromatization of the bis product through barium hydroxide and copper decarboxylation. Additionally, the Wagner-Jauregg reaction produces phenyl-substituted naphthalene (Bergmann, Szmuszkowicz et al. 1947) (figure.1).

Developing novel and useful regioselective synthesis techniques of polysubstituted naphthalene derivatives have captivated the pharmaceutical industries (Batt, Maynard et al. 1990). Presently accessible natural, semisynthetic, and synthetic medicines with naphthalene or one of its derivatives in their chemical structures have been identified to possess different biological activities (Bashir, Oglah et al. 2021).

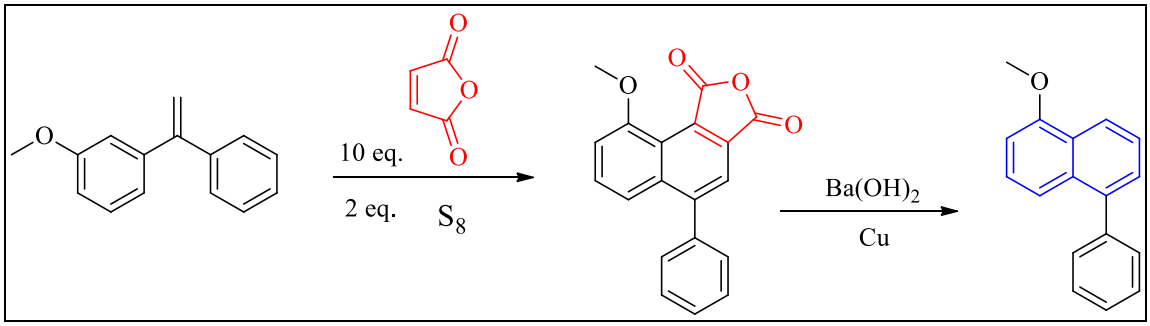


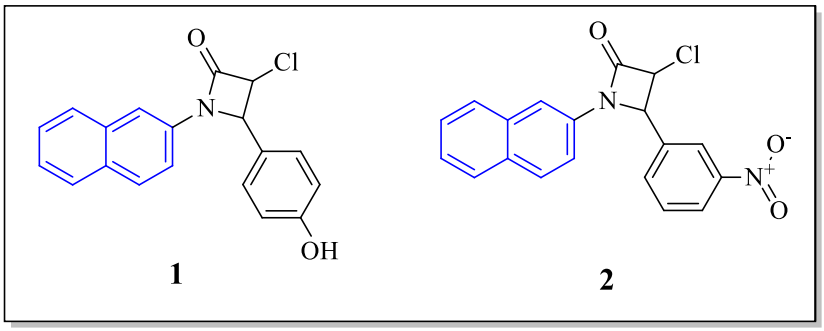
Figure 1: Synthesis of naphthalene using a Diels-Alder reaction between maleic anhydride and 1,1 diaryl ethylene.

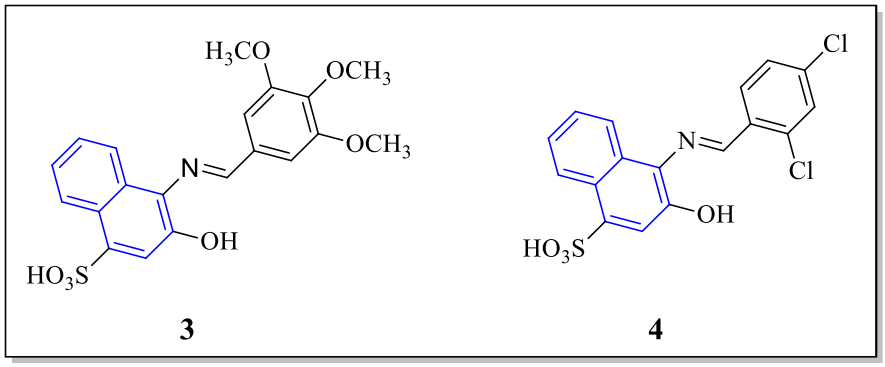
1.1. Anti-microbial activity

Antibiotic-resistant bacteria become more prevalent as the use of antibacterial drugs increases(Mustafa, Khalil et al. 2020). This event needs the investigation and efficient development of novel antibacterial agents to battle these antibiotic-resistant microorganisms(York 2017). The antibacterial action of a naphthalene ring on bacterial and fungal strains has been supported by numerous research(Ersan, Yuksel et al. 2021). Anti-microbial medications containing naphthalene, such as nafcillin, naftifine, tolnafate, and terbinafine, are commercially available. Many naphthalene derivatives synthesized have also exhibited notable and satisfactory anti-microbial activity(Makar, Saha et al. 2019, Kalariya, Pandya et al. 2022).

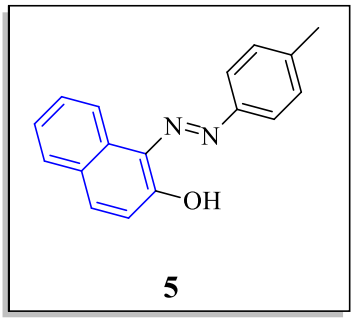
Bhawna Chopra et al. synthesized naphthylamine analogs having azetidinone moiety for anti-microbial activity. Compounds (**1)** and (**2)** were found to exhibit broad-spectrum activity against *Bacillus subtilis, Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa*(Chopra, Dhingra et al. 2017).

R. Kumar et al. synthesized 4-amino-3-hydroxy-naphthalene-1-sulfonic acid derivatives and evaluated the anti-microbial activity. They concluded that 3,4,5 trimethoxy (**3**) and 2,4 dichloro (**4**) groups on the benzylidene amino portion were essential for activity against various bacteria and fungi(Kumar, Kumar et al. 2012).



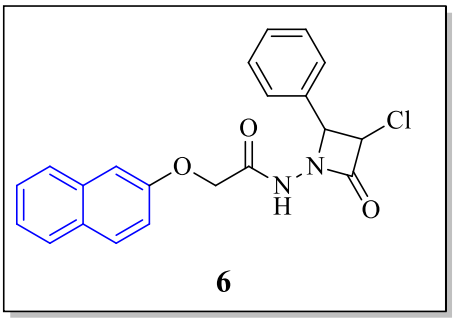


K.M. Rathod et al. evaluated azo-2 naphthol (**5**) against five representative human pathogenic microorganisms, i.e., *S.aureus*, *E.coli*, *B.subtilis*, *P.aeruginosa*, and *S.faecalis*(Rathod 2011). The possibility of antibacterial action due to the resorcinol moiety of azo compounds was suggested.



5

Yogesh Rokade et al. synthesized and evaluated the anti-microbial activity of azetidinone derivatives connected with the B-naphthol ring. Among the synthesized compounds, compound (**6**) showed activity against *E. coli*, *S. aureus*, *P. aeruginosa*, and *A. niger*. The methyl, methoxy, and chloro substitutions in the aromatic ring showed potent anti-microbial activity as compared to standard drug ampicillin and griseofulvin (Rokade and Dongare 2010).

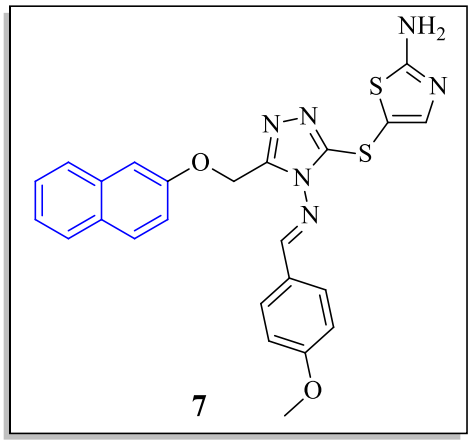


6

1.2. Anti-inflammatory activity

Inflammation is a protective process developed in the host in response to damage or infection(Medzhitov 2008, Ahmed 2011). Severe inflammatory disorders can occur from the overexpression of pro-inflammatory factors due to an excessive inflammatory response(Jang, Kim et al. 2013). Therefore, inhibiting and preventing inflammatory processes are significant research objectives(Chang, Liao et al. 2017). Currently, the naphthalene derivatives naproxen and nabumetone are utilized to treat inflammatory diseases(Sharma, Singh et al. 2006).

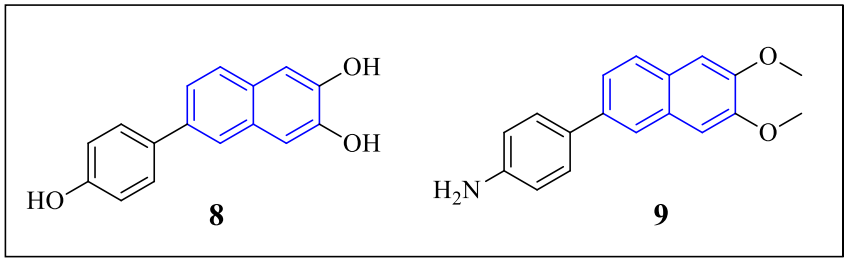
Elrayess et al. synthesized a new series of 1,2,4-triazole Schiff bases scaffold with aryl and heteroaryl systems. The biological activity of the compounds was evaluated as a potent COX-2 blocker. Among the triazole–thiazole hybrids, the one with the para-methoxy moiety linked to a phenyl ring (**7**) showed the highest In vitro selectivity by COX-2 inhibition assay (IC_{50} of 0.04 µM) and in situ anti-inflammatory activity when evaluated using the protein denaturation assay (IC_{50} of 0.88 µM) in comparison with commercially available selective COX-2 inhibitor, Celecoxib (IC_{50} of 0.05 µM) (Elrayess, Elgawish et al. 2020).

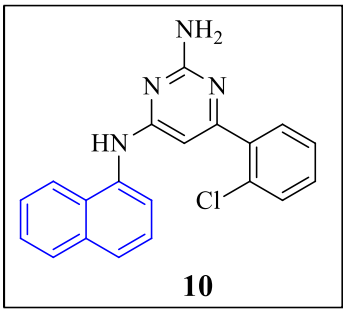


7

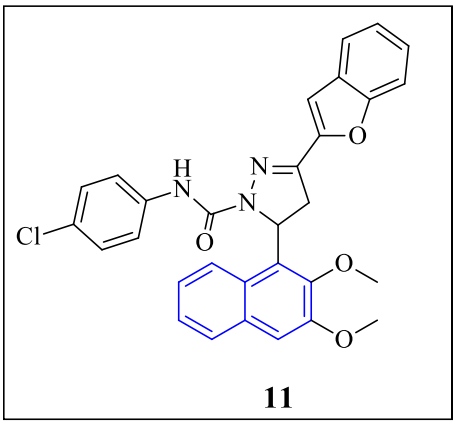
Chi-Fen Chang et al. synthesized 2-phenylnaphthalene derivatives, which inhibited lipopolysaccharide-influenced pro-inflammatory mediators. Compounds (**8**) and (**9**) significantly decreased the expression of induced nitric oxide synthase and cyclooxygenase-II. Also, they inhibited the production of nitric oxide, interleukin-6, and tumor necrosis factor-a in LPS-induced cells(Chang, Liao et al. 2017).

V. Muralidharan et al. synthesized novel naphthalene-pyrimidine derivatives as an anti-inflammatory agent. 2-amino-4-[1-napthalene amino]-5-phenyl pyrimidine derivatives were synthesized from the reaction of N-(napthalene-1-yl)-3-aryl acryl amides with guanidine nitrate. The compounds were evaluated for anti-inflammatory activity using the HRBC membrane stabilization method and diclofenac sodium as a reference. Compound 6-(2-chlorophenyl)-N^4-(naphthalen-1-yl)pyrimidine-2,4-diamine (**10**) showed the most potent anti-inflammatory activity within the series(Muralidharan, Seetaramswamy et al. 2015).





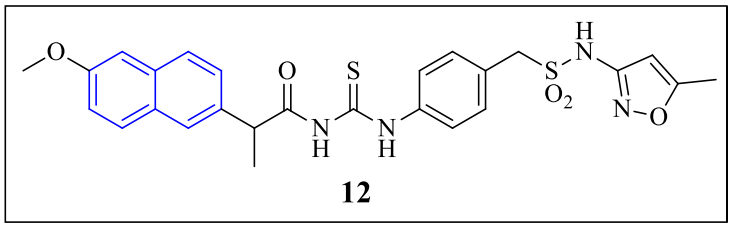
Bukhari et al. reported a novel series of 1, 3-diphenyl-2-propen-1-one-based pyrazolines and used them as intermediates for synthesizing new pyrazoline derivatives. The biological activity of the compounds was evaluated by inhibiting phospholipase A_2, cyclooxygenases (COX-1 and COX-2), IL-6, and TNF-α as anti-inflammatory agents. Compound (**11**) showed the maximum inhibition of phospholipase A_2 and high inhibition of LPS-induced TNF-a and IL-6 release compared to LPS-control(Bukhari, Zhang et al. 2015).

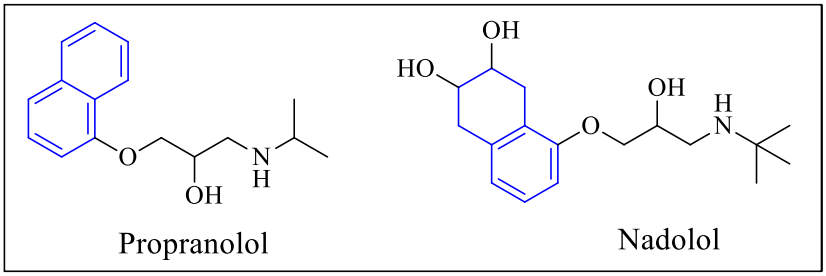


Eissa et al. synthesized a series of novel 6-methoxy naphthalene derivatives (non-carboxylic analogues of aryl propionic acid) and evaluated the anti-inflammatory activity by carrageenan-induced rat paw edema model. Compound (**12**) showed better anti-inflammatory activity (89.77%) than the standard drug naproxen (85.02%). In the case of thiourea derivatives, aromatic substitution with electron-withdrawing groups such as aryl sulphonamide and chlorine was necessary for good activity rather than the electron-donating NH_2 group(Eissa, Farrag et al. 2014).

1.3. Antihypertensive activity

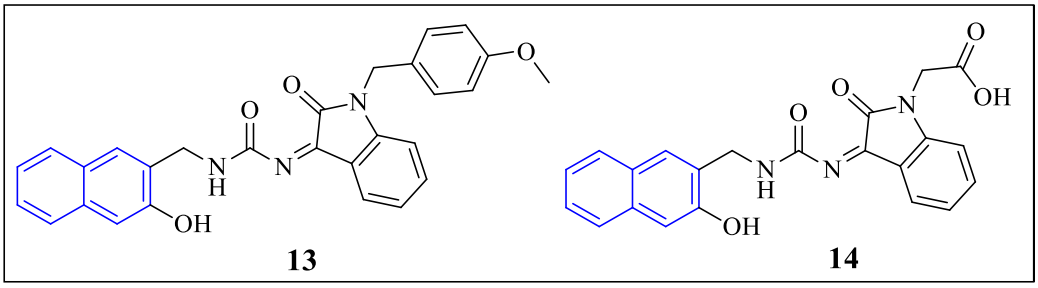
Naphthalene-derived propranolol and tetrahydronaphthalene-derived nadolol are two non-selective beta-adrenergic blocking agents used as antihypertensive drugs(Bekhradnia and Ebrahimzadeh 2012)





Manikandan et al. synthesized a series of naphthalene-2-ol-indolin-2-one-thiocarbamide derivatives and reported their activity against angiotensin-converting enzyme (ACE).

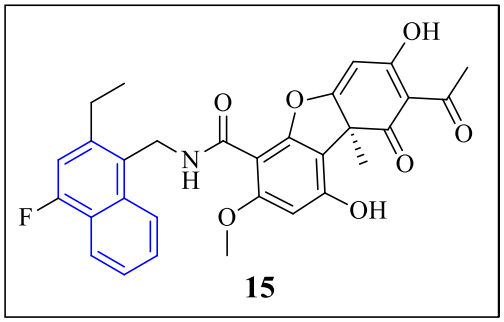
Oxo-indolin-based naphthalene containing compounds (**13**) and (**14**) exhibited significant ACE inhibitory activity(Manikandan, Moharil et al. 2017).



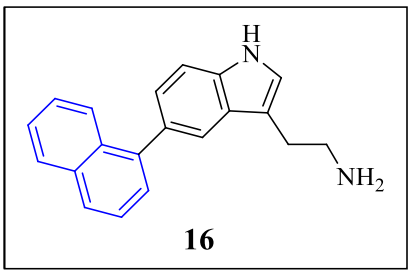
1.4. Anti-diabetic activity

Diabetes mellitus (DM) is a chronic metabolic condition characterized by abnormally high glucose levels in the blood (hyperglycemia). Diabetes can create long-term complications by destroying essential organs, blood vessels, and nerves(Okur, Karantas et al. 2017, Kerru, Singh-Pillay et al. 2018).

Furukawa et al. synthesized compound (**15**), which showed potent agonistic activity and lowered blood glucose levels. It especially showed PPAR$_{\gamma}$ agonist activity, and its potassium salt showed almost equal potency to rosiglitazone(Furukawa, Arita et al. 2012).



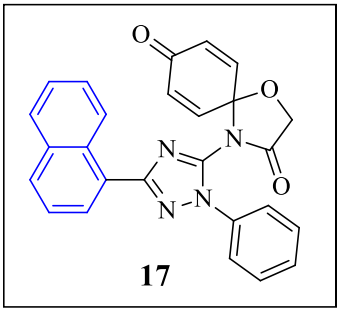
Patch et al. reported 2-(5-(naphthalen-1-yl)-1H-indol-3-yl)ethanamine (**16**) having Estrogen-related receptor α (ERR α) agonistic activity with anti-diabetic activity(Patch, Searle et al. 2011).



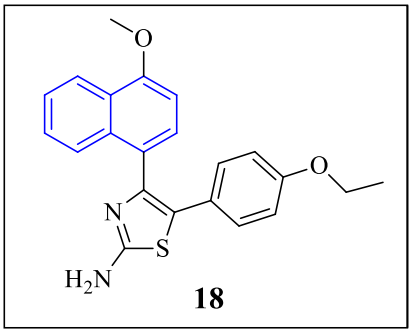
1.5. Anti-cancer activity

Cancer is a fatal disease that profoundly impacts the world today. It is one of the gravest hazards to public health and a formidable obstacle to medical science(Franks, Knowles et al. 1990).

L. Luo et al. synthesized a series of novel naphthalene-substituted triazole spirodienones and evaluated their antineoplastic activity. Compound **(17)** exhibited the most potent anti-cancer activity by inducing cell cycle arrest and apoptosis. Furthermore, compound **(17)** significantly inhibited tumor growth in a metastatic 4T1murine breast cancer model(Luo, Jia et al. 2021).

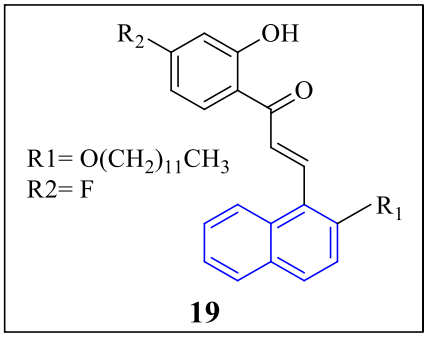


G. Wang et al. synthesized a novel series of thiazole-naphthalene derivatives as tubulin polymerization inhibitors and evaluated their anti-proliferative activities. Compound **(18)** was the most active and significantly inhibited tubulin polymerization with an IC_{50} value of 3.3 μM, compared to the standard drug colchicine (IC_{50} = 9.1 μM)(Wang, Liu et al. 2021).



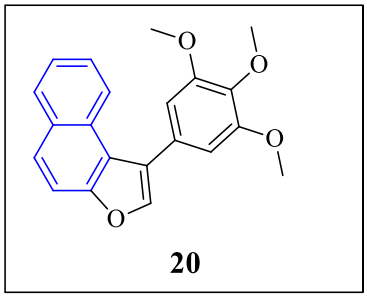
18

Lim et al. synthesized two series of naphthalene-based chalcones and evaluated their anti-cancer activity. The results showed that the fluorinated chalcones exhibited more potent cytotoxic activity towards the breast cancer cell lines (4T1) than non-fluorinated chalcone derivatives. Remarkably, the selectivity index of (**19**) against the breast cancer 4T1 cell line was higher than cisplatin, which is one of the most frequently deployed chemotherapy agents in current medical practice(Lim, Oo et al. 2020)



19

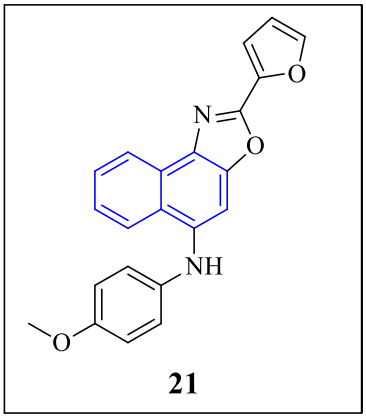
V. Srivastava et al. synthesized 1-(3,4,5-trimethoxyphenyl)naphtho[2,1-b]furan derivatives, compound (**20**) showed significant cytotoxicity against both colon cancer cell line and liver cancer cell line with IC_{50} values of 0.5, and 0.7 µM respectively(Srivastava, Negi et al. 2006).



20

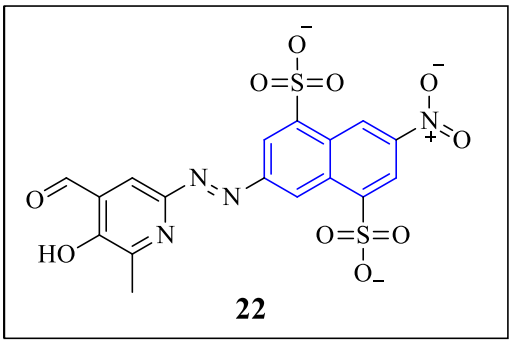
1.6. Antiviral activity

Tseng et al. reported novel naphtho [1,2-d] oxazole derivatives and evaluated their anti-HCV activity by promoting heme oxygenase-1 expression. Among the synthesized compounds, compound (**21**) was the most active and exhibited 21-fold higher anti-HCV activity than ribavirin (Tseng, Lin et al. 2018).



21

Tarantino et al. reported naphthalene-sulfonate as an inhibitor of human norovirus RNA-dependent RNA-polymerase(RdRp). RdRp contributes a critical role in the replication and amplification of genomic RNA. The enzyme is considered a promising target for antiviral drug development. The sodium salt of compound **(22)** exhibited significant inhibitory activity against human Norovirus RdRp(Tarantino, Pezzullo et al. 2014).

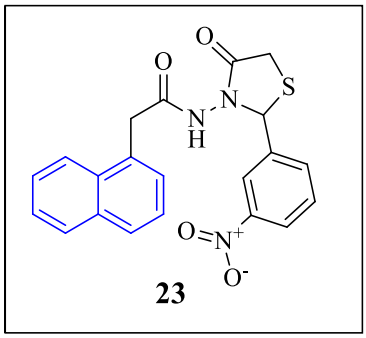


22

1.7. Anti-neurodegenerative activity

Neurodegenerative disorders are neuronal diseases that progressively degenerate the structure and function of the central or peripheral nervous system, affecting the components of the brain. It is a leading cause of death and affects a large number of people around the world(Ayeni, Gong et al. 2022).

Gomathy et al. synthesized novel 2-(naphthalen-1-yl)-N-[2-substituted (4- oxothiazolidin-3-yl)]acetamide derivatives, among these **(23)** exhibited potent anti-parkinsonian activity(Gomathy, Singh et al. 2012).

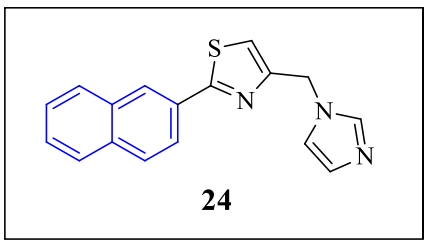


23

1.8. Anticonvulsant activity

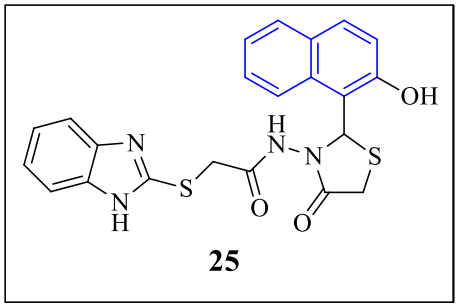
Epilepsy is the umbrella name for various chronic central nervous system (CNS) disorders. It is characterized by excessive and rapid neuronal electrical discharges that result in seizures (Ayati, Emami et al. 2016, Al-Otaibi 2019). In medicinal chemistry, searching for anticonvulsant molecules with a more selective activity and reduced toxicity is a significant area of research (Malawska 2005).

M. Valipour et al. designed and synthesized naphthyl analogs of (arylalkyl) azoles (A.A.A.s) containing thiazole or oxazole heterocycles in the middle of the structure and evaluated their anticonvulsant activity. Among tested compounds, imidazolylmethyl-thiazole (**24**) showed the best activity profile without any sign of neurotoxicity. The results demonstrated that prototype compound **24** could be a new lead for developing anticonvulsant agents (Valipour, Naderi et al. 2021).



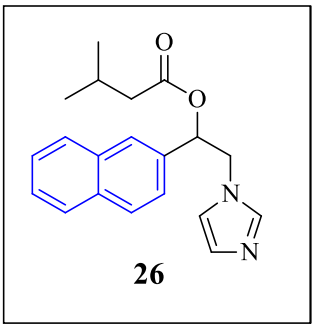
24

Shingalapur et al. synthesized thiazolidinone containing 2-mercapto benzimidazole derivatives and evaluated their anticonvulsant activity. SAR studies revealed the critical role of (OH) function in the target compounds that were found to be the main structural requirement for maintaining anticonvulsant activity. Compound (**25**) was considered significant compared to the control group for anticonvulsant activity(Shingalapur, Hosamani et al. 2010).



25

A. Karakurt et al. designed and synthesized a series of 2-acetylnaphthalene derivatives and evaluated their anticonvulsant activity. The molecular design of the compounds was based on the modification of nafimidone. Among the synthesized compounds, compound **(26)** was the most active anticonvulsant agent(Karakurt, Özalp et al. 2010).



26

References :

Ahmed, A. U. J. F. i. B. (2011). "An overview of inflammation: mechanism and consequences." **6**(4): 274.

Al-Otaibi, F. J. A. P. (2019). "An overview of structurally diversified anticonvulsant agents." **69**(3): 321-344.

Ayati, A., S. Emami and A. J. E. j. o. m. c. Foroumadi (2016). "The importance of triazole scaffold in the development of anticonvulsant agents." **109**: 380-392.

Ayeni, E. A., Y. Gong, H. Yuan, Y. Hu, X. Bai and X. J. J. o. E. Liao (2022). "Medicinal plants for anti-neurodegenerative diseases in West Africa." **285**: 114468.

Bashir, M. K., M. K. Oglah and Y. F. J. A. o. t. R. S. f. C. B. Mustafa (2021). "The effect of aryl and heteroaryl conjugation on the biological activities of naphthalenes: A review." 13355-13379.

Batt, D. G., G. D. Maynard, J. J. Petraitis, J. E. Shaw, W. Galbraith and R. R. J. J. o. m. c. Harris (1990). "2-Substituted-1-naphthols as potent 5-lipoxygenase inhibitors with topical antiinflammatory activity." **33**(1): 360-370.

Bekhradnia, A. R. and M. A. J. M. C. R. Ebrahimzadeh (2012). "Theoretical study on some non-selective beta-adrenergic antagonists and correlation to their biologically active configurations." **21**: 2571-2578.

Bergmann, F., J. Szmuszkowicz and G. J. J. o. t. A. C. S. Fawaz (1947). "The Condensation of 1, 1-diarylethylenes with maleic anhydride." **69**(7): 1773-1777.

Bukhari, S. N. A., X. Zhang, I. Jantan, H. L. Zhu, M. W. Amjad, V. H. J. C. b. Masand and d. design (2015). "Synthesis, molecular modeling, and biological evaluation of novel 1, 3-diphenyl-2-propen-1-one based pyrazolines as anti-inflammatory agents." **85**(6): 729-742.

Chang, C.-F., K.-C. Liao and C.-H. J. P. O. Chen (2017). "2-Phenylnaphthalene derivatives inhibit lipopolysaccharide-induced pro-inflammatory mediators by downregulating of MAPK/NF-κB pathways in RAW 264.7 macrophage cells." **12**(1): e0168945.

Chopra, B., A. K. Dhingra, R. P. Kapoor and D. N. J. J. o. E. R. i. P. Parsad (2017). "Synthesis and antimicrobial activity of naphthylamine analogs having azetidinone and thiazolidinone moiety." **2**(4): 105-112.

Eissa, S., A. Farrag and A. J. D. r. Galeel (2014). "Non-carboxylic analogues of aryl propionic acid: synthesis, anti-inflammatory, analgesic, antipyretic and ulcerogenic potential." **64**(09): 485-492.

Elrayess, R., M. S. Elgawish, M. Elewa, M. S. Nafie, S. S. Elhady and A. S. J. P. Yassen (2020). "Synthesis, 3D-QSAR, and Molecular Modeling Studies of Triazole Bearing Compounds as a Promising Scaffold for Cyclooxygenase-2 Inhibition." **13**(11): 370.

Ersan, R. H., A. Yuksel, T. Ertan-Bolelli, A. Dogen, S. Burmaoglu and O. J. J. o. t. C. C. S. Algul (2021). "One-pot synthesis of novel benzimidazoles with a naphthalene moiety as antimicrobial agents and molecular docking studies." **68**(2): 374-383.

Franks, L. M., M. A. J. I. t. t. c. Knowles and m. b. o. cancer (1990). "What is cancer." **4**: 4-9.

Furukawa, A., T. Arita, T. Fukuzaki, M. Mori, T. Honda, S. Satoh, Y. Matsui, K. Wakabayashi, S. Hayashi and K. J. E. j. o. m. c. Nakamura (2012). "Synthesis and biological evaluation of novel (−)-cercosporamide derivatives as potent selective PPARγ modulators." **54**: 522-533.

Gomathy, S., G. Singh, B. Gowramma, A. S. Antony, K. J. I. J. o. H. Elango and A. Sciences (2012). "Synthesis and anti-Parkinson's screening of some novel 2-(naphthalen-1-yl)-N-[2-substituted (4-oxothiazolidin-3-yl)] acetamide derivatives." **1**(4): 244.

Ibrahim, S. R. and G. A. J. P. r. Mohamed (2016). "Naturally occurring naphthalenes: chemistry, biosynthesis, structural elucidation, and biological activities." **15**(2): 279-295.

Jang, K.-J., H. K. Kim, M. H. Han, Y. N. Oh, H.-M. Yoon, Y. H. Chung, G. Y. Kim, H. J. Hwang, B. W. Kim and Y. H. J. I. j. o. m. m. Choi (2013). "Anti-inflammatory effects of saponins derived from the roots of Platycodon grandiflorus in lipopolysaccharide-stimulated BV2 microglial cells." **31**(6): 1357-1366.

Kalariya, R., V. Pandya, N. Gohil, G. Bhattacharjee, V. Singh, D. P. Rajani, R. Bhosale and J. S. J. E. J. o. M. C. R. Yadav (2022). "Synthesis, biological evaluation and molecular docking study of novel amide-coupled naphthalene scaffolds as potent inhibitors of bacterial recombinase A." **6**: 100078.

Karakurt, A., M. Özalp, Ş. Işık, J. P. Stables, S. J. B. Dalkara and m. chemistry (2010). "Synthesis, anticonvulsant and antimicrobial activities of some new 2-acetylnaphthalene derivatives." **18**(8): 2902-2911.

Kerru, N., A. Singh-Pillay, P. Awolade and P. J. E. J. o. M. C. Singh (2018). "Current anti-diabetic agents and their molecular targets: A review." **152**: 436-488.

Kumar, R., P. Kumar, M. Kumar and B. J. M. C. R. Narasimhan (2012). "Synthesis, anti-microbial evaluation, and QSAR studies of 4-amino-3-hydroxy-naphthalene-1-sulfonic acid derivatives." **21**: 4301-4310.

Lim, Y. H., C. W. Oo, R. Y. Koh, G. L. Voon, M. Y. Yew, M. F. Yam and Y. C. J. D. d. r. Loh (2020).

"Synthesis, characterization, and anti-cancer activity of new chalcone derivatives containing naphthalene and fluorine moieties." **81**(8): 994-1003.

Luo, L., J. J. Jia, Q. Zhong, X. Zhong, S. Zheng, G. Wang and L. J. E. j. o. m. c. He (2021). "Synthesis and anticancer activity evaluation of naphthalene-substituted triazole spirodienones." **213**: 113039.

Makar, S., T. Saha and S. K. J. E. j. o. m. c. Singh (2019). "Naphthalene, a versatile platform in medicinal chemistry: Sky-high perspective." **161**: 252-276.

Malawska, B. J. C. t. i. m. c. (2005). "New anticonvulsant agents." **5**(1): 69-85.

Manikandan, A., P. Moharil, M. Sathishkumar, C. Muñoz-Garay and A. J. E. J. o. M. C. Sivakumar (2017). "Therapeutic investigations of novel indoxyl-based indolines: A drug target validation and Structure-Activity Relationship of angiotensin-converting enzyme inhibitors with cardiovascular regulation and thrombolytic potential." **141**: 417-426.

Medzhitov, R. J. N. (2008). "Origin and physiological roles of inflammation." **454**(7203): 428-435.

Muralidharan, V., S. Seetaramswamy, M. Bhanuprasad and J. J. I. A. J. o. P. S. Sindhu (2015). "Synthesis and characterization of some novel naphthalene-pyrimidine derivatives as anti-inflammatory agents." **2**(4): 851-856.

Mustafa, Y. F., R. R. Khalil and E. T. J. S. R. i. P. Mohammed (2020). "Antimicrobial activity of aqueous extracts acquired from the seeds of two apples' cultivars." **11**(2): 382-387.

Okur, M. E., I. D. Karantas and P. I. Siafaka (2017). "Diabetes mellitus: A review on pathophysiology, current status of oral medications and future perspectives."

Patch, R. J., L. L. Searle, A. J. Kim, D. De, X. Zhu, H. B. Askari, J. C. O'Neill, M. C. Abad, D. Rentzeperis and J. J. J. o. m. c. Liu (2011). "Identification of diaryl ether-based ligands for estrogen-related receptor α as potential antidiabetic agents." **54**(3): 788-808.

Rathod, K. J. A. J. o. R. i. C. (2011). "Synthesis and antimicrobial activity of azo compounds containing resorcinol moiety." **4**(5): 734-736.

Rokade, Y. and N. J. R. J. C. Dongare (2010). "Synthesis and antimicrobial activity of some azetidinone derivatives with the β-naphthol." **3**(4): 641.

Sharma, S., T. Singh, R. Mittal, K. Saxena, V. K. Srivastava, A. J. A. d. P. A. I. J. P. Kumar and M. Chemistry (2006). "A study of anti-inflammatory activity of some novel α-amino naphthalene and β-amino naphthalene derivatives." **339**(3): 145-152.

Shingalapur, R. V., K. M. Hosamani, R. S. Keri and M. H. J. E. j. o. m. c. Hugar (2010). "Derivatives of benzimidazole pharmacophore: Synthesis, anticonvulsant, antidiabetic and DNA cleavage studies." **45**(5): 1753-1759.

Srivastava, V., A. S. Negi, J. Kumar, U. Faridi, B. S. Sisodia, M. Darokar, S. Luqman, S. J. B. Khanuja and m. c. letters (2006). "Synthesis of 1-(3′, 4′, 5′-trimethoxy) phenyl naphtho [2, 1b] furan as a novel anticancer agent." **16**(4): 911-914.

Tarantino, D., M. Pezzullo, E. Mastrangelo, R. Croci, J. Rohayem, I. Robel, M. Bolognesi and M. J. A. r. Milani (2014). "Naphthalene-sulfonate inhibitors of human norovirus RNA-dependent RNA-polymerase." **102**: 23-28.

Thomas, J. M. J. E. and Science (1992). "The genius of michael faraday." **55**(4): 21-27.

Tseng, C.-H., C.-K. Lin, Y.-L. Chen, C.-K. Tseng, J.-Y. Lee and J.-C. J. E. J. o. M. C. Lee (2018). "Discovery of naphtho [1, 2-d] oxazole derivatives as potential anti-HCV agents through inducing heme oxygenase-1 expression." **143**: 970-982.

Valipour, M., N. Naderi, E. Heidarli, F. Shaki, F. Motafeghi, F. T. Amiri, S. Emami and H. J. E. J. o. P. S. Irannejad (2021). "Design, synthesis and biological evaluation of naphthalene-derived (arylalkyl) azoles containing heterocyclic linkers as new anticonvulsants: A comprehensive in silico, in vitro, and in vivo study." **166**: 105974.

Wang, G., W. Liu, M. Fan, M. He, Y. Li, Z. J. J. o. E. I. Peng and M. Chemistry (2021). "Design, synthesis and biological evaluation of novel thiazole-naphthalene derivatives as potential anticancer agents and tubulin polymerisation inhibitors." **36**(1): 1693-1701.

York, A. J. N. R. M. (2017). "Historical influences on antibiotic resistance." **15** (10): 577-577.