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Review Article

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A REVIEW ON: ELECTROSTATIC CATALYSIS OF ADIELS-ALDER REACTION

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Abstract

Electrostatic catalysis has emerged as a powerful and innovative approach in modern chemical transformations, offering a non-traditional pathway to accelerate reactions without the direct involvement of conventional chemical catalysts.The presence of oriented electric fields can stabilize transition states, influence charge distribution, and lower activation energy barriers, thereby enhancing reaction rates. Recent theoretical and experimental advancements demonstrate how external electric fields and charged environments can mimic enzymatic conditions, providing precise control over reaction pathways.The Diels–Alder reaction is one of the most widely studied pericyclic reactions, known for its ability to form six-membered cyclic compounds through a concerted [4+2] cycloaddition between a diene and a dienophile. This reaction plays a crucial role in the synthesis of natural products, pharmaceuticals, and advanced materials due to its high regioselectivity and stereospecificity.

Keywords: *Electrostatic catalysis,Diels–Alder reaction,cyclic compounds,Aliphatic compounds.*

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INTRODUCTION

Organic chemistry is a branch of chemistry that deals with the study of organic compounds, which are substances containing carbon atoms bonded with elements such as hydrogen, oxygen, nitrogen, and sulfur. This field mainly focuses on understanding the structure, properties, reactions, and applications of these compounds. It helps explain how life functions in our environment by studying chemical processes in living organisms at the molecular level. Important biological molecules like nucleic acids, proteins, and enzymes are organic in nature. By studying their structures and transformations, scientists can utilize them effectively, which is made possible through organic chemistry.

History of Organic Chemistry

The development of organic chemistry can be understood through different periods: Pre-1800s: Vitalism EraDuring this time, scientists believed that organic compounds could only be produced by living organisms due to a special "vital force."

In 1784, Carl Scheele extracted organic acids such as citric, malic, and tartaric acids from natural sources, showing that plants contain distinct chemical substances. In 1807, Jöns Berzelius introduced the term "organic chemistry" to describe compounds derived from living organisms, distinguishing them from inorganic substances obtained from minerals. However, since no one could synthesize organic compounds in the laboratory, the theory of vitalism remained widely accepted.

1828–1860: End of Vitalism and Beginning of Structure TheoryIn 1828, Friedrich Wöhler synthesized urea from ammonium cyanate, proving that organic compounds could be created from inorganic materials and thus disproving vitalism.

In 1845, Hermann Kolbe prepared acetic acid from simple elements, demonstrating that complex organic compounds could be built step by step.

In 1856, William Perkin accidentally discovered the first synthetic dye, mauveine, which marked the beginning of the industrial organic chemistry era.

In 1858, Friedrich Kekulé and Archibald Couper proposed that carbon is tetravalent and can form chains by bonding with itself.

In 1861, Kekulé introduced the ring structure of

benzene, explaining the stability of C_6H_6 and establishing the concept of aromatic compounds.

1860s–1900: Growth of Structure Theory and Synthesis

With a better understanding of molecular structure, chemists began designing and synthesizing compounds deliberately.

In 1865, Adolf von Baeyer worked on synthesizing indigo dye, proving that complex natural compounds could be artificially produced.

In 1874, Jacobus van't Hoff and Joseph Le Bel proposed the tetrahedral arrangement of carbon atoms, explaining optical isomerism.

In 1884, Emil Fischer determined the structure of glucose and contributed to peptide synthesis, laying the foundation for biochemistry.

In 1899, Bayer introduced Aspirin, one of the first widely used synthetic drugs.

1900–1950: Development of Tools and Reaction Mechanisms

Advances in scientific instruments helped chemists better understand chemical reactions.

In 1907, Leo Baekeland developed Bakelite, the first completely synthetic plastic.

In 1912, Victor Grignard discovered Grignard reagents, which revolutionized organic synthesis and earned him the Nobel Prize.

During the 1920s, scientists like G.N. Lewis, Robinson, and Ingold developed electronic theories of bonding, explaining the behavior of functional groups.

In the 1930s and 1940s, techniques like infrared (IR) and ultraviolet (UV) spectroscopy were introduced, allowing identification of compounds without destroying them.

1950–Present: Modern Organic Chemistry Modern organic chemistry combines advanced instruments, biology, and computational methods.

In 1951, Robert Woodward successfully synthesized complex natural products like cholesterol and strychnine.In the 1960s, Nuclear Magnetic Resonance (NMR) became a standard tool for determining molecular structures quickly.

In 1965, the Woodward–Hoffmann rules explained pericyclic reactions using quantum theory.

From the 1980s onwards, asymmetric catalysis developed by scientists like Sharpless, Noyori, and Knowles enabled the production of single-enantiomer drugs such as L-DOPA.

In recent decades, green chemistry, click chemistry, flow chemistry, and enzyme catalysis have focused on making chemical processes more efficient and environmentally friendly.

In 2010, palladium-catalyzed cross-coupling reactions developed by Heck, Negishi, and Suzuki became widely used methods for forming carbon–carbon bonds, earning them the Nobel Prize in Chemistry.

CLASSIFICATION OF ORGANIC CHEMISTRY

Since there are more than 50 million organic compounds, it is important to classify them for easier study. These compounds can be grouped based on the following criteria:

1. Based on Origin: Organic compounds are divided into natural and synthetic types. Natural compounds are obtained from living organisms or their by-products, while synthetic (artificial) compounds are produced in laboratories through chemical processes.

2. Based on Structure: Organic compounds can also be classified according to their structural arrangement. Aliphatic compounds consist of carbon atoms arranged in straight or branched chains. Aromatic compounds contain ring structures with alternating double bonds. Organometallic compounds are those in which carbon atoms are directly bonded to metal atoms. Heterocyclic compounds are ring structures that include atoms other than carbon, such as nitrogen, oxygen, or sulfur.

3. Based on Functional Groups: Another way to classify organic compounds is by their functional groups. Hydrocarbons such as alkanes, alkenes, and alkynes are made up only of carbon and hydrogen; alkanes have single bonds, alkenes contain double bonds, and alkynes have triple bonds. Alcohols are formed when a hydrogen atom in a hydrocarbon is replaced by a hydroxyl group, and multiple hydroxyl groups result in polyalcohols. Ketones are compounds that contain a carbonyl group bonded to two carbon atoms, whereas aldehydes have a carbonyl group attached to at least one hydrogen atom. Carboxylic acids contain a carboxyl functional group. Amines are formed when one or more hydrogen atoms of an ammonia molecule are replaced by carbon-containing groups.

Their molecular weight or size: Organic compounds can also be classified according to their size. Monomers are small molecular units that can join together through chemical bonds to form larger structures. Polymers, on the other hand, are large macromolecules made up of repeating monomer units.In organic chemistry, the Diels–Alder reaction is categorized as a [4+2] cycloaddition reaction. It is an important example of a pericyclic reaction that occurs through a concerted mechanism, where bond formation and bond breaking take place simultaneously in a single step without any intermediate.

CLASSIFICATIONS AND CHARACTERISTICS OF THE DIELS-ALDER REACTION INCLUDES

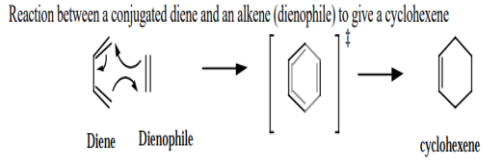
The Diels–Alder reaction is a type of cycloaddition reaction in which two π-electron systems combine-a conjugated diene contributing four π-electrons and a dienophile contributing two π-electrons-to produce a six-membered ring.It is classified as a pericyclic reaction because the bonding changes occur through a cyclic transition state, where electrons move in a continuous loop. This reaction is specifically known as a [4+2] cycloaddition, indicating the number of π-electrons involved from each reactant. The process is concerted and stereospecific, meaning it occurs in a

single step without intermediates, and the stereochemistry of the reactants is preserved in the product. Additionally, the reaction is thermally allowed and follows the Woodward-Hoffmann rules, which are based on orbital symmetry.

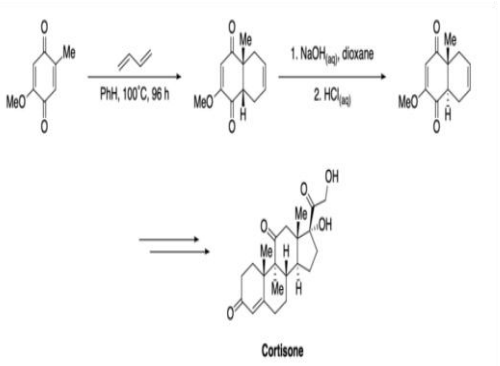
Diels–Alder Reaction

The Diels–Alder reaction is a chemical process between a conjugated diene and a substituted alkene, called the dienophile, resulting in the formation of a substituted cyclohexene compound. It is a classic example of a pericyclic reaction that proceeds through a concerted mechanism, represented as [π4s + π2s] according to Woodward–Hoffmann notation.

During this reaction, two new carbon–carbon bonds are formed simultaneously, leading to the efficient formation of six-membered rings. Because of its excellent control over regioselectivity and stereochemistry, the Diels–Alder reaction is widely used in organic synthesis, especially in the preparation of complex natural products and advanced materials.



The Diels–Alder reaction was first reported by Otto Diels and Kurt Alder in 1928, and they were later awarded the Nobel Prize in Chemistry in 1950 for this discovery. In organic chemistry, this reaction involves a conjugated diene reacting with a substituted alkene, known as the dienophile, to produce a substituted cyclohexene compound.

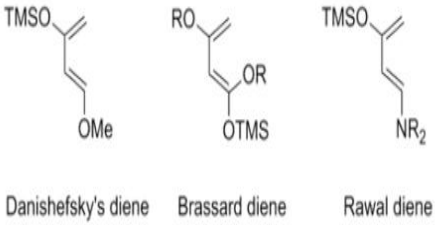


FUNDAMENTAL CONCEPTS - STRUCTURE OF DIENE AND DIENOPHILE

DIENE

In the Diels–Alder reaction, the diene component may be either open-chain or cyclic and can contain a variety of substituents. However, it must adopt the *s-cis* conformation, as only this form is capable of participating in the reaction. Although butadiene is generally more stable in the *s-trans* conformation, the energy difference between *s-trans* and *s-cis* is relatively small (about 2–5 kcal/mol).

The presence of a bulky substituent at the C2 or C3 position can increase the reaction rate by destabilizing the *s-trans* form and favoring the reactive *s-cis* conformation. For instance, 2-tert-butyl-1,3-butadiene is significantly more reactive-about 27 times-than simple butadiene. On the other hand, when bulky groups are present at both the C2 and C3 positions, steric hindrance destabilizes the *s-cis* conformation, making the diene less reactive.



Dienes that contain bulky substituents at the terminal positions (C1 and C4) tend to react more slowly, as these groups hinder the proper approach between the diene and the dienophile.A highly reactive example is Danishefsky's diene (1-methoxy-3-trimethylsiloxy-1,3-butadiene), which is widely used in synthesis. It is especially useful for producing α,β-unsaturated cyclohexenone systems after removal of the methoxy group and deprotection of the silyl ether.Other important derivatives include Brassard dienes and Rawal dienes, which also show enhanced reactivity. This increased reactivity is due to electron-donating groups at the C1 and C3 positions, which raise the HOMO energy level and make the diene more reactive compared to simple dienes.

Reactive and Stable Dienes

Highly unstable dienes, such as *o-quinodimethane*s, are extremely reactive and are often generated *in situ*. Their high reactivity is mainly due to the restoration of aromaticity during the reaction. These dienes can be produced by methods such as pyrolysis of benzocyclobutenes, elimination reactions, or reduction of specific substituted compounds.Incontrast, stable dienes are less reactive and usually require higher temperatures to undergo the Diels–Alder reaction. For example:

- **Naphthalene** reacts only with highly reactive dienophiles.
- **Anthracene** is more reactive and can form adducts with maleic anhydride at around 80 °C and even react with weaker dienophiles like acetylene at higher temperatures.

Dienophile in Diels–Alder Reaction

In a normal Diels–Alder reaction, the dienophile typically contains an electron-withdrawing group attached to the alkene, which increases its reactivity. In contrast, in inverse electron-demand reactions, the dienophile contains electron-donating groups.

Dienophiles can also include "masked functionalities," which are introduced into the product during the

reaction and later converted into desired functional groups through additional steps.

For example, **α-**chloroacrylonitrile(CH_2=CClCN) acts as a masked equivalent of ketene. It first introduces a chloronitrile group into the product, which can later be converted into a ketone. This approach is used because ketene itself does not behave properly in Diels–Alder reactions and instead undergoes unwanted side reactions.

Other masked functional groups include phosphonium groups, sulfoxides, sulfones, and nitro groups, which can later be transformed into useful functional groups.

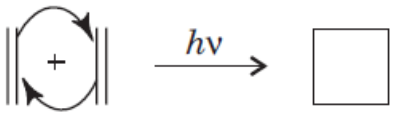
Basic Principle of Cycloaddition

A cycloaddition reaction is a type of addition reaction in which two unsaturated molecules combine to form a cyclic compound. During this process, π (pi) bonds in the reactants are broken, and new σ (sigma) bonds are formed, resulting in a ring structure.

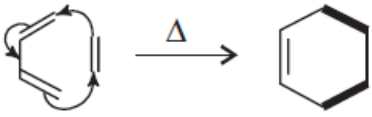
In general, two π bonds are lost from the reactants, and two σ bonds are formed in the product.

Types of Cycloaddition Reactions

- **[2 + 2] Cycloaddition:** Involves the interaction of two π-electron systems, each contributing two electrons.
- **[4 + 2] Cycloaddition:** Involves a diene (4 π-electrons) and a dienophile (2 π-electrons), as seen in the Diels–Alder reaction.
- **[m + n] Cycloaddition:** A general representation where *m* and *n* denote the number of π-electrons contributed by each reacting component.



Loss of two π bonds and gain of two σ bonds



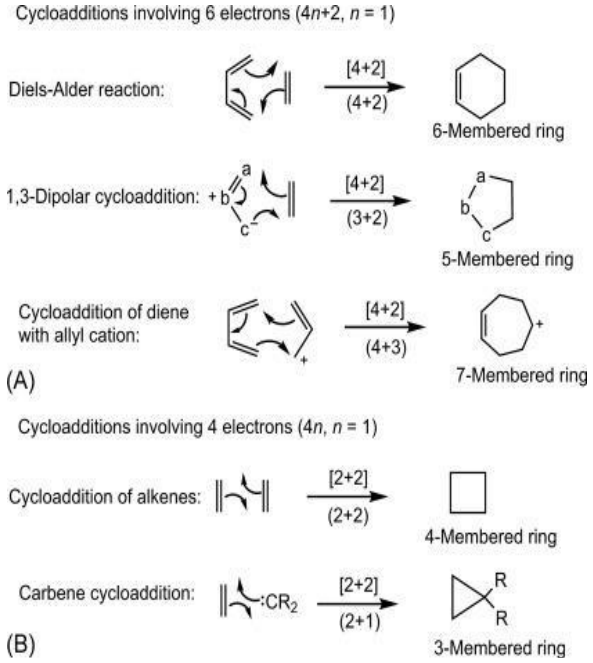
CLASSIFICATION OF CYCLOADDITION REACTIONS

Cycloaddition reactions can be classified based on several important aspects of the reaction:

1. They are categorized according to the number of electrons contributed by each reacting component, as well as whether the reaction occurs under thermal (heat) or photochemical (light) conditions.
2. Classification also depends on the type of orbitals involved in the reaction, such as π (pi) or σ (sigma) orbitals.
3. Another basis of classification is the stereochemical pathway of the reaction, which may occur in a suprafacial (syn) or antarafacial (anti) manner.
4. Regioselectivity is also considered, which refers to the preferred orientation of bond formation in the product.

The stereochemical mode of cycloaddition is indicated by subscripts 's' (suprafacial) or 'a' (antarafacial), showing how the addition occurs on each reacting unit. A cycloaddition reaction may take place either on the same face or on opposite faces of the reacting π systems.

When the reaction occurs on the same face of a π system, it is called a suprafacial addition, which is equivalent to syn addition. In contrast, when the reaction takes place across opposite faces, it is termed antarafacial addition, which corresponds to anti addition.



ELECTROSTATIC CATALYST ON OVERVIEW

DEFINITION

Electrostatic catalysis is the process by which a chemical reaction is accelerated due to a reduction in activation energy, achieved through a preorganized and polarized environment at the active site. This environment stabilizes the charge separation or high dipole moment that develops in the transition state (TS) more effectively than the surrounding solvent, such as water.

THEORETICAL BACKGROUND

The theoretical basis of electrostatic catalysis, mainly developed by Arieh Warshel and experimentally supported by Steven Boxer, is based on the following concepts:

Preorganization

Enzyme active sites are structurally arranged in advance to provide an optimal electrostatic environment for stabilizing the transition state, avoiding the energy cost required for solvent reorganization.

Transition State Stabilization

Catalysis is explained by comparing the free energy of the reaction in the enzyme environment with that in solution. Electrostatic interactions stabilize the transition state more than the reactants, lowering the activation energy.

Vibrational Stark Effect (VSE): This effect measures electric fields within enzyme active sites using IR spectroscopy. Experimental results show that the strength of the electric field is directly related to the reduction in activation energy.

Electrostatic Stress: Some enzymes destabilize the ground state using repulsive forces, in addition to stabilizing the transition state, further enhancing the reaction rate.

ROLE OF ELECTRIC FIELD IN CHEMICAL REACTION Electric fields play a major role in electrostatic catalysis of Diels–Alder reactions by stabilizing charged or polar transition states, reducing activation energy, and influencing selectivity. Strong external electric fields can act as virtual catalysts, sometimes converting a concerted reaction into a stepwise process.

Roles of Electric Field in Diels-Alder Reactions

Activation Barrier Reduction: Electric fields lower the energy of the transition state relative to reactants, making the reaction faster.

Stepwise Mechanism Induction: Under strong fields, a normally concerted reaction may proceed via a stepwise pathway, forming intermediate species.

Stereo- and Regioselectivity Control: The orientation and strength of the field determine the preferred formation of specific isomers.

Resonance Stabilization: Electric fields stabilize dipolar resonance forms of the transition state, reducing energy requirements.

Environmental Simulation (Enzymatic): Enzyme active sites naturally generate electric fields that mimic externally applied fields, aiding catalysis.

Single-Molecule Control: Techniques like scanning tunneling microscopy show that electric fields can control reactions at the molecular level.

Polarity Effects: Highly polar solvents may reduce the effectiveness of electrostatic catalysis due to strong solvation.

Reaction Field Effect: Solvents themselves can generate reaction fields that stabilize transition states.

INFLUENCES OF ELECTROSTATIC FORCES ON TRANSITION STATE

Electrostatic interactions, including electric fields and ion pairing, significantly affect the stability of transition states and thus influence reaction rates.

Key Influences of Electrostatic Forces on Transition States:

Enzyme Catalysis (Preorganization):

Electric fields in enzyme active sites are arranged to stabilize the transition state efficiently.

Ion Pairing and Selectivity:

Interactions between charged intermediates and counterions can influence reaction pathways and selectivity.

Secondary Electrostatic Interactions (SEIs): Weak, non-covalent interactions help stabilize transition states and lower energy barriers.

Switching Reaction Pathways (SN1/SN2): Electrostatic environments can favor different reaction mechanisms by stabilizing or destabilizing charges.

Long-Range Effects in Protein Folding: Electrostatic forces influence protein folding and stability by affecting intermediate structures.

EFFECT OF ELECTRIC FIELDS ON REACTIVITY Oriented External Electric Fields (OEEFs) act as controllable tools that influence chemical reactions by modifying energy landscapes without adding chemical catalysts.

MECHANISMS OF REACTIVITY ENHANCEMENT

Stabilization of Transition States: Aligned electric fields lower the energy of the transition state, increasing reaction rates.

Bond Polarization: Electric fields can distort electron distribution, making bonds more reactive.

Controlling Selectivity: Adjusting the direction of the field allows control over reaction pathways and product formation.

Biological Inspiration – Enzyme Catalysis Nature uses electrostatic catalysis effectively through enzymes.

Active-Site Alignment: Enzymes position reactants precisely to maximize the effect of internal electric fields.

Electrostatic Preorganization: Protein structures maintain optimal orientation for efficient catalysis.

STABILIZATION OF TRANSITION STATES Electrostatic catalysis enhances reaction rates by stabilizing high-energy transition states through strong and organized electric fields.

Detailed Mechanisms of Electrostatic TS Stabilization

Active Site Preorganization: Charged and polar groups are arranged to stabilize the transition state.

Charge Density Enhancement: Hydrogen bonding and other interactions increase charge concentration in the transition state.

Desolation: Removal of solvent molecules allows stronger enzyme–substrate interactions.

Conformational Changes: Structural adjustments bring stabilizing groups closer to the transition state.

Preferential Binding: The catalyst binds the transition state more strongly than the reactants.

Electrostatic Complementarity: The active site is designed to match the charge distribution of the transition state.

Case Studies: Studies on enzymes like chorismate mutase and ketosteroid isomerase show the importance of electrostatic effects.

APPLICATIONS

Synthesis of Complex Molecules: Used in forming cyclic structures found in natural products.
Enantioselective Synthesis: Helps produce optically active compounds.
Regioselectivity Control: Electric fields guide formation of specific products.
Heterocycle Formation: Used in constructing complex ring systems.

PHARMACEUTICAL RELEVANCE

The Diels–Alder reaction is widely applied in synthesizing biologically active compounds.
Antiviral Agents: Used in preparing intermediates for drugs like saquinavir, darunavir, and oseltamivir.
Natural Compounds: Helps in synthesizing complex molecules such as wickerols.
Drug Delivery Systems: Applied in designing polymers and hydrogels for controlled drug release.

ELECTROSTATIC CATALYSIS OF DIELS-ALDER REACTIONS

This method uses electric fields or charged groups to stabilize transition states and accelerate bond formation, with applications in materials science.
Self-Healing Polymers: Used to create materials that can repair themselves.
Functionalized Nanomaterials: Enhances surface properties of nanomaterials.
Smart Hydrogels: Used in responsive drug delivery systems.
Single-Molecule Switches: Enables control of molecular electronic devices.

ADVANTAGES OF ELECTROSTATIC CATALYSIS

Electrostatic catalysis provides a flexible and efficient alternative to traditional catalysts.
Significant Rate Acceleration: Electric fields lower activation energy and speed up reactions.
Selective Control of Products: Allows control over stereochemistry and regioselectivity.
Manipulation of Chemical Pathways: Can alter reaction mechanisms.

CATALYST-FREE ENHANCEMENT

Electrostatic catalysis enables reaction acceleration without adding chemical catalysts, using external electric fields to lower activation barriers.

LIMITATIONS AND CHALLENGES

Despite its advantages, electrostatic catalysis faces practical difficulties such as maintaining field alignment, solvent interference, and challenges in experimental implementation.

CONCLUSION

Electrostatic catalysis offers a modern and powerful approach to controlling chemical reactions without traditional catalysts. In Diels–Alder reactions, electric fields improve reaction rates, selectivity, and transition state stability while supporting environmentally friendly synthesis. Although significant progress has been made, further research is needed to overcome challenges in applying this method on a larger scale and in practical systems.

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All are contributed equally.

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REFERENCES

1. Langade D, Dawane J, Dhande P. Sub-acute toxicity of Ashwagandha (*Withania somnifera*) root extract in Wistar rats. Toxicol Rep.
2. Paul S, Chakraborty S, Anand U, Dey S, Nandy S, Ghorai M, et al. *Withania somnifera* (L.) Dunal (Ashwagandha): A comprehensive review on ethnopharmacology, pharmacotherapeutics, biomedicinal and toxicological aspects. Biomed Pharmacother.
3. Langade D, Dawane J, Dhande P. Sub-acute toxicity of Ashwagandha (*Withania somnifera*) root extract in Wistar rats. Toxicol Rep.
4. Singh N, Bhalla M, de Jager P, Gilca M. An overview on Ashwagandha: A Rasayana (rejuvenator) of Ayurveda. Afr J Tradit Complement Altern Med.
5. Połumackanycz M, Forencewicz A, Wesołowski M, Viapiana A. Ashwagandha (*Withania somnifera* L.)—The plant with proven health-promoting properties. Farm Pol.
6. Kurapati KRV, Atluri VSR, Samikkannu T, Nair MPN. Ashwagandha (*Withania somnifera*) reverses β-amyloid1-42 induced toxicity in human neuronal cells: Implications in HIV-associated neurocognitive disorders (HAND). PLoS One.
7. Sikandan A, Shinomiya T, Nagahara Y. Ashwagandha root extract exerts anti-inflammatory effects in HaCaT cells by inhibiting the MAPK/NF-κB pathways and by regulating cytokines.
8. Gupta M, Kaur G. *Withania somnifera* as a potential anxiolytic and anti-inflammatory candidate against systemic lipopolysaccharide-induced neuroinflammation. Neuromolecular Med.

9. Grunz-Borgmann E, Mossine V, Fritsche K, Parrish AR. Ashwagandha attenuates TNF-α- and LPS-induced NF-κB activation and CCL2 and CCL5 gene expression in NRK-52E cells. BMC Complement Altern Med.
10. Pezzani R, Vitalini S, Iriti M. Bioactivities of *Origanum vulgare* L.: An update. Phytochem Rev. 2017;16(6):1253-68. doi:10.1007/s11101-017-9535-z.
11. Pereira DM, Oliveira J, Ferreres F, Valentão P, Andrade PB, Sottomayor M. Targeted metabolite analysis of *Catharanthus roseus* and its biological potential.
12. Singh A, Singh PK, Singh RK. Antidiabetic and wound healing activity of *Catharanthus roseus* L. in streptozotocin-induced diabetic mice. Am J Phytomed Clin Ther. 2014.
13. Wang Y, Dou L, He H, Zhang Y, Shen Q. Multifunctional nanoparticles as nanocarrier for vincristine sulfate delivery to overcome tumor multidrug resistance. Mol Pharm. 2014.
14. Farha AK, Yang QQ, Kim G, Li HB, Zhu F, Liu HY, et al. Tannins as an alternative to antibiotics. Food Biosci. 2020.
15. Amde A, Masresha G, Hansha H, Asafa O. Ethnobotanical study of traditional medicinal plants in Debark District, North Gondar, Ethiopia. Int J Sci Res Multidiscip Stud. 2020.
16. Tibebe D, Belete A, Kassa Y. Evaluation of total phenolic, flavonoid contents, and antioxidant activities of seed extracted from coriander (*Coriandrum sativum* L.) and black cumin (*Nigella sativa*). Food Anal Methods. 2024.
17. Gajewski JJ, Peterson KB, Kagel JR. Transition-state structure variation in the Diels-Alder reaction from secondary deuterium kinetic isotope effects: The reaction of a nearly symmetrical diene and dienophile is nearly synchronous. J Am Chem Soc. 1987;109(18):5545-6. doi:10.1021/ja00252a052.
18. Sethi J, Yadav M, Sood S, Dahiya K, Singh V. Effect of tulsi (*Ocimum sanctum* Linn.) on sperm count and reproductive hormones in male albino rats.
19. Sah AK, Vijaysimha M, Mahamood M. The tulsi, queen of green medicines: Biochemistry and pathophysiology-A review. Int J Pharm Sci Rev Res. 2018;50(2):106-14.
20. Sah AK, Vijaysimha M, Mahamood M. The tulsi, queen of green medicines: Biochemistry and pathophysiology-A review. Int J Pharm Sci Rev Res. 2018;50(2):106-14.