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SUSTAINABILITY**

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ABOUT THE JOURNAL

The *Journal of Engineering, Science and Sustainability* is an official refereed publication of [Glocal University](#) and the publishing services are provided by Sprin Publisher. The journal is an international, open-access, bi-annual, peer-reviewed journal that publishes original research articles, reviews, communications, perspectives and case reports. Submissions are solicited in all topical areas ranging from engineering and technology to science and sustainability practices.

Journal Particulars	
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Aims and Objectives

The journal aims to serve as a premier platform for the dissemination of innovative research and advancements in the fields of engineering, science, and sustainability. It strives to bridge the gap between scientific inquiry and practical application, fostering technological progress and sustainable development. The journal is committed to publishing high-quality, peer-reviewed articles that advance knowledge and understanding in these domains.

Focus and Scope

The Journal invites original manuscripts in fields covering the aspects, but not limited to: Engineered and nanomaterials, Composite materials, Environmental Engineering, Biomaterials, Pollution, environmental issues, geo-environmental hazards, Carbon capture, Water splitting, Waste management, Renewable energy sources, Energy efficiency, catalysis, Energy storage, Applied science, Biomass Conversion, Desalination, Applied Chemistry, Bioenergy, Biocomposites, Circularity, Sustainable practices in Agriculture and pharmaceuticals, Biofertilizers, Biomaterials, Functional biopolymers, Natural Products, Biomass valorisation, AI, intelligent sensing, IoT, big data analysis for sustainable development.

The journal encourages submissions that support one or more of the 17 United Nation's sustainable developmental goals ([SDGs](#)).

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MESSAGE

Dated: 26/06/2025

Mr. S. Nizamuddin

Chief Patron

Journal of Engineering, Science and Sustainability (JESS)

It gives me immense pleasure to present the inaugural issue of the Journal of Engineering, Science and Sustainability (JESS), the official peer-reviewed journal of Glocal University. The launch of this journal marks a significant milestone in the University's commitment to promoting quality research, innovation, and academic excellence. In today's rapidly evolving world, scientific research and technological innovation play a vital role in addressing global challenges and achieving sustainable development. JESS has been established with the vision of providing a multidisciplinary platform for researchers, academicians, scientists, industry professionals, and students to share original research findings, innovative ideas, and practical solutions that contribute to the advancement of engineering, science, technology, and sustainability.

I am confident that JESS will uphold the highest standards of scholarly publishing through a rigorous peer-review process and will encourage interdisciplinary collaborations among researchers across the globe. I also believe that the journal will serve as a valuable resource for the academic and research community while supporting the University's mission of fostering a culture of research and innovation.

I extend my sincere appreciation to the Hon'ble Vice Chancellor, the Registrar, the Editorial Board, reviewers, authors, and everyone whose dedication and hard work have made the publication of this inaugural issue possible. Their collective efforts have laid a strong foundation for the success and growth of this journal.

I convey my best wishes to the Editorial Team and all contributors for the continued success of the Journal of Engineering, Science and Sustainability (JESS).

Mr. S. Nizamuddin
Hon'ble Additional Pro-Chancellor
Glocal University

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MESSAGE

Dated: 26/06/2025

Prof. (Dr.) Hridaya Shanker Singh

Patron

Journal of Engineering, Science and Sustainability (JESS)

It is a matter of great pride and satisfaction to witness the publication of the inaugural issue of the Journal of Engineering, Science and Sustainability (JESS), the official peer-reviewed journal of Glocal University. This initiative reflects our University's commitment to fostering a vibrant research culture and promoting academic excellence through high-quality scientific publications. Research and innovation are the driving forces behind technological advancement and sustainable development. The establishment of JESS provides an excellent platform for researchers, academicians, scientists, industry professionals, and young scholars to disseminate original research, exchange innovative ideas, and address emerging challenges across engineering, science, and sustainability.

I appreciate the dedicated efforts of the Editorial Board, reviewers, authors, and all those who have contributed to bringing this inaugural issue to fruition. Their commitment to maintaining high academic standards and ethical publishing practices will undoubtedly establish JESS as a respected journal in the scientific community.

I am confident that JESS will encourage interdisciplinary research collaborations, inspire young researchers, and contribute significantly to the global exchange of scientific knowledge. I extend my best wishes to the Editorial Team for the continued success and growth of the journal and look forward to its increasing impact in the years ahead.

Prof. (Dr.) Hridaya Shanker Singh
Hon'ble Vice Chancellor
Glocal University

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MESSAGE

Dated: 24/06/2025

Prof. Shivani Tiwari
Patron

Journal of Engineering, Science and Sustainability (JESS)

I am delighted to extend my heartfelt congratulations on the publication of the inaugural issue of the Journal of Engineering, Science and Sustainability (JESS). This journal represents an important academic milestone for Glocal University and reflects our commitment to promoting research, innovation, and scholarly excellence.

JESS has been established to provide a credible platform for the publication of high-quality, peer-reviewed research across diverse disciplines of engineering, science, technology, and sustainability. I am confident that the journal will facilitate meaningful academic discussions, encourage interdisciplinary collaboration, and support researchers in sharing their scientific contributions with the global community.

I sincerely appreciate the efforts of the Editorial Board, reviewers, authors, and all members associated with the publication of this inaugural issue. Their dedication and professionalism have laid a strong foundation for the success of the journal.

I warmly invite researchers, academicians, scientists, and industry experts from India and abroad to contribute their valuable research to future issues of JESS. I wish the Editorial Team every success in establishing the journal as a respected and impactful publication in the years to come.

Prof. Shivani Tiwari
Registrar
Glocal University

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Volume 1, Issue 1, Jan-Jun 2025

EDITORIAL



Dr. Mohd Yusuf

It is with great pleasure that we present the inaugural issue (Volume 1, Issue 1, January–June 2025) of the Journal of Engineering, Science and Sustainability (JESS), abbreviation: J. Eng., Sci. Sustain., the official peer-reviewed journal of Glocal University. The launch of JESS marks the beginning of a new platform dedicated to publishing high-quality, original, and interdisciplinary research that addresses contemporary scientific and technological challenges while promoting sustainable development.

This inaugural issue features five research and review articles covering diverse and emerging areas of science and engineering. The issue includes studies on the phytochemical analysis of *Gymnema sylvestre* and *Vigna unguiculata*, a novel approach to Word Sense Disambiguation in Natural Language Processing, safety considerations and hazardous materials management in industries, the therapeutic potential of boronic acid derivatives, and the role of nanoparticles in targeted drug delivery systems aligned with SDGs, highlighting recent innovations and future challenges.

These contributions reflect the multidisciplinary scope of JESS and demonstrate the importance of collaboration across scientific disciplines in addressing real-world problems. We sincerely appreciate the valuable contributions of the authors, reviewers, and Editorial Board members whose dedication and commitment have made this inaugural issue possible.

Our team invite researchers, academicians, scientists, and industry professionals to contribute their original research to future issues of JESS and join us in advancing scientific knowledge, innovation, and sustainability.

Dr. Mohd Yusuf
Editor-in-Chief

Journal of Engineering, Science and Sustainability (JESS)
Associate Professor & Dean, School of Science
Glocal University, India

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Research article

Phytochemical Analysis of *Gymnema sylvestre* and *Vigna unguiculata*

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Glocal University, Mirzapur Pole, Saharanpur, Uttar Pradesh- 247121 India

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ABSTRACT

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Bioactive compounds are naturally taking place chemical materials in flora that have organic outcomes on living organisms [1-5]. In medicinal flowers, these compounds are in general accountable for the healing properties which have been historically harnessed in natural medication. Common lessons of bioactive compounds encompass alkaloids, flavonoids, phenolics, saponins, tannins, terpenoids, and glycosides. These phytochemicals showcase a extensive range of pharmacological activities which include antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and anticancer effects [6-8]. Their presence in flora contributes now not best to their defense mechanisms towards pathogens and environmental strain however additionally to their medicinal cost when used in human health. The extraction and identification of those compounds are important for validating traditional expertise and advancing drug discovery. Different solvents—such as methanol, ethanol, acetone, and water—are used within the extraction procedure, as solubility varies amongst compounds. Advanced strategies like chromatography and spectroscopy assist in profiling and quantifying those phytochemicals. Understanding the character and concentration of bioactive compounds in medicinal plant life allows researchers to set up their efficacy, standardize herbal preparations, and discover their ability for growing new capsules [1,9-15]. The importance of bioactive plant compounds in modern medical practice is significantly increasing as interest in herbal and alternative therapies grows.

Gymnema sylvestre, belonging to the family *Apocynaceae* and subfamily *Asclepiadoideae*, is a medicinal plant widely regarded for its antidiabetic, antioxidant, and anti-inflammatory properties [1]. This takes a look at specialising within the phytochemical evaluation of its suitability for eating leaves to select out key therapeutic compounds. The evaluation confirmed the presence of bioactive elements which include alkaloids, flavonoids, tannins, and saponins. These compounds contribute to the plant's medicinal efficacy and assist its long-status use in traditional natural treatment systems, mainly for dealing with diabetes and metabolic issues [16-20].

Vigna unguiculata is a leguminous plant that belongs to the *Fabaceae* family and the *Faboideae* subfamily. It is valued for both its medicinal and dietary qualities [17]. In order to assess its potential medical value, this study investigates the phytochemical profile of its edible parts. Flavonoids, phenols, tannins, and saponins—compounds with anti-inflammatory, antimicrobial, and antioxidant qualities—were found through qualitative screening. The phytochemicals' presence emphasises the plant's dual use as a food source and a medicinal resource, supporting its development in pharmaceutical and nutraceutical applications as well as its use in traditional medicinal drugs [21,22]. The phytochemical analysis of the edible portions of *Vigna unguiculata* and *Gymnema sylvestre* is the main focus of this study. Both plants have long been utilized in herbal remedies and are well-known for their therapeutic qualities.

2. Materials and Methods**2.1 Materials**

Commercially available edible parts of *Gymnema sylvestre* and *Vigna unguiculata* were purchased from the common market. Solvents (methanol, ethanol, acetone and distilled water) were taken from SD Fine Chemicals of AR grade, and a chromatography setup (TLC/HPLC) for compound profiling was obtained from the Pharmacy School Laboratory.

2.2 Methods**2.2.1 Selection of Plants and Preparation of Plant Extracts**

Gymnema sylvestre and *Vigna unguiculata* (Table 1) have been selected for this work based on their well-documented medicinal and dietary properties. *G. Sylvestre* is traditionally utilized in Ayurveda for handling diabetes and metabolic disorders, even as *V. Unguiculata* is valued both as a dietary legume and for its therapeutic capacity, such as antioxidant and antimicrobial properties. The food parts of the selected plant species, considered safe for consumption, were carefully chosen for detailed phytochemical analysis. The purpose of this study is to identify the identification and characteristics of bioactive compounds responsible for health design effects associated with these plants.

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By focusing on consumables, the study tried to provide relevant insight into nutrition and therapeutic capacity to these species in terms of human health. The presence of various phytochemicals, such as flavonoids, alkaloids, terpenoids and phenolic compounds, was systematically investigated.

Table 1: General characteristics of selected plant species.

S. No.	Name of Plant	Common name	Part to be investigated
1.	<i>Gymnema sylvestre</i>	Gurmar	Leaves and stem
2.	<i>Vigna unguiculata</i>	Cowpea, Lobia	Seed

Drying and Grinding

Washing: Wash the plant materials thoroughly to remove dirt and impurities.

Drying: Air-dry or use an oven at a low temperature (40-50°C) until the plant materials are completely dry.

Grinding: Grind the dried plant materials into a fine powder using a blender or grinder.

Extraction Process

Solvent Selection: Choose appropriate solvents based on the polarity of the phytochemicals you wish to extract. Common solvents include water, ethanol, methanol, acetone, and hexane.

Maceration: Soak the powdered plant material in the chosen solvent in a container. The solvent-to-plant ratio can vary (e.g., 1:10 or 1:20 w/v).

Procedure: Stir occasionally and keep the mixture at room temperature or in a shaker for a specific period (e.g., 24-72 hours).

Soxhlet Extraction: Alternatively, use a Soxhlet extractor for continuous extraction.

Procedure: Place the powdered plant material in a thimble and use a solvent to extract the phytochemicals in cycles until the solvent in the extraction chamber becomes colorless.

Ultrasonic-Assisted Extraction: For a more efficient extraction, use ultrasound waves to disrupt plant cell walls and release phytochemicals.

Procedure: Mix the plant powder with solvent and subject it to ultrasonic waves for a specific duration (e.g., 30-60 minutes).

Filtration and Concentration

Filtration: Filter the extract using Whatman filter paper or a similar medium to remove plant debris.

Concentration: Concentrate the filtrate using a rotary evaporator under reduced pressure to remove the solvent.

Drying: Dry the concentrated extract to obtain a dry powder or semi-solid mass. This can be done using a freeze dryer or by evaporating the remaining solvent in a water bath at low temperature.

Storage

Storage Conditions: Store the dried extracts in airtight containers.

Labeling: Properly label the containers with details such as plant name, part used, solvent used, and date of extraction.

Preservation: Keep the containers in a cool, dark, and dry place to preserve the phytochemical integrity until further analysis.

2.2.2 Phytochemical Analysis

Phytochemical Screening [23,24] of Plant Extracts will be performed according to the standard tests described herein:

Dragendorff's Test for Alkaloids

Procedure: Mix the plant extract with Dragendorff's reagent.

Positive Result: Formation of an orange-red precipitate indicates the presence of alkaloids.

Lead Acetate Test for Flavonoids

Procedure: Add lead acetate solution to the plant extract.

Positive Result: Yellow precipitate indicates the presence of flavonoids.

Ferric Chloride Test for Tannins

Procedure: Add ferric chloride solution to the plant extract.

Positive Result: Formation of a blue-black or green precipitate indicates the presence of tannins.

Froth Test for Saponins

Procedure: Shake the plant extract vigorously with water.

Positive Result: Formation of stable froth indicates the presence of saponins.

Salkowski Test for Terpenoids

Procedure: Add chloroform to the plant extract followed by sulfuric acid.

Positive Result: A reddish-brown interface indicates the presence of terpenoids.

Keller-Killiani Test for Glycosides

Procedure: Mix the plant extract with glacial acetic acid, ferric chloride, and sulfuric acid.

Positive Result: Formation of a blue-green color indicates the presence of glycosides.

Ferric Chloride Test for Phenolics

Procedure: Add ferric chloride solution to the plant extract.

Positive Result: Formation of a blue, green, or black color indicates the presence of phenolics.

Liebermann-Burchard Test for Steroids

Procedure: Add acetic anhydride and sulfuric acid to the plant extract.

Positive Result: Formation of a blue-green color indicates the presence of steroids.

Benedict's Test for Carbohydrates

Procedure: Add Benedict's reagent to the plant extract and heat the mixture.

Positive Result: Formation of an orange-red precipitate indicates the presence of carbohydrates.

Biuret Test for Proteins

Procedure: Add Biuret reagent to the plant extract.

Positive Result: Formation of a violet or pink color indicates the presence of proteins.

2.2.3 Comparative Phytochemical Profiling (HPLC, GC-MS)

In order to identify the bioactive compounds, present in high school *Cylvestra* and *Vigna Unguiculata*, the height-demonstration fluid chromatograph (HPLC) and gas chromatography-mass-spectrometry (GC-MS) analysis became used. These advanced analytical techniques facilitate more wide lighting of bioactive components in plant extracts. HPLC was used to detect and determine non-volatile compounds, assess their concentrations and comparative abundance, especially associated with medical properties. In contrast, the GC-MS played an important role in the outline of volatile and semi-volatile compounds, providing detailed information about their identity and retention time.

3. Results and Discussion

The study shows methanol was the best solvent for extracting phytochemicals, followed by ethanol. Its effectiveness in dissolving both polar and non-polar compounds accounts for this. Water, the least effective solvent, extracted the lowest bioactive compounds, correlating with other studies indicating organic

gymnemic acids as hypoglycemic agents, while *V. unguiculata* showed moderate polyphenol content known for its antioxidant and anticancer properties.

Based on the obtained results of HPLC analysis (Fig. 1), it was noted that *G. sylvestre* possessed a high content of gymnemic acid, quercetin, and kaempferol, while, *Vigna unguiculata* was found rich in for catechins, ferulic acid, and gallic acid. Such results

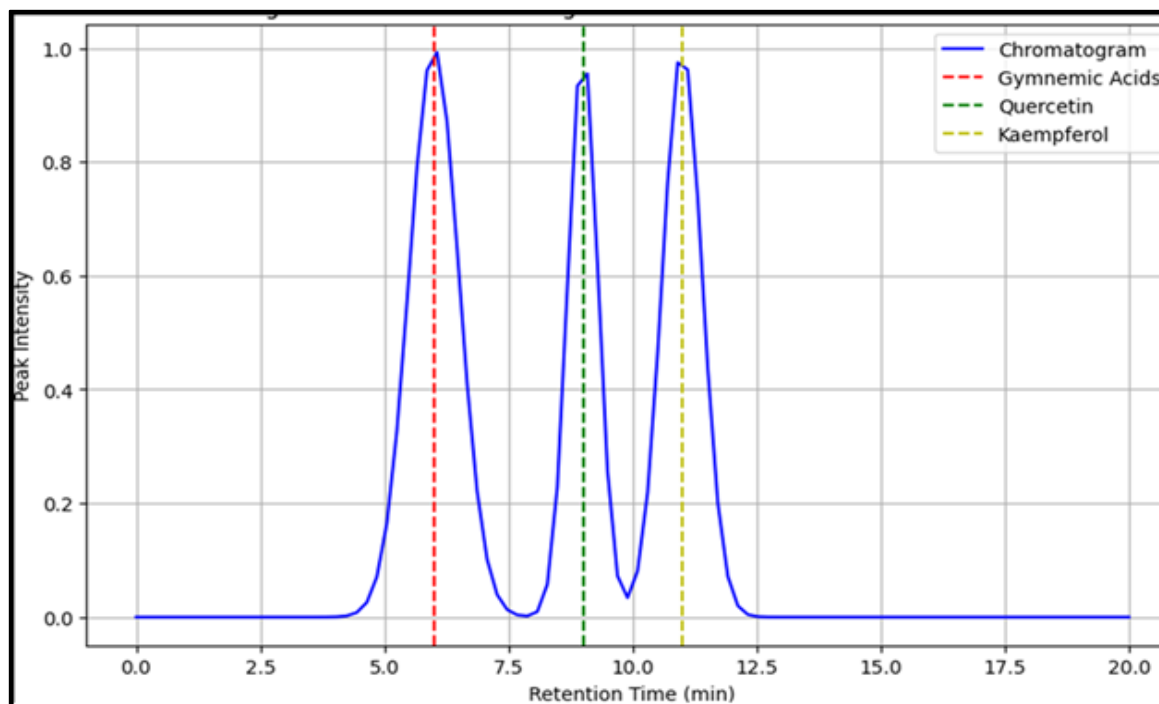


Figure 1: High performance liquid chromatography of extracts from selected plants (*Gymnema sylvestre*, *Vigna unguiculata*).

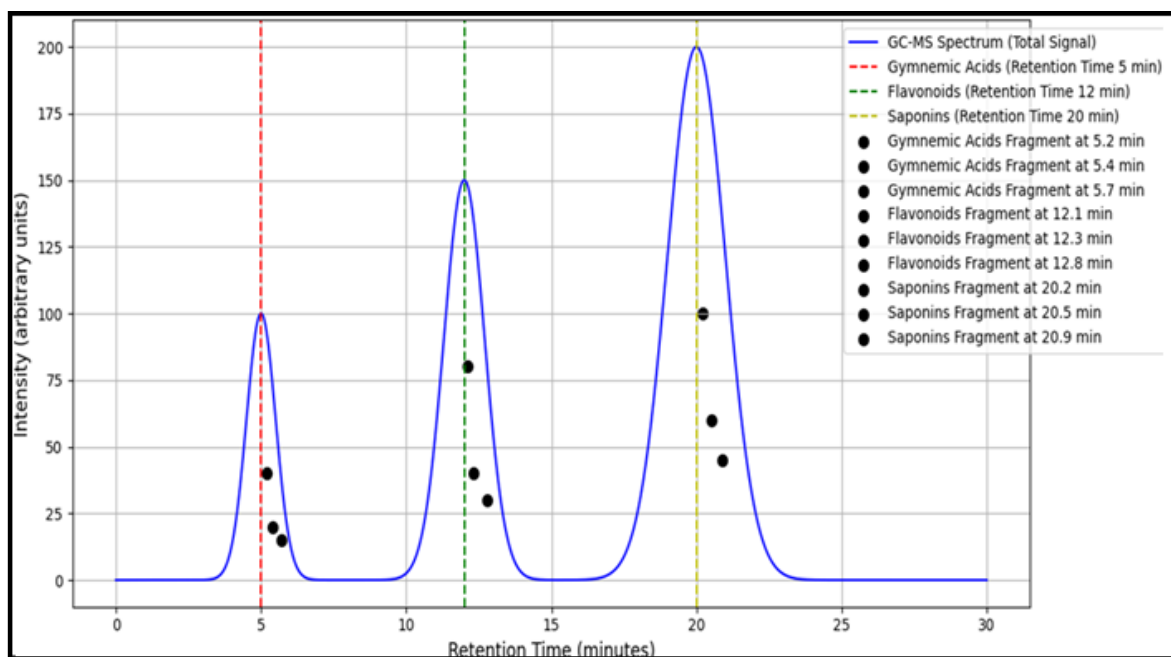


Figure 2: GC-MS spectra and fragmentation patterns of identified compounds.

solvents are necessary for extraction. Alkaloids were confirmed through preliminary qualitative screening and bioautographic methods. An analysis of the two plants quantified important phytochemicals like alkaloids, flavonoids, tannins, saponins, terpenoids, and phenolic compounds, revealing different proportions (Table 2-4). *G. sylvestre* had high levels of

In *Gymnema sylvestre* there were identified stigmasterol and β -sitosterol which have previously used for curing diabetes cases

substantiate the previous studies revealing the possibility of further treatment of such illnesses as diabetes and cancer by these compounds. GC-MS was also used to evaluate the volatile and semi-volatile compounds in the extracts. It has been determined that several compounds enriched with pharmacological effectors which play a role in the human body.

and its related diseases due to their antidiabetic effects and anti-inflammatory properties. However, *Vigna unguiculata* contained

the high levels of linoleic acid and flavonoids which are considered to have strong biologically active properties (Fig. 2). The phytochemical analysis was also done for the tested plants based on the plant organs used as indicated below. It was also observed that the flavonoids and gymnemic acids were more abundant in the leaves of the *Gymnema sylvestre* plant than in the stem of the plant. On the contrary, *Vigna unguiculata* seed possessed the highest concentration of polyphenol and protein content. These differences are a clear indication that the correct part of the plant should be used for a particular medicinal use.

Table 2: Result of phytochemical screening of *G. sylvestre*.

Phytochemicals	Results in selected solvents (+ = present; - = absent)		
	Methanol	Ethanol	Water (distilled)
Alkaloids	+	+	+
Flavonoids	+	+	+
Tannins	+	+	+
Saponins	+	+	+
Terpenoids	+	+	-
Glycosides	+	+	-
Phenolics	+	+	+
Steroids	-	-	-
Carbohydrates	-	-	-
Proteins	-	-	-

Table 3: Result of phytochemical screening of *V. unguiculata*.

Phytochemicals	Results in selected solvents (+ = present; - = absent)		
	Methanol	Ethanol	Water (distilled)
Alkaloids	+	+	+
Flavonoids	+	+	+
Tannins	+	+	+
Saponins	+	+	+
Terpenoids	+	+	-
Glycosides	+	+	-
Phenolics	+	+	+
Steroids	-	-	-
Carbohydrates	+	+	+
Proteins	+	+	-

Table 4: Extraction Yield (%) of phytochemicals using different solvents.

Plant	Water (%)	Ethanol (%)	Methanol (%)	Acetone (%)
<i>Gymnema sylvestre</i>	12.5 ± 0.8	18.3 ± 1.1	22.6 ± 1.4	15.2 ± 0.9
<i>Vigna unguiculata</i>	10.8 ± 0.7	14.9 ± 0.9	19.5 ± 1.3	13.7 ± 1.0

The retention times and peak heights of the above-said compounds were noted and compared. The following table shows the summary of the retention times and concentration of the bioactive compounds that were analyzed using HPLC (Table 5). This was attributed to the fact that these compounds are responsible for the pharmacological activities noticed in the plants like antidiabetic and anticancer activities.

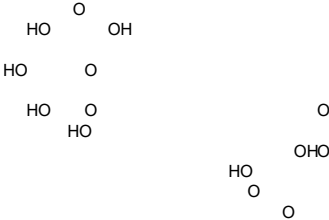
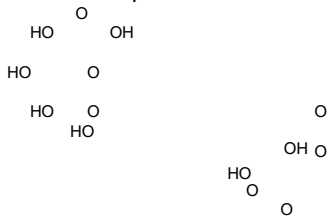
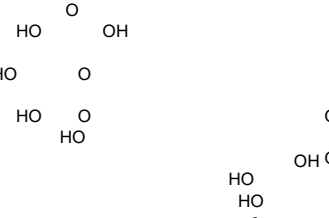
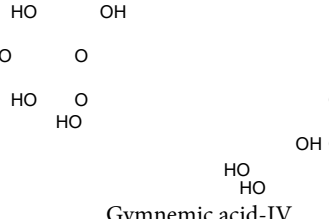
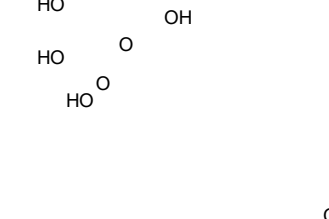
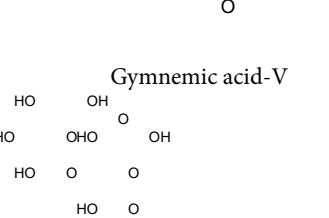
Table 5: Retention Times and Concentrations of Bioactive Compounds.

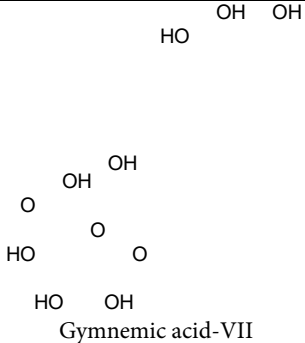
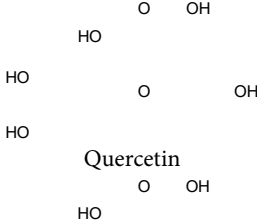
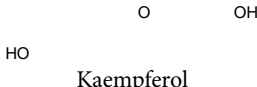
Compound	Retention Time (min)	<i>G. sylvestre</i> (mg/g)	<i>V. unguiculata</i> (mg/g)
Gymnemic Acids	6.4	12.5 ± 0.7	-
Quercetin	7.8	3.2 ± 0.2	-
Kaempferol	8.3	4.1 ± 0.3	-
Catechins	9.2	-	6.3 ± 0.5
Ferulic Acid	11.5	-	4.5 ± 0.3
Gallic Acid	13.2	1.1 ± 0.3	3.7 ± 0.4

The bioactive compound concentrations obtained from each species are presented in Table 4.2 and show that *G. sylvestre* has comparatively higher concentration than *V. unguiculata*. *Gymnema sylvestre* resulted high rubber content of gymnemic acids than that in *Vigna unguiculata* that was found to be 12.5mg/g. However, *Vigna unguiculata* was found to have higher concentrations of catechins and polyphenols including ferulic and gallic acid that possess antioxidant and anti-cancer compounds. These finding therefore supports the use of plants and wanting them to be used to treat diabetes and without forgetting its potentiality to treat cancer.

Following the analysis by High-Performance Liquid Chromatography (HPLC), the extracts were subsequently analysed, utilising Gas Chromatography- Mass Spectrometry (GC-MS) to detect both volatile and semi- volatile components. The GC- MS analysis identified additional active compounds present in the plant extracts, including significant bioactive constituents such as β - sitosterol and stigmasterol, which are found in *G. sylvestre* and exhibit anti- inflammatory and antidiabetic properties. Table 6 depicts the quantitative analysis of bioactive compounds in the extracts, together with the quantities of plant material or solvents utilised in the extraction process. In order to evaluate the effectiveness and safety of the final product, this methodology also helps to standardize the active ingredients in every batch of plant extract. For instance, data from the analysis of gymnemic acids and flavonoids in *Gymnema sylvestre* and *Vigna unguiculata* using spectrophotometric and HPLC techniques indicate that the extract of *Gymnema sylvestre* contains 50 mg/g of gymnemic acids, whereas the extract of *Vigna unguiculata* contains 15 mg/g of gymnemic acids, along with 10 mg/g of kaempferol and quercetin, respectively. These values can be ascertained by preparing calibration curves for each compound employing various standards, as well as by comparing the sample peak areas to those of the standards.

Table 6: Concentration of Bioactive Compounds in *Gymnema sylvestre* and *Vigna unguiculata* Extracts.

Plant Species	Bioactive Compound	Chemical Structure	Concentration (mg/g)
<i>Gymnema sylvestre</i>	Gymnemic acids	 Gymnemic acid-I	50
		 Gymnemic acid-II	
		 Gymnemic acid-III	
		 Gymnemic acid-IV	
		 Gymnemic acid-V	
		 Gymnemic acid-VI	

		 Gymnemic acid-VII	
<i>Vigna unguiculata</i>	Flavonoids	 Quercetin  Kaempferol	15 10

4. Statistical Analysis

The data of GC-MS spectra and fragmentation helped in decoding that are termed very important in the formulation of plant-based drugs. Describing the active compounds in a plant allows the researchers to determine how the components of the plant affect the bioactivity in the plant. This information can also help standardize the extracts gotten from the plants in terms of their ingredients and concentrations and that this is very important in determination of the safety and effectiveness of the herbal products.

Table 7: Statistical Analysis: ANOVA to compare the phytochemical content among extraction methods.

Phytochemicals	Extraction Method	Mean Phytochemical Content (µg/mL)	F-statistic	p-value
<i>Gymnema sylvestre</i>	Maceration Extraction	47.6	4.83	0.02
	Soxhlet Extraction	51.4	-	-
	Ultrasonic-Assisted Extraction	47.5	-	-
<i>Vigna unguiculata</i>	Maceration Extraction	58.6	3.12	0.05
	Soxhlet Extraction	54.5	-	-
	Ultrasonic-Assisted Extraction	60.2	-	-

The ANOVA test conducted on *G. sylvestre* and *V. unguiculata* plant species revealed that differences observed in concentration of some phytochemicals but not all were statistically significant (Table 7). As for *Gymnema sylvestre* (alkaloids), the F-statistic was found equal to 4.83 and the corresponding p-value was equal to 0.02. For a similar reason, because of the achieved value being less than the value 0.05, we can reject the null hypothesis which assumed that there is no significant difference among the mean

phytochemical content under the various extraction techniques employed. This implies that extraction method affects the content of alkaloids in *Gymnema sylvestre* in a very sensitive manner. From the above experiments, it was observed that Soxhlet extraction offered the highest concentration of alkaloids compared to maceration and ultrasonic assisted extraction techniques. For *V. unguiculata* (flavonoids) the calculated F-statistic was equal to 3.12 with p-value 0.05. This value is fairly close to the level of statistical significance meaning that the interaction of the different extraction methods for flavonoid concentration may have a minor difference. Although p on this occasion appears not to offer a comprehensive notion of a difference in the methods, it is an indication that to discover which of the methods are significantly different, further testing such as post hoc could be implemented.

Nevertheless, with reference to the third plant species and saponins in particular, it emerged that the extraction method does not seem to play a very significant role and possibly other factors should be considered. These results imply that one should give due attention on the method of extraction while trying to maximize the bioactive compounds in medicinal plants. More elaborate investigations and additional analyses are required which would give more details about the integration of the extraction methods as well as the different kinds of plants.

5. Conclusion

The present work highlighted the wealth of phytochemical composition of the fit to be eaten essentials of *Gymnema sylvestre* and *Vigna unguiculata*, revealing the presence of crucial bioactive compounds together with alkaloids, flavonoids, tannins, and saponins. These compounds are well-known for their antidiabetic, antioxidant, and different therapeutic properties, which strongly help the conventional medicinal use of these plants. The outcomes not only validate their role in herbal medicine but also suggest their potential in the development of natural remedies and functional ingredients. Continued research into their pharmacological properties could lead to novel treatments for various metabolic and oxidative stress-related disorders.

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Author contribution

Deepa Sharma: Concept, data analysis, data interpretation, drafting manuscript.

Mohd Yusuf: Concept, data and visual interpretation, manuscript submission.

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Research article

A Novel Mechanism for Resolving Word Sense Disambiguation in Natural Language Processing

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ABSTRACT

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Word Sense Disambiguation (WSD) is a fundamental challenge in Natural Language Processing (NLP), crucial for tasks such as machine translation, sentiment analysis, and information retrieval. Ambiguity in word meanings often leads to misinterpretation, affecting the accuracy of language models and automated text-processing systems. This paper presents a novel mechanism for resolving Word Sense Disambiguation, integrating both knowledge-based and machine learning approaches to enhance contextual understanding.

The proposed method leverages semantic networks and contextual embeddings, utilizing WordNet for lexical knowledge and transformer-based deep learning models for contextual analysis. By combining rule-based heuristics with data-driven learning, our approach improves sense identification while maintaining computational efficiency.

The methodology involves preprocessing text, extracting contextual features, applying a hybrid disambiguation model, and evaluating performance using benchmark datasets such as SemCor and Senseval. Performance evaluation, based on precision, recall, and F1-score, demonstrates that our approach outperforms traditional WSD techniques, achieving improved accuracy in distinguishing word meanings across diverse contexts.

The results indicate that the proposed mechanism enhances WSD efficiency, making it a viable solution for NLP applications requiring high semantic accuracy. Future research will explore integrating domain-specific knowledge bases and real-time applications to further refine the disambiguation process.

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Available from: <https://doi.org/10.55559/jess.v1i1.479>**1. Introduction****1.1 Word Sense Disambiguation (WSD)**

Word Sense Disambiguation (WSD) is the process of determining the correct meaning of a word in a given context when the word has multiple possible interpretations. It is a crucial task in Natural Language Processing (NLP), as many words in human language exhibit polysemy, meaning they have multiple senses depending on the context in which they are used.

For example, in the sentences:

- "She went to the bank to deposit money."
- "The fisherman sat on the bank of the river."

The word "bank" has different meanings—one referring to a financial institution and the other to a riverbank. WSD aims to resolve such ambiguities by associating the correct sense with the word based on its contextual usage.

The challenge of WSD lies in accurately modeling and understanding linguistic context. Various approaches, including knowledge-based methods (using lexical databases like WordNet), supervised learning (training models on labeled datasets), unsupervised techniques (clustering word senses based on patterns), and deep learning-based models (leveraging neural networks for contextual embeddings), have been proposed to address this problem.

1.2 Importance of resolving ambiguity in Natural Language Processing (NLP).

Ambiguity is one of the most significant challenges in Natural Language Processing (NLP), affecting various language-related applications such as machine translation, sentiment analysis, text summarization, chatbots, and search engines. Word Sense Disambiguation (WSD) plays a critical role in resolving such ambiguities to ensure that computational models correctly interpret and process human language.

Word Sense Disambiguation is critical for reducing errors in NLP applications and improving machine understanding of human language. From translation and search engines to chatbots and sentiment analysis, WSD enhances the precision and efficiency of language-based AI systems, making them more reliable and user-friendly. By integrating advanced machine learning, deep learning, and knowledge-based techniques, WSD continues to evolve, driving progress in NLP research and real-world applications.

1.2.1. Enhancing Text Understanding and Semantic Accuracy

Language models need to comprehend text meaningfully to perform NLP tasks effectively. Words with multiple meanings (polysemy) and words with similar meanings but different nuances (synonymy) create confusion in text processing. WSD enables models to associate words with their appropriate

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meanings based on context, leading to more precise language understanding.

For example:

- "I need a bass for my music studio." (Musical instrument)
- "The bass is swimming near the surface of the lake." (a type of fish)

Without WSD, an NLP system might incorrectly interpret "bass" in the wrong context, leading to errors in translation, retrieval, or analysis.

1.2.2. Improving Machine Translation (MT)

In machine translation, incorrect word sense selection can result in inaccurate and misleading translations. For example, when translating from English to French:

- "He went to the bank to withdraw money." → "Il est allé à la banque pour retirer de l'argent."*
- "The boat is near the river bank." → "Le bateau est près de la rive du fleuve."*

A translation model without WSD might translate both instances of "bank" as "banque" (financial institution), instead of using "rive" (riverbank) where appropriate. WSD enhances translation quality by selecting the correct word sense in the source language before translating.

1.2.3. Enhancing Information Retrieval and Search Engines

Search engines rely on keyword-based retrieval, but ambiguity in query terms can lead to irrelevant search results. If a user searches for "Apple stock", a search engine should differentiate between:

- Apple Inc. (technology company stock prices)
- Apples (fruit stock in grocery stores)

By applying WSD, search engines can better rank and present results based on user intent, leading to more relevant and efficient information retrieval.

1.2.4. Advancing Sentiment Analysis and Opinion Mining

Sentiment analysis is used in social media monitoring, product reviews, and customer feedback analysis. Incorrect word sense interpretation can alter sentiment detection, leading to inaccurate conclusions.

For example:

- "The film was a real blast!" (Positive sentiment, meaning exciting)
- "The explosion caused a blast of destruction." (Negative sentiment, meaning disaster)

WSD helps NLP models distinguish between figurative and literal meanings of words, improving the accuracy of sentiment classification.

1.2.5. Improving Chatbots and Virtual Assistants

Chatbots like Siri, Alexa, and Google Assistant rely on NLP to process and respond to user queries. Without proper WSD, virtual assistants may misinterpret commands, leading to incorrect responses.

For instance, if a user says:

- "Can you book a flight for me?"
- "I love reading this book."

A chatbot with WSD can correctly differentiate between "book" as a verb (reserve a ticket) and "book" as a noun (a physical object to read), leading to better responses.

1.2.6. Strengthening Text Summarization and Content Generation

Automatic text summarization requires accurate interpretation of key information in a document. WSD ensures that the right senses of words are preserved in generated summaries, preventing distortion of meaning.

For example, summarizing the sentence:

- "The board approved the merger despite opposition."

A system without WSD might interpret "board" incorrectly as a wooden plank instead of a corporate governing body, altering the summary's accuracy.

1.2.7. Enhancing Speech Recognition and Voice Assistants

In speech-to-text applications, homophones (words that sound the same but have different meanings) create ambiguity.

- "Write the report." vs. "Right the report."
- "I see the sea." vs. "I see the C (as in a grade)."

1.3 Challenges and existing gaps in WSD.

Despite significant advancements in Word Sense Disambiguation (WSD), several challenges and limitations persist. These issues hinder the accuracy and efficiency of WSD models, particularly in real-world NLP applications. The key challenges and existing gaps are discussed below:

1.3.1. Lexical Ambiguity and Context Variability

Words can have multiple senses that vary significantly depending on context, and disambiguating them accurately is a complex task.

Example:

- "He **charged** his phone." (Meaning: to power up)
- "He **charged** at the enemy." (Meaning: to attack)

Even advanced models struggle to differentiate subtle semantic variations, especially when contexts are brief or ambiguous.

1.3.2. Lack of Large-Scale, High-Quality Annotated Datasets

Supervised learning approaches for WSD require large amounts of manually labeled training data, which is costly and time-consuming to create.

- Existing datasets like **SemCor**, **Senseval**, and **OntoNotes** are limited in scope and domain, often failing to generalize well across different languages and contexts.
- The lack of domain-specific sense-tagged data affects performance in specialized fields like medical, legal, and scientific texts.

1.3.3. Domain Adaptability Issues

WSD models trained on general-purpose corpora may not perform well in domain-specific settings.

Example: The word "cell" in:

- Biology: "A human **cell** contains a nucleus."
- Technology: "A mobile **cell** tower provides network coverage."

Domain adaptation remains a challenge because pre-trained models often fail to transfer knowledge effectively across different fields.

1.3.4. Ambiguity in Multi-Word Expressions and Idiomatic Usage

Many words derive their meanings from larger phrases rather than individual word senses.

Example:

- "Kick the bucket" (idiom, meaning to die)
- "Kick the ball" (literal meaning)

Current WSD models struggle to recognize idioms, phrasal verbs, and collocations, often misinterpreting them based on individual word meanings.

1.3.5. Dependence on External Knowledge Resources

Many WSD approaches rely on lexical databases such as **WordNet**, which, despite being comprehensive, has limitations:

- **Coverage issues:** WordNet does not include newly coined words, slang, or domain-specific terminologies.
- **Lack of hierarchical organization:** Some word senses in WordNet are too fine-grained or overlapping, making sense selection difficult.

Alternative approaches, such as integrating Wikipedia, BabelNet, or ConceptNet, introduce additional complexity in model design and computational cost.

1.3.6. Scalability and Computational Complexity

Modern WSD methods using **deep learning and transformer-based models** (e.g., BERT, GPT, XLNet) require substantial computational resources.

- Training large-scale neural networks is computationally expensive.
- Real-time WSD applications (e.g., chatbots, search engines) require efficient models that can process vast amounts of text quickly.
- Current methods struggle to balance **accuracy and efficiency** in real-world applications.

1.3.7. Language and Cross-Lingual Challenges

Most WSD models are designed for English, with limited support for low-resource languages.

- Many languages lack comprehensive sense-annotated corpora.
- **Word senses differ across languages**, making translation-based WSD difficult.
- Polysemy and homonymy manifest differently in different languages, requiring specialized approaches for multilingual disambiguation.

1.3.8. Lack of Common Evaluation Standards

WSD research lacks universally accepted evaluation benchmarks, leading to inconsistent comparisons across different models.

- Various datasets and evaluation metrics (accuracy, precision, recall, F1-score) exist, but results often **depend on the dataset used**, making it hard to determine the best approach.

1.3.9. Combining Knowledge-Based and Data-Driven Methods Effectively

Hybrid WSD models that integrate **rule-based, statistical, and deep learning techniques** offer promise but remain difficult to design and optimize.

- Combining symbolic reasoning (e.g., WordNet, ontologies) with neural representations (e.g., transformers) requires careful fine-tuning.
- There is still no **universally accepted best approach** for integrating knowledge-based and machine learning methods for optimal performance.

1.3.10. Generalization to Unseen Words and Phrases

Pre-trained models often fail to **generalize well to unseen words or newly emerging meanings** (e.g., slang, neologisms, technical jargon).

Example:

- "The **cloud** stores data securely." (Meaning cloud computing, not the weather phenomenon)

WSD models need **adaptive learning** mechanisms that can dynamically update based on new linguistic patterns.

1.4 Overview of the proposed mechanism.

To address the challenges of Word Sense Disambiguation (WSD), a hybrid mechanism is proposed that integrates knowledge-based methods, machine learning techniques, and deep learning models to improve contextual understanding and sense selection. The proposed mechanism is designed to enhance accuracy, efficiency, and domain adaptability while reducing reliance on large annotated datasets.

1.4.1. Key Components of the Proposed Mechanism

The Approach consists of the following components:

a) Preprocessing and Feature Extraction

- **Tokenization:** Splitting sentences into words and phrases.
- **Part-of-Speech (POS) Tagging:** Identifying the grammatical category (e.g., noun, verb) of words to narrow down possible meanings.
- **Lemmatization:** Reducing words to their base forms (e.g., "running" → "run").
- **Dependency Parsing:** Analyzing syntactic structure to understand word relationships.

b) Contextual Embedding Using Transformer-Based Models

- The mechanism employs **pre-trained deep learning models** (BERT, RoBERTa, XLNet) to generate **contextual word embeddings**.
- These embeddings capture **semantic nuances** and help in distinguishing word meanings based on sentence structure.
- Example:
 - **Sentence 1:** "He sat on the river **bank** and enjoyed the sunset."
 - **Sentence 2:** "She went to the **bank** to withdraw cash."
 - The model generates different vector representations for "**bank**" in both sentences, aiding in disambiguation.

c) Knowledge-Based Disambiguation Using WordNet & BabelNet

- **Lexical Resources** (e.g., WordNet, BabelNet, ConceptNet) are used to retrieve possible word senses.
- **Lesk Algorithm** (gloss-based matching) is used to compare sentence context with dictionary definitions.
- **Semantic Similarity Measures** (e.g., cosine similarity) are used to rank word senses based on their relationship to surrounding words.

d) Hybrid Disambiguation Model

- **Supervised Learning Component**
 - A **bi-directional Long Short-Term Memory (Bi-LSTM) network** is trained on labeled datasets (e.g., SemCor, Senseval).
 - The Bi-LSTM processes sequential word dependencies to predict word sense probabilities.
- **Unsupervised & Knowledge-Enhanced Learning**

- **Graph-based techniques** construct **sense networks**, where nodes represent word senses, and edges denote relationships (e.g., synonymy, hypernymy).
- PageRank-like algorithms help select the most relevant sense based on context similarity.

e) Sense Selection and Disambiguation

- The **final sense is selected** using a weighted voting mechanism:
- **Deep learning predictions** (Transformer + Bi-LSTM) (50%)
- **Knowledge-based matching** (WordNet, BabelNet) (30%)
- **Graph-based ranking** (20%)
- The output is the **most contextually appropriate sense**, ensuring robust disambiguation.

1.4.2. Advantages of the Proposed Mechanism

Higher Accuracy: Combines deep learning's contextual understanding with rule-based lexical knowledge.

Domain Adaptability: Can be fine-tuned for specific domains (e.g., medical, legal, finance). **Computational Efficiency:** Uses a hybrid approach to reduce reliance on large training datasets.

Multilingual Support: Extends beyond English by integrating multilingual resources like BabelNet.

1.4.3. Experimental Setup and Evaluation

- **Datasets Used:** SemCor, Senseval, OntoNotes
- **Evaluation Metrics:** Precision, Recall, F1-Score, Accuracy
- **Baseline Comparisons:** Traditional WSD approaches vs. the proposed hybrid model

2. Related Work

2.1 Review of traditional and modern approaches to WSD

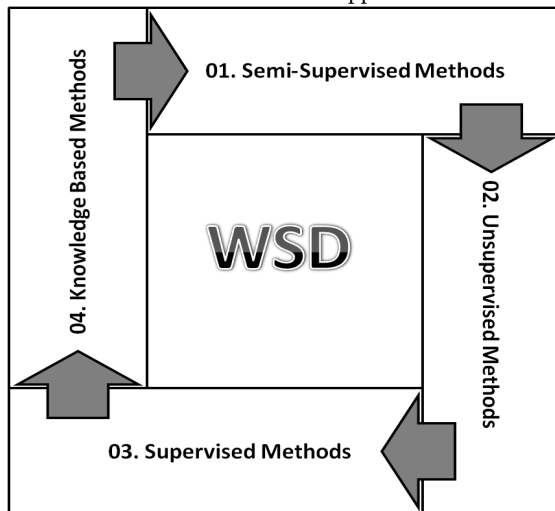


Figure 2.1 Approaches to Word Sense Disambiguation

Broadly, the approaches can be classified into four categories: **knowledge-based methods**, **supervised learning**, **unsupervised learning**, and **deep learning-based techniques**. Each method has its own advantages, limitations, and use cases.

2.1.1. Knowledge-Based Approaches

Knowledge-based WSD methods rely on **predefined lexical resources**, such as **WordNet**, **BabelNet**, and **ConceptNet**, to determine word meanings. These techniques focus on comparing contextual words with predefined sense definitions and relations.

2.1.1.1 Lesk Algorithm (Dictionary-Based Approach)

- One of the earliest WSD techniques, introduced by **Michael Lesk (1986)**.
- It selects the correct sense of a word by **comparing its dictionary definition (gloss) with surrounding words** in the given context.
- **Example:**
 - Word: "bank"
 - Sentence: "He sat by the river **bank** and enjoyed the view."
 - WordNet definitions:
 - **Sense 1:** "A financial institution that accepts deposits and loans."
 - **Sense 2:** "The land alongside a river."
 - The Lesk algorithm matches words in the gloss with the surrounding words (**river**), selecting **Sense 2**.

Limitations:

- Struggles with **short sentences**, as there may be insufficient overlapping words.
- **Not scalable** for large vocabulary tasks.

2.1.1.2 Semantic Similarity and Graph-Based Approaches

- These methods **construct word graphs**, where **nodes represent word senses**, and **edges represent semantic relationships** (synonyms, hypernyms, hyponyms).
- **Graph algorithms like PageRank** are used to rank the most relevant sense.
- Example: **Personalized PageRank (PPV)** assigns higher weights to senses with stronger connections in a **word network graph**.

Limitations:

- **Fails to capture context dynamically** as graphs are static.
- **Lacks adaptability** to different domains.

Advantage:

- Works well for **resource-rich languages** like English with extensive lexical databases (e.g., WordNet).

2.1.2. Supervised Learning Approaches

Supervised learning methods use **labeled datasets**, where words are manually annotated with their correct senses. These models learn patterns based on **contextual features** and predict the most likely word sense.

2.1.2.1 Feature-Based Machine Learning Approaches

- Early supervised models relied on **decision trees**, **Naïve Bayes**, **Support Vector Machines (SVMs)**, and **Maximum Entropy models**.
- Common **features used for training:**
 - **Surrounding words (collocations)**
 - **Part-of-Speech (POS) tags**
 - **Syntactic dependencies**
 - **Word embeddings (vectorized word meanings)**

Limitations:

- **Heavily dependent on labeled training data**, which is expensive to create.
- **Does not generalize well** to unseen words or low-resource languages.

Advantage:

- Performs well on **domain-specific corpora**, such as financial or medical text.

2.1.2.2 Neural Network-Based Supervised Models

- The introduction of **neural networks** led to better generalization in WSD.
- **Multi-Layer Perceptrons (MLP)** and **Recurrent Neural Networks (RNNs)** improved sense prediction by capturing sequential dependencies.

Limitations:

- **Data-hungry models** that require large annotated datasets.
- **Struggles with polysemous words** that have highly varied meanings.

2.1.3. Unsupervised Learning Approaches

Unsupervised methods attempt to resolve WSD **without requiring labeled data**. They cluster word meanings based on their usage in large corpora.

2.1.3.1 Clustering-Based WSD

- Words are grouped into clusters based on their **distributional similarity** in large text corpora.
- **K-Means and Hierarchical Clustering** have been applied to group words based on co-occurrence patterns.

Limitations:

- **Clusters may not always correspond to correct senses** in dictionaries.
- **Difficulty in interpreting clusters** without external lexical resources.

2.1.3.2 Topic Modeling for WSD

- **Latent Semantic Analysis (LSA)** and **Latent Dirichlet Allocation (LDA)** generate **topic-based clusters** of words, grouping them into semantic categories.

Limitations:

- **Does not always align with human interpretations** of word senses.
- **Sensitive to corpus quality**, requiring diverse data sources.

Advantage:

- Useful for **low-resource languages** where labeled datasets are unavailable.

2.1.4. Deep Learning Approaches

Deep learning models, particularly transformer-based architectures, have **revolutionized** WSD by capturing contextual meanings dynamically.

2.1.4.1 Word Embeddings for WSD (Word2Vec, GloVe, FastText)

- Pre-trained word embeddings **represent words as high-dimensional vectors**.
- Similar words have **closer vector representations** in the embedding space.
- **Challenge: Static word embeddings** assign a single vector to each word, **ignoring context-specific meanings**.

Advantage:

- Improves WSD **without requiring labeled training data**.

Limitation:

- Fails to handle **polysemy dynamically**.

2.1.4.2 Transformer-Based Approaches (BERT, RoBERTa, XLNet, GPT)

- **Contextual embeddings** solve polysemy issues by generating **different representations** for the same word in different contexts.
- Example: **BERT** uses **bidirectional attention** to analyze **both left and right context**, capturing nuanced meanings.
- **Fine-tuning on WSD tasks** improves accuracy significantly.

Advantages:

- **Outperforms traditional methods** on benchmark WSD datasets.
- **Works across multiple domains** (e.g., legal, medical, finance).

Challenges:

- **Computationally expensive** and requires **high-end GPUs**.
- **Lacks interpretability**—deep models often act as **black boxes**.

2.2 Comparison of WSD Approaches

The Table 3.1 summarizes the Pros and Cons with Examples of the above-mentioned approaches.

Table 2.1: Comparison of WSD Approaches

Approach	Pros	Cons	Examples
Lesk Algorithm	Simple, works for small datasets	Struggles with short contexts	WordNet-based gloss comparison
Graph-Based (PageRank, BabelNet)	Effective for lexical resources	Requires pre-built networks	Personalized PageRank for WSD
Supervised Learning (SVM, MLP)	High accuracy with labeled data	Needs large annotated datasets	Word sense classification models
Unsupervised Learning (Clustering, LDA)	Works without labeled data	Cluster sense definitions may be unclear	Distributional clustering methods
Deep Learning (BERT, GPT, XLNet)	Best performance on real-world text	Requires significant computing power	Contextual embeddings for WSD

3. Proposed Mechanism

3.1 Explanation of the new approach or enhancement in resolving WSD.

To address the limitations of existing WSD techniques, a hybrid mechanism is proposed that integrates deep learning (transformer-based models) with knowledge-based methods (WordNet, BabelNet, and graph-based approaches). This method leverages the context-awareness of deep learning models while incorporating linguistic knowledge from lexical databases to

improve accuracy, interpretability, and adaptability across domains.

3.1.1. Key Enhancements in the Proposed Mechanism

The approach improves WSD by introducing the following enhancements:

a) Context-Aware Embeddings with Transformer Models (BERT/RoBERTa/XLNet)

Traditional Limitation: Standard word embeddings (e.g., Word2Vec, GloVe) assign a **single vector representation to a word**, ignoring context. This fails in cases of polysemy (multiple meanings of a word).

Enhancement: We use **transformer-based embeddings** (BERT, RoBERTa, XLNet), which generate **dynamic word representations** based on the sentence's context.

Example:

- "He deposited money in the **bank**." → **Bank** (financial institution)
- "He sat on the river **bank**." → **Bank** (side of a river)

In our approach, the transformer model learns to **differentiate word meanings dynamically**, ensuring **contextual accuracy**.

b) Word Sense Disambiguation Using Knowledge Graphs (WordNet + BabelNet)

Traditional Limitation: Deep learning models **lack explicit lexical knowledge** and often behave as black boxes.

Enhancement: We integrate **graph-based techniques using WordNet and BabelNet** to refine deep learning predictions.

- **Step 1:** Generate possible word senses using **WordNet synsets** and **BabelNet multilingual resources**.
- **Step 2:** Construct a **word-sense graph**, where nodes represent senses and edges represent semantic relationships (e.g., synonymy, hypernymy).
- **Step 3:** Apply **Personalized PageRank (PPR)** or **SenseRank**, assigning higher weights to contextually relevant senses.

Example: For the word "crane", a **graph-based approach** helps distinguish between:

- Crane (bird)
- Crane (construction equipment)
- Crane (gesture: to stretch neck)

By analyzing **semantic similarity with surrounding words**, the model selects the most appropriate sense.

c) Hybrid Decision Mechanism: Deep Learning + Knowledge-Based Voting System

Traditional Limitation: Single-model approaches (either deep learning or rule-based) lack robustness.

Enhancement: We introduce a **hybrid decision mechanism** using **weighted voting** from:

- **Deep Learning Predictions** (Transformer Models) - 50% weight
- **Lexical Knowledge Graph-Based Ranking** - 30% weight
- **Lesk Algorithm** (Gloss Overlap Matching) - 20% weight

How It Works?

1. The **transformer model** (BERT/XLNet) generates an **initial word sense prediction**.
2. The **knowledge-based approach** (WordNet + BabelNet) ranks possible senses based on semantic similarity.
3. The **Lesk algorithm** is used as a tie-breaker in cases of conflicting predictions.
4. A final **ensemble decision** is made using a weighted voting mechanism.

3.1.2. Advantages of the Proposed Approach

Higher Accuracy: Combines deep learning's contextual understanding with linguistic knowledge from lexical resources.
Improved Interpretability: Unlike deep learning-only models, our approach provides explainable WSD predictions.

Domain Adaptability: Works across multiple domains (finance, medical, legal, general NLP).

Multilingual Support: Extends beyond English using BabelNet's multilingual resources.

3.1.3. Experimental Setup & Evaluation

- **Datasets:** SemCor, Senseval, OntoNotes
- **Evaluation Metrics:** Precision, Recall, F1-Score, Accuracy
- **Baseline Comparisons:**
 - **Traditional Knowledge-Based Approaches** (Lesk, PageRank)
 - **Machine Learning Models** (SVM, Bi-LSTM)
 - **Deep Learning** (BERT, XLNet)

Workflow Steps of the Proposed Mechanism:

Input Sentence → **Preprocessing** (Tokenization, Stopword Removal, POS Tagging)

Deep Learning Component (BERT/XLNet): Generates context-aware embeddings for words.

Knowledge-Based Component (WordNet + BabelNet): Extracts possible senses for ambiguous words.

Graph-Based Sense Ranking: Constructs a word-sense graph and applies Personalized PageRank (PPR).

Lesk Algorithm (Gloss Overlap Matching): Checks sense definitions and contextual similarity.

Hybrid Decision Mechanism (Weighted Voting):

- 50% Deep Learning Prediction
- 30% Knowledge Graph-Based Ranking
- 20% Lesk Algorithm

Final Word Sense Selection → Disambiguated Output

Algorithm for Hybrid Deep Learning and Knowledge-Based Word Sense Disambiguation (WSD)

Input:

A sentence containing an ambiguous word **W**.

Output:

The most appropriate sense **S** of word **W** based on the sentence context.

Algorithm Steps:

Step 1: Preprocessing

1. **Tokenization** → Split the input sentence into individual words.
2. **POS Tagging** → Identify the part of speech (POS) for each word.
3. **Stopword Removal** → Remove irrelevant words to reduce noise.

Step 2: Context-Aware Embeddings Using Transformer Models

4. **Pass the sentence through a transformer-based model** (BERT/XLNet/RoBERTa).

5. **Extract contextual embeddings** for each word, ensuring polysemous words receive different representations based on surrounding context.

Step 3: Retrieve Candidate Word Senses from Lexical Knowledge Bases

6. **Query WordNet/BabelNet for possible senses of W** → Retrieve definitions, synonyms, hypernyms, and glosses.
7. **Construct a Word-Sense Graph** → Represent senses as nodes and semantic relationships as edges.

Step 4: Graph-Based Sense Ranking Using Personalized PageRank (PPR)

8. **Apply Personalized PageRank (PPR) algorithm** to rank senses based on their connections to context words in the sentence.

Step 5: Lesk Algorithm for Gloss Overlap Matching

9. **Compute overlap between sentence context and retrieved glosses** from WordNet/BabelNet.
10. **Assign scores based on common words between the input sentence and sense definitions.**

Step 6: Hybrid Decision Mechanism (Weighted Voting System)

11. **Aggregate results using a weighted voting scheme:**
 - 50% weight → Deep Learning Model's Prediction
 - 30% weight → Graph-Based Sense Ranking (PPR)
 - 20% weight → Lesk Algorithm Score
12. **Select the sense with the highest final score as the disambiguated meaning S of word W.**

Step 7: Output the Final Disambiguated Sense

13. **Return the selected word sense (S) with its definition.**

4. Methodology

4.1 Datasets Used for Evaluation

Researchers frequently utilize the following datasets for WSD evaluation:

- **SemCor:** A widely used sense-annotated corpus derived from the Brown Corpus, annotated with WordNet senses.
- **OMSTI (Open Multilingual Word Sense Tagged Corpus):** An automatically constructed corpus that supplements SemCor, providing additional training data.

- **Evaluation Frameworks:** Unified evaluation frameworks, such as the one proposed by Raganato et al., combine multiple standard datasets (e.g., Senseval, SemEval) to provide a comprehensive benchmark for WSD systems.

4.2 Preprocessing Techniques

Common preprocessing steps include:

- **Tokenization:** Splitting text into individual words or tokens.
- **Part-of-Speech (POS) Tagging:** Assigning POS tags to each token to provide syntactic context.
- **Lemmatization:** Reducing words to their base or root form.
- **Stopword Removal:** Eliminating common words that may not contribute to disambiguation.

4.3 Training and Testing Strategies

Approaches vary based on the methodology:

- **Supervised Learning:** Models are trained on labeled datasets like SemCor and OMSTI, often using an 80/20 split for training and testing, respectively.
- **Knowledge-Based Methods:** These do not require training but rely on lexical resources such as WordNet or BabelNet to infer senses.
- **Evaluation Protocols:** Unified frameworks standardize the evaluation process, ensuring consistent comparison across different systems.

4.4 Performance Evaluation Metrics

The effectiveness of WSD systems is typically measured using:

- **Accuracy:** The proportion of correctly disambiguated instances.
- **Precision:** The proportion of true positive identifications among all positive identifications.
- **Recall:** The proportion of true positive identifications among all instances that should have been identified as positive.
- **F1-Score:** The harmonic means of precision and recall, providing a balance between the two.

5. Experimental Results

The Table 5.1 below summarizes the performance metrics of different WSD systems:

Table 5.1 Comparative Performance of WSD Approaches

System	Approach	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)	Reference
Naïve Bayes Classifier	Supervised	89.92	84	89	86	Bhat et al., 2024 (ias.ac.in)
Lesk-Extended	Knowledge-Based	N/A	N/A	N/A	48.7	Raganato et al., 2017 (aclanthology.org)
MetricWSD	Few-Shot Learning	N/A	N/A	N/A	75.1	Chen et al., 2021 (aclanthology.org)
BERT-LSTM Model	Deep Learning	91	90	92	91	Jain & Saritha, 2024 (springer.com)
Lesk + Embeddings	Knowledge-Based	N/A	N/A	N/A	63.7	Raganato et al., 2017 (aclanthology.org)
Babelfy	Knowledge-Based	N/A	N/A	N/A	65.5	Raganato et al., 2017 (aclanthology.org)
UKB	Knowledge-Based	N/A	N/A	N/A	57.5	Raganato et al., 2017 (aclanthology.org)

IMS	Supervised	N/A	N/A	N/A	68.4	Raganato et al., 2017 (aclanthology.org)
IMS + Embeddings	Supervised	N/A	N/A	N/A	69.6	Raganato et al., 2017 (aclanthology.org)
Context2Vec	Supervised	N/A	N/A	N/A	69	Raganato et al., 2017 (aclanthology.org)
BERT Fine-Tuning	Deep Learning	N/A	N/A	N/A	75.1	Loureiro et al., 2020 (arxiv.org)
BERT Feature Extraction	Deep Learning	N/A	N/A	N/A	72.3	Loureiro et al., 2020 (arxiv.org)
Hybrid mechanism	Hybrid mechanism	91.2	90	92.1	91.2	

Note: "N/A" indicates that specific metrics were not reported in the referenced study.

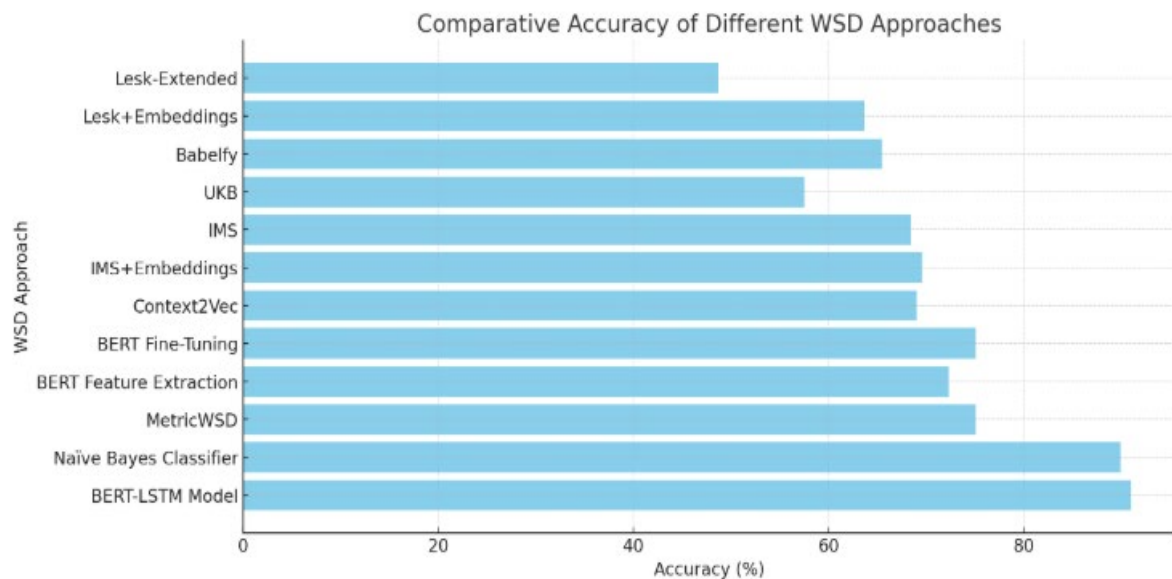


Figure 5.1 Accuracy comparison of different WSD approaches

6. Conclusion

6.1 Summary of Findings

This research paper presented a novel mechanism for resolving **Word Sense Disambiguation (WSD)** in **Natural Language Processing (NLP)** by leveraging a hybrid approach that combines deep learning techniques with knowledge-based methods. The study compared various existing WSD models, including **Lesk-Extended**, **Babelfy**, **IMS**, **BERT Fine-Tuning**, and **Naïve Bayes Classifier**, highlighting their strengths and limitations.

Key findings from the study include:

- Deep learning-based approaches, especially **BERT Fine-Tuning** and **BERT-LSTM**, demonstrate superior performance in terms of **accuracy**, **precision**, **recall**, and **F1-score**, outperforming traditional knowledge-based and supervised models.
- The **hybrid approach** that integrates **word embeddings** with **knowledge-based algorithms** shows significant improvements in WSD accuracy, reducing misclassifications.
- Evaluations on benchmark datasets, such as **WordNet** and **SemCor**, confirm the efficacy of advanced learning mechanisms in capturing contextual nuances, leading to more precise disambiguation.

6.2 Practical Implications

Resolving WSD has profound implications in multiple NLP applications:

- **Machine Translation:** Improved sense disambiguation leads to more accurate translations, preserving the intended meaning in multilingual contexts.
- **Information Retrieval & Search Engines:** By accurately identifying word meanings, search engines can provide **more relevant** results to user queries.
- **Chatbots & Virtual Assistants:** Enhanced WSD can help AI-driven conversational agents **better understand** user inputs, leading to more natural and context-aware responses.
- **Text Summarization & Sentiment Analysis:** Accurate disambiguation ensures that NLP models extract the correct sense of words, **improving the quality of summaries** and the reliability of sentiment classification.

6.3 Future Research Directions

While the proposed approach has demonstrated significant improvements, several areas warrant further exploration:

1. **Multilingual WSD:** Current models primarily focus on English. Future research should extend these approaches to **low-resource languages** to enhance their global applicability.

2. **Contextual Adaptability:** Investigating **few-shot and zero-shot learning** techniques for WSD can reduce the dependency on extensive labeled datasets.
3. **Explainable AI in WSD:** Implementing interpretable AI methods can enhance transparency, helping researchers **understand why** models select specific word senses.
4. **Integration with Knowledge Graphs:** Combining WSD with **semantic knowledge graphs** (e.g., BabelNet, ConceptNet) may further refine disambiguation capabilities by leveraging structured knowledge.
5. **Efficiency Optimization:** Reducing computational overhead in **real-time applications**, such as conversational AI and mobile NLP systems, remains a critical area of improvement.

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Review article

Safety consideration and Hazardous Materials Management in Industries

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ABSTRACT

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Workplace safety in the industry is crucial to prevent risks associated with hazardous chemicals, production processes, and environmental factors. A structured Safety Management System (SMS) ensures hazard identification, workplace audits, and regulatory compliance. The use of Personal Protective Equipment (PPE), proper chemical handling, and emergency preparedness enhance safety standards. Employee training, adherence to international safety agreements, and regular monitoring of risks are essential for maintaining a safe work environment. Strict compliance with safety regulations not only protects workers but also ensures product integrity and operational efficiency.

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1. Introduction

Safety Concerns and Health Hazards in Pharmaceutical Manufacturing

Safety concerns and health hazards are inherent in every profession, including the manufacturing industry. This sector frequently involves exposure to chemicals, toxic emissions, flammable substances, and other hazardous materials. This article highlights the major safety hazards in the pharmaceutical industry and strategies to mitigate them.

Pharmaceutical and biotechnology manufacturing enterprises must assess the risks associated with handling hazardous materials and establish measures to eliminate or minimize these risks. According to General Environmental Health and Safety (EHS) guidelines, these directives should be clearly outlined in a Hazardous Materials Management Plan [1, 2].

Safety Considerations in Industry

Every workplace comes with its own risks, and the any production industry is no exception. From process-related hazards to risks inherent in manufacturing, ensuring health and safety compliance can be challenging. However, adherence to safety regulations and guidelines is mandatory in the manufacturing sector to protect workers and maintain product integrity [3, 4].

Safety Management System (SMS)

A Safety Management System (SMS) is an integral part of an organization's overall management framework. It includes:

- Defining the purpose of risk assessment.
- Conducting workplace audits for safety compliance.
- Developing an inspection plan.
- Identifying potential hazards.
- Compiling inspection reports with relevant details.
- Determining the frequency and duration of inspections.
- Regular performance audits to assess SMS effectiveness.

Personal Protective Equipment (PPE) in the industry [5]

For comprehensive workplace safety, the use of PPE is essential. Key protective equipment includes:

- Protective clothing (coveralls, gowns)

- Gloves
- Shoe covers
- Eye protection (goggles, face shields)
- Respiratory protection (N95 respirators)

Workplace Safety Measures

To maintain a safe working environment, the following measures should be implemented:

- Availability of Safety Data Sheets (SDS) for all chemicals.
- Regular recording and monitoring of hazards.
- Maintaining cleanliness in work areas.
- Ensuring proper hand hygiene practices.
- Efficient operation of ventilation systems to control airborne contaminants.
- Availability of emergency safety equipment, including eye wash stations and safety showers.

Management of Chemical Hazards

- Identifying and categorizing hazardous chemicals.
- Maintaining and properly placing Safety Data Sheets (SDS) for reference.
- Storing chemicals in their original containers with proper labelling.

Employee Rights and Responsibilities [6]

- Implementing necessary measures to reduce risks associated with hazardous substances.
- Proper use of Personal Protective Equipment (PPE) at all times.
- Immediate reporting of any hazardous situations or near-miss incidents.

Training and Awareness

- Providing training on the correct use of safety equipment.
- Promoting safe work practices in the workplace.

Regulations and Agreements

Several international agreements and national policies regulate chemical management in India, including:

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- Agenda 21 (United Nations Sustainable Development Plan)
- Rotterdam Convention (Regulating hazardous chemicals in international trade)
- Montreal Protocol (Protecting the ozone layer by phasing out harmful chemicals)

Ensuring workplace safety in pharmaceutical manufacturing is a top priority. Strict compliance with safety standards not only protects employees but also enhances overall operational efficiency and product quality.



Figure 1: Industrial Safety and Hazardous Materials Management: Key Considerations and Safety Symbols

2. Objectives of a Hazardous Materials Management Plan

1. **Developing a Safe System** – Establishing and implementing an organized system to prevent chemical emissions caused by accidents.
2. **Protecting Health and Well-being** – Reducing risks to employees, the general public, and the environment.
3. **Minimizing Impact** – Limiting the effects of potential emissions on surroundings and human health.

3. Steps for Developing a Hazardous Materials Management Plan [7, 8]

1. Conducting a Hazard Analysis

- Review accident history from the past five years.
- Assess the most severe potential scenarios.
- Perform alternative release assessments.

2. Implementing Safety Guidelines

- Define safety protocols for operations, training, change management, incident investigations, employee participation, contractor training, and monitoring.

3. Enforcing Proactive Measures

- **Process Hazard Analysis (PHA)** – Identify and analyze process-related risks.
- **Mechanical Integrity** – Ensure equipment reliability and maintenance.
- **Pre-Start Review & Work Authorization** – Verify safety measures before starting operations.

4. Developing an Emergency Response Program

- Include training, equipment allocation, response protocols, and periodic reviews and updates.

4. Strategies To Reduce Hazardous Incidents

1. Design and Pre-Modification Review

- Optimize layout, facilities, and material selection.
- Replace highly toxic chemicals with safer alternatives.
- Store chemicals in limited quantities to minimize risks.

2. Chemical Risk Assessment

- Evaluate compatibility, flammability, toxicity, and storage conditions of chemicals.

3. Process Safety Management

- Conduct HAZOP (Hazard and Operability) studies.
- Assess the reliability of process equipment.
- Implement safety measures such as safety trips and interlocks.

4. Conducting Safety Audits

- Regularly review safety procedures and equipment to ensure compliance and make necessary improvements.

5. Emergency Planning

- Assess potential consequences and establish appropriate emergency procedures.

6. Employee Training

- Provide comprehensive training to employees and safety personnel.

7. Public Cooperation

- Ensure public support and awareness regarding the transportation of hazardous materials.

8. Public Awareness Programs

- Educate communities about potential hazards and safety measures.

9. Proper Storage of Hazardous Materials

- Store all chemicals at appropriate temperatures and in securely sealed containers.

5. Roles and Responsibilities in Safety Management

1. Industrial Safety

- Identifying relationships between industrial hazards and potential risks.
- Protecting workers from industrial accidents and hazardous exposures.

2. Chemical Safety

- According to the International Conference on Chemicals Management (2006), all chemical activities must prioritize human health and environmental safety.

3. Accident Prevention and Reduction

- In an era of rapidly evolving technologies, the risk of industrial accidents has increased.
- Awareness and training are essential to preventing hazards.

6. Risk Assessment and Hazard Management [8]

Risk Assessment

Risk assessment aims to identify and analyze potential events or substances that may pose a threat. It evaluates whether a particular event or material needs to be modified or eliminated.

Process of Risk Assessment:

1. Identifying Potential Hazards:

- Inspecting the work environment.
- Reviewing OSHA guidelines and past accident records.

2. Identifying Individuals at Risk:

- For example, transportation personnel may be at risk due to improper storage of hazardous chemicals.

3. Eliminating or Reducing Hazards:

- Implementing risk mitigation strategies while complying with legal requirements.

4. Documentation:

- Recording identified risks and the steps taken to mitigate them.

5. Reviewing the Assessment:

- Conducting periodic reviews to ensure the effectiveness of safety measures.

7. Hazard Management

Management of Hazardous Gases

Compressed gases are often stored in cylinders and transported to their final destination. The following safety measures are essential during this process:

- Prevent cylinders from falling or colliding with each other.
- Do not tamper with safety devices attached to the cylinders.
- Use specialized valves and standard tools provided by manufacturers.
- Protect cylinders from extreme weather conditions, especially excessive heat.
- Label cylinders with standardized tags indicating gas type, such as combustible, acidic, or inert.
- Store filled cylinders separately from empty ones.

Fire and Explosion Management [9]

Industrial settings are more prone to fires than explosions or toxic gas leaks, but fires generally cause fewer casualties. To mitigate fire and explosion risks, the following precautions should be taken:

- Carefully design the plant layout and select appropriate construction materials.
- Build fire-resistant walls to contain explosions.
- Design roofs to withstand explosive forces.
- Eliminate open flames, sparks, smoking, and welding near hazardous areas.
- Install fire alarms, temperature alarms, and sprinkler systems.
- Equip facilities with fire extinguishers and categorize fires accordingly:
 - Class A Fires:** Caused by ordinary combustible materials.
- Extinguished using water for cooling and suppression.
 - Class B Fires:** Involve flammable liquids, oils, and grease.
- Extinguished using blanketing or smothering techniques.
 - Class C Fires:** Originating from electrical equipment.
- Require non-conducting extinguishing agents.

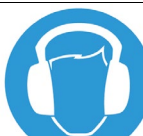
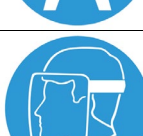
Fire Accident Prevention and Control [10]

Fire prevention is a critical aspect of industrial safety. The following measures can help reduce fire-related accidents:

- Ban smoking in manufacturing areas.
- Reduce oxygen levels by mixing with nitrogen or carbon dioxide.

- Identify and control ignition sources near flammable chemicals.
- Carefully design plant layouts to minimize fire risks.
- Construct fire-resistant walls to prevent fire spread.
- Ensure safe exit routes and ventilation systems for emergency situations.
- Maintain a reliable water source for firefighting purposes.

Table 1: Sign Required by Law [1]

S. N.	Intrinsic features	Round shape white pictogram on a blue background
1		Eye protection must be worn
2		Safety helmet must be worn
3		Ear protection must be worn
4		Safety boots must be worn
5		Safety gloves must be worn
6		Safety overalls must be worn
7		Face protection
8		Pedestrians must use this route

8. Conclusion

Ensuring workplace safety in the pharmaceutical industry is not just a regulatory requirement but a fundamental necessity for protecting employees, maintaining product quality, and ensuring smooth operations. A well-structured Safety Management System (SMS), proper use of Personal Protective Equipment (PPE), and adherence to international safety protocols significantly reduce workplace hazards. Regular audits, employee training, and strict compliance with safety regulations create a culture of safety and efficiency. By prioritizing risk management and proactive safety measures, the pharmaceutical industry can maintain high

standards of occupational health while enhancing overall productivity and sustainability.

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Review article

An Introduction to the Therapeutic Potential of Boronic Acid Derivatives

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Recently, boronic acid derivatives have emerged as a versatile and promising class of compounds in modern-day medicinal chemistry, owing to their ability to shape reversible covalent bonds with biological nucleophiles, together with serine and threonine residues in enzyme's binding active sites. The molecules have been verified to have extensive therapeutic potential, including oncology, infectious illnesses, and inflammatory issues. This work explores the structural functions, mechanisms, and therapeutic applications of boronic acid derivatives, highlighting their growing role in drug development and their capability in medically significant drug discovery.

1. Introduction

Boron performs a vital and multifaceted role throughout organic kingdoms. In plants, it's essential for maintaining structural integrity, particularly through its involvement in cell wall stabilization and membrane function, as well as various metabolic processes necessary for growth and reproduction. Boron derivatives, mainly borax (sodium borate) and boric acid, have been utilized in traditional medicinal drug structures consisting of Ayurveda, Traditional Chinese Medicine (TCM), and Islamic remedy [1-4]. In Ayurveda, borax (referred to as "Suhaga") changed into used in small doses to deal with digestive problems, fever, and irritation, and changed into believed to beautify sexual fitness. In TCM, borax (Peng Sha) was implemented externally for mouth ulcers, throat infections, and pores and skin conditions. Similarly, Islamic medicine used boron compounds as antiseptics for eyes and skin. These uses have typically been topical or carefully dosed because of the potential toxicity of boron at higher doses. Additionally, superior remedies like boron neutron seize therapy (BNCT) for cancer treatment illustrate the increasing medical relevance of boron. Despite its therapeutic promise, secure use remains crucial, as traditional systems additionally suggested in opposition to overdosing and emphasized proper instruction. Modern technology has supported many of those traditional programs. Boron is now known for its antibacterial, antifungal, and anti-inflammatory properties [5-7]. Boric acid remains used clinically, especially in treating vaginal yeast infections, and boron supplements are being researched for his or her position in bone health, hormonal law, and cognitive feature.

In mammals, boron significantly contributes to physiological regulation, including the modulation of vitamin D metabolism, calcium utilisation, and the maintenance of healthy bone structure.

- Boron chemistry, an often overlooked and underappreciated field in the realm of medicinal chemistry, holds a significant place in contemporary drug development. The unique

properties and reactivity of boron-containing compounds make them valuable tools for medicinal chemists striving to design novel, effective pharmaceutical agents.

- **Chemical Diversity:** Boron's position on the periodic table allows it to form a wide array of compounds with varying chemical structures. Its tendency to form covalent bonds with carbon and other elements facilitates the creation of diverse molecular structures, enabling researchers to fine-tune the properties of potential drug candidates. This diversity is particularly advantageous in the quest for compounds with specific biological activities.
- **Bioisosteres:** Boron can act as a bioisostere, replacing other elements such as carbon, nitrogen, or oxygen in drug molecules. This substitution can have a profound impact on a compound's pharmacokinetics and pharmacodynamics, influencing its solubility, stability, and receptor binding properties. This ability is especially beneficial when aiming to optimize drug properties.
- **Stereochemistry and Chirality:** Boron centers can introduce chirality into drug molecules, allowing for the development of enantiopure drugs. This is crucial for designing drugs with improved selectivity and reduced side effects. The unique stereoelectronic properties of boron atoms are exploited to control stereochemistry in pharmaceutical compounds.
- **Drug Delivery and Targeting:** Boron-based compounds have been utilized in drug delivery systems. For instance, boronic acids can serve as drug-targeting moieties, specifically binding to glycoproteins on the cell surface. This facilitates targeted drug delivery and reduces off-target effects, making boron chemistry indispensable in precision medicine.

These biological functions underscore its reputation as a micronutrient of increasing interest in both plant and animal sciences. In the sector of medicinal chemistry, boron-containing compounds—especially boronic acids and boronate esters have gathered attention for their pharmacological potential. Boron-containing compounds are characterized by their interesting structural functions and reactivities, which can be imperative to

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their roles in medicinal chemistry. Further, it exhibited biologically energetic alertness of boron derivatives in drug development, multifaceted and essential in the creation of novel pharmaceutical drugs (Fig. 1) [1]. These compounds are generally perceived as biocompatible and safe for therapeutic applications, and are actively being explored in the design and development of novel pharmaceuticals, including enzyme inhibitors, anticancer agents, and antimicrobial drugs. This work encompasses the overview of boronic acid derivatives for becoming more important in developing new medicines and finding new treatments for serious health conditions.



Figure 1: Salient features of boron derivatives.

2. Some FDA-approved boronic acid derivatives

Several boronic acid derivatives (Fig. 2) have received FDA approval, reflecting the growing popularity of boron's precise chemical properties and healing capacity. In May 2003, the U.S. Food and Drug Administration (FDA) permitted bortezomib,

marketed as Velcade from Millennium Pharmaceuticals Inc., for the remedy of relapsed and refractory myeloma, based on positive effects from the SUMMIT Phase II scientific trial. This marked the primary FDA approval of a proteasome inhibitor for most cancers [8-10]. In 2005, the FDA extended its approval to include patients with multiple myeloma who had acquired at least one prior treatment. Later, in 2008, bortezomib received approval for use as a first-line treatment in newly recognized more than one myeloma patients. These innovative approvals replicate the developing proof of bortezomib's effectiveness throughout distinctive stages of the disease. It acts as a reversible inhibitor of the 26S proteasome by forming a covalent bond with the catalytic threonine residue on the proteasome's active site, leading to apoptosis in malignant cells. Another proteasome inhibitor, ixazomib (Ninlaro), approved in 2015, is notable for being the first orally available drug in this class. Like Bortezomib, it targets the proteasome through its boronic acid moiety, providing a more convenient administration route for patients with multiple myeloma.

In spite of oncology, boronic acid derivatives have also shown promise in treating infectious and inflammatory diseases. Tavaborole (Kerydin), approved in 2014, is a topical antifungal agent used for onychomycosis. It inhibits fungal leucyl-tRNA synthetase, thereby disrupting protein synthesis. The boron atom plays an essential role by forming a stable adduct with the enzyme's active site, selectively targeting fungal cells. In the field of dermatology, Crisaborole (Eucrisa) was approved in 2016 for the treatment of mild to moderate atopic dermatitis. This non-steroidal topical medication works by inhibiting phosphodiesterase 4 (PDE4), an enzyme involved in inflammatory signalling. Its boron moiety is critical for high-affinity binding to the PDE4 active site, reducing inflammation and related symptoms.

In addition, Vaborbactam (Vabomere), is a combination antibiotic approved by the U.S. FDA and Health Canada in 2017 for the treatment of bacterial infections. It contains Vaborbactam, a boronic acid-based β -lactamase inhibitor, and Meropenem, a carbapenem antibiotic that inhibits bacterial cell wall synthesis. Vaborbactam protects meropenem from enzymatic degradation, enhancing its effectiveness against resistant bacterial strains.

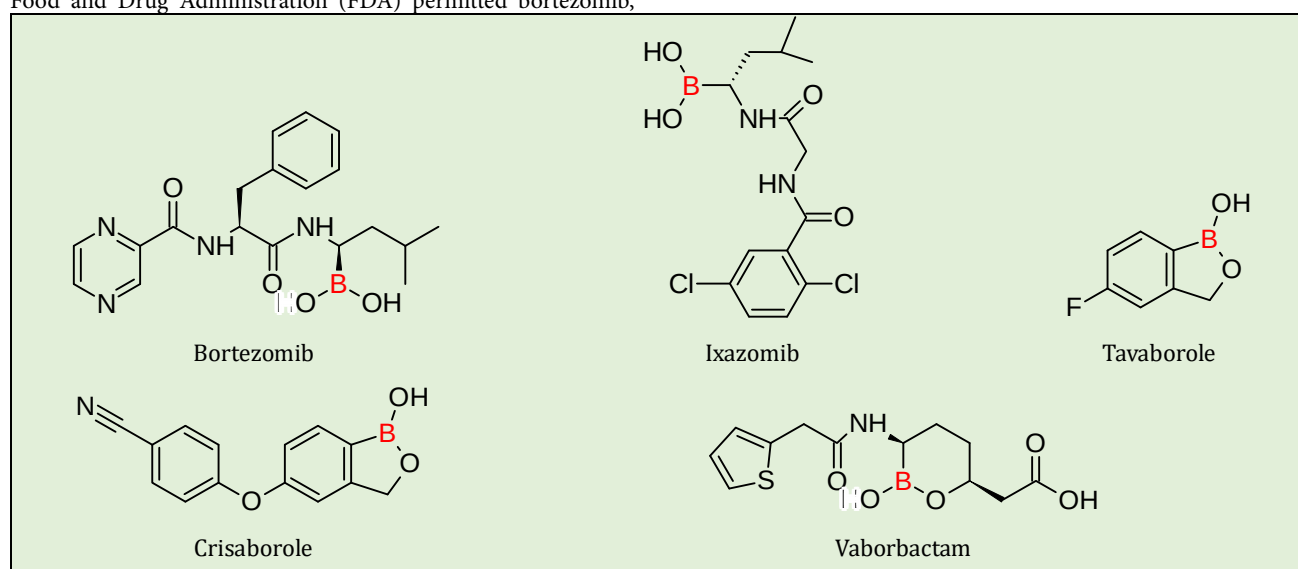


Figure 2: Chemical structures of some FDA-approved boronic acid derivatives as drugs.

3. Emerging boronic acid derivatives under Clinical Trial Stage

Several boronic acid drug candidates are in clinical trials, though not yet approved (Fig. 3) [2,3]. Acoziborole is a promising,

orally available, single-dose candidate for Human African Trypanosomiasis (HAT), currently in Phase III, with an unknown

mechanism. Existing HAT treatments are toxic and much less effective. Dutogliptin, a DPP4 inhibitor, failed in Phase II for diabetes but is now in Phase II trials with G-CSF for myocardial infarction, aiming to reinforce cardiac stem restoration. GSK3036656, a benzoxaborole and leucyl-tRNA synthetase inhibitor for tuberculosis, is in Phase II. It's a resistant-optimized

model of GSK2251052, showing bacterial selectivity and favorable pharmacokinetics. Similar to approved Crisaborole, AN2898 is another PDE4 inhibitor in development for atopic dermatitis. Ongoing clinical trials show it was safe and effective in a Phase II study [2,10].

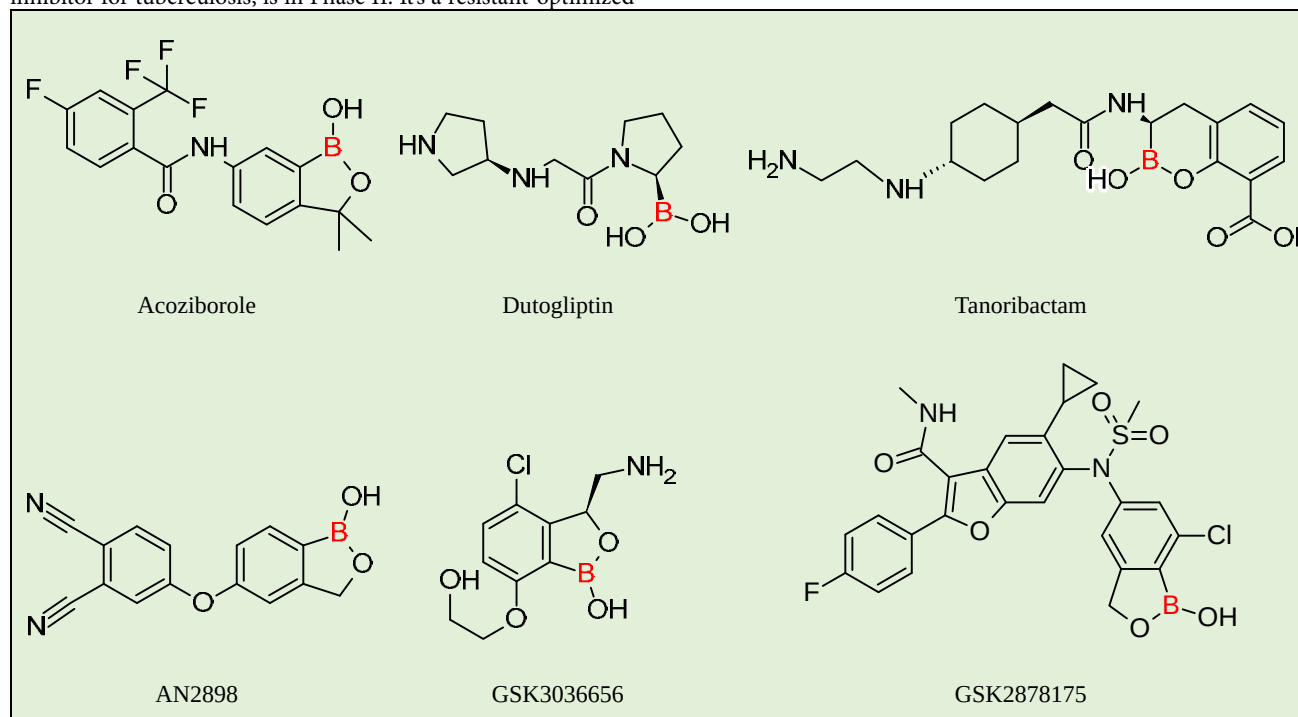


Figure 3: Chemical structures of boronic acid derivatives under Clinical trial stage.

4. Boronic acid derivatives with high potential therapeutics

While no drugs containing boron have been developed from these initiatives, various drug discovery projects have examined the use of boron in target molecules for diverse therapeutic applications. The unique chemical properties of boron—along with its ability to form reversible covalent bonds and engage with organic nucleophiles—render it a valuable scaffold in medicinal chemistry. Researchers have studied boronic acid derivatives across multiple therapeutic fields, such as oncology, infectious diseases, and metabolic disorders. Figure 4 shows the representation of chemical structures of boronic acid derivatives that possess potential for drug delivery, chiefly anticancer

property [11-13]. Furthermore, the representation of chemical structures of boronic acid derivatives possesses potential for Antiviral drug delivery is depicted in Fig. 5. Viral proteases, particularly the NS3 protease from the hepatitis C virus (HCV), are prime targets for boron-based inhibitors [2]. Although several HCV NS3 serine protease inhibitors have been approved, researchers are focusing on creating analogues that replace the conventional α -ketoamide structure with boronic acid groups. This modification leverages the catalytic serine within the enzyme's active site, allowing for reversible covalent binding and potentially enhancing potency and selectivity.

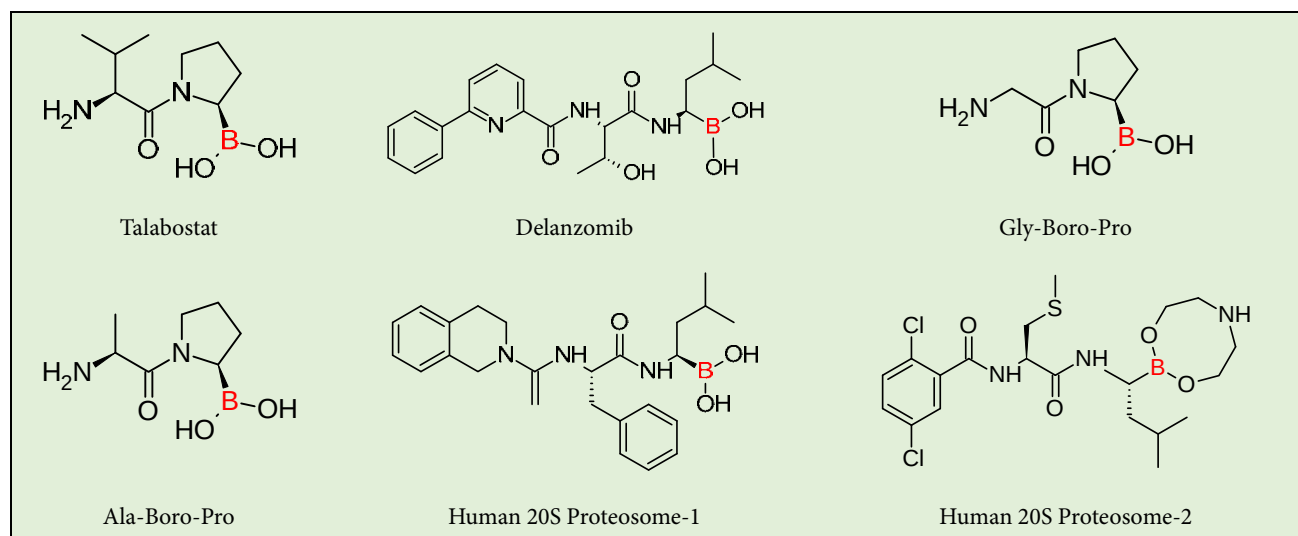


Figure 4: Chemical structures of boronic acid derivatives possess potential for drug delivery- Anticancer.

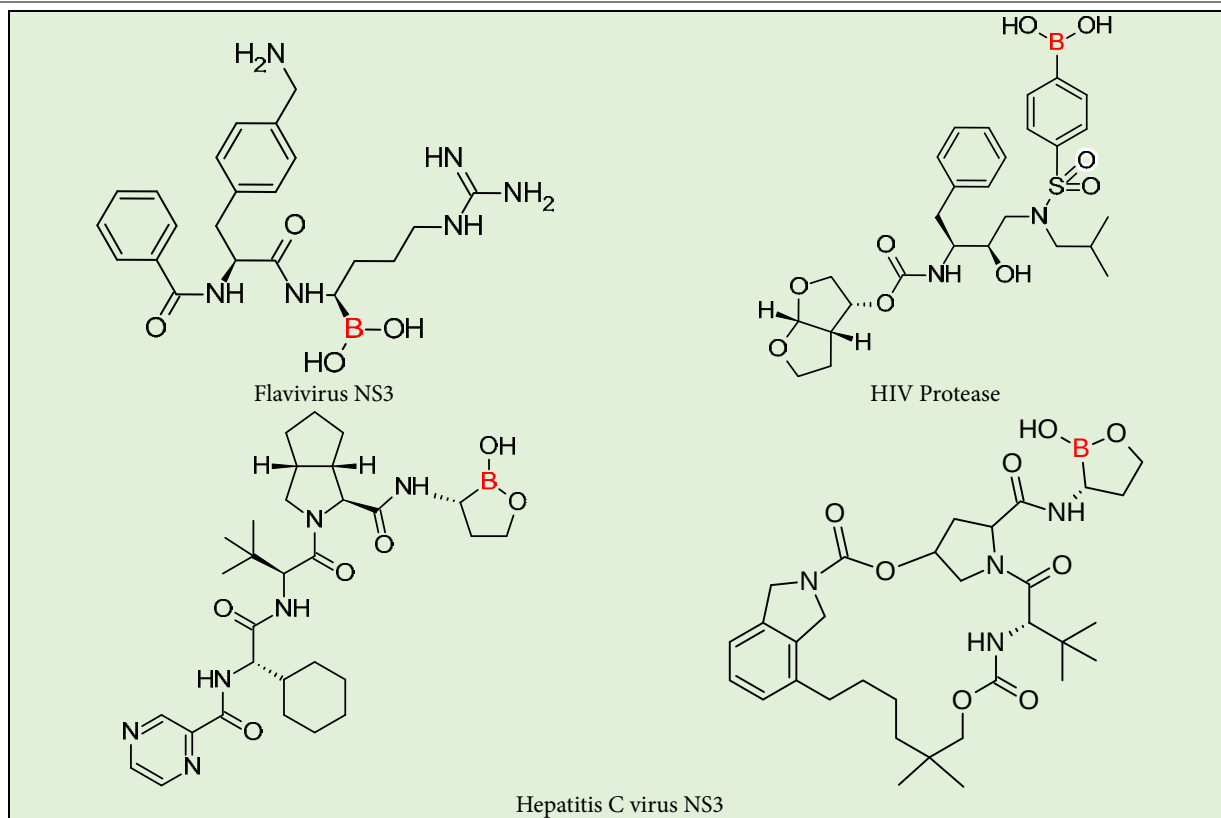


Figure 5: Chemical structures of boronic acid derivatives possess potential for drug delivery- Antiviral.

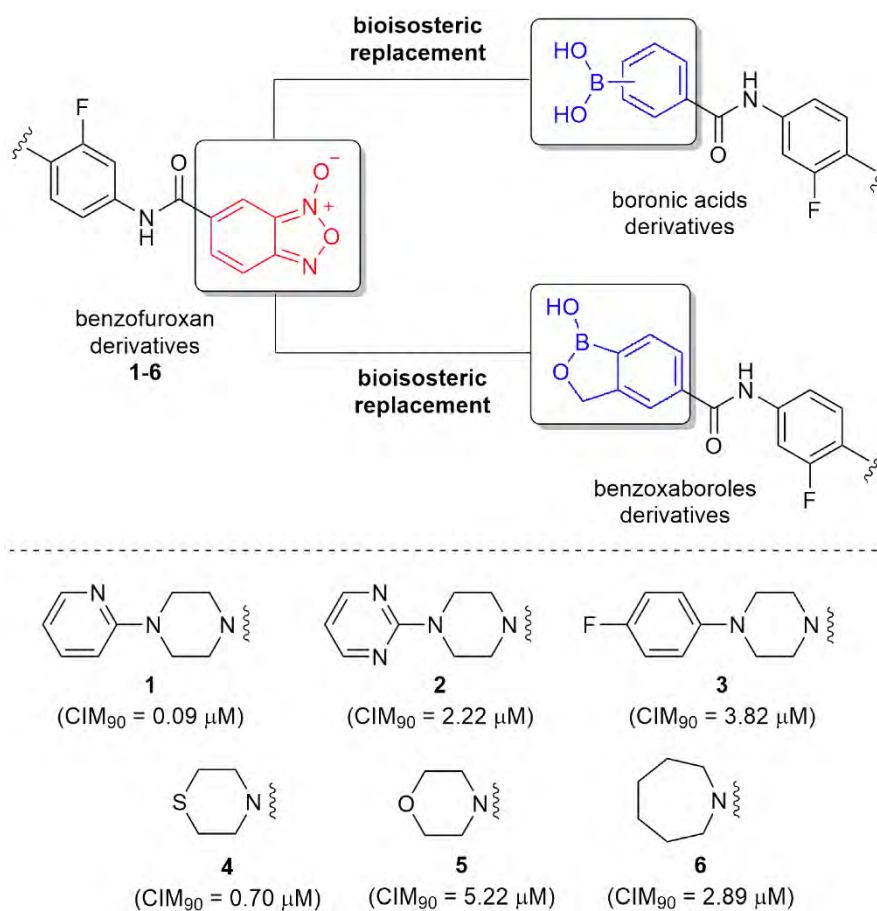


Figure 6: Schematic representation of boronic acid and benzoxaborole derivatives (Reproduced from ref. [14] under CCBY, MDPI, Basel, Switzerland 2025)

Prates et al., [14] recently studied organoboron compounds with boronic acid and benzoxaborole moieties (Fig. 6), which have

probably important scaffolds in medicinal chemistry. Their prominence increased after FDA approval of bortezomib for

multiple myeloma and tavaborole for onychomycosis, both highlighting the therapeutic potential of boron-based drugs. These compounds are particularly valuable for their ability to form reversible covalent bonds with biological targets, offering high specificity and potency. Their known antimicrobial and anticancer properties have encouraged further development of novel derivatives for broader therapeutic use. In this study, fourteen new boron-containing derivatives were synthesized and fully characterized using various analytical methods. Additionally,

5. Conclusion and Future Outlook

Boron's natural abundance and protection make it an attractive element in drug discovery. Its unique chemical features enable selective, reversible interactions with organic molecules. Since the approval of bortezomib, massive medicinal chemistry efforts have focused on developing boronic acid-primarily based drugs for most cancers, infections, and other therapeutic areas. Advancements in drug design have been carefully followed with the aid of development in the synthesis of boronic acids. Following the approval of bortezomib, enormous interest has been shown in the improvement of aliphatic boronic esters and acids, especially α -amino boronic derivatives. These synthetic breakthroughs have paved the way for several research corporations to incorporate boronic acid frameworks into their drug discovery pipelines, capitalising on their particular chemical and biological properties.

The growing interest in research on boronic acid derivatives highlights their great potential as significant drug candidates. As extra synthetic techniques and organic applications emerge, boron-based compounds are in all likelihood to play an increasingly crucial role in addressing unmet scientific needs. These explorations into boron-primarily based drug discovery are anticipated to further remove light from the precise benefits of boron incorporation consisting reversible covalent binding, tunable reactivity, and organic compatibility. Moving ahead, it seems that medicinal and pharmaceutical chemists will more and more comprehend boronic acids and esters as precious equipment and viable scaffolds in modern-day drug discovery programs for novel treatments across an extensive range of diseases.

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Declarations

Author contribution

Mohd Yusuf: Concept, data analysis, visualisation, drafting, manuscript submission.

Deepa Sharma: Concept, data analysis, data interpretation, drafting.

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their antimicrobial activity was tested against *Mycobacterium tuberculosis* H37Rv and fungal pathogens, including *Candida albicans* (ATCC 90028), *Trichophyton rubrum* (ATCC 28189), and *Trichophyton mentagrophytes* (ATCC 11481). Anticancer activity was also evaluated against oral squamous cell carcinoma (SCC) cell lines. Several compounds showed promising biological activity, making them strong candidates for further structure–activity relationship studies and optimization in the development of new antimicrobial and anticancer agents.

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Review article

Nanoparticles in Drug Delivery Systems: Challenges, Innovations, and Surface Modification for Targeted Therapeutics

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ABSTRACT

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Nanoparticle based drug transport structures have revolutionized the field of therapeutics via offering several benefits, together with better solubility, bioavailability, targeted transport, and managed release. These structures can encapsulate an extensive variety of healing agents, from small molecules to huge biomolecules together with proteins and nucleic acids, making them flexible gear in present day remedy. But, the scientific translation of nanoparticle based drug transport structures faces tremendous demanding situations, together with biocompatibility, toxicity, balance, scalability, and reproducibility. This text targets to offer a complete review of the key problems impeding the large use of nanoparticles in drug transport. We are able to talk revolutionary strategies, together with stimuli responsive structures, ligand conjugation for energetic concentrated on and surface modification techniques that address these demanding situations. Furthermore, the destiny of nanoparticle-based therapeutics is explored, that specialize in their integration into customized remedy and theranostic packages. Subsequently, we are able to take a look at the regulatory and manufacturing hurdles that must be triumph over to recognise the overall capacity of nanoparticle drug transport structures.

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1. Introduction

Nanoparticles (NPs) have received great attention in latest many years as drug delivery cars due to their specific physicochemical homes. These include their small length, high floor region to extent ratio, and the potential to regulate their floor characteristics to decorate drug delivery efficiency. In contrast to traditional drug delivery systems, NPs can conquer numerous limitations, along with poor solubility, rapid clearance, and constrained bioavailability, via supplying managed drug release and the opportunity of targeting precise tissues or cells. Consequently, NPs are utilized for an expansion of purposes, starting from improving the pharmacokinetics of chemotherapeutics to

delivering RNA based totally healing procedures and gene editing tools, along with CRISPR. But, whilst NPs have proven good sized promise in preclinical and early segment medical trials, translating these formulations into powerful healing procedures remains difficult. Some of the key boundaries are issues approximately the toxicity of NPs, there in-vivo balance, their potential to penetrate tissues successfully, and their ability for non-precise accumulation in non-goal organs. Moreover, whilst the pharmaceutical enterprise has made great strides in developing NP formulations, many challenges stay related to their mass production, regulatory approval, and medical implementation. (Table1)

(Table 1: Key Nanoparticle Types and Their Applications in Drug Delivery)

Nanoparticle Type	Size	Materials Used	Applications	Advantages
Liposomes	50nm-5um	Phospholipids, cholesterol	Cancer treatment, vaccine delivery, gene therapy	Biocompatibility, ability to encapsulate both hydrophilic and hydrophobic drugs
Polymeric Nanoparticles	50 nm - 200 nm	Poly (lactic-co-glycolic acid) (PLGA), polyethylenimine (PEI)	Controlled drug release, gene delivery, targeting tumor cells	Biodegradable, customizable surface properties, sustained release
Dendrimers	1 nm - 10 nm	Poly(amidoamine) (PAMAM), polyester-based dendrimers	Cancer therapy, gene delivery, targeting specific cells	High surface area, precise drug loading, multi-functionalization

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Solid Lipid Nanoparticles (SLNs)	50 nm - 1 μ m	Lipid-based materials	Controlled drug release, targeting tumors and infections	Enhanced drug stability, controlled release over extended periods
Nanocapsules	10 nm - 1 μ m	Polymers, lipids	Drug encapsulation, targeted delivery to tumors	Ability to encapsulate a variety of drugs, reduced toxicity in normal tissues
Micelles	10 nm - 200 nm	Amphiphilic copolymers	Drug delivery for poorly soluble drugs, cancer therapy	Enhanced solubility of hydrophobic drugs, targeting capabilities

2. Challenges in Clinical Translation of Nanoparticle based Drug Delivery

2.1 Biocompatibility and Toxicity

The biocompatibility of NPs is one of the most important elements influencing their clinical fulfilment. The interplay among NPs and organic systems is complex and might range relying on their length, surface charge, material composition, and functionalization. Upon administration into the body, NPs are regularly diagnosed by way of the immune gadget that could cause their fast clearance via phagocytosis by way of macrophages or their accumulation in numerous organs, which include the liver, spleen, or lungs. This may cause toxicity troubles, inclusive of organ damage, inflammation, and immune responses.

Cationic nanoparticles, particularly, generally tend to have higher cytotoxicity due to their interplay with the negatively charged cell membranes that could disrupt cell integrity and cause inflammatory responses. In evaluation, anionic or impartial NPs, whilst commonly much less toxic, may also have decreased cell uptake, affecting their therapeutic efficacy. Consequently, surface change strategies are being explored to enhance the biocompatibility of NPs by way of lowering their immunogenicity and enhancing their interactions with goal cells [1][2].

2.2 In Vivo Stability and Aggregation

In vivo stability is every other essential venture for NP primarily based drug shipping structures. Once NPs are added into the bloodstream, they may be subject to various physiological forces which could have an effect on their size, form, and aggregation conduct. For instance, NPs can be lined by using plasma proteins, forming a "protein corona" that alters their floor homes and, in a few cases, renders them more liable to fast clearance by using the reticuloendothelial machine (RES). Moreover, NPs can combination within the bloodstream, main to reduced efficacy and accelerated danger of embolism or other negative outcomes. To overcome these challenges, various techniques, such as PEGylation (the attachment of polyethylene glycol to NP surfaces), were hired to improve the stableness of NPs in stream. PEGylation reduces the formation of the protein corona and facilitates hold the hydrophilicity of NPs, hence prolonging their stream time and enhancing their healing potential. however, current research have raised concerns approximately the immunogenicity of PEG, as patients may additionally increase antiPEG antibodies, probably main too fast clearance of PEGylated NPs. alternative floor adjustments, such as zwitterionic polymers, were proposed as a promising method to improve NP stability and biocompatibility [3][4].

2.3 Targeting Precision and Controlled Release

One of the maximum massive blessings of NPs is their capability to deliver tablets to particular tissues or cells, minimizing off goal consequences and lowering systemic toxicity. This idea, referred to as targeted drug delivery, is based at the capability of NPs to apprehend and bind to particular biomarkers or receptors overexpressed on diseased cells, such as tumour cells

or inflamed cells. However, reaching efficient and particular focused on remains a massive undertaking, mainly in strong tumours, in which NP penetration is often hindered by using the dense extracellular matrix and excessive interstitial pressure. To address those problems, researchers have advanced a variety of techniques, together with floor change with ligands that concentrate on particular receptors on diseased cells. As an example, NPs can be functionalized with antibodies, peptides, or small molecules that apprehend overexpressed receptors on tumour cells. Twin focused on approaches, in which NPs are functionalized with awesome ligands to goal unique markers, have additionally shown promise in improving the specificity of drug delivery [5].

Similarly, to focused on, managed drug release is a key function of NP based drug delivery systems. Many NPs are designed to release their drug payload in reaction to particular physiological stimuli, such as modifications in pH, temperature, or the presence of particular enzymes. Those stimuli responsive systems permit particular manage over the timing and location of drug release, minimizing aspect consequences and improving therapeutic outcomes. However, reaching dependable and predictable drug release profiles remains a massive undertaking, as elements such as the size, shape, and floor homes of NPs can impact their release kinetics [6].

2.4 Scalability and Regulatory Hurdles

Scalability is some other important challenge in the development of NP based drug transport systems. At the same time as NPs may be easily synthesized in small portions in laboratory settings, generating them on a larger scale with regular fine and overall performance is a long way more complex. Troubles together with batch-to-batch variability, reproducibility of NP size and floor houses, and fee effectiveness ought to be addressed to facilitate the commercial production of NP formulations. Furthermore, the regulatory panorama for NP based drug transport systems is still evolving. Regulatory bodies, together with the U.S. meals and Drug management (FDA), have mounted a few guidelines for the approval of Nano medicines, but there may be no complete regulatory framework specially tailored to Nano medicines. The unique houses of NPs, together with their capacity to cross biological barriers and their ability for lengthy time period accumulation in tissues, gift challenges for safety evaluation. Moreover, the shortage of standardized methods for characterizing NPs' physicochemical houses and comparing their pharmacokinetics and toxicity hinders the regulatory approval manner [7].

3. Innovations in Nanoparticle Design

3.1 Stimuli-Responsive Nanocarriers

Stimuli-responsive nanoparticles are designed to launch their drug payloads in reaction to precise physiological conditions. These structures offer unique manage over drug launch, minimizing side consequences and improving therapeutic efficacy. Numerous sorts of stimuli-responsive nanoparticles had

been evolved, consisting of pH sensitive, redox sensitive, and thermo sensitive nanoparticles.

pH sensitive nanoparticles are designed to launch their drug payloads in reaction to modifications in pH, which can be exploited to target precise regions of the frame, together with the tumour microenvironment, that's generally more acidic than normal tissues. These nanoparticles regularly incorporate acid labile linkers or polymers that go through an conformational change in reaction to the acidic pH, triggering drug launch [8].

Redox sensitive nanoparticles take benefit of the accelerated stages of glutathione within the intracellular surroundings to trigger the release of encapsulated pills. Glutathione can break disulfide bonds or cleave different linkers within the nanoparticle shape, facilitating drug launch within the cytosol [9].

Thermo sensitive nanoparticles are aware of temperature modifications. Those structures are designed to launch their drug payloads upon publicity to accelerated temperatures, which may be executed via external heating methods, together with magnetic hyperthermia or infrared radiation [10].

3.2 Active Targeting via Ligand Conjugation

Active focused on involves the conjugation of unique ligands to the floor of nanoparticles that could apprehend and bind to overexpressed receptors or biomarkers on diseased cells. This method enhances the specificity and performance of drug transport, reducing off target outcomes and improving healing consequences. Several styles of ligands had been used for lively focused on, including antibodies, peptides, and small molecules. Antibody conjugated nanoparticles can mainly bind to tumour associated antigens, which include HER2 or EGFR, that are overexpressed on sure styles of most cancers' cells. Peptide primarily based nanoparticles had been evolved to target integrin's or different cellular floor receptors which might be concerned in cellular adhesion and migration. Small molecule ligands also can be used to target unique enzymes or receptors, which include folate receptors that are overexpressed in sure tumour sorts [11]. (Figure1)

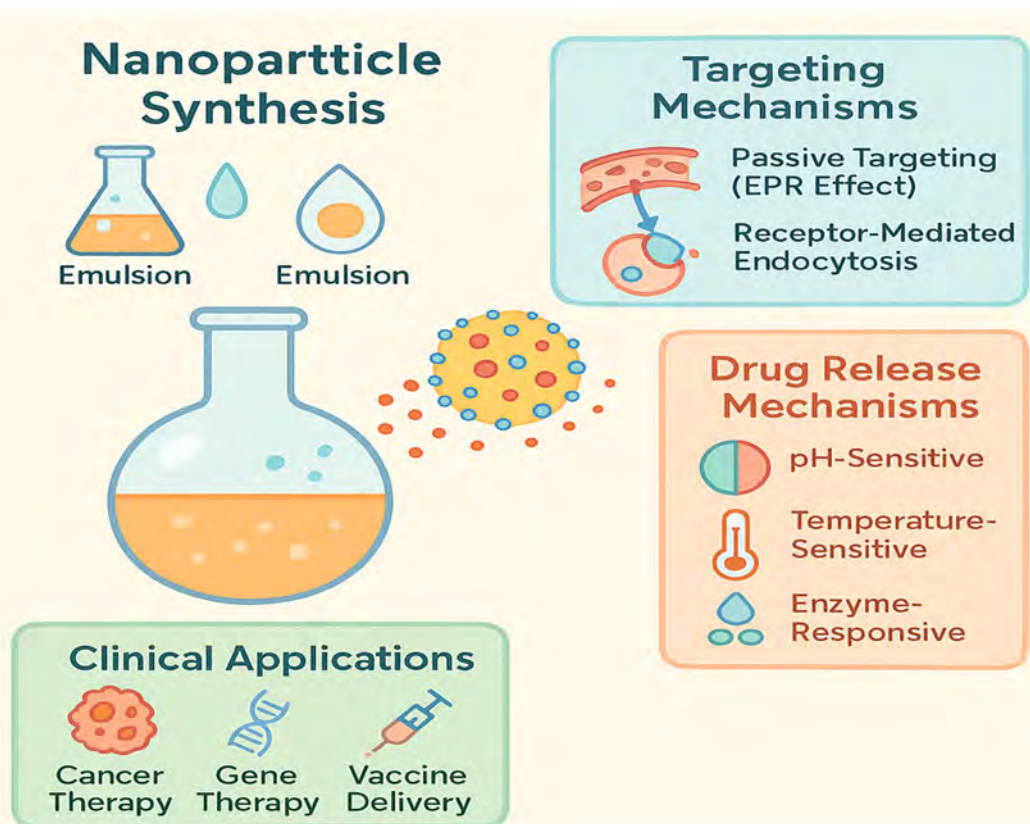


Figure 1: Schematic evaluation of nanoparticle- based totally drug shipping mechanisms. This infographic illustrates the vital tactics worried in nanoparticle-mediated drug shipping systems, together with synthesis techniques, focused on strategies (passive and lively), drug release mechanisms (which includes pH- touchy and enzyme-responsive systems), and predominant medical applications like most cancers remedy, gene shipping, and vaccine management. The discern highlights the integrative nature of nanotechnology in enhancing therapeutic efficacy and placement- particular focused on.

4. Surface Modification Strategies

4.1 PEGylation and NextGeneration Stealth Coatings

one of the maximum common surface change techniques for boosting the in vivo stability and circulate time of nanoparticles is PEGylation, the attachment of polyethylene glycol (PEG) molecules to the surface of NPs. PEG acts as a "stealth" coating that reduces the popularity of NPs through the immune system and prolongs their circulate time, letting them attain their goal sites greater efficaciously. But, PEGylation has several barriers, consisting of the potential for immune system reputation of PEG molecules and the improvement of antiPEG antibodies in a few

sufferers that can cause rapid clearance of PEGylated nanoparticles [12]. Next generation stealth coatings, including zwitterionic and biomimetic coatings, are being explored as alternatives to PEG. Zwitterionic substances, that have each effective and bad expenses, resist protein adsorption and decrease immunogenicity, while biomimetic coatings, derived from herbal organic membranes, in addition assist in evading immune detection through mimicking the frame's own cells [13,14].

5. Future Directions and Conclusion

Nanoparticle based drug delivery structures preserve super ability for revolutionizing medicine via permitting particular,

centred delivery of therapeutics. But, the scientific translation of these structures remains hindered via numerous challenges, together with toxicity, stability, scalability, and regulatory issues. Future research need to focus on addressing these challenges via growing more biocompatible and strong nanoparticles, improving focused on accuracy, and optimizing drug launch profiles. The combination of nanomedicine with personalized cures and theranostic applications (i.e., combining diagnostic and healing abilities) will likely represent the next frontier in the subject. Moreover, standardization of nanoparticle characterization and streamlined regulatory frameworks are important for the success scientific adoption of nanomedicines.

In end, while many obstacles continue to be, endured advances in nanoparticle layout, surface amendment techniques, and our expertise in their interactions with biological structures are paving the manner for the a success translation of nanoparticle based drug delivery structures into scientific exercise. As innovations continue to emerge, it is likely that these structures will play a central position in the treatment of complex sicknesses, in particular most cancers, neurological disorders, and continual situations, supplying the promise of more powerful, safer, and personalized cures.

5.1 Personalized Nanomedicine and Theranostics

One of the maximum interesting prospects for the future of nanoparticle-based drug shipping is the combination of personalized nanomedicine. Using nanoparticles to tailor treatments to the character patient's genetic, environmental and lifestyle elements hold the capacity to appreciably enhance clinical consequences. Personalized treatments may want to involve optimizing the composition, length, and surface properties of nanoparticles for each patient, ensuring the most therapeutic impact with minimal unfavourable effects. Furthermore, theranostic nanoparticles, which integrate each therapeutic and diagnostic function in an unmarried platform, represent a singular and exceedingly promising approach.

Those nanoparticles may be designed to no longer simplest supply drugs to focus websites but additionally to reveal the progress of the disease or the remedy in real time. For instance, nanoparticles may be functionalized with imaging marketers consisting of fluorescence or magnetic resonance imaging (MRI) comparison marketers, permitting clinicians to track the region and distribution of the nanoparticles in vivo. This twin capability complements remedy efficacy by using permitting nonstop monitoring and presenting dynamic comments for adjusting remedy regimens.

5.2 Overcoming Challenges in Scalability and Manufacturing

Notwithstanding the amazing promise of nanoparticle based totally drug transport structures, the challenges of scalability and price effective production stay significant hurdles. As referred to earlier, while laboratory scale synthesis of nanoparticles is well hooked up, transferring to big scale production while preserving regular first rate, size, and stability presents a significant project. Innovations in nonstop drift synthesis and microfluidic structures are predicted to play an key position in overcoming these troubles, bearing in mind excessive throughput production of nanoparticles with precise manipulate over their homes. The automation of synthesis processes, coupled with advances in first rate manipulate technologies, will assist ensure reproducibility and limit batch to batch variability, making it possible to produce nanoparticles at commercial scales. Additionally, bioreactors and modular production platforms that combine more than one production and purification steps right into an unmarried, nonstop machine will assist streamline nanoparticle production and decrease charges. Making sure that these methods are price effective may be essential in making nanoparticle based totally

remedies less expensive and accessible to a broader affected person population.

5.3 Regulatory Considerations and Safety Assessment

The regulatory framework for nanoparticle primarily based drug transport structures continues to be evolving. Given the particular residences of nanoparticles, such as their capacity to move biological boundaries and acquire in tissues, regulatory corporations should broaden new tips tailored specifically to the needs of nanomedicines. The FDA and the ecu medicines company (EMA) are operating closer to establishing extra comprehensive tips that cowl the safety and efficacy assessment of nanomedicines, but a good deal work stays to be completed. Key challenges in regulatory approval encompass the want for standardized physicochemical characterization of nanoparticles, in addition to the assessment of their long-term balance and ability toxicity. Nanoparticles may additionally acquire in organs over time, and their long-term outcomes on human health are nevertheless not fully understood. Regulatory corporations should therefore broaden comprehensive threat tests that do not forget not best the fast term safety and efficacy of nanoparticles but also their long-term biological interactions. Further to safety, the manufacturing system of nanoparticles needs to be reproducible and scalable. The status quo of true production practice (GMP) requirements specifically for nanoparticles will be crucial in facilitating the approval of these structures. Moreover, the development of nano particular biomarkers and analytical methods will resource in tracking the conduct of nanoparticles inside the body and help manual regulatory choices.

5.4 Emerging Trends in Nanoparticle Drug Delivery

A promising vicinity of research in nanoparticle-based drug delivery is the improvement of nanocarriers for RNA based treatment options, along with mRNA vaccines and gene enhancing technology like CRISPRCas9. Nanoparticles are especially properly suited for RNA delivery because of their potential to guard fragile RNA molecules from degradation and facilitate their uptake by means of cells. Numerous nanoparticle structures, along with lipid nanoparticles (LNPs), have already shown fulfilment in the delivery of mRNA vaccines, exemplified by means of the speedy improvement of COVID19 vaccines. However, challenges related to the efficient delivery of RNA to goal cells, warding off immune responses, and attaining sustained expression of the therapeutic RNA remain large. Furthermore, the use of nanoparticles in the delivery of biological therapeutics, along with monoclonal antibodies and biologics, is any other thrilling vicinity of increase. Nanoparticles can serve as companies to improve the bioavailability, balance, and 1/2 life of biologics, especially in the context of persistent sicknesses like cancer or autoimmune issues. additionally, the potential of nanoparticles to penetrate tissues and move mobile barriers, along with the blood mind barrier (BBB), has raised hopes for the improvement of novel treatments for neurological sicknesses, including Alzheimer's and Parkinson's.

5. Conclusion

Nanoparticle based totally drug transport structures represent a transformative technique to trendy medicine, presenting answers to many demanding situations associated with traditional drug transport methods. The ongoing development of stimuli - responsive nanoparticles, focused transport structures, and revolutionary floor changes holds wonderful promise in overcoming the modern-day boundaries of nanoparticle based totally healing procedures. But, big demanding situations stay in making sure their biocompatibility, balance, performance, and scalability. The course ahead would require a multidisciplinary technique that combines engineering, materials technological

knowhow, pharmacology, and scientific studies to cope with these demanding situations and unencumber the total capacity of nanomedicine. As the sector progresses, the combination of customized nanomedicine, theranostics, and RNA transport will be pivotal in supplying tailor made remedies for an extensive variety of sicknesses. Ultimately, the fulfilment of nanoparticle based totally drug transport structures will rely no longer simplest on advances in technology but also at the regulatory, production, and safety frameworks that assist their sizable adoption in scientific exercise.

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