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Research Article

Green Chemistry approach for synthesis of Schiff bases and their applications

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Abstract

Reducing the quantity of hazardous substances utilized in synthesis and their release into the environment is the aim of green synthesis. Green procedures need to reduce reaction time, increase selectivity, and make product separation easier than with standard methods. The pharmacological effects of schiff base ligands and their metal complexes are widely recognized, and they find extensive application across various industries. They perform a number of vital biological and pharmacological tasks. The goal of this study is to identify the most effective, environmentally friendly, and time- and labor-efficient methods for synthesizing Schiff bases while concentrating on environmentally friendly synthetic processes. The study examines seven green synthesis techniques for creating Schiff base ligands and their metal complexes, such as irradiating the material using microwaves, using water as a green solvent, grinding, using natural acids as catalysts, Ultrasonic, Ball milling method and from industrial waste.

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1. Introduction

Because schiff bases are organic molecules with a variety of uses, including as catalysts, their metal complexes have been thoroughly studied. [1] In the 1800s, Hugo Schiff documented the first instance of Schiff bases (imines) being synthesized. An aldehyde with a C=N group (azomethine -N=CH- group) instead of a C=O group is referred to as a Schiff base [2, 3]. It is typically created when primary amines and aldehydes react. [4] RCH=NR1 (where R and R1 describe aryl or alkyl substituents) is the usual chemical expression for Schiff bases [5]. The NH_2 group is regularly added nucleophilically to the C=O of the aldehyde to form a hemiamine compound under an azeotropic reflexing condition. Water is simultaneously eliminated, and the compound dehydrates to produce an imine. [6,7] This gave rise to its name, and these bases were given various names as well, such as Anil and Ketimines when they were produced from ketone. And (Aldimimes) when the carbonyl group and primary amines condense to produce them from aldehyde.

An intermediate molecule is created when the carbon of the carbonyl group of the aldehyde or ketone is added to the mono alkyl amine (NH_2-R) or monoaryl amine (NH_2-Ar). Carbinolamine Substitutedimine-N is created by losing a water molecule after this. This serves as the ultimate representation of Schiff's rule. The scientific community has given Schiff base metallic complexes a lot of attention because of their special qualities and numerous uses in a variety of sectors, including biology and industry. The biological activity of these complexes include cytostatic, antiviral, antibacterial, anticancer, and antifungal effects. Furthermore, they exhibit remarkable catalytic activity for an extensive variety of chemicals. [8]

2. Schiff bases prepared mechanically:

The carbonyl group must be joined by a nucleophile in order to create Schiff bases. It entails reacting an aldehyde or ketone's amine and carbonyl groups to form the stable chemical carbonylamine, which undergoes multiple ways of losing a water molecule by the use of an acid or base catalyst.[9]

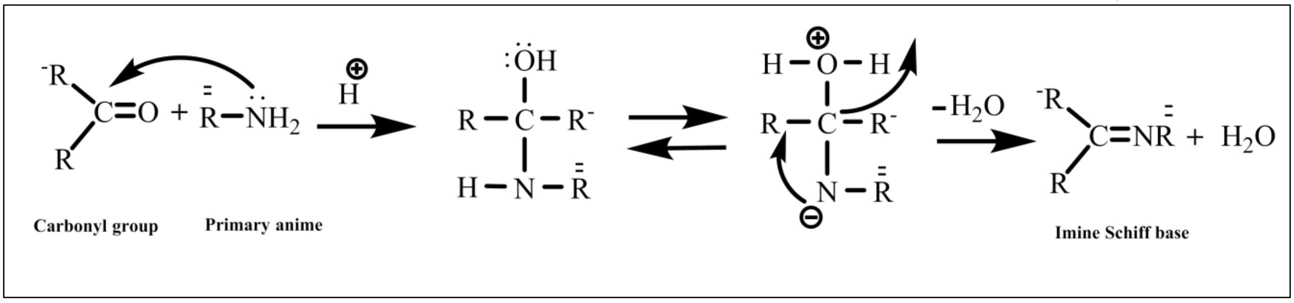


Figure 1. Preparation Imine Schiff base from Carbonyl group and Primary anime.

If the amine group is protonated, the nucleophilic addition reaction does not occur because the primary amine is no longer a nucleophile that can react. The reactions to prepare Schiff bases include two types of reactions: a nucleophilic addition reaction and a water molecule deletion reaction.

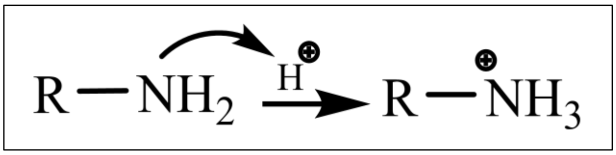


Figure 2. Protonation of amine group.

3. Schiff base preparation

Schiff bases can be prepared in a variety of ways, which are summed up as follows:

3.1. The primary amine and aldehyde or ketone's reaction.

It is the most significant and widely used approach because it includes the removal of a water molecule after the primary amine is added nucleophilically to the aldehyde or ketone. [9]

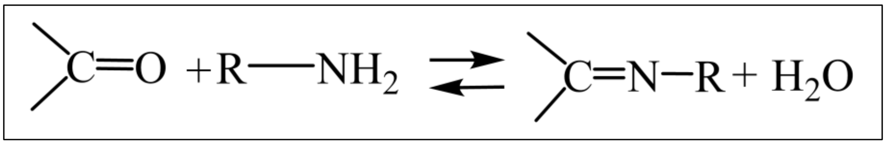


Figure 3. Preparation of Schiff base from primary amine and aldehyde or ketone.

3.2. Alcohol oxidation

When Schiff bases are formed, the alcohol is oxidized to produce an aldehyde or ketone, which then reacts with the primary amine

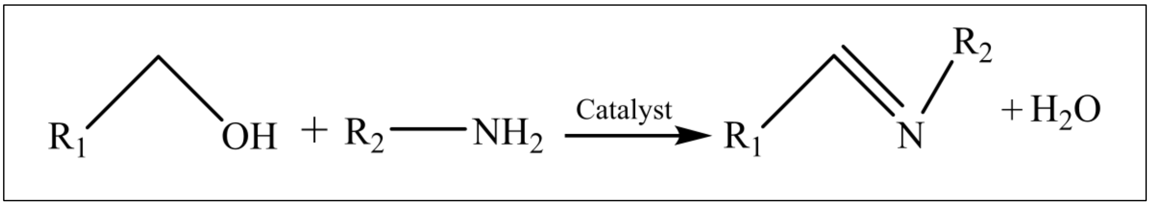


Figure 4. Preparation of Schiff base from alcohol oxidation.

4. Phenol ether and nitriles react

When acid is present as a catalyst, alkyl or aryl cyanide combines with phenol or phenol ether derivatives to produce ketamine, also known as a Schiff base derivative or ketone. It is better to combine nitriles with ether and phenol, then add hydrochloric acid to achieve this reaction.[9]

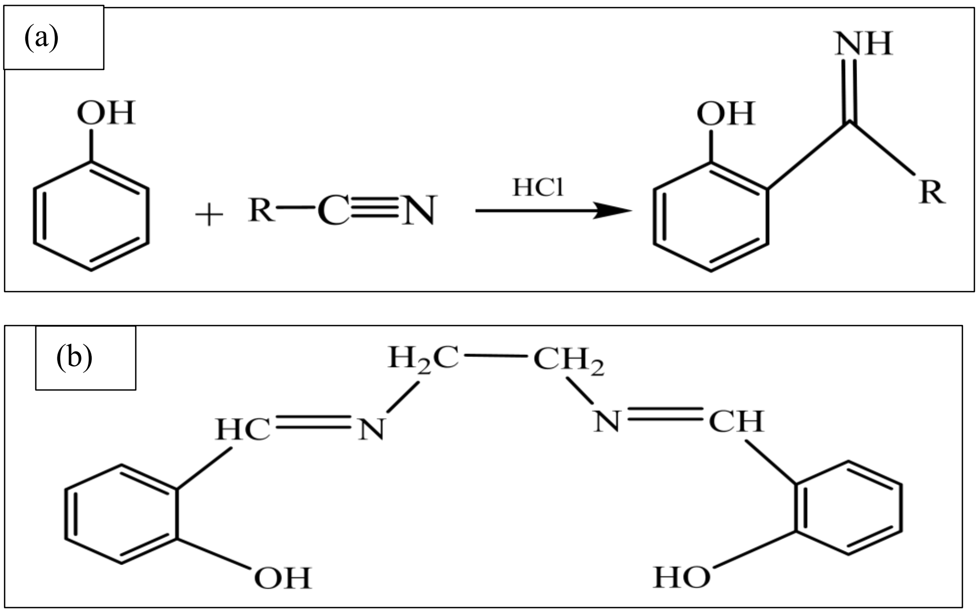


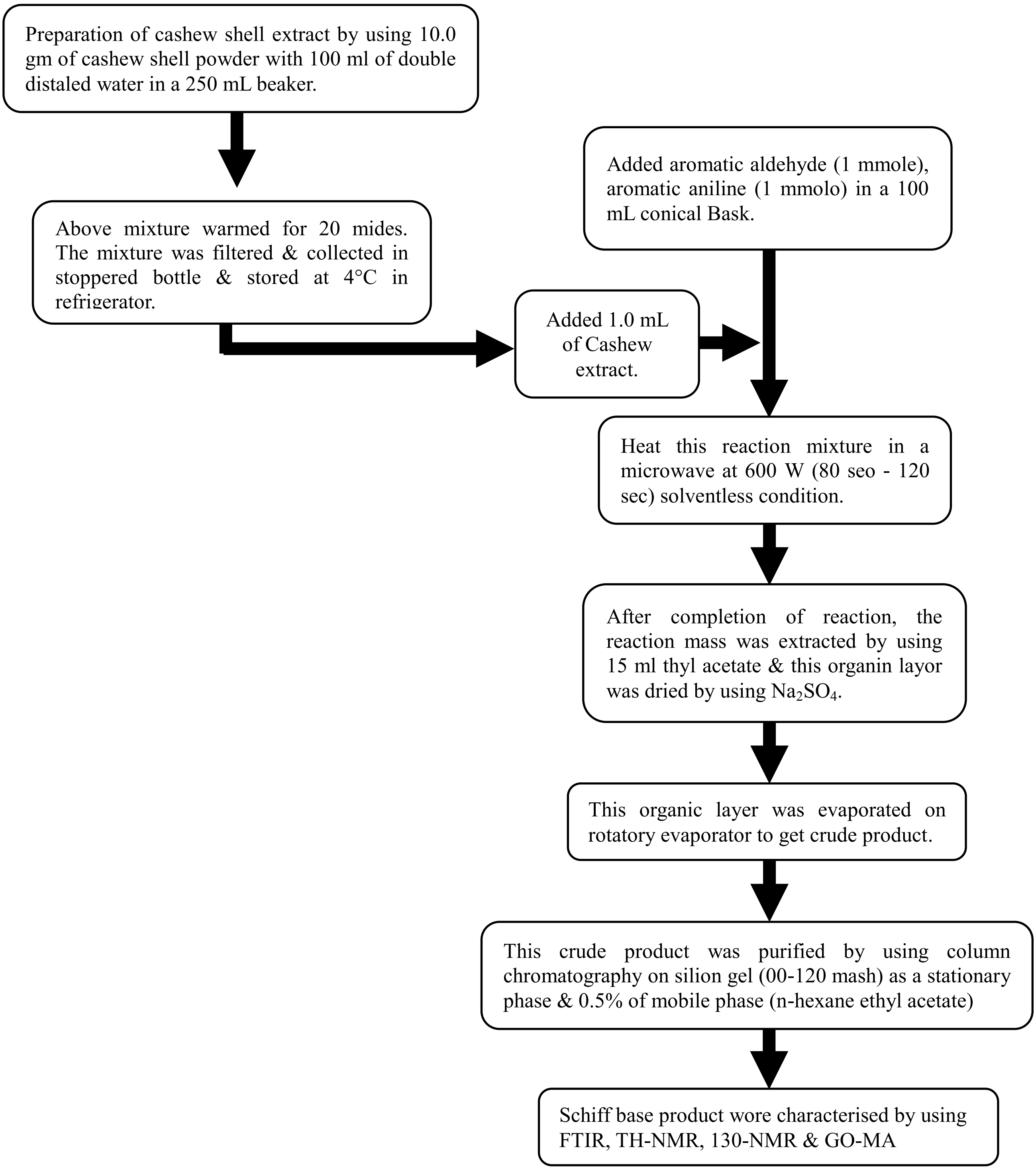
Figure 5. Preparation of Schiff base a) and (b) from phenol ether and nitriles react.

4.1. The method of microwave irradiation

Since the last few decades, chemists have found microwave-assisted synthesis to be a very exciting green chemistry technique. The chemical transformations carried out by microwave irradiation are pollution-free, environmentally benign, inexpensive, and provide excellent yields. together with ease of handling and processing. Using non-conventional synthesis methods is a key component of green chemistry due to its ease of isolation, little or no solvent needs, eco-friendliness, short reaction times, high target molecule purity, and good yield [10–11]. The synthesis of organic compounds has seen the appearance of microwave-supported organic reactions as a contemporary tool. Not only does this technique improve yield and product quality, but it also has significant advantages over traditional approaches, including a simpler procedure and an exceptionally accelerated reaction rate that minimizes reaction period [12].

Piperonal-chitosan, a novel Schiff base of chitosan synthesized by Dheeraj Singh Chauhan et al. (2020), was created by microwave Irradiation and studied by spectroscopic methods. In 15% HCl Media, the new Schiff base's capacity to inhibit corrosion on carbon steel was evaluated using gravimetric and electrochemical techniques. In the acidifying environment of an oil well, this is the first investigation to use chemically functionalized chitosan as a corrosion inhibitor [13]. have documented synthesizing SBs using a grindstone approach in addition to a UV Chamber sonicator. SBs have been synthesized by Valvi et al. in both insolvent-free conditions and CH_3OH solvent under microwave irradiations. Without a catalyst Synthesis of SBs at room temperature using grindstone chemistry Synthesis of SBs in a MW-irradiated water medium Naqvi et al. have also documented the synthesis of SBs in DMSO solvent in literature [14].

A 100 mL conical flask was filled with 1 mL of cashew shell extract, 1 mmol of aromatic amine, and 1 mmol of aromatic aldehyde. Aluminum foil was used to cover this conical flask. The reaction mixture was maintained at 600 W in the microwave. The preparation of Schiff bases under microwave irradiation takes 80–120 seconds on average. There was no solvent used in this process. TLC was used to track the reactions (Scheme 1). Following the reaction's completion, the reaction mass was discovered utilizing15 mL of ethyl acetate. It lasted for three minutes. Then, Na_2SO_4 was used to dry this organic layer. The crude product was obtained by evaporating this organic layer using a rotatory evaporator. Using column chromatography with a stationary phase of 60–120 mesh silica gel and a mobile phase of 0–5% n-hexane/ethyl acetate, this crude product was refined. The FTIR, 1H NMR, 13C NMR, and GC-MS methods were used to describe the refined Schiff base derivative. Every prepared Schiff base is identified, and their spectral data agrees with the values described in the literature.[15]. These spectral data are provided in the Supporting Information. Scheme 1 shows the flow chart for the synthesis of Schiff bases.



Scheme 1. Schiff Base Derivatives Prepared under a Microwave Irradiation Mechanism.

5. Green synthetic methods for Schiff bases

5.1. Water as a green solvent

The use of water as a reaction Medium offers several advantages as it is Cheap, non-inflammable, non-toxic and Safety to use [16,17, 18]. Undoubtedly the best alternative as there are generally no harsh reaction conditions and no need of Vigorous drying of the solvents. Schiff's bases have been playing vital roles in Pharmaceuticals, rubber additives [19] General Synthesis of the Schiff Derivatives. Aldehyde (1 mmol) and the corresponding amine (1.1 mmol) were taken in dry MeOH and refluxed for 12 h. The reaction mixture was Cooled to room temperature and washed with MeOH several Times to obtain the title compound as a solid. In the case of Compound 2, after completion of the reaction, the solvent was Removed on a rotary evaporator and then subjected to column Chromatography on a 60-120 mesh silica gel column using Hexane as the eluent to obtain the desired [20]

S.H. Shirangi et al. (2022) synthesised Schiff bases of pyrimidoazepine derivatives in high yields by combining reactions Involving stains, alkyl bromides, activated acetylenic compounds, Guanidine, and aldehydes with a high-performance catalyst made of Fe_3O_4/CuO/ZnO, Multi Walled Carbon Nanotubes (MWCNT). Using Petasites hybridus rhizome water extract as a green media and mild Base, Fe_3O_4/CuO/ZnO MWCNT is synthesised. The disc diffusion test Was used to demonstrate the antibacterial activity of various synthetic Substances against both Gram-positive and Gram-negative bacteria [21]

5.2. Natural acid-catalyzed methods

Due to these beneficial properties, concern for the Environmental demands and strong interest in the Development of green chemistry, new sustainable catalysts And new environmentally benign processes10 have been Investigated which are both economically and Technologically feasible [22]. Present study also involves some Eco-friendly and inexpensive natural catalysts like grapes (Vitis lanata) juice, sweet lemon(Citrus limetta) juice and Aqueous extract of mango (Magnifier indica) for the Synthesis of Schiff bases Preparation of Solanum Lyopersicum juice Fresh Solanum Lyopersicum fruits were procured locally and washed with tap water followed By distilled water and were pressed into fruit juicer to get semisolid mass which was then Filtered with cotton to get liquid juice to use as catalyst.[23]

The metal complexes were prepared by the stoichiometric reaction of the corresponding Metal chloride with Schiff base ligand in the molar ratio (M:L) of 1:2. Metal salt (1mmol in 15mL ethanol) was added to the ligand (2mmol in 20mL methanol) with continuous stirring. The obtained colored products were separated by filtration, washed with distilled water and Methanol, and dried under vacuum. Recrystallization from hot methanol gave the metal Complexes. Purity of the complexes was confirmed by TLC[24]. Alikhani (2018) has synthesized Schiff base from the reaction of aldehyde and 4,6 diamino-2-thiol pyrimidine with a catalyst (lemonjuice) and stirred it at 55 ◦C. The focus of this work is on the significance of fruit juice in exclusively natural and biocatalytic organic transformations. Fruit juice is advantageous for organic synthesis because of environmental profile, and acidic qualities. The synthesized product was evaluated for its physical characteristics, melting point, and TLC before being tested for in vitro antibacterial activity against gram-positive and gram-negative strains [25]. its low cost, economic viability, enzymatic activity.

As well as, by using lemon juice as a naturally catalyzed acid under solvent-free Circumstances, Bentoum et al. (2022) synthesized a novel Schiff Bases containing 2-oxo-3H-benzoxazole scaffold. All molecules were Separated with moderate yields following shorter reaction durations. The in vitro antioxidant properties of several synthesized compounds Were evaluated. The findings of the test to see if the synthesized molecules could pass the clinical test using the ADMET prediction showed That the compounds have outstanding drug-like qualities [26].

5.3.Grinding method

Many exothermic reactions can be accomplished in high yield by just grinding solids together using a mortar and pestle, a technique known as "grindstone chemistry", Which is one of the "green chemistry techniques". Reactions are initiated by grinding, with the transfer of very Small amounts of energy through friction [27]. Mixture of p-toluidine (2.5mmol), substituted benzaldehyde (2.5mmol) and a piece of garlic were grinded together in a mortar with a pestle in a completely solvent free condition for specific time duration. The mixture turns pasty after few minutes of grinding. The progress of the reaction was successively monitored by checking TLC. The solid crude product obtained at the end of the reaction, was recrystallized from absolute ethyl alcohol to get pure SBs as white/yellowish solid. The characterizations of obtained SBs were done by melting point, IR and NMR. The melting point, IR and NMR spectra of the obtained compounds were identical to those of reported ones.[28]

Ma'rufah, L. et al. (2021) have used a grinding process to create Schiff bases (47) by combining vanillin and p-aminoacetophenone with lime juice (Citrus aurantifolia) as a natural acid catalyst. The yield of synthesised chemicals was estimated, and physical characteristics including colour and melting point were also established. The NaOH reaction was also used to describe the product. NaOH reacts with 1-(4- hydroxy-3-methoxybenzylidene)-amino]-phenyl)-etanone to form a bright yellow. Substances have an inhibitory effectiveness ranging from 23.11 % to 86.16 % (Scheme 13).[29]

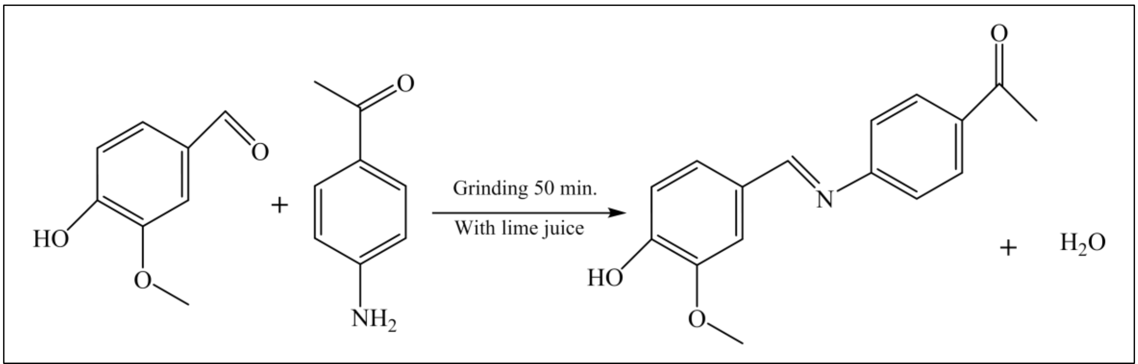


Figure 6. Synthesis of Schiff bases by grinding vanillin and p-aminoacetophenone with lime juice as a natural acid catalyst.

5.4. Ultrasonic methods

Green chemistry techniques have attracted in many areas, especially in the field of Synthetic organic chemistry. Microwave and ultrasound mediated organic synthesis have Become an increasingly used techniques for the production of new molecules. [30] This method proposes Benefits such as minimizing reaction Time, mild condition and higher yields. They made a mixture of azo-linked Aldehydes and aminopyrazole in 10 mL Ethanol, and then they irradiated the Mixture in a water bath by (45 kHz) Ultrasound at 60°C for (5-15min). The Pure products collected in 85-96% Yields. They conducted that the higher Yield and less reaction time by ultrasonic Method attributed to the developed Bubbles burst, which develops elevated Temperature and pressure that assist the Intermolecular reaction. [31]

5.5.Ball milling method

The Schiff base ligand (H_2IH) produced by R. Shah et al. (2020) were synthesised using the standard condensation procedure of 3-(2-thiazolylamino)-3-oxopropanehydrazide and isatin in an ethanol solvent at reflux for three hours. Using a green method called ball milling, UO_2(II), Co(II), Cu(II), Pd(II), and Zn(II) complexes were made using a new Schiff base ligand (H2IH). High-yielding products were producedusing a simple, solvent-free procedure, and excellent inhibitory activity for the H2IH ligand was identified in the biological screening. In-silico research supports the in-vitro findings by confirming the ligand'sinteraction characteristics with the amino acid residues of various pathogen proteins [32]. T. A. Yousef (2020) synthesised schiff base via the condensation of 2-hydrazino-2-oxo-N-phenylacetamide with 2-hydroxy-1-naphthaldehyde and its Cu (II) complexes from the conventional reflux and ball mining methods. Studies on molar conductance have supported the metal complexes' non-electrolytic character [33].

In order to create pure Ni(ll), Co(ll), Cu(ll), Zn(ll), Pd(ll), and Cd(ll) complexes with a high yield (99 %), the waste-free and simple solid-state ball milling process was utilised. Theoretical, analytical, and spectroscopic methods were used to characterise all substances. Long-term biological screening was conducted to assess all novel compounds' efficacy in comparison to established medications. The most potent molecules against different microorganisms, free radical generators, and colorectal cancer cell lines were the ligand and its Zn(II) complex [34]. Ball milling, which is thought of as a green technique of preparation, was utilized to create novel Schiff-base complexes from Co(II), Fe(III), Ni(II), and Zn(II) ions. To investigate the antibacterial activity of ligands and complexes against TOS aureus, E. coli, and the Candida albicans fungus, standard procedures were used. ABTS-antioxidant screening and cytotoxicity tests against liver cancer cells (HepG2) were also carried out to evaluate their inhibitory impact. Regarding the chosen microorganisms and liver cancer cell line, most complexes showed medium to significant activity [35]. Fe (III), Cu (II), Zn (II), and Ni (II)-Schiff's base complexes were synthesised by ballmilling from 2-oxo-N-(pyridine-2-yl)-2-(2-(1-(pyridine-2-yl)ethylidene)hydrazinyl) acetamide (H_2L) ligand. All of the substances exhibited noteworthy biological characteristics both against A. flavus and C. albicans as antifungal and against E. coli, P. aeuroginosa, B. subtilis, and S. aureus as antibacterial. [36]

5.6. From industrial waste

In order to create certain substituted amino benzothiazoles from 2,4- dimethylaniline, ubashshir Ahmed et al. (2022) used industrial waste (a mixture of NaCl and NaBr In comparison to reference medications, 3-(1E)-1- [2-(4, 6-dimethyl-1, 3-benzothiazol-2-yl) hydrazinylidene] ethyl-2-hydroxy-6-methyltetrahydro-4H-pyran-4-one was shown to be the most effective against all of the studied bacteria and fungi. Because it saves on labour, time, utilities, human health, and safety, this technique is very beneficial from a business standpoint. Because industrial trash, which is essential to dispose of, was utilized, it is environmentally good. [37]

6. Another green syntheses of Schiff bases

6.1.Magnetic nanoparticles

Magnetic nanoparticles (MNPs) considered as fascinating and desirable stuffs due to their high surface area and exceptional magnetic characteristics [38]. Nezhad and Tahmasebi (2019) consume ionic liquid carried on magnetic nanoparticles as an effective and recyclable eco-friendly catalyst for benzimidazoles synthesis in solvent or solvent-free environments. A mixture of o-phenylenediamine and corresponding aldehyde was well-stirred with catalyst (Fe_3O_4 magnetic nanoparticles) in 10 mL of water, or under solvent-free conditions at 80 °C, both methods for 25-40 min. The benefits of this methods were its easiness procedure, minimum reaction times in comparison to the other procedures, and the good yields of products. In addition, the catalyst can be reused several times and recovered easily by simple magnetic decantation with no loss of activity [38].

6.2. Mixing at room temperature

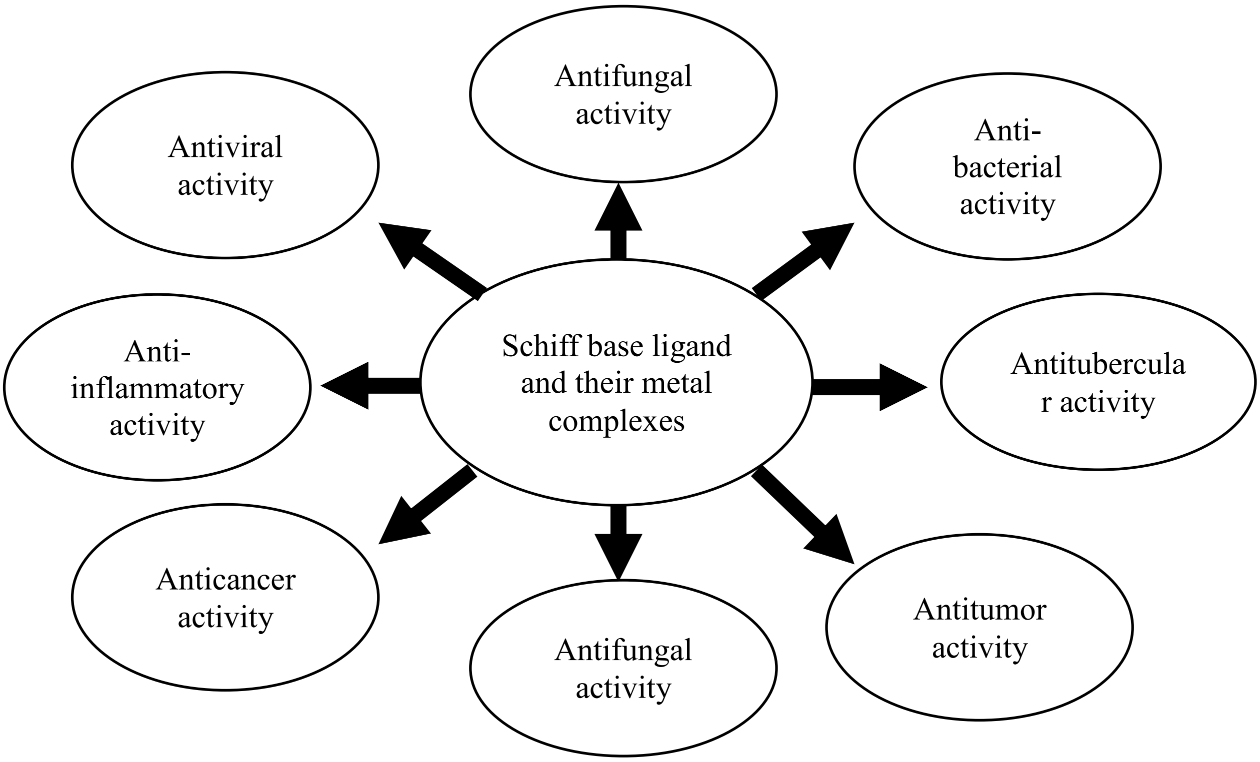
While Ariyaeifar and coworker (2018) synthesized a series of chiral Schiff base compounds by the addition of 3,5-dichlorosalicylaldehyde to an aqueous solution of (R)-3-Amino-1,2-propanediol at 25°C which yielded a yellow precipitate almost immediately [39].

6.3. Garlic as natural biocatalyst

Bedi and coworkers (2020) established the use of natural biocatalyst(garlic) for eco-friendly synthesis for a group of Schiff bases, they utilizing ptoluidine and many aromatic aldehydes as reactants. The Schiff bases produced high yields by merely grinding the reactants collectively with a pestle in a mortar with the existence of a piece of garlic in solvent free procedure. Their method was very easy, eco-friendly, efficient, cost-effective it is within the green chemistry protocols [40].

7. Application of Schiff bases and its metal complexes

Schiff bases and their metal complexes find widespread use in various industries and applications, including the food industry, the agrochemical industry, the dye industry, analytical chemistry, catalysis, energy storage, environmental, chemo- sensing, bio-sensing, nanotechnology, and biomedical applications.



Scheme 2. Applications of Schiff base ligands and its metal complexes in various

7.1.Catalysis:

Catalytic activity is enhanced in both homogeneous and heterogeneous reactions by Schiff base metal complexes. The ligands, coordination sites, and metal ions employed in a given compound determine its activity. Many different reactions, such as polymerization, ring-opening polymerization, oxidation, epoxidation, allylic alkylation, reduction of ketones, hydrazination of acetophenones, the Michael addition reaction, the decomposition of hydrogen peroxide, the annulation reaction, the Heck reaction, the carbonylation reaction, and the Diels-Alder reaction, have been used to critically evaluate the catalytic activity of metal complexes. There is significant potential for Schiff base ligands to be used as metal complexes in catalysis due to their simple synthesis method and heat stability. The catalytic activity of Schiff base complexes differed greatly depending on the structure and kind of ligands used [41,42]

7.2.Dye industry:

The dyeing technique employs a wide range of Schiff bases and complexes, many of which have been synthesized, investigated, and employed as mordents [43]. As a dye, transition metal complexes such asiron (III), nickel (II), cobalt (II), and copper (II) complexes, among others, have been prepared from a variety of Schiff bases and employed to produce a variety of transition metal complexes. Aldehyde groups that include azo dyestuff are known to synthesized many azomethine linkages that contain azo dyes due to condensation with primer amines. The textile industry utilizes these dyestuffs to color a variety of materials. Outside the textile sector, the field of photochemistry places a significant emphasis on using azo dyes that include the amine group. The Schiff base on fluorene showed desirable properties including sensitivity to pH, as well as heat and color stability. For making a water-based ink, it showed promise as a functional pigment material [44]

7.3. Food industry:

Various research groups have recently concentrated on producing natural novel and active materials for food packaging applications. Because of their antibacterial action, chitosan-derived Schiff base films developed may not only boost the safety of such foods and hence lengthen their shelf life, but also provide a flavor that is well- accepted by the consumer. Schiff's base (SB) modified zirconium dioxide reinforced PLA (Poly(lactic acid) or polylactide (PLA), a biodegradable polyester produced from renewable resources, is used for various applications (biomedical, packaging, textile fibers and technical items). Due to its inherent properties, PLA has a key-position in the market of biopolymers, being one of the most promising candidates for further developments). bio-composite film serves as an alternate packing material to replace single waste synthetic manufactured materials that pollute the environment. For active packaging applications, Schiff base (SB) modified poly lactic acid (PLA) film can provide improved barrier and antifungal qualities [45-47] .

7.4. Agrochemical industry:

Metal complexes with diverse Schiff base ligands have attracted the attention of chemists in recent years due to their agricultural applications, such as pesticidal, nematicidal, and insecticidal. Unsymmetrical Schiff bases glyoxal salicylaldehyde succinic acid dihydrazide and its Ni(II), Co(II), Zn(II), and Cu(II) complexes have been synthesized and studied; at greater concentrations, they display considerable insecticidal action [48]. H_2L [2, 2'-[(1E, 2E)-ethane-1,2- diylidenedi (E) azany- lylidene] dibenzenethiol] and its new Zn(II), Ni(II) metal complexes have been employed as insect repellent agents [49]. Coumarin-based Schiff base and its earth metal complexes [50] have been used to treat pests (Tribolium castaneu) and worms (Meloidogyneincognita).

7.5.Analytical applications:

Schiff bases have been used as analytical probes or reagents by researchers. These are used to analyze primary amines, carbonyl compounds, and functional groups. In complexes, azomethine bonds are formed through complex formation reactions or changes in their spectroscopic properties caused by pH and solvent variations (pH of solvent polarity indicators). Schiff bases are a great carrier for the selective and efficient extraction of certain metal ions. They are well-known for their effective chelating capabilities. Schiff bases extract metal ions, essential in regulating heavy metal pollution. N, N-bis(3-methylsalicylidene)-ortho-phenylene diamine, Schiff base used in spectrophotometric detection of nickel. The approach has been used successfully to quantify trace quantities of nickel in natural food samples [51]. Schiff bases are renowned for their ability to form complexes and serve as good chelating ligands. They have been widely employed as analytical reagents due to their ligation property. Schiff bases made of salicylaldehyde are employed in gravimetric and spectrophotometric analyses. In addition, the same reagent was recently employed for the spectrophotometric detection of Ni (II) at a trace level. Cu2+ ions have been detected using the fluorescent 4-(1-phenyl-1-methylcyclobutane3-yl)-2-(2-hydroxy- 5-bromobenzylidene) aminothiazole Schiff base. This chemical sensor operates in the visible region, has a wide dynamic operating range, and may be used over a wide pH range [52].

7.6.Energy storage:

There is a resurgence of interest in the search for effective, clean, and sustainable energy sources (like wind and solar) as well as cutting-edge energy conversion and storage technologies as are salt of the rapid growth of the world economy, the depletion of fossil fuels, and rising environmental pollution. Energy storage technologies are more important in our lives since the sun does not shine at night and the wind does not blow all the time. Currently, there is a lot of interest in electrical energy storage technologies including batteries and electrochemical capacitors (super- capacitors). Recent research has shown that organic oligomeric Schiff bases and electro active polymeric (linear or hyper branched) Schiff bases perform satisfactorily as negative electrodes (anodes) in sodium-ion batteries. [53]

Lithium-ion batteries have also made use of nitrogen-rich carbon nano sheets produced by the Schiff base reaction in a molten salt solution as anode materials [54]. The linear polymeric Schiff bases developed by Armand et al. [55] as a consequence of the condensation of aromatic dialdehydes with aliphatic and aromatic diamines performed well as anodes for sodium-ion batteries. Polymeric Schiff bases are also produced by combining terephthalic-aldehyde, phenylenediamine, and polyether amine blocks, resulting in polymers with high adhesive qualities that can be used as redox-active binders for sodium-ion anodes. Similarly, Zhang et al. [56] developed another ImCOF (Imine bonds containing covalent organic frameworks) that performed again as an anode material for lithium-ion batteries derived from 2,4,6-triaminopyrimidine and terephthalaldehyde

7.7.Environmental applications:

Most firms worldwide need copper, silver, lead cadmium, aluminum and cobalt. These metals can be present in nearly all dairy products. Their widespread prevalence in industrial processes, chronic metal contamination from occupational contact, and health risks associated with these metals necessitate their identification and control in biological and dietary samples. Metals are used in electroplating, alloy production, and battery manufacturing. As a result, excessive metal concentrations have been discovered in diverse water sources, soil, and plants. Products such as cigarettes, beers, oils, and supplements necessitate metals monitoring and quality control. [57]

Metal corrosion has a tremendous impact on the national economy and critical safety and pollution issues. Although many inhibitors have good inhibitory proper- ties, they are insufficient for environmental protection and sustainable development initiatives for various reasons (such as difficulty in degradation, toxicity or high- temperature resistance). Stable, efficient, and ecologically friendly inhibitors are the inhibitors of the future. Many inhibitors, including imidazolines, Mannich bases, and Schiff bases, contain heteroatoms (N, S, O) or chemical interactions with electrons (p bonds). N, O, and S heteroatoms, as well as unsaturated >C=N- bonds, can create strong and durable corrosion-inhibiting adsorption films on metal surfaces, demonstrating outstanding inhibitory effects. At the same time, Schiff base compounds are attractive to researchers due to their inexpensive cost, ease of synthesis and purification, strong water solubility, and low toxicity. [58]

7.8.Chemo-sensing applications:

Schiff base-based fluorescent probes have recently been invented for detecting and monitoring numerous hazardous analyses in biological systems. Schiff base compounds with nitrogen-oxygen-rich coordination as a receptor site provide a stable platform for fluorescence sensing with significant, visible color shifts. Detecting metal ions with diverse mechanisms in an accurate sample using Schiff base-based sensors is appealing currently. In the recent decade, Schiff base probes based on fluorescence live-cell imaging have been used to detect metal ions such as Co^{2+}, Cu^{2+}, Zn^{2+}, Hg^{2+}, Ag^{+}, Al^{3+}, and ClO^{-} ions [59-61]

7.9.Bio-sensing applications:

Within cells, Schiff base compounds have been used as biosensors for H_2O_2, glucose, and Oncomarker CA-125 [62] Evaluation of the sensitivity and specificity of the gold Schiff base complex-doped sol gel nano optical sensor for the detection of CA-125 in ovarian cancer patient samples was performed and compared to results obtained from samples taken from healthy women serving as a control group [63]. Sheta M. Sheta et al. created an ultrasensitive method of detecting human creatinine using a cerium(III)-isatin Schiff base complex as an optical sensor [64].

7.10. Biomedical applications:

Schiff bases and their metal complexes have numerous applications in various biomedical pharmaceuticals such as antimicrobial, anti-malarial, anticancer, antiviral, anti-inflammatory, antioxidant, anticonvulsant, anti-anthelmintic, bio printing, tissue regenerating, enzyme inhibition and drug delivery. In biological systems, the azomethine nitrogen of Schiff bases serves as a binding site for metal ions to attach to diverse biomolecules such as proteins and amino acids for anti-germ activity. Our bodies' Schiff bases catalyzed many metabolic events in the form of enzymes that are active against certain bacteria. Several studies have been conducted to improve the bio-functions of Schiff bases and their metal complexes. Schiff bases can fight cancer, fungus, germs, ulcers, and viruses, depending on which transition metal ions they contain. [65-67]

7.11. DNA interaction:

Schiff bases ligands and the metal complexes The DNA cleavage study showed the ability of some nano sized Schiff bases complexes to degrade DNA and surrounding to DNA and carried out necrosis. The ability of Schiff bases nano-sized complexes to cleavage DNA has been tested by the gel electrophoresis method with two experimental procedures: fixed concentration of DNA with different concentrations of complex, and fixed concentration of complex with different concentrations of DNA. Electrophoretic separation of DNA induced by these complexes The obtained results showed the ability of investigated nano-sized complex, at the concentration of 15 μg/mL, to degrade DNA at the concentration of 100 mg, which supporting the activity of these complexes as strong antitumor agent capable to DNA-binding, and inhibits growth of the tumor cell. While, some complexes have no ability to cleavage DNA at different concentrations. However, the obtained results reveal to another type of binding occurred between the investigated complexes and DNA. Where, a non-covalent bond may be formed between the complex and a phosphate group of DNA strands. Formation of this bond led to surrounding of the complex to DNA, in a process called necrosis, which affect on DNA.

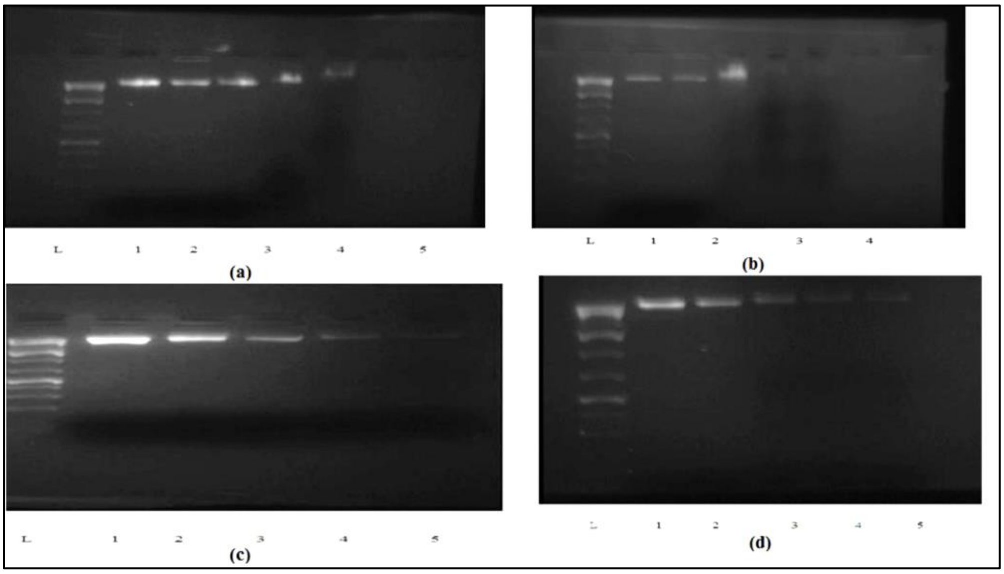


Figure 7. Electrophoretic separation of DNA induced by nano-sized Cu(II) complexes. [68,69]

7.12. Semiconducting Properties:

The electrical conductivity study confirmed that some of Schiff bases ligands and there complexes had semiconducting properties.From the electrical conductivity studies which indicated the semiconducting character for the Schiff base ligand, and there investigated complexes within the temperature range 308–408 K, and the conduction process is carried out via the hopping mechanism.

7.13. Molecular docking:

Molecular docking studies are very important for predicting the possible binding modes of the Schiff base ligand and its metal complexes against the receptors of breast cancer mutant oxido reductase (PDB ID: 3HB5), crystal structure of Rotavirus NSP4 (PDB ID: 3MIW), crystal structure of human Astrovirus capsid protein (PDB ID: 5IBV), crystal structure of human Enterovirus D68 (PDB ID: 4WM8). Docking is an interactive molecular graphics program that can be used to calculate and display feasible docking modes of the receptors with HL ligand and complex molecules. It necessitates the ligand, its complex and the receptors as input in PDB format. The water molecules, co- crystallized ligands and other unsupported elements (e.g., Na, K, Hg, etc.,) were removed but the amino acid chain was kept. [72,73,74] The structure of the ligand and it complex in PDB file format was created by Gaussian software. The crystal structures of 3HB5, 3MIW, 5IBV and 4WM8 were downloaded from the protein data bank. These studies were examined by using MOE 2008 software that it is rigid molecular docking software. [75,76]

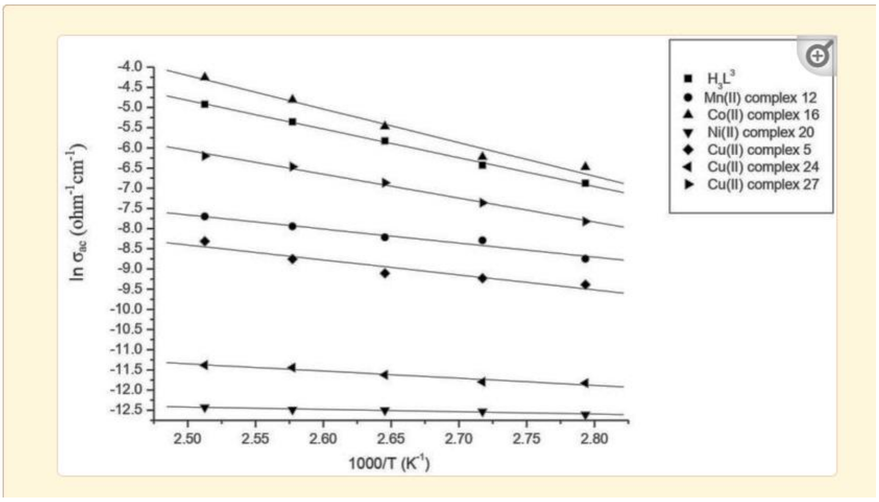


Figure3: Temperature dependence of σ_{ac} of the ligand, DBAPB, and its complexes 5, 12, 16, 20, 24, 27. [70,71]

***DBAPB: 2-{(2-[(2,3-dihydroxy-benzylidene)-amino]-6-oxo-1H-purine-9-yl)methoxy}ethyl-2-amino-3-mehyl butanoate**

CONCLUSION

Green chemistry offers significant environmental and financial benefits above traditional synthetic methods. The green synthetic methods must enhance the selectivity, shorten reaction time, and make the purification of products simpler than the traditional methods. A Schiff bases formed by condensation of primary amines with aldehydes. This study focused on the green synthetic methods that are used for Schiff bases synthesis in order to find the best technique that offers higher yields in a shorter time in ecofriendly environment. The review considered many green synthetics techniques, from which the microwaves irradiation method considered the best followed by the ultrasonic, natural acids utilizing and grinding methods. Molecular docking studies of the free Schiff bases ligands and there metal ion complexes with receptors of 3HB5, 3MIW, 5IBV and 4WM8 showed that the lowest binding energy were −6.4, −4.4, −4.1 and −1.4 kcal mol^{-1} for the ligands and −26.6, −27.3, −16.9 and −24.6 kcal mol^{-1} for the complexes, respectively. These values indicated that binding energy decreased upon coordination.

References

[1] Boulechfar, C., Ferkous, H., Delimi, A., Djedouani, A., Kahlouche, A., Boublia, A., Darwish, A., S., Lemaoui, T., Verma, R., & Benguerba, Y. (2023). Schiff bases and their metal Complexes: A review on the history, synthesis, and applications. *Inorganic Chemistry Communications*, *150*, 110451.

[2] Avram, S., Udrea, A. M., Nuta, D. C., Limban, C., Balea, A. C., Caproiu, M. T., . Dumitrascu, F., Buiu, C., & Bordei, A. T. (2021). Synthesis and bioinformatic characterization of new Schiff bases with possible applicability in brain disorders. *Molecules*, *26*(14), 4160.

[3] Hameed, A., Al-Rashida, M., Uroos, M., Abid Ali, S., & Khan, K. M. (2017). Schiff bases in medicinal chemistry: a patent review (2010-2015). *Expert opinion on therapeutic patents*, *27*(1), 63-79.

[4] Malik, S., & Nema, B. (2016). Antimicrobial activities of Schiff Bases: A review. *International Journal of Theoretical & Applied Sciences*, *8*(1), 28-30.

[5] Gupta, D., Pathak, D. P., Kapoor, G., & Bhutani, R. (2019). A comprehensive review on synthesis and biological activity of Schiff bases. *Int. Res. J. Pharm*, *10*(5), 1-8.

[6] Yadav, P., Sarkar, A., & Kumar, A. (2019). Synthesis and biological activities of schiff bases and their derivatives: a review of recent work. *Journal of Basic and Applied Engineering Research*, *6*(1), 62-65.
[7] Prakash, A., & Adhikari, D. (2011). Application of Schiff bases and their metal complexes-A Review. *Int. J. Chem. Tech. Res*, *3*(4), 1891-1896.
[8] Thakur, S., Jaryal, A., & Bhalla, A. (2024). Recent advances in biological and medicinal profile of schiff bases and their metal complexes: An updated version (2018–2023). *Results in Chemistry*, 101350.
[9] Akitsu, T. (Ed.). (2023). *Schiff Base in Organic, Inorganic and Physical Chemistry*. BoD–Books on Demand.
[10] Mohammed, T., Nasreen, A., Alqahtani, Y. S., Shaikh, I. A., Iqubal, S., Fathima, S. H., & Khan, A. A. (2023). Green Synthesis of Therapeutically Active Heterocyclic Scaffolds: A Review. *Science of Advanced Materials*, *15*(6), 725-747.
[11] Naglah, A. M., Awad, H. M., Bhat, M. A., Al-Omar, M. A., & Amr, A. E. G. E. (2015). Microwave- Assisted Synthesis and Antimicrobial Activity of Some Novel Isatin Schiff Bases Linked to Nicotinic Acid via Certain Amino Acid Bridge. *Journal of chemistry*, *2015*(1), 364841.
[12] Bhusnure, O. G., Vibhute, Y. B., Giram, P. S., Vibhute, A. Y., & Bhusnure, O. G. (2015). Innovative Green synthesis of Schiff bases and their Antimicrobial Activity. *Journal of Pharmacy Research*, *9*(12), 670-677.
[13] Chauhan, D. S., Mazumder, M. J., Quraishi, M. A., Ansari, K. R., & Suleiman, R. K. (2020). Microwave-assisted synthesis of a new Piperonal-Chitosan Schiff base as a bio-inspired corrosion inhibitor for oil-well acidizing. *International journal of biological macromolecules*, *158*, 231-243.
[14] Naqvi, A., Shahnawaaz, M., Rao, A. V., Seth, D. S., & Sharma, N. K. (2009). Synthesis of Schiff Bases via Environmentally Benign and Energy-Efficient Greener Methodologies. *Journal of Chemistry*, *6*, S75-S78.
[15] Pooja, B., Lalit, M., Richa, G., & Pramanik, T. (2018). Microwave assisted green synthesis of Schiff bases in lemon juice medium. *Research Journal of Chemistry and Environment*, *22*(8), 19-23.
[16] Bhat, A. R., & Wagay, M. H. (2017). Synthesis of Schiff's base derivatives using water as solvent.(A green methodology). *International Journal for Research in Applied Science & Engineering Technology*, *5*(11), 971-982.
[17] Habibi, A., Valizadeh, Y., Mollazadeh, M., & Alizadeh, A. (2015). Green and high efficient synthesis of 2-aryl benzimidazoles: reaction of arylidene malononitrile and 1, 2-phenylenediamine derivatives in water or solvent-free conditions. *International Journal of Organic Chemistry*, *5*(04), 256-263.
[18] Shamly, P., Nelson, M. P., Antony, A., Varkey, J. T., Teresa, S., & Albert, S. (2018). Synthesis of Salicylaldehyde Based Schiff Bases and Their Metal Complexes In aqueous Media-Characterization and Antibacterial Study. *Int J Recent Sci Res*, *9*(5), 26566-26570.
[19] Rao, V. K., Reddy, S. S., Krishna, B. S., Naidu, K. R. M., Raju, C. N., & Ghosh, S. K. (2010). Synthesis of Schiff's bases in aqueous medium: a green alternative approach with effective mass yield and high reaction rates. *Green Chemistry Letters and Reviews*, *3*(3), 217-223.
[20] Pramanik, B., & Das, D. (2018). Aggregation-induced emission or hydrolysis by water? The case of Schiff bases in aqueous organic solvents. *The Journal of Physical Chemistry C*, *122*(6), 3655-3661.
[21] Shirangi, H. S., Moradi, A. V., Golsefidi, M. A., Hossaini, Z., & Jalilian, H. R. (2022). Green synthesis and

investigation of antioxidant and antimicrobial activity of new schiff base of pyrimidoazepine derivatives: application of Fe_3O_4/CuO/ZnO@ MWCNT MNCs as an efficient organometallic nanocatalyst. *Molecular Diversity*, *26*(6), 3003-3019.

[22] Pal, R. (2013). Fruit juice: a natural, green and biocatalyst system in organic synthesis. *Open J. Org. Chem*, *1*(4), 47-56.

[23] Rana, M. S., Islam, M. A., Islam, M. S., Sarafi, M. S., Kudrat- E- Zahan, M., Hossen, M. F., & Asraf, M. A. (2024). A review on synthesis and biological activities of 2- aminophenol- based schiff bases and their transition metal complexes. *Applied Organometallic Chemistry*, *38*(12), e7724.

[24] Punitha, N., Mangalam, M., Vijayalakshmi, K., & Selvan, C. S. A. (2015). Microwave Promoted Synthesis of Schiff Base Ligand Using Natural Acid Catalyst and its Nickel (II) and Copper (II) Complexes. *Int J Nano Corr Sci and Engg*, *2*(6), 78-84.

[25] Alikhani, A., Foroughifar, N., & Pasdar, H. (2018). Lemon juice as a natural catalyse for synthesis of Shiff's base: a green chemistry approach. *International Journal of Advanced Engineering Research and Science*, *5*(2), 61-65.

[26] Bentoumi, H., Tliba, S., K'tir, H., Chohra, D., Aouf, Z., Adjeroud, Y., Amira, A., Zerrouki, R., Ibrahim-Ouali, M., Aouf, N., & Liacha, M. (2022). Experimental synthesis, biological evaluation, theoretical investigations of some novel benzoxazolinone based Schiff under eco-environmental conditions as potential antioxidant agents. *Journal of Molecular Structure*, *1270*, 133986.

[27] Sachdeva, H., Saroj, R., Khaturia, S., & Dwivedi, D. (2012). Operationally simple green synthesis of some Schiff bases using grinding chemistry technique and evaluation of antimicrobial activities. *Green Processing and Synthesis*, *1*(5), 469-477.

[28] Bedi, P., Pramanik, G., & Pramanik, T. (2020). Garlic catalyzed and grindstone assisted solvent free green synthesis of pharmaceutically important schiff bases. *Research Journal of Pharmacy and Technology*, *13*(1), 152-156.

[29] Ma'rufah, L., Hanapi, A., Ningsih, R., & Fasya, A. G. (2021). Synthesis of Schiff Base Compounds from Vanillin and p-Aminoacetophenone Using Lime Juice as a Natural Acid Catalyst and Their Utilization as Corrosion Inhibitors. In *International Conference on Engineering, Technology and Social Science (ICONETOS 2020)* (pp. 297-301). Atlantis Press.

[30] Yadav, M., Mishra, N., Sharma, N., Chandra, S., & Kumar, D. (2014). Microwave assisted synthesis, characterization and biocidal activities of some new chelates of carbazole derived Schiff bases of cadmium and tin metals. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *132*, 733-742.

[31] Nikpassand, M., Fekri, L. Z., & Sharafi, S. (2013). An efficient and green synthesis of novel azo Schiff base and its complex under ultrasound irradiation. *Orient J Chem*, *29*(3), 1041-1046.

[32] Shah, R., Katouah, H., Sedayo, A. A., Abualnaja, M., Aljohani, M. M., Saad, F., Zaky, R., & El-Metwaly, N. M. (2020). Practical and computational studies on novel Schiff base complexes derived from green synthesis approach: conductometry as well as in-vitro screening supported by in-silico study. *Journal of Molecular Liquids*, *319*, 114116.

[33] Yousef, T. A. (2020). Structural, optical, morphology characterization and DFT studies of nano sized Cu (II) complexes containing schiff base using green synthesis. *Journal of Molecular Structure*, *1215*, 128180.

[34] Katouah, H., Hameed, A. M., Alharbi, A., Alkhatib, F., Shah, R., Alzahrani, S., Zaky, R., & El□Metwaly, N. M. (2020). Green Synthesis Strategy for New Schiff□Base Complexes:

Characterization, Conductometry, In Vitro Assay Confirmed by In Silico Approach. *ChemistrySelect*, *5*(33), 10256-10268.

[35] Alharbi, A., Alsoliemy, A., Alzahrani, S. O., Alkhamis, K., Almehmadi, S. J., Khalifa, M. E., Zaky, R., & El-Metwaly, N. M. (2022). Green synthesis approach for new Schiff's-base complexes; theoretical and spectral based characterization with in-vitro and in-silico screening. *Journal of Molecular Liquids*, *345*, 117803.

[36] Al□Hazmi, G. A., Abou□Melha, K. S., El□Metwaly, N. M., Althagafi, I., Shaaban, F., & Zaky, R. (2020). Green synthesis approach for Fe (III), Cu (II), Zn (II) and Ni (II)□Schiff base complexes, spectral, conformational, MOE□docking and biological studies. *Applied Organometallic Chemistry*, *34*(3), e5403.

[37] Ahmed, M., Kothari, S., & Lokhande, M. V. (2022). Green synthesis, characterization of substituted benzothiazole Schiff's Bases and their biological activities. *International Journal of Applied Chemistry*, *18*(1), 49-65.

[38] Rao, V. K., Reddy, S. S., Krishna, B. S., Naidu, K. R. M., Raju, C. N., & Ghosh, S. K. (2010). Synthesis of Schiff's bases in aqueous medium: a green alternative approach with effective mass yield and high reaction rates. *Green Chemistry Letters and Reviews*, *3*(3), 217-223.

[39] Kamble, D., & Chavan, P. (2022). One-pot synthesis of substituted benzimidazole derivatives under ultrasonic irradiation using $ZnFe_2O_4$ reusable catalyst. *Chemistry Journal of Moldova*, *17*(2), 94-100.

[40] Bedi, P., Pramanik, G., & Pramanik, T. (2020). Garlic catalyzed and grindstone assisted solvent free green synthesis of pharmaceutically important schiff bases. *Research Journal of Pharmacy and Technology*, *13*(1), 152-156. doi: 10.5958/0974-360X.2020.00030.X

[41] Alshaheri, A. A., Tahir, M. I. M., Rahman, M. B. A., Begum, T., & Saleh, T. A. (2017). Synthesis, characterisation and catalytic activity of dithiocarbazate Schiff base complexes in oxidation of cyclohexane. *Journal of Molecular Liquids*, *240*, 486-496. DOI: 10.1016/j molliq, 2017.05.081

[42] Gupta, K. C., & Sutar, A. K. (2008). Catalytic activities of Schiff base transition metal complexes. *Coordination Chemistry Reviews*, *252*(12-14), 1420-1450. DOI: 10.1016/j.ccr.2007.09.005

[43] Abuamer, K. M., Maihub, A. A., El-Ajaily, M. M., Etorki, A. M., Abou-Krisha, M. M., & Almagani, M. A. (2014). The role of aromatic Schiff bases in the dyes techniques. *International Journal of Organic Chemistry*, *2014*. DOI: 10.4236/ijoc.2014.41002

[44] Kazemnejadi, M., Dehno Khalaji, A., & Mighani, H. (2017). Synthesis and characterization of Schiff-base polymer derived from 2, 5-dichloroaniline and 2-hydroxybenzaldehyde. *Iranian chemical communication*, *5*(3, pp. 237-363, Serial No. 16), 237-241.

[45] Higueras, L., López-Carballo, G., Gavara, R., & Hernández-Muñoz, P. (2015). Reversible covalent immobilization of cinnamaldehyde on chitosan films via schiff base formation and their application in active food packaging. *Food and Bioprocess technology*, *8*, 526-538. DOI: 10.1007/ s11947-014-1421-8

[46] Mr, S. N., Srinivasan, A. K., Keerthana, P., & Kumar, A. (2021). Schiff's base (SB) modified zirconium dioxide reinforced PLA bio-composite film for industrial packaging applications. *Composites Communications*, *25*, 100750. DOI: 10.1016/j.coco.2021.100750

[47] Natesan, S., Samuel, J. S., & Srinivasan, A. K. (2022). Design and development of Schiff's base (SB)-modified polylactic acid (PLA) antimicrobial film for packaging applications. *Polymer Bulletin*, *79*(7), 4627-4646. DOI: 10.1007/ s00289-021-03703-z

[48] Singh, S. (2021). Synthesis, spectroscopic studies and pesticidal activity of transition metal complexes with

unsymmetrical schiff base. *Indian Journal of Biochemistry and Biophysics (IJBB)*, *58*(6), 565-571. DOI: 10.56042/ijbbv58i6.57792

[49] Karmakar, I., Mandal, S., & Mitra, A. (2015). Evaluation of antimicrobial and insect repellent properties of two novel Zinc (II), and Nickel (II) complexes containing a tetradentate Schiff Base. *Journal of Integrated Science and Technology*, *3*(2), 60-67.

[50] Kapoor, P., Singh, R. V., & Fahmi, N. (2012). Coordination chemistry of rare earth metal complexes with coumarin-based imines: Ecofriendly synthesis, characterization, antimicrobial, DNA cleavage, pesticidal, and nematicidal activity evaluations. *Journal of Coordination Chemistry*, *65*(2), 262-277. DOI: 10.1080/00958972.2011. 649265

[51] Fakhari, A. R., Khorrami, A. R., & Naeimi, H. (2005). Synthesis and analytical application of a novel tetradentate N_2O_2 Schiff base as a chromogenic reagent for determination of nickel in some natural food samples. *Talanta*, *66*(4), 813-817. DOI: 10.1016/j.talanta. 2004.12.043

[52] Aksuner, N., Henden, E., Yilmaz, I., & Cukurovali, A. (2009). A highly sensitive and selective fluorescent sensor for the determination of copper (II) based on a schiff base. *Dyes and Pigments*, *83*(2), 211-217. DOI: 10.1016/j. dyepig.2009.04.012

[53] López-Herraiz, M., Castillo-Martínez, E., Carretero-González, J., Carrasco, J., Rojo, T., & Armand, M. (2015). Oligomeric-Schiff bases as negative electrodes for sodium ion batteries: unveiling the nature of their active redox centers. *Energy & Environmental Science*, *8*(11), 3233-3241. DOI: 10.1039/C5EE01832C

[54] Yang, X., Zhuang, X., Huang, Y., Jiang, J., Tian, H., Wu, D., ... & Feng, X. (2015). Nitrogen-enriched hierarchically porous carbon materials fabricated by graphene aerogel templated Schiff-base chemistry for high performance electrochemical capacitors. *Polymer Chemistry*, *6*(7), 1088-1095. DOI: 10.1039/C4PY01408A

[55] Castillo□Martínez, E., Carretero□González, J., & Armand, M. (2014). Polymeric Schiff bases as low□voltage redox centers for sodium□ion batteries. *Angewandte Chemie International Edition*, *53*(21), 5341-5345. DOI: 10.1002/anie.201402402

[56] Chen, H., Zhang, Y., Xu, C., Cao, M., Dou, H., & Zhang, X. (2019). Two π□Conjugated Covalent Organic Frameworks with Long□Term Cyclability at High Current Density for Lithium Ion Battery. *Chemistry–A European Journal*, *25*(68), 15472-15476. DOI: 10.1002/chem.201903733

[57] Oiye, É. N., Ribeiro, M. F. M., Katayama, J. M. T., Tadini, M. C., Balbino, M. A., Eleotério, I. C., Magalhães, J., Castro, A., S., Silva, R., S., M., Júnior, J., W., C., Dockal, E., R., & de Oliveira, M. F. (2019). Electrochemical sensors containing Schiff bases and their transition metal complexes to detect analytes of forensic, pharmaceutical and environmental interest. A review. *Critical Reviews in Analytical Chemistry*, *49*(6), 488-509. DOI: 10.1080/1040834720181561242

[58] Wei, W., Liu, Z., Liang, C., Han, G. C., Han, J., & Zhang, S. (2020). Synthesis, characterization and corrosion inhibition behavior of 2-aminofluorene bis-Schiff bases in circulating cooling water. *RSC advances*, *10*(30), 17816-17828. DOI: 10.1039/DORA01903H

[59] Krishnan, U., & Iyer, S. K. (2022). Iminothiophenol Schiff base-based fluorescent probe for dual detection of Hg^{2+} and Cr^{3+} ions and its application in real sample analysis. *Journal of Photochemistry and Photobiology A: Chemistry*, *425*, 113663. DOI: 10.1016/j.jphotochem.2021. 113663

[60] Bharali, B., Talukdar, H., Phukan, P., & Das, D. K. (2020). A new Schiff base based fluorescent sensor for Al (III) based on 2-hydroxyacetophenone and o-phenylenediamine. *Journal of*

Fluorescence, *30*, 751-757. DOI: 10.1007/s10895-020-02527-w J
[61] Yuan, C., Liu, X., Wu, Y., Lu, L., & Zhu, M. (2016). A triazole Schiff base-based selective and sensitive fluorescent probe for Zn^{2+}: A combined experimental and theoretical study. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *154*, 215-219. DOI: 10.1016/j.saa.2015.10.035
[62] Fatima, B., Hussain, D., Bashir, S., Hussain, H. T., Aslam, R., Nawaz, R., Rashid, H., N., Bashir, N., Majeed, S., Ashiq, M., N., & Najam-ul-Haq, M. (2020). Catalase immobilized antimonene quantum dots used as an electrochemical biosensor for quantitative determination of H_2O_2 from CA-125 diagnosed ovarian cancer samples. *Materials Science and Engineering: C*, *117*, 111296. DOI: 10.1016/j.msec.2020.111296
[63] Abou-Omar, M. N., Attia, M. S., Afify, H. G., Amin, M. A., Boukherroub, R., & Mohamed, E. H. (2021). Novel optical biosensor based on a nano-gold coated by Schiff base doped in sol/gel matrix for sensitive screening of oncomarker CA-125. *ACS omega*, *6*(32), 20812-20821. DOI: 10.1021/acsomega.1c01974
[64] Sheta, S. M., Akl, M. A., Saad, H. E., & El-Gharkawy, E. S. R. (2020). A novel cerium (iii)–isatin Schiff base complex: spectrofluorometric and DFT studies and application as a kidney biomarker for ultrasensitive detection of human creatinine. *RSC advances*, *10*(10), 5853-5863. DOI: 10.1039/ C9RA10133K
[65] Fahmi, N., Shrivastava, S., Meena, R., Joshi, S. C., & Singh, R. V. (2013). Microwave assisted synthesis, spectroscopic characterization and biological aspects of some new chromium (iii) complexes derived from N〈 O donor Schiff bases. *New Journal of Chemistry*, *37*(5), 1445-1453. DOI: 10.1039/C3NJ40907D
[66] Sharma, S., Meena, R., Singh, R. V., & Fahmi, N. (2016). Synthesis, characterization, antimicrobial, and DNA cleavage evaluation of some organotin (IV) complexes derived from ligands containing the 1 H-indole-2, 3-dione moiety. *Main Group Metal Chemistry*, *39*(1-2), 31-40. DOI: 10.1515/ mgmc-2015-0030
[67] FAHMI, N., KUMARI, A., MEENA, R., & SINGH, R. (2021). Synthesis, characterization, antimicrobial and DNA cleavage study of organoantimony (III) and organoarsenic (III) complexes with monofunctional bidentate Schiff base. *Indian Journal of Chemistry-Section A (IJCA)*, *60*(3), 341-347.
[68] Nassir, K. M., El-ghamry, M., Elzawawi, F. M., Aziz, A. A., & Abu-El-Wafa, S. M. (2020). Novel nanoSchiffbase M (II) and M (III) complexes derived from antiviral valacyclovir and 2-hydroxy-1-naphthaldehyde (HNAPB). Structural characterization, bio-efficiency, DNA interaction, molecular modeling, docking and conductivity studies. *IOSR J. Appl. Chem.*, *13*, 1-25.
[69] Kavitha, B., Sravanthi, M., & Reddy, P. S. (2019). DNA interaction, docking, molecular modelling and biological studies of o-Vanillin derived Schiff base metal complexes. *Journal of Molecular Structure*, *1185*, 153-167.
[70] El-Ghamry, M. A., Elzawawi, F. M., Aziz, A. A. A., Nassir, K. M., & Abu-El-Wafa, S. M. (2022). New Schiff base ligand and its novel Cr (III), Mn (II), Co (II), Ni (II), Cu (II), Zn (II) complexes: spectral investigation, biological applications, and semiconducting properties. *Scientific Reports*, *12*(1), 17942.
[71] El□Shwiniy, W. H., Ibrahim, A. G., Sadeek, S. A., & Zordok, W. A. (2021). Synthesis, structural elucidation, molecular modeling and antimicrobial studies of 6□(2□hydroxyphenylimine)□ 2□thioxotetrahydropyrimidin□4 (1H)□ one (L) Schiff base metal complexes. *Applied Organometallic Chemistry*, *35*(5), e6174.
[72] Dhanaraj, C. J., & Johnson, J. (2015). Quinoxaline based bio-active mixed ligand transition metal complexes: Synthesis, characterization, electrochemical, antimicrobial, DNA binding, cleavage, antioxidant and

molecular docking studies. *Journal of Photochemistry and Photobiology B: Biology*, *151*, 100-109.

[73] Subha, L., Balakrishnan, C., Thalamuthu, S., & Neelakantan, M. A. (2015). Mixed ligand Cu (II) complexes containing o-vanillin-L-tryptophan Schiff base and heterocyclic nitrogen bases: synthesis, structural characterization, and biological properties. *Journal of Coordination Chemistry*, *68*(6), 1021-1039.

[74] Mahmoud, W., Refaat, A. M., & Mohamed, G. G. (2020). Nano Schiff base and its metal complexes: synthesis, characterization tools, biological applications and molecular docking studies. *Egyptian Journal of Chemistry*, *63*(6), 2157-2176.

[75] Mahmoud, W. H., Deghadi, R. G., & Mohamed, G. G. (2020). Cyclometalated complexes containing ferrocenyl Schiff base: Preparation, characterization, DFT calculations, application in cancer and biological researches and MOE studies. *Arabian Journal of Chemistry*, *13*(5), 5390-5405.

[76] Mahmoud, W. H., Mahmoud, N. F., Mohamed, G. G., El-Sonbati, A. Z., & El-Bindary, A. A. (2015). Ternary metal complexes of guaifenesin drug: Synthesis, spectroscopic characterization and in vitro anticancer activity of the metal complexes. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *150*, 451-460.