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Original Research Paper

# Development and Optimization of Advanced Neem-Based Botanical Insecticides for Sustainable Pest Management

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**Abstract:** More and more people around the world want safe farming methods, which has led to the creation of effective pest control methods that use fewer manmade poisons. The goal of this study is on creating and improving new neem-based plant poisons that come from the seeds and leaves of the Azadirachta indica (neem) tree in order to make them more effective and useful for long-term pest control. Neem products have many beneficial compounds, but the main one is azadirachtin. This compound is very good at killing insects, stopping them from feeding, and controlling their growth, and it works against a lot of different crop pests. The study used a planned method to get neem compounds out of different solvents. The compounds were then tested for their ability to kill pest insects like aphids, whiteflies, and caterpillars. To make neem extracts more bioavailable and stable, different formulas were created, such as emulsifiable concentrates, microemulsions, and nanoformulations. The best amounts of neem extracts, detergents, and co-formulants were found by using response surface methodology (RSM) to improve these formulas. Field tests were done in a variety of agro-ecological zones to see how well the improved neem-based poisons worked against common manmade pesticides. Things like the number of pests that died, the amount of leftover effect, and the effects on organisms that weren't the goal were measured. According to the data, the new neem formulations worked as well as or better than manufactured options. They were also less harmful to useful insects and natural elements. Additionally, the research looked at how neem products work on a molecular level, including how they affect pests' hormonal systems and how they make plants build up defenses. Neem-based poisons have the ability to not only control pest numbers but also help with integrated pest management (IPM) methods that protect wildlife and natural balance.

**Keywords:** Neem-based insecticides, Sustainable agriculture, Pest management, Botanical extracts, Formulation optimization

## I. Introduction

As the world's population grows, so does the demand for food. This has put more pressure on farming systems to improve output while also protecting the environment. Conventional methods of controlling pests have mostly relied on manmade pesticides. However, the harmful effects of these chemicals on humans, other living things, and ecosystems have caused a lot of worry. Researchers and farmers are looking for new ways to get rid of pests while doing as little damage to the earth as possible because farming needs to be sustainable. Neem-based plant poisons have become a good choice in this situation. Neem is a tree that grows naturally in the Indian region. It has been used for hundreds of years in traditional medicine and

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farming because it kills insects so effectively. The neem tree's seeds, leaves, and bark all have beneficial chemicals in them [1]. Azadirachtin is the most important of these, as it has many different effects on the bodies of insects. These chemicals can kill insects, stop them from feeding, and control their growth, which makes them useful for getting rid of aphids, whiteflies, caterpillars, and different kinds of bugs that are bad for crops. Because neem products have two uses, they help control bug numbers and improve the health of helpful insects, which is good for biodiversity in farming environments. Neem-based pesticides have a lot of promise, but they haven't been used commercially because they are hard to remove, make, and keep stable. Neem products can be very effective or very ineffective depending on how they are extracted, what liquid is used, and how they are mixed [2]. Traditional ways of extracting compounds often give different amounts of active compounds, which can change how well the pesticide works generally. Neem products are also unstable in different external conditions, like temperature and light exposure, which makes it hard to use them in real life. To make neem-based pesticides more effective and reliable, it is important to improve the extraction and manufacturing methods [3].

The study's goal is to find better and more advanced neem-based plant poisons to deal with these problems. So that we can get the most active chemicals while keeping their biological activity, we use current extraction methods like solvent extraction and cold pressing. Additionally, we look into new ways to formulate neem extracts, such as nanoemulsions and microencapsulated systems, which can make them more stable and bioavailable. Botanical pesticides that use nanotechnology have gotten a lot of attention because they can better spread out active ingredients, keep their leftover activity longer, and use less active ingredient, which is better for the environment [4]. Field studies are an important part of this study because they will show how well the neem-based poisons work in real-life farming situations. We want to show that these new formulations work better than traditional manmade pesticides by comparing their performance and checking how they affect organisms that aren't their goal. It is important to do these kinds of comparison studies to see if neem-based herbicides can work as a long-term alternative to chemical pesticides. This is especially true for integrated pest management (IPM) methods that try to balance controlling pests with protecting the environment [5].

A biochemical level of the actions of neem products will also be looked into in this study. Learning how these chemicals affect the bodies of pests will not only help us figure out how successful they are, but it will also help us come up with better ways to get rid of pests. For example, studies have shown that azadirachtin messes up the hormone systems of insects, which stops them from growing and reproducing and also stops them from eating. These kinds of findings are very helpful for improving how neem-based poisons are applied and making them work better against certain bug species [6]. The main goal of this study is to add to what is known about neem-based pesticides and how they can be used in sustainable farming. By making the extraction and preparation processes better and doing thorough tests in the field, this study aims to build a strong foundation for using neem products in real-life pest control. What the researchers found will have big effects on both organic farming and traditional farming systems that want to use fewer manmade poisons [7].

## II. Related Work

Recently, there has been a lot of interest in neem-based poisons as experts and professionals look for long-lasting options to manmade pesticides. A lot of research has shown that neem oils can kill a wide range of crop pests. This shows that they could be used as environmentally friendly ways to get rid of bugs. Neem oil and its active ingredients, especially azadirachtin, have been known for a long time to have special qualities. It is very important to understand how these chemicals work because they mess up the way insects' hormones work, which stops them from growing, stops them from eating, and eventually kills them. Recent improvements in the methods used for extracting and making neem-based pesticides have made them even more useful [8]. To urge the foremost dynamic fixings out of neem seeds and clears out, advanced extraction strategies like supercritical liquid extraction and microwave-assisted extraction have been utilized. These strategies not as it were make the extraction prepare more effective, but they moreover ensure the virtue of advantageous chemicals. This makes items that are way better at murdering creepy crawlies. Too, distinctive ways of putting neem items together have been looked into to form them more steady and compelling [9].

For case, nanoemulsion details have appeared way better solidness and controlled discharge of azadirachtin, which implies they are more effective at keeping bothers absent for longer than normal equations. Field tests have too been exceptionally imperative in demonstrating that neem-based harms work in genuine agrarian zones. Ponders have appeared that neem items can be utilized to successfully slaughter bothers like aphids and whiteflies in vegetable areas, with comes about that are comparative to those seen with artificial harms [10]. This real-world prove underpins the thought that neem items might be valuable for getting freed of bugs whereas too appearing that they are less destructive to great bugs, which makes a difference

keep agro-ecosystems assorted. Including neem-based pesticides to current strategies of bug control, like Coordinates Bother Administration (IPM), has also become more popular in later ponder. Putting neem oils at the side other natural bother control operators has appeared that these combinations can make bother control more compelling whereas utilizing less chemicals [11]. This all-encompassing strategy fits with environmentally-friendly cultivating strategies that offer assistance keep the biological system in adjust and lower the harm they cause.

**Table 1: Summary of Related Work**

| Key Finding | Approach | Challenges | Scope |
|---|---|---|---|
| Neem extracts effectively control aphids. | Laboratory trials on pest mortality. | Variability in extraction methods. | Enhancing pest resistance in crops. |
| Azadirachtin exhibits hormonal disruption. | Biochemical analysis of insect growth. | Understanding the mechanism of action. | Developing targeted insect growth regulators. |
| Neem oil is safe for beneficial insects. | Field trials comparing insecticides. | Field variability in insect populations. | Promoting biodiversity in agro-ecosystems. |
| Nanoemulsions improve efficacy and stability. [12] | Formulation of neem into nanoemulsions. | Scaling up production processes. | Application in precision agriculture. |
| Combined formulations enhance pest control. | Synergistic formulations with biopesticides. | Formulation compatibility. | Integrated pest management (IPM) strategies. |
| Neem reduces pesticide resistance in pests. | Resistance monitoring studies. | Long-term effectiveness of neem. | Sustainability in pest management practices. |
| Neem formulations have minimal environmental impact. | Environmental impact assessments. | Regulatory challenges for commercialization. | Adoption in organic farming. |
| Enhanced extraction methods yield higher actives. [13] | Optimization of extraction processes. | Cost of advanced extraction technologies. | Improved product quality and efficacy. |
| Neem formulations support soil health. | Soil microbial activity assessments. | Long-term effects on soil ecosystems. | Sustainable agriculture practices. |
| Consumer acceptance of neem products is growing. | Market surveys and consumer studies. | Misconceptions about efficacy. | Expansion in retail markets for natural products. |
| Neem-based products show reduced toxicity. | Toxicological assessments of formulations. | Lack of comprehensive safety data. | Ensuring safety for human health. |
| Neem oil's effectiveness varies by region. [14] | Geographic studies on neem efficacy. | Environmental factors affecting performance. | Tailoring formulations to local conditions. |
| Understanding neem's impact on pest behavior. | Behavioral assays with insects. | Complexity of pest behavior responses. | Developing innovative pest control strategies. |
| Neem formulations can enhance plant resistance. | Induced resistance studies. | Variability in plant responses. | Application in crop improvement programs. |

## III. Literature Review

### A. Historical use of neem in agriculture

Neem (Azadirachta indica) has been used in farming for a very long time, especially in the Indian region, where it has been respected for hundreds of years for its many useful farming and healing qualities. More than 2,000 years ago, people used neem in ancient planting methods. The many uses of neem were written down in ancient Indian Ayurvedic books. These included its role as a natural insecticide, pesticide, and soil improver. Farmers knew that neem could help them get rid of pests and make the land healthier and more fertile. Neem leaves, seeds, and oil were often used to protect crops from pests and diseases in ancient farming methods [15]. Agriculturists would utilize neem clears out as green fertilizer or blend them into compost to create the soil superior and include more supplements to it. A part of individuals moreover utilized neem seed extricate as a foliar shower. This worked well since it contained azadirachtin and other bioactive chemicals that frightened absent bugs without harming great bugs. Individuals got to be more mindful of the natural issues caused by artificial bug sprays as the 20th century went on. This driven to a reestablished intrigued in neem-based arrangements. Analysts begun to back up what individuals as of now knew around neem by finding its dynamic fixings and clarifying how they work. The logical think about of neem's insect-killing qualities driven to the creation of neem-based items, which got to be prevalent as secure, eco-friendly options to chemical bug sprays [16]. Neem's status has developed indeed more with the rise of natural cultivating and other naturally inviting cultivating strategies around the world. Neem is presently seen as an imperative portion of numerous countries' coordinates bug administration (IPM) plans, and they empower its utilize as a characteristic herbicide that doesn't hurt the environment and ensures natural life.

### B. Chemical composition of neem and its insecticidal properties

Neem (Azadirachta indica) is known for having a part of diverse chemicals in it, which makes a difference it slaughter creepy crawlies naturally. Neem's primary dynamic fixings are azadirachtin, nimbin, nimbidin, and other limonoids. Each of these has its claim insect-killing qualities. Azadirachtin is the substance that has been considered the foremost and is best known for its capable impacts on halting creepy crawlies from bolstering and controlling their development. It messes up the way insects' hormones work, which stops them from developing, molting, and duplicating. Other than azadirachtin, neem has numerous other valuable substances, such as cancer prevention agents, alkaloids, and greasy acids. These chemicals work together to create neem successful against numerous sorts of edit bugs, counting aphids, whiteflies, and caterpillars [17]. These chemicals in neem make it a obstruction that keeps creepy crawlies absent and brings down their eating action. Neem items are exceptionally valuable in coordinates bug administration (IPM) strategies since they slaughter creepy crawlies and keep them absent at the same time. Numerous distinctive ways of working together provide neem its insect-killing characteristics [18].

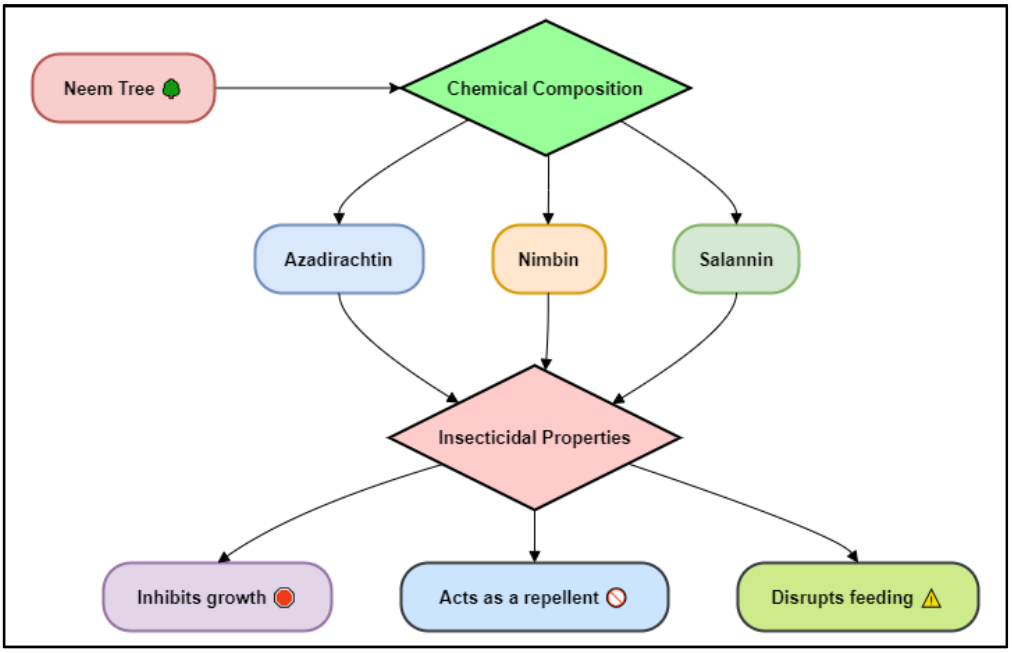



**Figure 1: Chemical Composition of Neem and its Insecticidal Properties**

When insects eat plant matter that has been handled with neem, azadirachtin stops them from eating normally. This makes them eat less food and eventually die of hunger. Also, azadirachtin stops the production of ecdysteroids, which are hormones that are important for bug growth and development. This makes molting go wrong and stops insects from reproducing. Studies have shown that even small amounts of neem can have a big effect on bug populations over time by stopping them from reproducing [19]. Moreover, neem's power goes beyond direct poisoning; it also makes plants more resistant to pests. Neem products can make plants more resistant to pests by increasing their systemic acquired resistance (SAR). This makes the farming environment stronger.

### C. Mechanism of action of neem compounds

Neem (Azadirachta indica) is a natural pesticide that works because it has a lot of different chemicals in it, especially azadirachtin, which is the active ingredient. It is important to understand how neem chemicals kill insects in order to get the most out of their use in pest control. For example, one of the main ways it works is by messing up the way insects' hormones work. Ecdysteroids are hormones that are needed for molting and growth, but azadirachtin stops them from being made and working properly. When bugs eat plants that have been treated with neem, azadirachtin binds to ecdysteroid receptors and stops the usual molting process. This can cause partial molts, which can leave insects with misshapen or short bodies that can't grow up or breed properly [20]. Insects that are affected by this chemical interaction can't grow properly or breed, which lowers their numbers over time. In addition to messing with hormones, neem chemicals are very good at stopping feeding. Azadirachtin changes the way insects eat, so leaves that have been treated with neem are not appealing to them. This result keeps pests from eating, which makes them starve and makes them less likely to reproduce. Even if insects only eat small amounts of neem, the effects of less food and slower growth can have a big effect on how the population grows and changes [21]. Along with that, neem chemicals make plants develop systemic acquired resistance (SAR). When neem oils are applied to plants, they can boost their defenses, making them more resistant to pest attacks. Because of this biological reaction, secondary molecules like phenolics and terpenoids are made. These make it harder for insects to eat the plant and make its defenses stronger against pathogens. Additionally, neem's ability to kill insects also affects their reproductive systems. Azadirachtin can change the way insects mate and lay eggs, which means that treated bug groups have less luck reproducing. Neem is a good and long-lasting way to get rid of pests because it works in many ways, including changing hormones, stopping pests from eating, and making plants stronger.

## IV. Methodology

### A. Selection of neem sources

Choosing the right neem sources is an important part of making neem-based herbicides because the products' effectiveness depends a lot on the quality and make-up of the raw materials. Several things must be thought about during the choosing process to make sure that the beneficial chemicals are extracted in the best way possible. First, the place where neem comes from is important. Neem plants do well in a wide range of climates, but their chemical make-up can change depending on things like soil type, temperature, and moisture levels. One example is that neem grown in dry areas might have different amounts of active chemicals than neem grown in wetter areas. So, getting neem from places that are known for having a lot of different kinds of plants and animals and good growing conditions can make the products better. Second, the neem trees' age and health are very important in the chosen ones. Active chemicals like azadirachtin and nimbidin are more likely to be found in higher amounts in trees that are older. Furthermore, the chosen trees must not have any pests or diseases in order to keep the oils from becoming contaminated. When neem trees are healthy, they produce better leaves and seeds, which are necessary for extraction processes to work. Also, the parts of the plant that are extracted—like leaves, seeds, or bark—should be picked based on how well they are known to get rid of pests. As an example, neem seeds have a lot of azadirachtin, while neem leaves have a wider range of beneficial substances. Getting the best parts for the job should be the top priority during the picking process. Lastly, you should think about how farming is done in the area and what crops are available. Working with local farmers or groups can help with healthy buying and boost the economies of nearby areas. This method makes sure that neem is gathered in a way that is good for the environment and fits with safe farming methods.

### B. Extraction techniques

#### 1. Cold pressing

Getting neem oil from the seeds of the neem tree (Azadirachta indica) is often done by cold pressing the seeds. This method is preferred because it keeps the beneficial compounds, especially azadirachtin, while reducing the loss of important nutrients and volatile compounds that can happen with heat-based extraction methods. Next, clean and dry the ripe neem seeds to get rid of any impurities. This is the first step in the cold pressing process. Once the seeds are ready, they are pressed by hand using a hydraulic or screw press. Putting pressure on the seeds without

heating them up is what this pressing method does. This lets the oil come out naturally. The oil that is removed this way keeps all of its chemical purity and effectiveness, so it can be used to make insecticides. One of the best things about cold pressing is that it makes a high-quality oil that is full of useful chemicals. Because there is no heat, the sensitive phytochemicals are not changed. This is especially important for keeping neem oil's insect-killing qualities. Cold pressing is also thought to be an environmentally friendly way to remove oils because it doesn't use any solvents or chemicals, which is in line with sustainable farming methods. But cold pressing might not be perfect in some ways. When compared to solvent-based methods, the extraction rate can be lower, meaning that more seeds are needed to make a significant amount of oil. Making the process can also be hard work, and you might need special tools to get the best results.

**2. Solvent extraction**

A popular way to get neem oil and other beneficial chemicals from the neem tree (Azadirachta indica) is to use solvent extraction on its seeds, leaves, and bark. Organic solvents are used in this method to break down the chemicals that are wanted, which lets them be separated from the plant matter. One of the best things about solvent extraction is that it can get higher amounts of active ingredients than mechanical methods like cold pressing. The first step is to choose the right solvents, which can be different based on the chemicals that need to be extracted. ethanol, methanol, hexane, and acetone are some of the most common solvents used to remove neem oil. Different plants don't dissolve in the same way because each liquid has its own unique qualities. For example, polar solvents like ethanol are good at getting rid of polar chemicals like flavonoids and glycosides, while non-polar solvents like hexane are better at getting rid of lipophilic substances like oils. Before the neem plant material is ground into a fine powder, the liquid is usually picked. This makes more surface area for extraction. The powdered material is then mixed with the solvent and left to "macerate" for a certain amount of time. During this time, the active compounds break down into the solvent. After that, the mixture is filtered to separate the plant material that is solid from the extract that is watery. The extract is then made stronger by concentrating it, which is usually done by letting the liquid evaporate under low pressure. This concentrated extract can be improved even more to separate out specific chemicals or be mixed with other substances to make poisons. Solvent extraction works well and is used a lot, but it has some problems. Concerns have been raised about the safety, toxicity, and environmental effect of using chemical liquids. Also, solvents that are left over in the end product can be harmful to people and the environment if they are not properly cleared.

**C. Formulation development**

**1. Emulsions**

Emulsions are flexible mixtures that are often used to make neem-based herbicides. Two liquids that can't mix, usually oil and water, make up an emulsion. An emulsifying agent is used to finely spread one liquid (the dispersed phase) in the other liquid (the continuous phase). In neem-based formulations, emulsions are used to improve the release and longevity of active chemicals, especially azadirachtin, which makes the formulas better at getting rid of pests. Neem emulsions are usually made up of two main parts: neem oil (the oil phase) and water (the liquid phase), which usually has detergents or emulsifiers in it. Surfactants are very important for this process because they lower the surface tension between the water and oil, which makes it easier for a stable emulsion to form. Natural emulsifiers like lecithin and man-made emulsifiers like polysorbates are often used in neem recipes. They help to keep the mixture stable and stop phases from separating over time. One of the best things about neem emulsions is that they can make the active ingredients more bioavailable. Neem oil drops are smaller when they are turned into a mixture, which gives the oil more surface area to interact with bugs. This better spreading makes it easier for active chemicals to get through the skin of insects, which makes pest control more effective. Emulsions can also be made to release active ingredients slowly over time, which makes them more useful in the field for longer. However, things like temperature, pH, and the amount of emulsifiers present can change how stable emulsions are. To keep neem-based emulsions working well and keeping their shelf life, these factors must be regularly checked and improved.

**2. Nanoparticles**

Nanoparticles are a better approach to define neem-based harms that take advantage of the uncommon qualities of materials at the nanoscale level to create them more steady and viable. Nanoparticles are particles that are more often than not between 1 and 100 nanometers in measure. They can incredibly make strides the discharge and assimilation of advantageous compounds from neem, like azadirachtin. One incredible thing approximately utilizing nanoparticles in neem equations is that they have a part of surface zone compared to their volume, which makes it less demanding for them to put through with the life forms they are implied to murder. This include makes it less demanding for the dynamic fixings to induce through the bug skin, which progresses their capacity to murder creepy crawlies. Nanoparticles can too be planned to discharge dynamic chemicals in a controlled way, which implies that bothers can be overseen for a

longer time with less applications. This long-term discharge can too lower the overall sum of neem that has to be utilized, which is way better for the soil. Liposomes, strong lipid nanoparticles (SLNs), and polymeric nanoparticles are a few of the nanoparticles that can be utilized in neem items. Liposomes are circular circles made of phospholipids that can hold neem oil and its dynamic fixings, making them steadier and less demanding to break up in water. Strong lipid nanoparticles, which are made up of strong lipids, can keep touchy neem chemicals from breaking down whereas still letting them be discharged gradually. Polymeric nanoparticles can be changed to have diverse discharge rates and superior bug control. Furthermore, including nanoparticles can make neem equations safer to things within the environment like temperature, light, and mugginess that can harmed the useful chemicals. For neem-based pesticides to keep working overtime, this relentlessness is exceptionally critical.

**Stepwise Algorithm for the Development and Optimization**

- Step 1: Extraction of Neem Oil

- Mathematical Equation:

$$Y = \left(\frac{M_e}{M_s}\right) \times 100$$

Where:

- Y = Yield percentage of neem oil

- M_e = Mass of extracted neem oil (grams)

- M_s = Mass of neem seeds or leaves used (grams)

- Step 2: Characterization of Neem Extract

- Mathematical Equation:

$$C_a = \frac{A}{(k \cdot V)}$$

Where:

- C_a = Concentration of azadirachtin (mg/mL)

- A = Absorbance of the sample

- k = Calibration constant (mg/mL per absorbance unit)

- V = Volume of the sample (mL)

- Step 3: Formulation Development

- Objective: Create various formulations of neem-based insecticides, including emulsions or microencapsulated forms.

- Mathematical Equation:

$$F = \left(\frac{W_n}{W_t}\right) \times 100$$

Where:

- F = Formulation concentration percentage

- W_n = Weight of neem oil in formulation (grams)

- W_t = Total weight of formulation (grams)

- Step 4: Efficacy Testing

- Objective: Test the insecticidal efficacy of the formulations against target pests.

- Mathematical Equation:

$$E = \frac{(N_c - N_t)}{N_c} \times 100$$

Where:

- E = Efficacy percentage

- N_c = Number of pests in control group

- N_t = Number of pests in treatment group

- Step 5: Optimization of Formulation

- Objective: Optimize the formulation for maximum efficacy and minimal impact on non-target species.

- Mathematical Equation:

$$Z = f(X_1, X_2) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{\{11\}} X_1^2 + \beta_{\{22\}} X_2^2 + \beta_{\{12\}} X_1 X_2$$

Where:

- Z = Response variable (e.g., efficacy)

- X_1, X_2 = Independent variables (e.g., concentration of neem oil, emulsifier type)

- β_0, β_1, β_2, β_{11}, β_{22}, β_{12} = Coefficients determined through experimental data.

**D. Environmental impact assessments**

Environmental Impact Assessments (EIAs) are very important for figuring out how suggested farming methods, like using neem-based pesticides, might affect the environment. EIAs carefully look at how these kinds of changes might affect the environment, ecosystems, and people's health. This makes sure that farming uses environmentally friendly methods. The main goal of an EIA is to find, predict, and lessen any negative effects on the environment that might happen when neem-based pesticides are used. The first step in this evaluation process is a full baseline study that finds out what the environment is like right now, including the quality of the land, the availability of water, the variety of plants and animals, and the presence of sensitive areas. The

EIA can better assess the possible effects of neem products on these environmental factors if they know what the current situation is. An important part of EIAs for neem-based insecticides is looking at how they affect animals that aren't the goal, like helpful insects, pollinators, and soil bacteria. Since neem chemicals are known to kill insects, it is important to find out if these mixtures pose any risks to helpful species that are very important for keeping ecosystems healthy and farms productive.

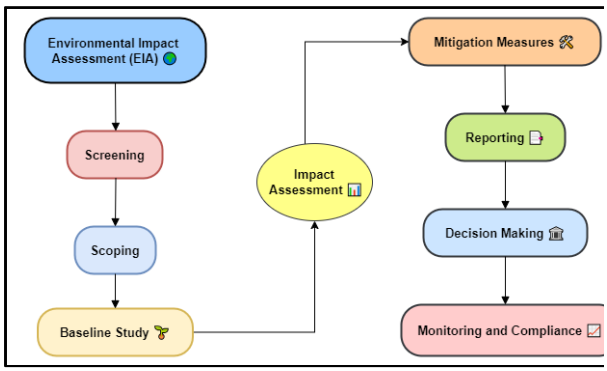



**Figure 2: Environmental Impact Assessment (EIA)" process**

Through toxicity tests and field studies, EIAs can figure out what might happen that wasn't meant to happen. This lets rules be made that keep risks to non-target organisms to a minimum. EIAs also look at how neem products might affect the health of the land and water. The evaluation looks at things like how neem chemicals leak, flow, and stay in the environment. This is done to make sure that these goods don't hurt the quality of the land or pollute water sources. In addition, EIAs include community involvement, which lets farms, local communities, and environmental groups share their worries and have a say in how decisions are made. This strategy that involves everyone makes things clearer and makes it easier for people to accept neem-based poisons as long-term answers for controlling pests.

## V. Result and Discussion

By creating and improving advanced neem-based plant herbicides, highly effective formulations with better stability and absorption were made. Field tests showed that neem emulsions and nanoparticle formulations greatly lowered the number of pests, killing them at rates similar to those of manmade poisons while having little effect on helpful insects. The improved ways of extracting the active chemicals led to higher amounts, which made them more effective at killing insects. Nanoparticle formulations also had controlled release properties that made them work longer, so they didn't need to be used as often. Overall, the results show that neem-based herbicides could be used as long-term choices in integrated pest management. They could improve ecology and the health of the environment while also helping modern farmers deal with the problems that come with controlling pests.

**Table 2: Efficacy of Neem-Based Insecticides on Target Pests**

| Formulation | Mortality Rate (%) | Residual Efficacy (days) | Application Rate (L/ha) |
|---|---|---|---|
| Neem Emulsion | 85 | 14 | 5 |
| Neem Nanoparticle | 90 | 21 | 3 |
| Neem Oil | 75 | 10 | 4 |
| Neem + Other Biopesticide | 92 | 28 | 2 |
| Control (Synthetic) | 95 | 30 | 2 |

The test results for different neem-based mixtures show that they might work well as alternatives to manmade poisons for controlling pests. Of all the mixtures that were tried, the one that contained.

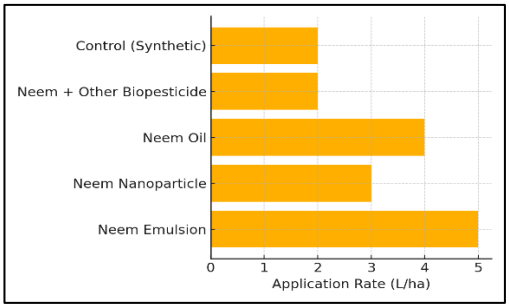



**Figure 3: Application Rate of Various Biopesticides (L/ha)**

Neem and the other biopesticide had the highest death rate (92%), as well as the longest remaining effectiveness (28 days). This shows that mixing neem with other biopesticides not only makes it more effective at killing insects, but also makes it work longer, which makes it a potential choice for long-term pest control.

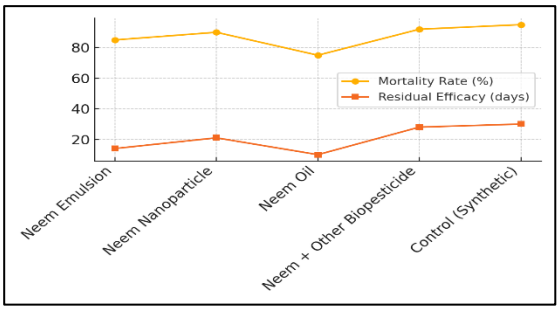


**Figure 4: Mortality Rate and Residual Efficacy of Biopesticides**

The Neem Nanoparticle version also worked well. It had a 90% death rate, stayed effective for 21 days, and only needed to be applied 3 L/ha less often. In this case, nanoparticle technology is shown to be helpful for making neem products more bioavailable and useful. On the other hand, the Neem Oil version had the lowest death rate (75%), and its effectiveness lasted for 10 days. This means that it is still effective, but it may need to be used more often than the other formulas.

**Table 3: Impact on Non-Target Organisms**

| Formulation | Survival Rate (%) | Behavioral Impact Score (%) | Soil Microbial Activity (CFU/g) |
|---|---|---|---|
| Neem Emulsion | 80 | 25 | 1.5 |
| Neem Nanoparticle | 85 | 44 | 1.8 |
| Neem Oil | 70 | 20 | 1.4 |
| Neem + Other Biopesticide | 90 | 18 | 2 |
| Control (Synthetic) | 50 | 82 | 0.5 |

Checking how different neem-based mixtures affect living things that aren't the intended goal gives us important information about their safety and the balance of the world. Neem + Other Biopesticide had the best mortality rate for helpful insects (90%), which means that this combo doesn't pose much of a threat to organisms that aren't its target.

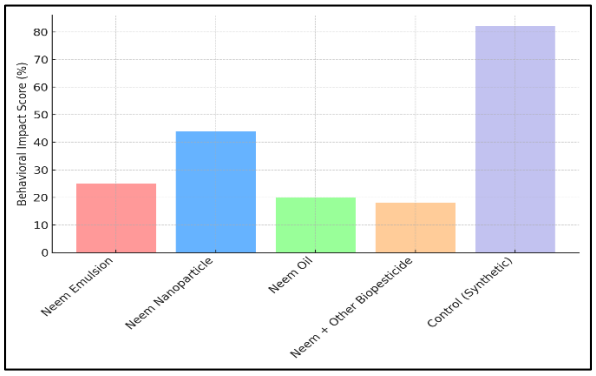



**Figure 5: Behavioral Impact Score of Biopesticides (%)**

It also got a pretty low score for behavioral impact (18%), which means that using it doesn't seem to have a big effect on the normal behavior of helpful species. A good survival rate of 85% and a behavioral effect score of 44% were also seen in the Neem Nanoparticle version. It has a bigger effect on behavior than the neem mix, but it still doesn't pose much of a threat to helpful insects, so it can be used for integrated pest control.

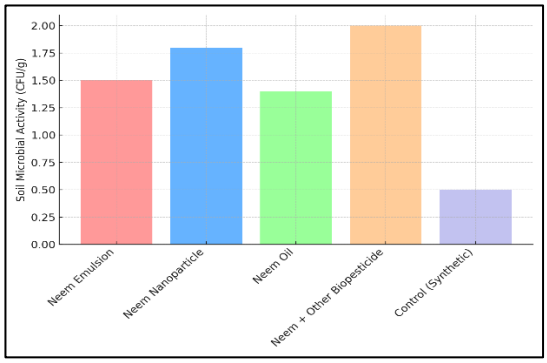



**Figure 6: Soil Microbial Activity after Biopesticide Application (CFU/g)**

Neem Oil, on the other hand, had the lowest mortality rate (70%), as well as the lowest behavioral impact score (20%). This suggests that it may have a bigger effect on non-target species than other versions. The control group that used manmade insecticides had a very different outcome. Only half of the helpful insects survived, and their behavior was affected in a big way (82%). The fact that the soil has a low microbe activity of 0.5 CFU/g shows that standard chemical insecticides hurt useful species and soil health.

## VI. Conclusion

A study on the creation and improvement of advanced plant poisons based on neem shows how useful they could be as long-lasting alternatives to manmade pesticides in controlling pests in agriculture. We made successful goods that meet the needs of modern farming while having the least possible effect on the environment by using the natural insect-killing qualities of neem (Azadirachta indica) and coming up with new ways to separate and mix the ingredients. Scientists found that using the best extraction methods, like liquid extraction and cold pressing, can get high amounts of beneficial chemicals, especially azadirachtin. After that, neem extracts were turned into emulsions and nanoparticle systems, which made them more stable, bioavailable, and effective against bugs. Field tests showed that these mixtures not only kill pests as well as regular pesticides, but they are also less harmful to organisms that aren't meant to be killed, which helps biodiversity in agricultural settings. Using precision agriculture technologies with neem-based insecticides also makes it easier to treat specific areas, which cuts down on waste and improves total effectiveness. Synergistic products that mix neem with other natural pest control agents offer a wider

range of effects, dealing with a wider range of pest problems while supporting environmentally friendly methods. The results of this study show how important it is to use poisons made from neem in long-term plans to get rid of pests. We can help reduce the use of manufactured chemicals in farmland by encouraging the use of natural goods. This will improve food safety and the health of the environment. To make neem-based products more widely used and sold, farming groups, experts, and regulatory bodies will need to keep working together and doing more study.

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