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| RESEARCH ARTICLE

Efficacy of Plant Extracts for the Control of Pepper Insect Pest (Green Peach Aphid (*Myzus persicae L.*)

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| ABSTRACT

Aphids pose significant threats to crop productivity, necessitating effective and sustainable pest management strategies. This study investigated the repellent properties of neem and papaya leaf extracts on green peach aphids and the impact of the extracts on plant growth in pepper (*Capsicum* spp.). The experiment involved 7 treatments and 3 treatment replications with varying concentrations of neem and papaya extracts (6.5 v:v, 7.5 v:v, and 8.5 v:v) compared to a control group (Distilled water). The Randomized Complete Block Design (RCBD) was used as an experimental design. The study site was Cuttington University's College of Agriculture Research site. The distances between plots and blocks were 0.6 m and 1 m, correspondingly. In the laboratory bioassay, results uncovered distinct trends, with the control treatment exhibiting the highest mean aphid count (41.0), while neem 8.5 v:v (6.0) and papaya 8.5 v:v (8.1) treatments established substantial effectiveness in reducing aphid populations. The highest mean aphid counts following biopesticidal application were 48.0 and 76.7 after 1 and 2 weeks, respectively and were recorded in the untreated control plots, while the lowest mean aphid counts were 21.3 and 6.0 after 1 and 2 weeks, respectively. Furthermore, neem 8.5 v:v treatment consistently showed the highest mean values across plant height (16.2 cm), leaf length (8.2 cm), leaf width (5.2 cm), and repellency index (3.0), indicating potential positive impacts on plant growth and repellency. Untreated control measured the lowest values for plant height (13.8 cm), leaf length (6.0 cm) and repellency index (1.0). The study demonstrated the potential of both extracts to suppress aphid populations and enhance plant growth. Applying these natural extracts as part of an integrated pest management (IPM) strategy can be beneficial for controlling aphid infestations in pepper crops. Their use as repellents can reduce aphid populations, minimizing potential crop damage and yield losses.

| KEYWORDS

Crop productivity, Aphid populations, Pest Management, Pepper, Neem

| ARTICLE INFORMATION

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1. Introduction

Pepper (*Capsicum annuum*) is a versatile crop eaten by many people universally, and it is very important socio-economically. It is better grown in a hot climate. Pepper is a major source of pro-vitamin A (carotene) and E (beta-tocopherol), and one of its main ingredients is vitamin C (ascorbic acid) (Penella and Calatayud, 2018). Pepper is one of the most significant vegetables widely produced around the globe. However, yields obtained from production are very scanty most of the time, particularly in less developed countries. This reduction in yield is mostly the result of infestations by insect pests.

The green peach aphid, *Myzus persicae* (Sulzer), is worldwide in distribution and is one of the most economically principal polyphagous pests, infecting hundreds of plants in more than 40 plant families, comprising a host of vegetables and ornamental plants cultivated in both field and greenhouses (Dagnoko *et al*., 2013). Aphids are silent feeders that cause less tissue damage than chewing insects and, during feeding, release effector proteins in their saliva that suppress host plant defense responses (Ali *et al*., 2021). The destruction caused by aphids reduces plant fitness due to their feeding on phloem sap, which causes the plant to become nutritionally feebler compared to uninfected ones (Goggin, 2007). They also serve as important vectors for the transmission of plant viruses and produce honeydew that functions as a breeding channel for pathogens, which disturb plant photosynthetic activities (Ali *et al*., 2021). Moreover, *M. persicae* has a dangerous capability to kill crops in that it transfers over 100 plant viruses (Blackman & Eastop, 2000).

Plants contain several ingredients that contain antifeedant or antirepellent properties against insects. Since antiquity, farmers in India, China, and Africa have been including conventional plant ingredients to protect field crops and stored products (Kayange *et al*., 2022). Pervin *et al*. (2012) stated that plants have the richest source of renewable natural pesticides, and their extracts provide a safe and viable alternative to synthetic pesticides. Botanicals are also compatible with the use of beneficial organisms such as pest-resistant plants and with preserving a healthy environment in an effort to decrease reliance on synthetic pesticides.

Among the wider range of plants, Neem derivatives have shown great potential in controlling insect pests (Mahmoud and Maha, 2008). Neem (*Azadirachta indica*) is a wild-growing perennial tree widespread in India, Africa, and America, and it has the potential to be a replacement for synthetic pesticides (Pingale, 2010). Preparation of new biopesticides, especially those based on neem extracts, is a possible option for integrated pest management plans because such plant-based insecticides are very beneficial. These benefits consist of selectivity, higher safety level for non-target organisms, and compatibility with biological significant natural enemies of pests (Tang *et al*., 2002).

The foremost active element of most neem-based pesticides is azadiractin, a liminoid compound which possesses manifold biological activities on more than 400 insect species from numerous orders (Schmutterer and Singh, 1995). Azadirachtin is extracted from crushed neem seeds, concentrated, and purified (Kwaifa *et al*., 2015). Besides azadirachtin, there are other active components in some formulations. Azadirachtin is known to have antiallergenic, antidermatic, antifeedant, antifungal, insecticidal, larvicidal, diuretic, and other biological activities (Pankaj *et al*., 2011). They have an effect on some important physiological processes in insects, such as survival, longevity, molting, and reproduction (Mordue and Blackwell, 1993).

2. Literature Review

2.1 Taxonomy, Origin and Geographical Distribution of Pepper

Solanaceae is a complex, cosmopolitan family that consists of at least 98 genera and as many as 2716 species, including Capsicum, an economically significant plant (Olmstead and Bohs, 2007). The genus Capsicum can be known by its shrubby habit, actinomorphic flowers, characteristic truncate calyx with or without appendages, anthers opening by longitudinal slits, nectaries at the base of the ovary and the variously colored and typically spicy fruits.

The precise origin of pepper remains a topic of ongoing research, with various regions proposed as centers of domestication. Archaeological findings from Mexico and South America suggest that peppers have been cultivated and utilized by indigenous communities for millennia. Recent genetic studies indicate multiple independent domestication events across different regions of the Americas. *Capsicum annuum* is believed to have been domesticated in Mexico and Central America, while *Capsicum chinense* and *Capsicum frutescens* likely originated in the Amazon basin and surrounding areas (Kraft *et al*., 2014). *Capsicum baccatum* is thought to have originated in the Andean region of South America, whereas *Capsicum pubescens* is believed to have been domesticated in the highlands of Peru and Bolivia (Gonzalez *et al*., 2020).

2.2 World Pepper Production and Economic Importance

The consumption of chilli peppers fruits (*Capsicum* spp.), probably ranked among the first spices or food additives, is constantly increasing globally. In recent times, world chilli pepper production has steadily increased from 10,769,000 tons in 1991 to 22,168,000 tons in 2002 (FAO, 2003), doubling in size within a decade. Furthermore, the world production of chilli peppers was evaluated in 2012 by FAO to more than 31 million tons. FAO statistics estimate the global chilli pepper production at 38,415,621 tonnes in 2016 in a cultivated territory of 3,737,635 ha (FAO, 2018). Several varieties are cultivated around the world. India is the largest producer of chilli peppers in the world, contributing 25% of the world's production. In Africa, Nigeria, Egypt, and Ghana, regular production is found in the international market. West Africa alone produces 1,703,612 tons for an area of 290,574 ha (or 4,435% of world production). The largest producers in West Africa are Nigeria and Ghana, respectively ranked eighth and thirteenth in the world (FAO, 2016).

The vast majority of chilli peppers produced in Africa are sold in local, regional (Senegal, Gambia, Liberia, Sierra Leone and Mali) and international markets (Europe and North America). *Capsicum annuum* cultivation significantly contributes to the economic well-being of producing nations. The income generated from pepper cultivation supports the livelihoods of numerous smallholder farmers and their communities. In countries like Mexico and India, the cultivation of chili peppers has been a traditional occupation for many farmers, playing a pivotal role in rural economies. The economic impact also extends to employment generation, as pepper cultivation and processing create jobs in various stages of the supply chain. The socio-economic implications of *Capsicum annuum* cultivation are diverse, encompassing poverty alleviation, gender dynamics, and rural development. Studies indicate that pepper cultivation has played a role in reducing poverty in certain regions by providing farmers with a stable source of income (Olagunju *et al*., 2018). Additionally, the participation of women in pepper cultivation and processing has enabled them economically and socially, contributing to gender equality in some communities.

2.3 Constraints to Pepper Production

Despite its economic importance, the *Capsicum annuum* industry faces challenges such as climate change, pests, and market fluctuations. Climate change can impact suitable regions for cultivation, affecting yields and quality. Pests and diseases, such as bacterial wilt and aphids, pose threats to crops (Thakur *et al*., 2021).

In a study conducted in Malaysia by Wong *et al*. (2010), they elaborated that most of the farmers are smallholders, consequently affecting the amount of pepper production to smaller capacities. Therefore, the major problems and constraints faced by pepper farmers are escalating costs for managing disease and pest problems, increasing the cost of fertilizer, pesticides and labor inputs and also fluctuating export market prices. Furthermore, climate change has brought a new generation of pests and pathogens separately from causing erosion to native gene banks, which has made it essential to strategize and set up urgencies to meet the challenges through sustainable production (Kandiannan, 2014). The pepper industry is expected to increase rapidly over the next decades. However, production is expected to grow slowly because of low productivity and price volatility. Moreover, price is the most important factor that contributes to the reduction in pepper production, thus creating a situation for farmers to switch to other lucrative cash crops such as palm oil and rubber (Nelson, 2014). In Liberia, the challenges encountered in pepper production encompass inadequate inputs, including low quality seeds, lack of sufficient fertilizers, low irrigation during the dry season, low access to markets, and the lack of contemporary farming techniques. Addressing these challenges requires sustainable agricultural practices, technological interventions, and international collaborations.

2.4 Background on Green Peach Aphid (Myzus Persicae)

The green peach aphid (*Myzus persicae*) is a notorious agricultural pest that feeds on a wide variety of plants, including numerous crops such as potato, tomato, and lettuce, as well as many weed species. This aphid is native to North America but is now found throughout the world, causing significant economic damage to agriculture in many regions. In this discussion, we will provide an overview of the green peach aphid's biology, ecology, and management strategies, drawing upon academic literature for support. The green peach aphid is a small, soft-bodied insect that is typically green or yellow-green in color, with elongated antennae and a pair of cornicles on the abdomen (Blackman and Eastop, 2000). The aphid feeds on the sap of host plants using its piercing-sucking mouthparts, causing a range of symptoms, including stunted growth, wilting, and distortion of plant tissues (Shrestha *et al*., 2018). In addition to direct damage, the green peach aphid is a vector for numerous plant viruses, making it a significant threat to crop health (Blackman and Eastop, 2000).

The green peach aphid has a complex life cycle that includes sexual and asexual reproduction, with females capable of giving birth to live offspring without mating (Blackman and Eastop, 2000). The aphid can reproduce rapidly under favorable conditions, with populations increasing exponentially in a matter of weeks (Zohdi *et al*., 2014). This high reproductive rate, combined with the aphid's ability to disperse over long distances, makes it difficult to control using traditional management strategies such as chemical insecticides (Blackman and Eastop, 2000). In recent years, there has been increasing interest in developing alternative approaches to managing green peach aphids, including biological control using natural enemies such as parasitoids and predators (Shrestha *et al*., 2018). Studies have shown that certain natural enemies, such as the parasitoid wasp *Aphidius colemani*, can be effective at reducing green peach aphid populations in greenhouses and other controlled environments (Shrestha *et al*., 2018). However, the efficacy of biological control varies depending on environmental conditions and the specific natural enemy being used.

The green peach aphid remains a significant pest in agriculture, with the potential to cause significant economic damage and transmit plant viruses. Continued research into the biology, ecology, and management of this pest is essential to develop effective strategies for control and mitigation.

2.4.1 Hosts of Myzus Persicae

Myzus persicae is a very important agricultural pest that feeds on a broad range of host plants, causing considerable destruction to crops around the globe. The literature review below examines the various host of *M. Persicae.*

One study conducted by Blackman and Eastop (2000) investigated the host range of *M. persicae* in the UK and found that the aphid feeds on over 400 plant species, including many crops such as potato, tomato, and lettuce, as well as a range of weed species. The study also found that the aphid is capable of adapting to different host plants and may develop new biotypes that can specialize in feeding on a particular plant species. Another study by Shrestha *et al*. (2018) investigated the host range of *M. persicae* in Nepal and found that the aphid feeds on a wide range of crops, including cauliflower, cabbage, radish, and mustard, as well as various weeds. The study also found that different biotypes of *M. persicae* were present in different locations, with some biotypes showing a preference for specific crop species.

Similarly, in a study conducted in Iran, Zohdi *et al.* (2014) found that *M. persicae* feeds on a range of crops, including tomato, cucumber, pepper, and eggplant, as well as various weed species. The study also found that the aphid population increased significantly on tomato plants, indicating that this crop species may be particularly susceptible to infestation by *M. persicae*. In addition to crop plants, *M. persicae* has been reported to feed on a range of wild plant species. For example, a study by Doring *et al*. (2009) found that the aphid feeds on a variety of wild plant species, including hogweed, wild carrot, and cow parsley. The study also found that different biotypes of *M. persicae* were present in different plant species, suggesting that the aphid may be adapting to its host plants in the wild as well as in agricultural settings.

The literature review specifies that *M. persicae* has a wide host range, with the ability to feed on different food crops and wild plant species. The aphid has the capability to develop new biotypes and is highly adaptable. These characteristics make the green peach aphid an important pest in agricultural settings and emphasize the significance of developing efficacious management strategies that are environmentally friendly and sustainable.

2.4.2 Symptoms of Myzus Persicae Infestation

The green peach aphid (*Myzus persicae*) is a notorious agricultural pest that feeds on a wide variety of plants and causes significant economic damage. One of the most noticeable symptoms of green peach aphid infestation is the presence of large numbers of aphids on plant tissue. These aphids characteristically assemble on the undersides of leaves and on the growing tips of plants, where they feed on the sap of host plants using their piercing-sucking mouthparts. As a result, infested plants may exhibit stunted growth, wilting, and distortion of plant tissues (Shrestha *et al*., 2018).

In addition to direct damage, the green peach aphid is a vector for numerous plant viruses, making it a significant threat to crop health (Blackman and Eastop, 2000). Infected plants may exhibit a range of symptoms, including yellowing, mottling, and necrosis of plant tissues (Smith, 2018). Green peach aphids are known to exhibit a high reproductive rate, and under favorable conditions, populations can increase exponentially in a matter of weeks (Zohdi *et al*., 2014). This rapid population growth can result in significant damage to crops, with infested plants exhibiting reduced yields and quality. The symptoms of green peach aphid infestation include the presence of large numbers of aphids on plant tissue, stunted growth, wilting, distortion of plant tissues, and the transmission of plant viruses. Early detection and management of infestations are important for controlling this pest and curtailing crop damage.

2.4.3 Life Cycle of Myzus Persicae

The life cycle of *Myzus persicae* begins with eggs, which are typically laid on the undersides of leaves. These eggs hatch into wingless, parthenogenetic females that feed on the sap of host plants using their piercing-sucking mouthparts (Blackman and Eastop, 2000). The overwintering eggs produced *by Myzus persicae* females are laid on the bark of trees or in other protected areas. These eggs are dark in color and can withstand low temperatures and harsh conditions during the winter months (Blackman and Eastop, 2000). These females are capable of reproducing without mating and can give birth to live young without the need for egg-laying.

Under favorable conditions, *Myzus persicae* can produce several generations of offspring within a single growing season. As the population grows, winged females may be produced in response to overcrowding and/or the depletion of food resources. These winged females are capable of dispersing to new host plants, allowing the population to colonize new areas (Blackman and Eastop, 2000). Aphids can quickly approach pest magnitudes; they reproduce all year round on different secondary hosts, including potatoes, tomatoes, brassicas, beets, cereals, pasture clovers, peas and peppers (Al-Antary and Khader, 2011) asexually. As the growing season comes to a close, *Myzus persicae* females begin to produce sexually reproducing males and females. These males and females mate and the females lay overwintering eggs, which can survive the cold winter months and hatch in the spring to begin a new generation (Blackman and Eastop, 2000).

In addition to its flexible life cycle*, Myzus persicae* is also known for its ability to rapidly adapt to changing environments. For example, this pest can develop resistance to insecticides through a variety of mechanisms, including metabolic detoxification and target site insensitivity (Bass *et al*., 2014).

2.4.4 Resistance Mechanisms in Green Peach Aphid

Green peach aphids (*Myzus persicae*) have developed resistance to several types of insecticides due to their ability to speedily acclimatize to fluctuating environments. Some common resistance mechanisms observed in green peach aphids are:

Target site insensitivity: This is the most common mechanism of insecticide resistance in green peach aphids. In this mechanism, mutations occur in the target sites of the insecticide, making it ineffective against the aphid. For example, a study by Bass *et al*. (2014) found that mutations in the nicotinic acetylcholine receptor β subunit were associated with resistance to neonicotinoid insecticides in green peach aphids.

Metabolic detoxification: In this mechanism, green peach aphids increase the activity of metabolic enzymes that can break down the insecticide before it can have an effect on the aphid. For example, the cytochrome P450 monooxygenase system is known to be involved in metabolic detoxification in green peach aphids (Puinean *et al*., 2010).

Reduced penetration: In this mechanism, the cuticle of the green peach aphid becomes more impermeable to insecticides, preventing it from entering the aphid's body. A study by Silva *et al.* (2018) found that green peach aphids that were resistant to insecticides had thicker cuticles than susceptible aphids, suggesting that reduced penetration may be a mechanism of resistance in this pest.

Behavioral avoidance: In this mechanism, green peach aphids change their behavior in response to insecticides, avoiding treated areas or host plants. For example, a study by Mo *et al.* (2019) found that green peach aphids were more likely to avoid host plants that had been treated with imidacloprid, a neonicotinoid insecticide.

The ability of green peach aphids to cultivate resistance to insecticides presents a momentous challenge for pest management. Henceforth, comprehending the mechanisms of resistance in green peach aphids can help enlighten the advancement of effective control strategies that take into consideration the adaptive capacity of this pest. (Bass *et al.*, 2014).

2.5 Management and Control of Myzus Persicae

Aphids are very troublesome insect pests. Henceforth, several control methods have been developed to manage these pests.

2.5.1 Biological Control

Aphidius colemani Viereck is a prominent parasitoid employed in the biological regulation of *M. persicae* and *Aphis gossypii* Glover, as explained by Zamani *et al.* (2007). This parasitoid species is commercially cultivated for utilization as a biocontrol agent in greenhouse environments, principally via the careful release of adult individuals, as outlined by Yano (2006). In a divergence from conventional biological control methods, an advanced approach includes the implementation of a banker plant system. This system characteristically requires the deliberate infestation of a non-crop plant with a non-pest herbivore, aiding as a substitute host for the natural enemies of the targeted crop pest. The principal objective of the banker plant system is to maintain a self-sustaining population of these natural enemies within a crop, thereby imparting control over a specific pest throughout the cropping season, as expounded by Frank (2010).

While the natural enemies are intentionally introduced into the crop both in the banker plants and in the inoculative control, only the first approach delivers resources (hosts or food) to the natural enemies so that they can survive and reproduce even when the pest is in a very low density or is absent. This distinctive trait makes the banker plant system more defensive and of long-term action likened to the augmentative system. Furthermore, this strategy is considered to be a less time, money and effort consuming system compared to other biological control practices (Xiao *et al.*, 2011). Banker plant systems have been verified to regulate vegetable pests (mainly aphids but also whiteflies, thrips and mites) through the use of different combinations of host plant- alternative host-natural enemy (parasitoid or predator) (Frank, 2010). To be precise, the system comprising of cereal plants – *Rhopalosiphum padi* – *A. colemani* was repeatedly evaluated to control *A. gossypii*, recording parasitism levels grander and aphid populations lower in greenhouses with banker plants compared to those without banker (Van Driesche *et al.,* 2008).

Harmonia axyridis (Pallas) (Coleoptera: Coccinellidae), originating from Asia, is a predator of small arthropods, especially aphids, of numerous species in natural and managed landscapes. Both larvae and adults tend to aggregate and prey on aphids, while aphid consumption increases with larval instar, increasing prey aggregation and density (Koch, 2003). *H. axyridis* has been widely applied to control *M. persicae* and other aphid species in a wide range of ecosystems, such as trees, field crops (i.e., wheat and cotton fields) and greenhouse vegetables (Riddick, 2017). Nevertheless, because of its accumulation and extraordinary development, several nations considered it an invasive species while focusing on its adverse effects on the environment, overall, and particularly on ladybird diversity (Roy and Brown, 2015).

Aphidoletes aphidimyza (Rondani) (Diptera: Cecidomyiidae) is a common aphid predator that can feed on 85 aphid species (Boulanger *et al.*, 2019). Females can sense aphid colonies and lay eggs proficiently in a 45m radius. Only larvae can prey on aphids, leaving desiccated aphid bodies affixed to plants, particularly the older larvae that have higher predation rates. Furthermore, the number of aphids killed varies with prey density (i.e., more aphids were killed than predators nutritionally needed when in high aphid densities) (Lin *et al*., 2017). *A. aphidimyza* has been commercially released in greenhouse crops such as sweet pepper, cucumber, eggplant, potted ornamentals and woody ornamentals in North America and Europe (Jandricic *et al*., 2016). Management of insect pests using entomopathogenic fungi (EPF) is considered a significant alternative method for the organic cultivation of vegetables under protected conditions (Ali *et al*., 2018).

2.5.2 Chemical Control

Chemical pesticides are common due to their availability, efficacy, and ease of use (Deguine *et al*., 2021). Therefore, the majority of current management practices for *M. persicae* are based on chemical pesticides (Wu and Song, 2007). Synthetic pesticides containing active ingredients, such as pyrethroids, carbamate, organophosphates, and neonicotinoids, have a robust negative consequence on a number of herbivores, including *M. persicae* (Rawat *et al*., 2013). Even though *M. persicae* shows a positive level of resistance to most of these chemical compounds, some of them still have a high capability to be used as synergists with other control measures against *M. persicae* (Faraone *et al*., 2015). Conversely, growing concerns about their adverse effect on the environment and non-target organisms are leading to restrictions on their use (Geiger *et al*., 2010).

2.5.3 Cultural Control

Cultural methods are regularly used to create unfavorable environments for pests, which is one of the foremost objectives of pest management approaches (Abate *et al*., 2000). Cultural practices, such as crop rotation and sanitation, intercropping, the demolition of plant debris, and the prevention of adjacent planting of crops, as well as trap crops, play a vital part in pest management. For example, winter peach pruning is practiced, predominantly in fruit orchards, to regulate plant load, which ultimately affects the performance of pests, i.e., *M. persicae*. Reportedly, *M. persicae* is primarily found on mature leaves; therefore, winter pruning has been found to be an effective way to decrease pest infestations (Grechi *et al*., 2008). By removing some buds, a potential habitat for egg-laying is reduced, leading to a decrease in the overall population of *M. persicae*. Similarly, intercropping companion plants with horticultural crops can be an effective method for pest management. For instance, *Tagetes patula*, as a companion plant with *C. annuum*, considerably affects the population of *M. persicae* by releasing a mixture of deterrent volatile compounds (Dardouri *et al*., 2017).

Nevertheless, because of the wide range of host plants, cultural practices may be a difficult and overwhelming method to control *M. persicae*. Furthermore, insect-proof nets have been found to be an effective method for controlling *M. persicae* infestations in crops (Dader *et al*., 2015). A study conducted by Martin *et al*. (2013) showed that covering plants with insect-proof nets (treated with repellent compounds) significantly reduced the population of *M. persicae* in *B. oleracea*. Similarly, insect-free seedlings are also effective in preventing *M. persicae* infestations. A study conducted by Mpumi *et al.* (2020) showed that using insect-free seedlings reduced the severity of aphid infestations (including *M. persicae*) in *B. oleracea*.

2.6 Neem Extracts and Insecticidal Properties

Neem (*Azadirachta indica*) has gained attention for its pesticidal properties attributed to various bioactive compounds present in both its leaves and seeds. Azadirachtin, a key component, has been identified as a potent insect growth regulator, disrupting the molting process and causing mortality in various insect species (Isman, 2006). In the context of *Myzus persicae*, neem extracts have demonstrated deterrent effects, impeding feeding and reproductive activities (Regnault-Roger *et al*., 2004). Studies have elucidated the mode of action of neem extracts on *Myzus persicae*. Azadirachtin interferes with the aphid's hormonal balance, disrupting the growth and development of nymphs and adults (Mordue & Nisbet, 2000).

Additionally, neem extracts exhibit antifeedant properties, reducing the aphid's ability to extract nutrients from the pepper plant (Isman, 2006). Additionally, field trials evaluating the efficacy of neem extracts in pepper production have yielded encouraging results. A study by Sharma *et al*. (2018) demonstrated a significant reduction in *Myzus persicae* populations following the application of neem leaf and seed extracts. The extracts not only controlled aphid infestations but also contributed to enhanced plant growth and overall pepper yield.

One important advantage of neem-based insecticides is their eco-friendly nature. Neem extracts are biodegradable and pose minimal risk to non-target organisms, advancing sustainable agricultural practices (Regnault-Roger *et al*., 2004). The cost-effectiveness of neem-based solutions further increases their demand for integrated pest management strategies in pepper production (Isman, 2006). Extracts from various parts of *A. indica* have been compared with commercial pesticides on various crop pests, where they have been found to be efficacious and equally or more cost-effective (Mondal and Mondal, 2012).

A laboratory study by Rimpi-Das *et al*. (2010) to evaluate the effect of Neem kernel aqueous extract on larval weight, larval duration, mortality percent, adult emergence percent and antifeedant of a red slug caterpillar (*Eterusia magnifica*) in tea plant revealed that the aqueous extract was effective in deterring the growth and development of the pest as the concentration of the extract increased. Boursier *et al.* (2011) reported that crude water extracts of Neem seeds have been tested in the field against several pests in tropical and subtropical countries, and their efficacy has been found to be satisfactory to excellent. In another study conducted by Shannag *et al.* (2014), results revealed that spraying neem-based products onto potted sweet pepper plants in the greenhouse significantly reduced the densities of aphids by half to three-fourths by 7 days post-treatment. By day 14, control aphid populations in control treatment increased about 8-fold. Aphids demonstrated a bigger vulnerability to Azatrol and Pure Neem Oil than to Triple Action Neem Oil.

Lowery and Isman (1994) established that nine species of aphids were susceptible to the insect growth regulating (IGR) activities of Neem seed oil or AZA, and the mortality generally occurred during failed attempts to molt. Similarly, studies by Egho and Ilondu (2012) also showed that Neem seed extract significantly reduced the aphid population (*A. craccivora*) when compared to the unprotected plots (control). Laboratory and field trials with formulated Neem seed oil (NSO) and Neem seed extract (NSE) by Lowery (1992) validated that these ingredients were potentially very active as aphicides. In the same study, laboratory trails indicated a significant decrease in the numbers of green peach aphids, *Myzus persicae* (Sulzer), on pepper; the study additionally disclosed that mortality of aphids was between 94-100% within nine days when Neem seed oil was applied to leaf disk at a concentration of 1.0%.

While the efficacy of neem extracts against *Myzus persicae* is well-established, challenges such as formulation stability and standardized application procedures need further investigation. Additionally, factors influencing the variability in neem's effectiveness, such as extraction methods and geographical variations in neem composition, need a comprehensive inquiry.

3. Methodology

3.1 Site Description, Plant Rearing, and Experimental Design

A field and laboratory experiment was conducted at the Research Field and Plant and Soil Science (PSS) Laboratory at the College of Agriculture and Sustainable Development (Cuttington University) located in Suakoko, Bong County, Liberia. The Global Positioning System coordinates are latitude 6.99°, longitude -9.58°. The elevation of the site is 263.3m above sea level. The annual temperature of the study site ranges from 19°C to 30°C. Grassland and forest vegetation are dominant in the study area. Latosols, lithosols, regosols, and alluvial swamp soils are the major soil types found in the study area. The Pepper seeds were pre-germinated using a method described by Shannag et al. (2014) in a nursery. Pepper was transplanted (after 35 days of nursery raising) in the field, and experimental plots were arranged in a randomized complete block design (RCBD) with three replicates. Each replicate consisted of 7 treatment plots, including a standard control plot. The treatments are:

Treatment 1:	Control
Treatment 2:	Neem 6.5 v:v
Treatment 3:	Papaya 6.5 v:v
Treatment 4:	Neem 7.5 v:v
Treatment 5:	Papaya 7.5 v:v
Treatment 6:	Neem 8.5 v:v
Treatment 7:	Papaya 8.5 v:v

The entire experiment comprised of 21 plots. Each plot measured 1.5m x 1.5m, amounting to a total area of 2.25 m^2. A walkway of 0.6m was measured between plots. Spraying was done during the early morning and cool evening hours to avoid spray drift of biopesticides. In the laboratory, plastic petri dishes were arranged in a design similar to that of the field design.

3.2 Preparation of Plant Extracts

Plant extracts were prepared using a procedure explained by (El-Shafie and Basedow, 2003). Aqueous neem leaf extracts (ANLE) and aqueous papaya leaf extracts (APLE) were dried under shade, and each was formulated by pounding 500 grams into powder and then mixed in 5 liters of water. The mixtures were then allowed to stay for twenty 24 hours. After that, the concoctions were frequently purified using cheesecloth to remove coarser substances. Carbolic soap was added to the concoctions as an emulsifier to properly blend the active ingredients in the plant extracts powder and to promote adhesiveness when applied on the leave surface. The aqueous plant extracts were serially diluted with tap water to obtain the following concentrations: 65% (6.5:3.5 v:v), 75% (7.5:2.5 v:v) and 85% (8.5:2.5 v:v). Tap water was used as an untreated control (UC). Neem and papaya leaves that were used as extracts were collected from mature trees on the Cuttington University Campus in Suakoko, Bong County.

3.3 Aphid Culture

Myzus persicae species that were used for the study were collected from infected cabbage and pepper fields at the experimental field of the College of Agriculture and Sustainable Development (CASD) at Cuttington University in Suakoko, Bong County, Liberia. Leaves of cabbage and pepper plants that were infested with aphids were carefully handpicked with the aid of a magnifying glass and placed in a container covered with a net to allow air entry. Verification of insects as *Myzus persicae* was conducted in the Plant and Soil Science Laboratory at the College of Agriculture and Sustainable Development (CASD), Cuttington University. Identification was properly done by examining the insects under a microscope and confirming the species with an established classification. Aphid colony was maintained on pepper plants in wooden boxes covered with fine mesh and kept at 25°C to prevent the insects from escaping. A periodic supply of pepper plants was done to restock aphids in the colony.

3.4 Aphid Infusion

Aphids (*Myzus persicae*) were introduced to pepper plants in the field at the flowering stage. About fifteen (15) *M. persicae* were brushed from the infested leaves of the aphid colony and infused on young, fully expanded leaves of each experimental pepper plant in the field using a soft hair brush. Application of treatments was conducted after a period of five (5) days. By this time, aphids had multiplied. Subsequent treatment applications were performed at regular intervals (weekly). In the laboratory, aphids were fed pepper leaves that had been treated with the proposed plant extracts. Plastic petri dishes were used as experimental plots and were arranged in a randomized complete block design (RCBD). A leaf disc choice test, as described by Kayange *et al*. (2022), was employed in conducting laboratory bioassay. Seven (7) aphids were infused on pepper leaf discs in plastic petri dishes in the laboratory.

3.5 Growth Medium Physio-Chemical Properties Analysis

Analysis of the physical and chemical properties of the soil was conducted before the initiation of the study. It is well established that the physio-chemical properties of a growth medium can have a considerable impact on the overall results of experimental research. Properties that were analyzed are pH level, soil drainage, soil structure, and soil texture.

Table 1: Basic soil properties at the experimental site

Soil Property	Characteristic
pH level	6.2
Soil Drainage	Well-drained
Soil Structure	Granular
Soil Texture	Sandy clay loam

3.6 Plant Growth Parameters and Aphid Infestation Degree

Pepper plant height, leaf with, and leaf length were measured using a tape rule. The number of aphids before and after the application of treatments was counted and recorded both in the field and in the laboratory. The Repellency Index, after applying biopesticides, was also calculated using a formula as depicted by Campbell (1983).

3.7 Statistical Analysis

Statistical analyses were conducted using Statistical Package for Social Sciences (SPSS version 21.0). Data visualization was done using the R Plotting Library (ggplot2). Analysis of Variance (ANOVA) was used to test for significant differences between treatments in the study. To separate means of treatment, the Tukey Honestly Significant Difference (HSD) test was used. Significant differences were identified at a probability level of 0.05 ($p = 0.05$).

4. Findings

Table 2: Mean number of aphids settled on leaf disc 10 hours after treatments with different concentrations of plants (neem and papaya) extracts (Laboratory bioassay)

Treatments	Mean number of aphids
Control	41.0
Neem 6.5 v:v	12.0
Papaya 6.5 v:v	11.4
Neem 7.5 v:v	12.6
Papaya 7.5 v:v	8.1
Neem 8.5 v:v	6.0
Papaya 8.5 v:v	13.4

The laboratory bioassay evaluating the mean number of aphids settled on leaf discs 10 hours after treatments with neem and papaya extracts revealed distinct trends. The control treatment exhibited the highest mean aphid count (41.0), emphasizing the potential of neem and papaya extracts in reducing aphid populations. Particularly, neem 8.5 v:v and papaya 8.5 v:v treatments demonstrated the most significant effectiveness, suggesting that higher concentrations of these extracts may be particularly potent in controlling aphid infestations. However, the similarity in mean aphid numbers among neem 6.5 v:v (12.0), papaya 6.5 v:v (11.0), and neem 7.5 v:v (12.0) treatments implies comparable efficacy in diminishing aphid damage. Papaya 7.5 v:v stood out with a lower mean aphid count, indicating its potential as a particularly effective treatment.

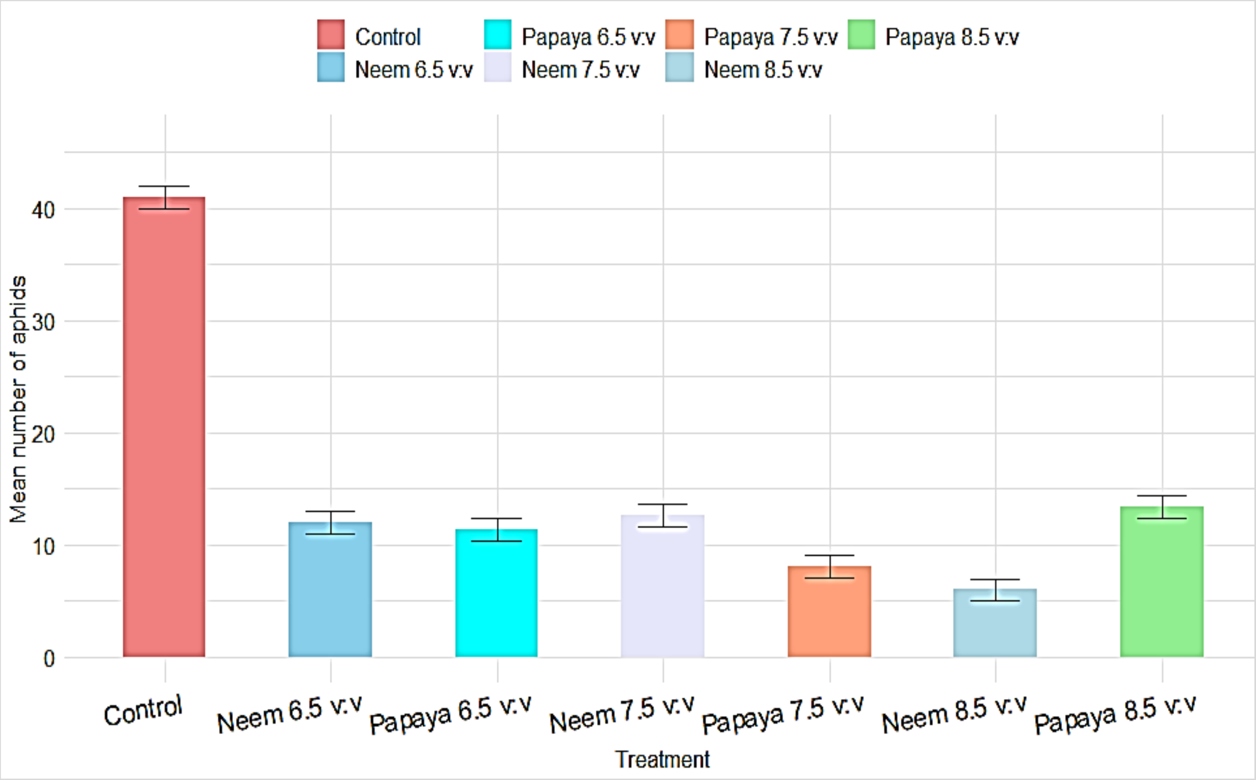


Figure 1: Mean number of aphids settled on leaf disc 10 hours after treatments with different concentrations of plants (neem and papaya) extracts (Laboratory bioassay)

Table 3: Effect of plant extracts on mean number of aphids 1 and 2 weeks after application (field experiment)

Treatment	**Mean number of aphids after**	
	1 week	***2 weeks***
Control	48.0 ^{a}	76.7 ^{b}
Neem 6.5 v:v	29.3 ^{a}	9.3 ^{a}
Papaya 6.5 v:v	34.0 ^{a}	15.0 ^{a}
Neem 7.5 v:v	26.0 ^{a}	8.0 ^{a}
Papaya 7.5 v:v	29.0 ^{a}	9.7 ^{a}
Neem 8.5 v:v	21.0 ^{a}	5.3 ^{a}
Papaya 8.5 v:v	27.0 ^{a}	9.7 ^{a}

*Means with the same letters are not significantly different at p = 0.05 (Tukey HSD test)

The above table illuminates the mean number of aphids observed after different treatment applications over a one and two-week period. The treatments, including a control group and various concentrations of Neem and Papaya solutions (6.5 v:v, 7.5 v:v, and 8.5 v:v), were subjected to examination for their influence on aphid populations. The results indicate important variations in aphid populations across the treatments. After one week, the control group exhibited the highest mean number of aphids (48.0), while Neem 8.5 v:v treatment displayed the lowest mean (21.0). This indicates a potential suppressive effect of Neem 8.5 v:v on aphid populations compared to the control.

After two weeks, a similar trend was observed. The control group showed a substantial increase in the mean number of aphids (76.7), signifying a rise compared to the Neem 6.5 v:v, Neem 7.5 v:v, Neem 8.5 v:v, and Papaya 8.5 v:v treatments, which maintained relatively lower aphid counts. This outcome suggests that Neem-based treatments may contribute to sustained aphid control over a more extended period compared to the untreated control.

Figure 2: Effect of plant extracts on mean number of aphids 1 and 2 weeks after application

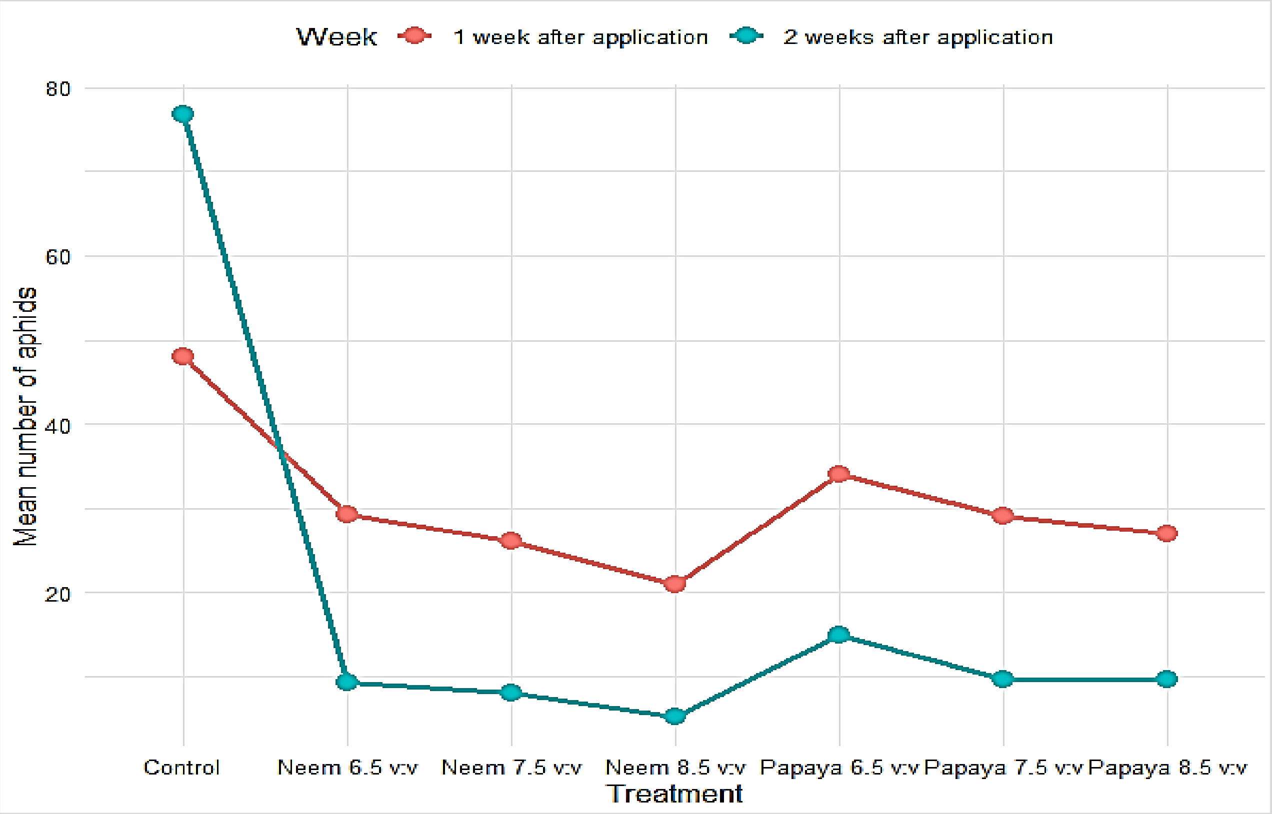


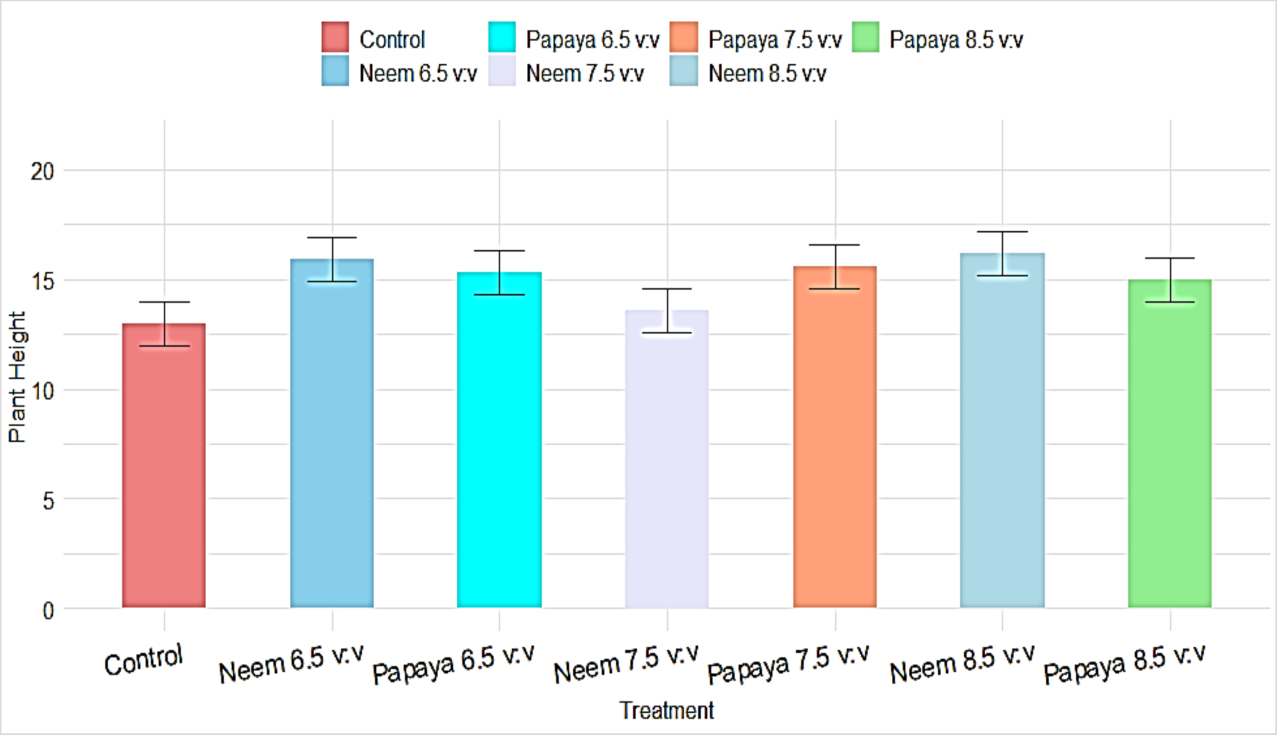
Table 4: Mean Variations in Growth Parameters Measured

Treatment	Plant Height	Leaf length	Leaf width	Repellency Index
Control	13.0 ^{a}	6.8 ^{a}	3.8 ^{a}	1.0 ^{b}
Neem 6.5 v:v	15.9 ^{a}	7.7 ^{a}	4.1 ^{a}	2.8 ^{a}
Papaya 6.5 v:v	15.3 ^{a}	6.8 ^{a}	3.8 ^{a}	2.1 ^{b}
Neem 7.5 v:v	13.6 ^{a}	7.1 ^{a}	3.7 ^{a}	2.6 ^{a}
Papaya 7.5 v:v	15.6 ^{a}	7.2 ^{a}	4.3 ^{a}	2.5 ^{a}
Neem 8.5 v:v	16.2 ^{a}	8.5 ^{a}	4.5 ^{a}	3.0 ^{a}
Papaya 8.5 v:v	15.0 ^{a}	7.0 ^{a}	3.6 ^{a}	2.7 ^{a}

*Means with the same letters are not significantly different at p = 0.05 (Tukey HSD test)

The above table illustrates the mean variations in growth parameters measured for different treatments applied to plants. Each treatment is associated with specific values for plant height, leaf length, leaf width, and the repellency index. For plant height, plants under the control treatment exhibit a mean height of 13.0 cm, which is lower than the Neem 6.5 v:v, Papaya 6.5 v:v, Neem 7.5 v:v, Papaya 7.5 v:v, Neem 8.5 v:v, and Papaya 8.5 v:v treatments. Among the treatments, Neem 8.5 v:v recorded the highest mean plant height at 16.2 cm. Regarding leaf length, the control treatment recorded a mean leaf length of 6.8 cm, which is comparable to Neem 7.5 v:v, Papaya 6.5 v:v, and Papaya 8.5 v:v treatments. Neem 6.5 v:v exhibited the highest mean leaf length at 7.7 cm. The mean leaf width for the control treatment was measured at 3.8 cm, similar to Papaya 6.5 v:v and Papaya 8.5 v:v treatments. Neem 8.5 v:v shows the highest mean leaf width at 4.5 cm. The repellency index for the control treatment was recorded at 1.0, which is significantly lower than all other treatments. Neem 8.5 v:v demonstrates the highest mean repellency index at 3.0. Neem 8.5 v:v consistently showed the highest mean values across plant height, leaf length, leaf width, and repellency index, signifying a potential positive impact on plant growth and repellency. The control treatment steadily exhibited lower mean values compared to the other treatments, indicating a potential baseline or reference for comparison.

Figure 3: Mean plant height as affected by treatments



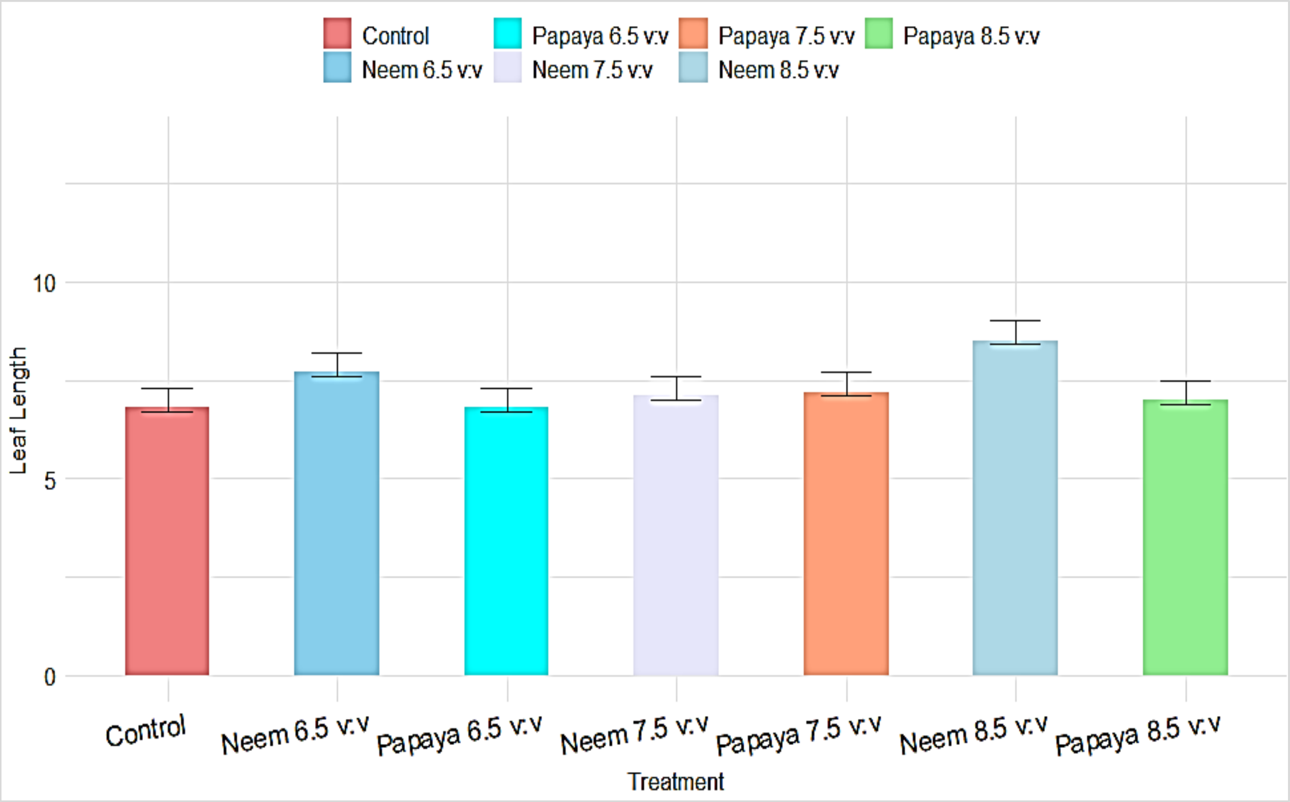


Figure 4: Mean leaf length as influenced by treatments

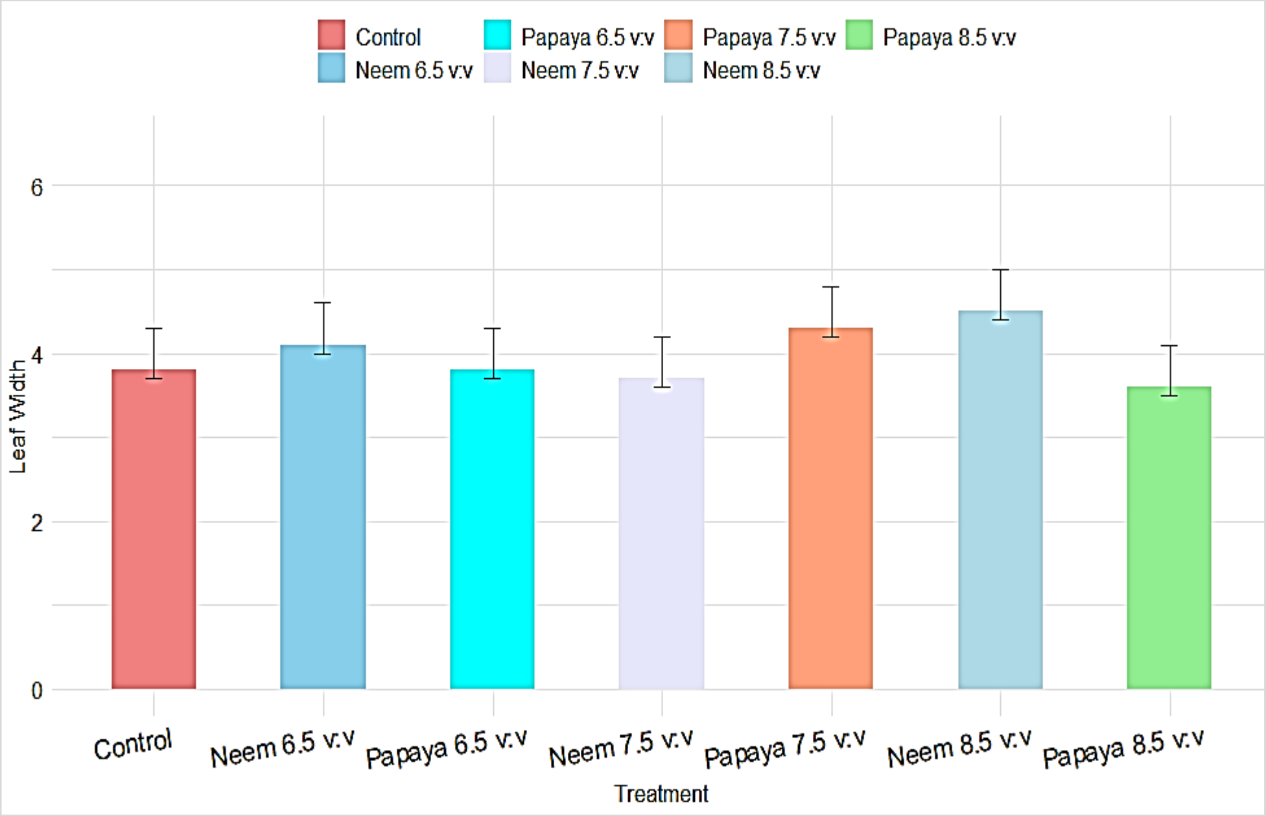


Figure 5: Mean leaf width as affected by treatments

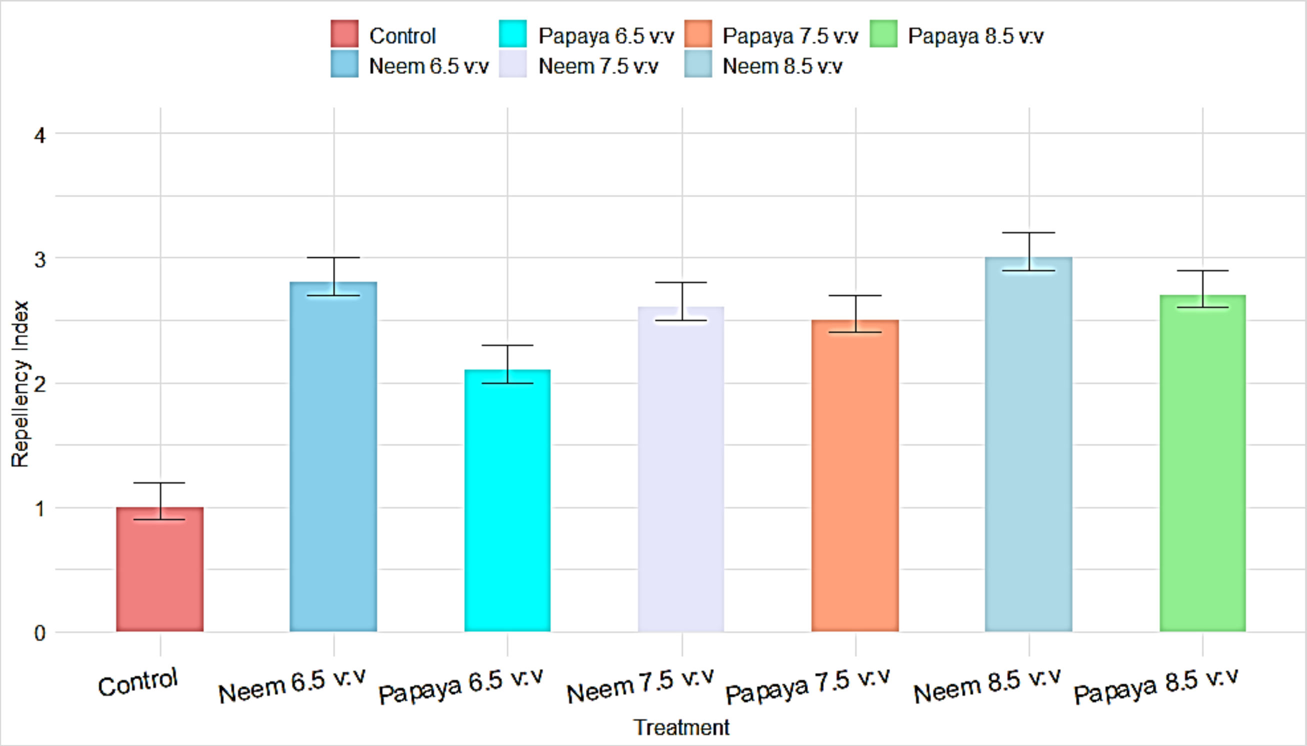


Figure 6: Repellency Index of various treatments

5. Discussion

Field and laboratory trials validated the efficacy of neem and papaya based treatments in controlling aphid infestations and increasing plant health. Previous studies by Sharma *et al*. (2018) and Shannag *et al*. (2014) describe significant reductions in *Myzus persicae* populations following the application of neem leaf and seed extracts. The presence of Azadirachtin in various parts of the plants is widely known for its biopesticidal properties. Additionally, a study by Lowery and Isman (1994) emphasizes the aphicidal efficacy of neem seed oil, validating its effectiveness as a potent botanical insecticide. Furthermore, studies by Egho and Ilondu (2012) and Nisbet *et al*. (1993) demonstrate the inhibitory effects of neem extracts on aphid feeding activities and reproduction, further stressing their complex mechanisms of action.

Foster *et al*. (2003) conveyed that some clones of *Myzus persicae* (926B) used in their study were still alive and reproducing 7 days after treatment with the complete commended dose of imidacloprid (2mg per plant). This demonstrates a potential for aphids with this level of resistance to withstand field applications. On the contrary, in this study, signs of aphids' fecundity after the application of biopesticides were not observed. This could probably be attributed to the specific clone of *Myzus persicae*. Furthermore, Stark and Walter (1995) elaborated that in addition to the concentration levels, products containing azadirachtin in combination with other ingredients (for example, Nimbin and Salanin), which have been reported to be present in water extract of neem, exhibit better aphicidal activities than either ingredient alone.

The collective findings from laboratory bioassays and field trials emphasize the promising potential of neem-based treatments in controlling aphid infestations and promoting plant health and yield. However, as with any area of research, there are possibilities for future investigation and improvement in this field. One key aspect for future research could involve revealing the underlying mechanisms of action of neem extracts on aphids at the molecular level. Investigating the specific bioactive compounds responsible for the repellent, antifeedant, and insecticidal properties of neem could lead to the development of more targeted and effective formulations.

Moreover, given the increasing interest in sustainable agriculture practices, further studies focusing on the ecological impacts of neem-based treatments are warranted. Assessing the long-term effects of neem extracts on non-target organisms, soil health, and ecosystem dynamics could provide valuable insights into their overall sustainability and compatibility with integrated pest management strategies. Additionally, research efforts could be directed towards optimizing the formulation and application methods of neem-based products to enhance their efficacy and stability under different environmental conditions. Discovering innovative delivery systems, such as nanoformulations or encapsulation techniques, could improve the bioavailability and longevity of neem extracts in the field, thereby maximizing their pest control potential while reducing environmental risks.

6. Conclusion

Neem and papaya extracts show promise as natural repellents for managing aphid infestations in pepper crops. The study demonstrated the potential of both extracts to suppress aphid populations and enhance plant growth. The results underscore the significance of exploring plant-based solutions for pest management in agriculture adopting sustainable and environmentally friendly practices. Supplementary investigations into the specific mechanisms of repellency and the long-term effects on crop health are necessary to optimize the use of neem and papaya extracts in integrated pest management strategies for peppers and other crops.

6.1 Recommendations

Based on the results obtained from the study, the following are recommended:

1. Both neem and papaya extracts have shown promising repellent properties against aphids. Implementing these natural extracts as part of an integrated pest management (IPM) strategy can be beneficial for controlling aphid infestations in pepper crops. Their use as repellents can reduce aphid populations, minimizing potential crop damage and yield losses.
2. The effectiveness of neem and papaya extracts varied depending on the concentration used. The 8.5 v:v neem extract demonstrated the highest repellency index and resulted in significant reductions in aphid

populations. Similarly, the 7.5 v:v papaya extract showed good repellent properties. Growers should consider using these optimal concentrations when applying the extracts to their pepper plants for better pest management outcomes.

3. In addition to their repellent properties, neem and papaya extracts have been shown to promote plant growth. Pepper plants treated with higher concentrations of neem and papaya extracts exhibited improved plant height, leaf length, and leaf width compared to the control group. Incorporating these natural extracts into crop management practices can contribute to healthier and more vigorous plant growth.

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