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Evaluation of botanical leaf extracts in the cultivation of tomato (*Solanum lycopersicum*)

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Key words: Biopesticide, Open-pollinated variety, Tomato, Pest management, Leaf extract

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Abstract

The effect of leaf extracts as biopesticide was conducted from December 2023 to February 2024 at the Jerry D' Agri Integrated Farm at Barangay Bannawag, Aurora, Isabela to determine the effect against insect pest to open-pollinated tomato variety. The study was laid out in a Randomized Complete Block Design with three replications and six types of leaf extracts as treatments applied as foliar sprays. Their efficacy was tested among the insects prevalent in the area like common cutworms, white flies, and spider mites. Results of the study indicated that the application of papaya leaf extract positively influenced plant vigor specifically at 30 days after transplanting while uniform growth was noted at later stages of the plants. Despite its insect-repellent properties, papaya leaf extract application significantly reduced non-marketable fruits per plant, highlighting its effectiveness as a pest management control scheme. Most importantly, papaya leaf extract not only minimized fruit damage due to insects but also contributed to increased fruit length and yield per hectare. Its integration into Integrated Pest Management programs for tomato cultivation is recommended, emphasizing its dual benefits in minimizing insect damage and plant health promotion. Further validation on a larger scale and across diverse geographical locations is suggested to corroborate these findings. Ultimately, the study promotes the adoption of papaya leaf extract as a sustainable solution for enhancing tomato cultivation through effective pest management and improved plant vitality.

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Introduction

In the Philippines, the use of biopesticides offers a promising path to meet sustainable development objectives amidst agricultural challenges like pest control and environmental concerns. Unlike traditional pesticides, biopesticides are made from natural sources, minimizing harm to ecosystems and human health. The adoption of biopesticides can help to reduce chemical pollution in soil and water, protecting biodiversity and ecosystem resilience. Additionally, promoting their use supports sustainable agriculture, enhancing long-term food security and decreasing reliance on synthetic chemicals.

Insects primarily cause harm to agricultural products through direct feeding. Certain species consume the endosperm, leading to a reduction in weight and quality, while others target the germ, leading to compromised seed germination and decreased viability. Consequently, the damage inflicted by insects diminishes the value of the yield for marketing, consumption, or planting purposes.

Homemade leaf extract and bio-pesticides are prepared by household using local resources such as plant extracts and other alternative organic ingredients for pest and disease control especially in vegetables. Nowadays, is now gaining popularity due to several advantages in terms of preventing the development of disease resistance due to the usual presence of several bio-active compounds, their low persistence in the environment and their generally low cost of use, particularly for smallholder farmers with limited income (Angioni *et al.*, 2005; Caboni *et al.*, 2006; Isman, 2008).

Tomato (*Solanum lycopersicum)* is a very important vegetable crop and consumed in most parts of the world, from home gardens and greenhouses to large commercial farms due to its wider adaptability to various agro-climatic conditions.

It is one of the most fashionable salad vegetables and is taken with great relish. It matures fairly quickly, needing just 60 to 85 days before it is ready to be harvested. However, tomatoes, being a widely cultivated crop, are susceptible to various pests and diseases that can impact their growth and yield. Factors such as the succulent nature of tomatoes, favorable environmental conditions, and the high nutritional value make them attractive targets for a range of pests, including insects and pathogens.

This study was designed to look for alternative agricultural inputs that can boost production of farmers, specifically, it aimed to determine the effect of leaf extracts as insect repellant on open pollinated tomato, determine the common pest that affect the growth and yield performance of common pollinated tomato, and determine which among the plant extracts lessen/control insect pest of open-pollinated tomato.

Materials and methods

Location of the study

The experiment was set-up at the Techno Demo farms located at Bannawag, Aurora, Isabela. The area is accessible to irrigation and suitable for planting vegetables.

Description of techno demo farm training center

The area is located along the creek of Bannawag, Auoram Isabela. The terrain is plain/flat, and the soil type is classified as sandy loam which most of the crops can be grown on this type of soil. Sandy loam soil promotes good drainage, with the nutrient-retaining capacity of loam soil. This makes it highly suitable for a wide range of crops, including cereals, vegetables, and fruits.

Land preparation

An area of 291.50 square meters was cleared from grasses and foreign materials, and plowed using a tractor. Final plowing and harrowing were done to maintain good tilth one week after the first plowing.

Securing of seeds

The seeds of tomato were purchased from a reliable agricultural supply at Santiago City, Isabela.

Seedling production and management

Sowing of the seeds

The seedlings of open-pollinated variety were raised in a seedling tray filled with organic soil, garden soil, rice hull ash at 1:1:1 ratio. The seedling trays were treated with organic fungicide before sowing. The seeds were sown thinly and covered with a thin layer of soil, after which these were watered evenly.

Seedling production

Watering was done as the need arises until the seedlings were ready for transplanting. The seedlings were sprayed with organic fungicide to protect them from the attack of pests and diseases.

Pricking of Seedlings

Pricking of seedlings was done by pressing the roots of the plants using the thumb and forefinger of each hand. Hardening was done by exposing the seedlings under the sun in the morning for two to three hours.

4. Plant spacing. Generally, the ideal spacing for tomato plants is between 40 by 50 centimeters apart at one seedling per hill.

Preparing the experimental area and layout

After thorough land preparation, the area was divided into three equal blocks and further subdivided into six equal plots with alleyways of one meter between blocks and half meters between plots. The Randomized Complete Block Design was used for the layout of the experiment and is shown in Figure 1.

Application of fertilizer and biopesticide

The application of vermicast was applied per hill as basal at 6 kg per plot. Biopesticide was sprayed based on the presence of insects or pests.

Collection of Pesticidal plant materials

The plants were collected from different sites in San Mateo, Isabela. These were appropriately coded. The plant materials were selected based on their application in tomato pest control.

All plant materials were washed with clean water to remove foreign materials from the samples. These were ground using a blender, mortar, and pestle. The ground materials were sieved in a 2 mm mesh and kept container ready for use.

Preparation of the different plant materials and treatments

Organic biopesticide was applied as foliar spray following the of rate of 2 table spoonful per liter of water and sprayed to the leaves of the plants. In all cases 0.1% soap was added to the water during extraction as detergent increases the extraction efficiency of non-polar compounds from plant material (Belmain *et al.,* 2012). Extracts was placed in the shaded and cool area before application. Prior to application, these was filtered twice through a coarse and then fine cloth to remove all plant material that may inadvertently clog the sprayer. The control treatment was consisted of 0.1% soap and water only. For the other treatments, this were prepared as follows:

a) Papaya, Moringa, Neem and Trumpet Leaves. One kilogram each of papaya, moringa, neem leaves and aloe vera were extracted and mixed with 3 liters of water.

b) Onion, Garlic and Ginger. Onion, Garlic and Ginger were peeled and chopped into small pieces and place in a ceramic or glass jar. These were added with 3 kilograms' crude sugar and added with 1.5 liters of 20 proof gin/liquor. The lid of the jar was covered and fermented from 7 days.

The biopesticide as treatments used in the study are as follows:

T1 – Control (Soap and Water)
T2 – Neem Leaves (30 ml/liter water)
T3 – Onion, Garlic and ginger (30 ml/liter water)
T4 – Papaya Leaves (30 ml/liter water)
T5 – Moringa Leaves (30 ml/liter water)
T6 – Aloe vera (30 ml/liter water)

Care and management of the plants

Proper care and management were done throughout the whole duration of the experiment.

Irrigation

The plants were watered properly during the period of no rainfall using the sprinkler method.

Cultivation.

Shallow cultivation was done constantly with the use of hand trowel to enhance aeration and tilth. Soil bed was covered with plastic mulch

Weeding Weeding was done regularly by hand pulling using hand trowel.

Insect and disease control

The occurrence of insect pests and diseases was minimized by spraying organic fungicide following the protocol of the Department of Agriculture (Region 02).

Harvesting

Harvesting was done 60 days after transplanting. Harvesting was done by using garden pruners or by twisting the fruit until it comes free from the vine.

Pulling of fruit when picking was avoided as this can break the tender tomato branches.

Data gathered

Plant height

Ten sample plants were randomly taken within the central portion of each plot. The height of the plants was measured at 15 days' interval, 30, 45 and 60 days after transplanting.

These were measured from the base of the plants up to the tip of the tallest leaf using yard stick.

Number of fruits per plant

The fruits of the plant were counted during harvesting. The number of fruits was counted among the ten representative samples and divided by ten to get the average per plant.

Fruit size at harvest.

The fruit size of the plants at harvest was recorded by using a tape measure.

Number of infected plants

The plants affected by various insects were determined through the application of each leaf extracts.

Number of marketable and non-marketable fruits.

Marketable fruits are those free from damage due to pests and cracks was separated and counted. Those fruits with irregular in shape and with insect bites was considered as non-marketable fruits. These was counted from the ten representative plants.

Weight of fruit per plant

The fruit weight of ten sample plants was determined with the use of digital weighing balance and further divided by ten to obtain the average weight per plant.

Weight of fruits per plot

All the fruits in the plot were weighed and recorded.

Computed yield per hectare

The computation of the yield per hectare was based on the yield obtained per plot using the formula below:

$$\text{Yield Per Hectare} = \frac{\text{Yield per Sampling Area}}{\text{Sampling Area}} \times 10{,}000\ \text{m}^2$$

Statistical analysis of the data

All the data gathered were tabulated and analyzed following the Randomized Complete Block Design. The Tukey's Honest Significant Difference Test was used if the F computed is significant.

Results and discussion

Plant Height

The application of leaf extracts in tomato plants as one approach of integrated pest management system did not register harmful effect on the early growth of the plants (Table 1).

The non-significant difference in plant heights observed at 15 days after transplanting further indicates the safety and efficacy of leaf extracts regardless of sources in tomato plants. It shows that

the application of leaf extracts did not hinder the early growth stage and established healthy tomato plants. The mean height of the plants ranged from 24.30 to 27.35 centimeters. It shows that the non-significant height increment is due to resulted to unhindered growth of the plants.

Table 1. Plant Height at 15, 30, 45 and 60 Days after Transplanting (cm) as affected by Different Leaf Extracts.

TREATMENTS	Plant Height (cm)			
	15 DAT	30 DAT	45 DAT	60 DAT
T_1 – Soap and Water	27.36	64.26ab	96.62	126.32
T_2 – Neem Leaf Extract	27.35	64.45ab	98.78	122.51
T_3 - Spices	26.08	63.25ab	96.19	125.65
T_4 – Papaya Leaf Extract	27.81	65.96a	99.40	124.54
T_5 – Moringa Leaf Extract	25.91	61.04ab	96.01	128.86
T_6 – Aloe Vera Extract	24.30	59.52b	96.77	124.63
F- RESULTS	ns	*	ns	ns
C. V. (%)	4.93	3.23	2.06	2.18

Note: Means with common letter are not significant using HSD

**- significant at 5% level*

ns – not significant

At 30 days after planting, analysis revealed variations in the height of tomato plants treated with various leaf extracts. The tallest plants were observed in Treatment 4 (Papaya leaf extract) with an average height of 65.96 centimeters, representing a percentage increase of 2.64% compared to the control (T1) plants. The significant difference on this growth parameter at 30 days after transplanting can be attributed to the absorbed nutrients and the management practices that support plant growth.

The use of papaya leaf extract as pest control agent helps plants to vigorously grew and likely it has allelopathic effect which inhibit weed germination in the area thus reducing competition for water and nutrients.

Table 2. Number of Fruits at per Plant as affected by Different Leaf Extracts.

TREATMENTS	Number of Fruits
T_1 – Soap and Water	45.00
T_2 – Neem Leaf Extract	48.83
T_3 - Spices	49.33
T_4 – Papaya Leaf Extract	50.17
T_5 – Moringa Leaf Extract	49.17
T_6 – Aloe Vera Extract	49.00
F- RESULTS	ns

ns-not significant.

Further, Christobel *et al.,* (2017) cited that papaya is known to influence the growth of plants in its vicinity by releasing allelochemicals during decomposition. It agrees to Deshmukhe *et al.,* (2009) which claimed that the substantial effect of crude aqueous papaya leaf extracts on the mortality rate of fourth instar larvae of *Spodoptera litura*, a common tomato insect in its effectiveness in plant management. During the 45 to 60 days after transplanting, no further significant height increments were recorded in any of the treatments. Tomato heights at 45 days after transplanting (96.62 cm) and 60 days after transplanting (ranging from 122.51 cm to 128.86 cm) indicates a uniform growth, suggesting that the leaf extracts applied to the plants did not have any harmful effects and favorable for plant growth and limit insect injuries that hamper growth and development. Additionally, via their effects on plant quality and production, insects can alter soil communities and their function by selectively

consuming plant material, decreasing insect abundance and would increase carbon allocation belowground, stimulating the microbial community (Hunter, 2001). The different biopesticide managed to produce a healthy plant as indicated by the similar heights in all treatments by potentially reduced feeding due to antifeedant activity of the treatments employed.

Table 3. Number of Non-Marketable Fruits as affected by Different Leaf Extracts.

TREATMENTS	Non-Marketable Fruits
T_1 – Soap and Water	14.33[a]
T_2 – Neem Leaf Extract	7.67[b]
T_3 - Spices	8.33[b]
T_4 – Papaya Leaf Extract	7.33[b]
T_5 – Moringa Leaf Extract	7.67[b]
T_6 – Aloe Vera Extract	9.33[b]
F- RESULTS	**
C. V. (%)	17.43

Note: Means with common letter are not significant using HSD

*** significant at 1% level*

Number of fruits at per plant

There were no significant differences observed in the effect of leaf extracts on fruit production of tomatoes. Botanicals are safe for non-target organisms, such as predators and pollinator because target specificity of biochemicals are found in leaf extracts. The observation that the number of fruits from the control plots showed no significant difference compared to the other treatments can be attributed to the genetic characteristics of the variety.

This suggests that the specific variety possesses an inherent genetic trait that enables it to produce a consistent number of fruits regardless of the management practices applied. The control plots likewise had mean values ranging from 45.00 to 50.17 fruits. The results contradict to the findings of Zulfiqar (2020), that plant extracts can improve plant growth and yield characteristics by positively influencing physiological processes. This demonstrates that while leaf extracts used as pest control effectively managed insect population without affecting flower production or fruit yield, comparable number of fruits was produced by the plants. Botanical pesticides exhibit diverse modes of action against target pests including repellence, toxicity, growth regulation and structural modification making them suitable alternatives for crop pest management (Kushram, 2017).

Number of non-marketable fruits per plant

Leaf extract applied to the plants leads to reduced chances of increasing the number of non-marketable fruits. As shown in Table 3, all the plots applied with leaf extracts registered lower number of non-marketable fruits.

It shows that plots without leaf extract application registered the highest number of non-marketable fruits due to white flies and spider mites damage with mean value of 14.33 fruits. These caused significant damage to tomato plants that affect both the foliage and the fruits by piercing the leaves of the plants. Feeding can weaken the plants causing wilting and yellowing of leaves.

Although leaf extract's effectiveness depends on many factors, like plant species used, the extraction solvents, whether it is dry or fresh and the extraction methods used show different modes of action, such as toxicity, growth regulation, repellent and structural modification. However, it is often designed to control a pest population to a manageable level rather than completely eradicate the target pest as in the case of the treatments applied with different leaf extracts. Leaf extracts in this case make them suitable in insect pest management with no harmful residues on crop produce as well on environment by botanical extract (Dubey *et al.,* 2008).

Table 4. Number of Infected Plants as affected by Different Leaf Extracts.

TREATMENTS	Non-Marketable Fruits
T_1 – Soap and Water	6.80^{ab}
T_2 – Neem Leaf Extract	4.67^{bc}
T_3 - Spices	6.33^{ab}
T_4 – Papaya Leaf Extract	3.00^{c}
T_5 – Moringa Leaf Extract	6.33^{ab}
T_6 – Aloe Vera Extract	8.67^{a}
F- RESULTS	**
C. V. (%)	12.52

Note: Means with common letter are not significant using HSD.

*** significant at 1% level.*

Number of Infected Plants

There was a significant difference in the number of infected plants among the treatments (Table 4). Tomatoes treated with aloe vera leaf extracts have a higher number of infected plants with 8.67 though this was comparable to the plants treated with moringa leaves, spices and the control treatments. The lowest number of infected plants were found in those treated with papaya leaf extract and neem leaf extract. The increase in infestation as reflected by the number infected plants might be the reason for increasing the heavier fruit yield. Distortion of the plant leaves could reduce the supply of nutrients to plants which interfere with the functioning of the roots hence hindering essential functions like water and nutrients uptake (Sikora and Fernandez 2005).

Weight of Fruits (g)

Fruit yield of tomatoes at different treatments had significant differences in the weight of fruits per plant (Table 5). The treatment with the heaviest weight of fruits per plant was those at Treatment 4 due to lesser number of non-marketable fruits as applied with Papaya leaf extract as insect control measures with 1416.67 grams and a percentage increase in yield of 92.04 percent over the control plots.

This indicates that as insect repellent, plants applied with papaya leaf extract had reduced number of non-marketable fruits. The rest of the treatments had produced yield but not differed with each other with mean values ranged from 737.67 grams to 1062.90 grams.

Table 5. Weight of Fruit per Plant (g) as affected by Different Leaf Extracts.

TREATMENTS	Weight of Fruits
T_1 – Soap and Water	737.67^{b}
T_2 – Neem Leaf Extract	1062.90^{b}
T_3 - Spices	905.00^{b}
T_4 – Papaya Leaf Extract	1416.67^{a}
T_5 – Moringa Leaf Extract	886.67^{b}
T_6 – Aloe Vera Extract	941.67^{b}
F- RESULTS	**
C. V. (%)	7.16

Note: Means with common letter are not significant using HSD.

*** significant at 1% level.*

The probable reason for the superiority of papaya leaf extract in promoting the production of heavier fruits compared to other treatments though the numerical increase in fruit quantity may appear insignificant, could be associated with a higher number of marketable fruits per plant, contributing to overall fruit yield. Likewise, the diverse biological functions of papaya, driven by its high content of proteolytic enzymes like chymopapain, papain, and papaya peptidase, which possess antibacterial, antiviral, and antifungal properties (Baskaran *et al.,* 2012; Maisarah *et al.,* 2013). It also offers potential multiple health benefits against infections caused by pathogenic protozoa, bacteria, and fungi, without affecting beneficial lactobacilli that also reside in the normal flora of the plants.

Table 6. Weight of Fruit per Plot (kg) as affected by Different Leaf Extracts.

TREATMENTS	Weight of Fruits
T_1 – Soap and Water	22.13[b]
T_2 – Neem Leaf Extract	31.89[b]
T_3 - Spices	27.15[b]
T_4 – Papaya Leaf Extract	42.50[a]
T_5 – Moringa Leaf Extract	26.60[b]
T_6 – Aloe Vera Extract	28.25[b]
F- RESULTS	**
C. V. (%)	9.22

Note: Means with common letter are not significant using HSD.
*** significant at 1% level.*

On the other hand, the use of various plant leaf extracts, along with a control treatment, might influence the yield of plants differently. This variability could arise from the diverse characteristics of these leaf extracts. Each plant extract contains a unique combination of chemical compounds that include primary metabolites as well as secondary metabolites (such as alkaloids, flavonoids, and terpenoids). These compounds play various roles in plant growth and defense mechanisms. Additionally, some secondary metabolites may have growth-promoting properties under certain conditions.

During specific stress conditions, these act as toxins and antibiotics. In addition to their significant role in plants (D'Arcy, 2022).

Table 7. Fruit Diameter (mm) as affected by Different Leaf Extracts.

TREATMENTS	Fruit Diameter (mm)
T_1 – Soap and Water	11.27[c]
T_2 – Neem Leaf Extract	13.47[a]
T_3 - Spices	11.90[bc]
T_4 – Papaya Leaf Extract	12.80[ab]
T_5 – Moringa Leaf Extract	11.43[bc]
T_6 – Aloe Vera Extract	11.10[c]
F- RESULTS	**
C. V. (%)	3.39

Note: Means with common letter are not significant using HSD
*** significant at 1% level.*

This agrees to the claim of Al-Safi (2021) that plant extracts have different in the characteristics in increasing the yield of the plants due to its components as these belonging to multiple families and that they contain different chemical compounds and even secondary compounds that represent effective materials.

Table 8. Computed Fruit Yield per Hectare as affected by Different Leaf Extracts.

TREATMENTS	Weight per Hectare	
	Kilograms	Tons
T_1 – Soap and Water	18441.67	18.44
T_2 – Neem Leaf Extract	26575.00	26.58
T_3 - Spices	22625.00	22.63
T_4 – Papaya Leaf Extract	35416.67	35.42
T_5 – Moringa Leaf Extract	22166.67	22.17
T_6 – Aloe Vera Extract	23541.67	23.54

Weight of Fruit per Plot (kg)

Significant variations were noted in the weight of fruits per plot among tomato plants, as shown in Table 6. Tomato plants treated with papaya leaf extract as an insect repellent yielded heavier fruits per plot, averaging 42.50 kilograms. The percentage increase in yield compared to the control treatment was 92.46% in T4 (Papaya Leaf Extract), 44.13% in Treatment 2 (Neem Leaf Extract), 22.68% in T3 (Spices), 19.74% in T5 (Moringa Leaf Extract), and 27.65% in T6 (Aloe Vera), respectively. This indicates an increase in the percentage yield when these leaf extracts were applied, resulting in higher fruit yield per plot, although comparable to the control plants.

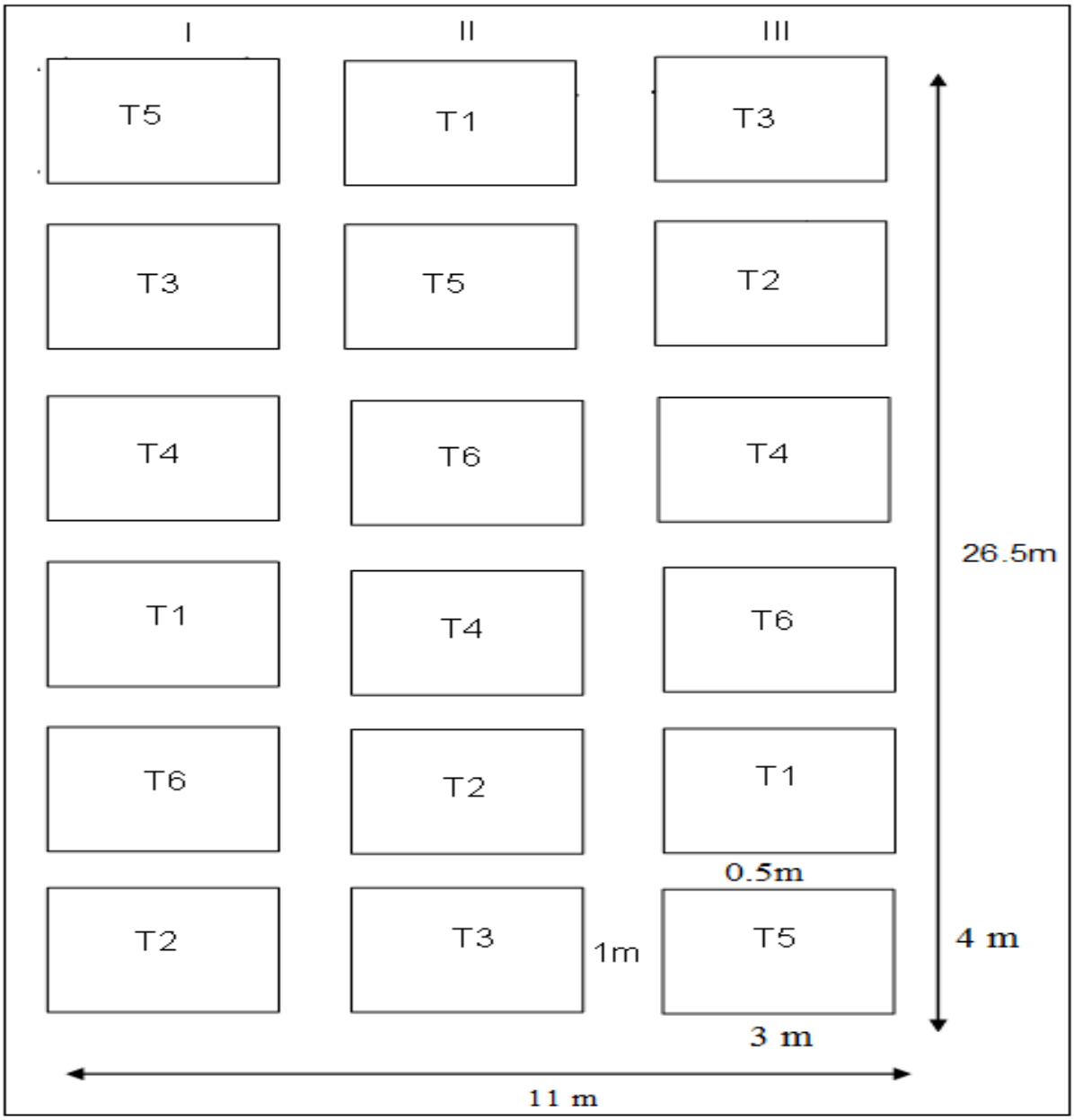

Fig. 1. Experimental Layout.

Among those leaf extract applied as insect repellant, a notable result existed particularly with papaya leaf extract application. The observed weight increase in fruits from plants treated with papaya leaf extract suggests the influence of additional nutrients, hormones, and bioactive compounds inherent in the extract. These compounds might help in fruit development, resulting in significantly heavier yields. These findings agree with prior studies highlighting the antimicrobial properties of papaya leaves that

includes macromolecules, that are functional due to its potent antiviral and immunity-enhancing properties (Ahmad, 2011).

Papaya leaves also contains fiber an essential component of plant cell walls providing structural support to the plant, minerals which playing roles in various physiological processes, and vitamins an organic compound that are responsible in various metabolic processes (Santana *et al.,* 2019). Thus, balanced supply of these nutrients ensures healthy plant growth, optimal fruit development, and improved fruit quality.

Diameter of Fruits per Plants (mm)

The fruits of tomatoes vary in diameter as shown in Table 7. The effect of neem extract (T2) and papaya leaf extract (T4) as insect repellant tend to produced bigger fruits. Consistently followed by the plants in Treatment 2 and Treatment 5 while the smallest fruits are exhibited in Treatment 1 (Control) and Treatment 6 (Aloe vera) however as shorter to the fruits produced by the plants applied with spices and moringa leaf extract.

It shows that while leaf extracts may play a role in supporting overall plant health and vigor, the primary cause of fruit size in tomatoes aside from their genetic characteristics. This inherent genetic diversity dictates the upper limit of fruit size attainable within a particular variety.

In the case of this study, the use of these two leaf extracts, as a pest and disease management strategies effectively help alleviate the negative effect of infestation on plant health and productivity particularly the use of neem and papaya extracts. This is due to neem and its derivatives have been extensively documented for their efficacy in managing insect pests, plant bacterial diseases, plant parasitic nematodes, and plant fungal diseases. Additionally, it is recognized as a promising agricultural fertilizer (Gajalakshmi &Abbasi, 2004). On the other hand, Dahunsi (2016) claimed that papaya plants also contain valuable nutrients and phytochemicals, making them a potential source of vitamins and minerals. The leaf and seed extracts of papaya have been shown to limit microbial growth efficiently. It has been shown that flavonoid, one of the phytochemicals found in papaya leaf extracts, inhibits the activity of proteases, an enzyme crucial to viral replication and assembly as claimed by Mude *et al.* (2009).

Projected fruit yield per hectare

The fruit yield per hectare of OPV tomato was influenced by various types of leaf extracts used in pest management. The yields are listed in descending order were as follows: Papaya leaf extract (T4) registered 35.42 tons per hectare. Treatment 2 yielded 26.58 tons, Neem extract treatment (T6) resulted in 23.54 tons, Treatment 3 yielded 22.63 tons, Moringa leaf extract treatment (T5) resulted in 22.17 tons and Treatment 1, which involved soap and water, resulted in 18.44 tons per hectare.

Conclusion

Among various leaf extracts, the application of papaya leaf extract as an insect repellent in tomato production not only lessen fruit damage but also boosts plant vigor effectively managing insect pests thus, resulted in a reduction in the quantity of non-marketable fruits per plant. The use of chemicals from the nearby areas helps to control the insect population resulting in a limited number of insect species observed. Despite the reduced insect count, the application of papaya leaf extract emerged as a promising strategy for insect management, promoting plant health and enhancing tomato fruit yield.

Based from the results of the study, it is recommended the use of papaya leaf extract as an insect repellent in tomato cultivation. The integration of papaya leaf extract as a component of Integrated Pest Management programs for tomato cultivation is recommended, highlighting its advantages in both insect management and enhancing plant health in tomato cultivation emphasizing its dual benefits as insect control and plant health promotion. Further studies are recommended to validate the findings on a

larger scale and across different geographical locations to validate the results of the study.

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