Original Research Article

Naturally Available Insecticidal Materials and their Mixtures: An Eco-friendly Approach for the Management of Soil dwelling Insect Pests of Potato

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ABSTRACT

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| The persistent use of synthetic insecticides against the soil-dwelling insect pests in potato may initially give some control against these pests, but in the long term, it will pose a threat to the ecosystem causing the resurgence of other pest species. Moreover, indiscriminate use of insecticides and their residues in the soil and plant system are causing hazardous effects on the Soil Microbial Biomass Carbon (SMBC), soil physico-chemical properties, soil enzymatic activities, beneficial insect fauna, human and animal health as well as environment. Furthermore, considering the present pest management scenario, there is an urgent need to embrace organic pest management strategies instead of chemocentric approaches. The aim of the study was to evaluate the effectiveness of some naturally available insecticidal materials against major soil insect pests of potato under laboratory conditions. During the study, locally and naturally available eco-friendly insecticidal materials (14 nos.) were collected and categorized into four groups (Physical poisons, Biopesticides & bio-enhancer, Botanicals and Minerals) based on their different properties. Individual screening of these 14 individual insecticidal materials was carried out under laboratory conditions against the test insects i.e. cutworm (*Agrotis ipsilon*), white grub (*Lepidiota mansueta*) and red ant (*Dorylus orientalis*). Based on the performance of 14 individual insecticidal materials, 11 insecticidal materials were selected and 3 materials (cow dung powder, lime powder and rock phosphate) were discarded. From 11 insecticidal materials, 15 mixtures (Mixture I-XV) were prepared by following the "Trial and Error" method. Considering the efficacy performance of these 15 insecticidal mixtures against the above-mentioned test insects, 5 superior insecticidal mixtures (Mixture-II, IV, VIII, XI and XIII) were selected. Highest mortality (100%) of *A. ipsilon* larvae was recorded in Mixture-II, Mixture-IV, Mixture-VIII, Mixture-XI and Mixture-XIII and found to be significantly superior over rest of the mixtures after 144 hrs of exposure (*P=.05*, CD=4.44). A similar trend of results was also registered against *L. mansueta* grubs. Likewise, significant mortality of *D. orientalis* was recorded in Mixture-II, Mixture-IV, Mixture-VIII, Mixture-XI and Mixture-XIII over the other mixtures (I, V, VI, VII, X, XIV & XV) after 48 hrs of exposure (*P=.05*, CD=17.42). This research relates to the development of organic insecticidal mixtures by using naturally available eco-friendly insecticidal materials with an aim to address the soil dwelling insect pests problems in potato grown organically. However, these organic insecticidal mixtures will act as ‘bioenhancers’ favouring the multiplication of beneficial soil microbes and other microarthropods besides improving the physico-chemical properties of soil and might be used to replace the commonly used synthetic insecticides. Exploration of these findings has enough scope for researchers to study the efficacy of these mixtures at field conditions against soil-dwelling insect pests with an aim to replace the commonly used synthetic insecticides.Farmers can reduce their reliance on synthetic pesticides and implement a more resilient and sustainable IPM strategy by combining these mixtures with biological, cultural and mechanical control techniques. |

Keywords: Agrotis ipsilon, Dorylus orientalis, Insecticidal mixture, Lepidiota mansueta, *Soil insect*

1. INTRODUCTION

Potato (*Solanum tuberosum* L.), the king of vegetables, is one of the leading staple food crops grown approximately in 140 countries around the world (Haase *et al.,* 2008). India, the world's second-largest producer of potatoes, witnessed an increase in area from 0.234 million hectares in 1949-50 to 2.332 million hectares in 2022-23 (Singh and Dutt, 2024), which corresponded to an increase in production from 1.54 to 60.14 million tonnes in 2023 (Singh and Dutt, 2024). This enabled India to recover its average productivity from 6.58 t/ha in 1949-50 to 25.79 t ha-1 in 2022-23 (Singh and Dutt, 2024). Being an important cash crop and major food item of the Indian diet, the potato is extensively cultivated in both plains and hills of the Northeastern region of India. A total of 773.37 thousand tonnes of potatoes were produced in Assam in 2022-2023 which contributes 1.29% of the total potato production in India during 2022-23 (Singh and Dutt, 2024). Insect pests cause an average of 16% of losses in potato crops worldwide, while decreases in tuber production and quality can range from 30% to 70% (Bairwa *et. el.,* 2024). In India, approximately 10-12% of total potato tuber production is lost annually due to pest damage, which is approximately worth Rupees 60 billion (Chandel *et al.,* 2013). This ubiquitous crop is attacked by more than 100 arthropods, about 10 diseases and a few species of nematodes throughout India. Out of which, soil-dwelling arthropod pests like cutworms, white grubs and red ants are among the most destructive and troublesome agricultural pests of potato in North East India both in hills and plains (Khaund, 1979; Bhattacharyya *et al.,* 2010; Bhattacharyya *et al.,* 2014; Nath *et al.,* 2014; Sarma *et al.,* 2016; Devi *et al.,* 2022; Dumala *et al.,* 2023).

The persistent use of synthetic insecticides against the soil-dwelling insect pests in potato may initially give some control against these pests, but in the long term, it will pose a threat to the ecosystem causing the resurgence of other pest species like *Polyphagotarsoneus latus*, *Bemisia tabaci* and *Aphis gossypii* (David, 1991). Moreover, indiscriminate use of insecticides and their residues in the soil and plant system are causing hazardous effects on the Soil Microbial Biomass Carbon (SMBC), soil physico-chemical properties, soil enzymatic activities, beneficial insect fauna, human and animal health as well as environment. Furthermore, considering the present pest management scenario, there is an urgent need to embrace organic pest management strategies instead of chemocentric approaches. Various earlier workers had attempted to evaluate the efficacy of different plant-origin botanicals *viz.,* neem cake, mustard oil cake (Bhattacharyya *et al.,* 20214; Munib, 2014, Dumala *et al.,* 2023), neem leaf crude extracts and other organic substances like lime, etc. in managing soil insect pests. But the expected results from the sole application of these organic materials are not achieved to manage the targeted insect pests for various reasons. Botanical pesticides are generally highly bio-degradable and rapidly break down in sunlight, air and water thus they become inactive within hours or a few days (Oguh *et al.,* 2019). It was realized that there may be an adequate improvement in terms of efficacy when different organic insecticidal materials are applied in combination as a mixture to manage the targeted insect pests since the organic substances have a different modes of entry/action. A safe, economical and effective "Insecticidal Mixture" could be a viable option to address soil insect pest problems in potato grown organically. Such types of insecticidal mixtures may also act as "Bioenhancer" favoring the multiplication of beneficial soil microbes and other microarthropods besides improving the biological as well as physico-chemical properties of soil. Because of the aforementioned facts and realizing the importance of eco-friendly management, the present study was undertaken to assess the effectiveness of some naturally available insecticidal materials against major soil insect pests of potato under laboratory conditions.

2. material and methods

Experiments were carried out to evaluate the effectiveness of insecticidal materials against some soil insect pests of potato during 2017-18 to 2019-20 in the Soil Arthropod Pests Laboratory, All India Network Project (AINP) on Soil Arthropod Pests (SAP), Department of Entomology, Assam Agricultural University (AAU), Jorhat. Initially, 14 numbers of naturally available eco-friendly insecticidal materials were selected and grouped into four groups (Group I-Physical poisons, Group II-Biopesticides & bio-enhancers, Group III-Botanicals and Group IV-Mineral origin) based on their different properties (Table 1). Individual screening of these materials was carried out against cutworm (*Agrotis ipsilon*), white grub (*Lepidiota mansueta*) and red ant (*Dorylus orientalis*). Considering the performance of 14 individual insecticidal materials, 15 numbers of insecticidal mixtures were prepared solely based on their laboratory efficacy and miscibility through trial and error method. Besides, screenings of these 15 insecticidal mixtures were also carried out against the above pest species to find the best 5 insecticidal mixtures based on their performance.

**Table 1. Different insecticidal materials tested**

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| **Sl. No.** | **Materials**  | **Mode of action**  |
| **Group I: Physical poisons** |
| 1. | Fine sand | Removes or absorbs epicuticular lipid layer, water loss through the cuticle (Ebeling and Wagner, 1961; Tarshis, 1961, Dumala *et al.,* 2023) |
| 2. | Wood ash |
| 3. | Saw dust |
| **Group II: Biopesticides & bioenhancers** |
| 4. | Cow dung powder  | Repellent (Pathak and Ram, 2002) |
| 5. | Cow urine  | Repellent (Pathak and Ram, 2002) |
| 6. | Mustard oil cake | Growth inhibition, prevention of moulting (Kaushik and Kathuria, 2005, Dumala *et al.,* 2023) |
| **Group III: Botanicals** |
| 7. | Neem leaf powder  | Contact & stomach poison, oviposition deterrent, repellent, metabolic disruptor and toxicant (Chand and Tiwari, 2010; Mishra and Pandey, 2014; Devanand and Kamala, 2017) |
| 8. | Jatropha leaf powder  | Antifeedant, toxicant (Kumari and Chandla, 2010; Ingle et al., 2017) |
| 9. | Pongamia seed powder  | Antifeedant and repellent (Devanand and Kamala, 2017) |
| 10. | Tobacco leaf powder | Stomach poison and repellent (Devanand and Kamala, 2017) |
| 11. | King chilli powder | Toxicant, stomach poison (Baskaran and Narayanasamy, 1995; Tesfayeand Gautam, 2003) |
| **Group IV: Mineral origin** |
| 12. | Lime powder | Removes or absorbs epicuticular lipid layer, water loss through the cuticle (Tarshis, 1961) |
| 13. | Charcoal powder  |
| 14. | Rock phosphate  | Desiccation by destroying the wax layer in the cuticle (Obeng Ofri, 2010) |

**2.1 Collection and preparation of insecticidal materials**

All readily and naturally available insecticidal materials (14 numbers) were collected from different villages of the Jorhat district of Assam and brought to the laboratory. After sun drying, these materials were powdered by using a mixer grinder followed by sieving (size: 125 mm). The materials so prepared were stored in plastic containers (5 lit capacity) for further use.

**2.1.1 Collection of test insects and rearing**

*2.1.1.1 Cutworm*

Third and fourth instar larvae of A. ipsilon were collected from diverse habitats from the Instruction-cum-Research (ICR) Farm, AAU Jorhat (26.72° N latitude and 94.19° E longitude) and Maharichuk Village of Majuli river island (27.0016° N latitude and 94.2243° E longitude), Assam from December to February 2017-18 and 2018-19. Collected larvae were brought to the laboratory and reared in disposable plastic cups (8 cm height × 7 cm diameter) by putting a single larva in each cup filled with 3/4th portion of each cup with sterilized soil. Soils were sterilized at 105°C by using a hot air oven. Cut potatoes were provided as larval feeding materials and the top of the cup was covered with a black muslin cloth. Each rearing cup was examined daily and water was sprayed as and when required to keep the soil in moist conditions.

*2.1.1.2 White grub*

Third instar grubs of L. mansueta were collected from the riverside area of Maharichuk Village of Majuli island (27.0016° N latitude and 94.2243° E longitude) from October to November 2018. To avoid cannibalism, grubs were kept individually in each disposable plastic cup and brought to the laboratory and reared in disposable plastic cups (8 cm height × 7 cm diameter). The 3/4th portion of each cup were filled up with sterilized soils collected from Majuli River Island and cut potatoes were offered as food to the grubs. Cups were roofed with a black muslin cloth and the soil inside the cup was kept moistened by sprinkling water at regular intervals.

*2.1.1.3 Red ant*

Matured red ants were collected from the potato fields of Charaibahi village (26.2886° N latitude and 92.4566° E longitude), Jorhat, Assam during February-March, 2019 by using bait prepared by mixing ripe banana, jaggery and clarified butter (@ 50:35:15). Collected ants were brought to the laboratory and reared in a plastic bowl (15 cm height × 48 cm diameter) half-filled with sterilized soil. The top of the bowl was covered with a black muslin cloth. Potato was provided as food to the ants inside the rearing bowl.

**2.1.2 Evaluation of insecticidal materials against the test insects**

To evaluate the efficacy, screening of 14 individual insecticidal materials (Table 1) was carried out separately under laboratory conditions against *A. ipsilon* larvae, *L. mansueta* grubs and *D. orientalis* workers. Initially, insecticidal materials were added separately @ 1 g, 3 g and 5 g in 50 g of sterilized soil and tested against these insects. In case of all the test insects, maximum per cent mortality was registered when materials were applied @ 5 g/50 g soil and hence this dose was considered for further evaluation. Materials were added separately @ 5 g in 50 g of sterilized soil in plastic disposable cups (8 cm height × 7 cm diameter) where laboratory-reared uniform-sized of *A. ipsilon* larvae and *L. mansueta* grubs were released and the top of the cups were wrapped with a black muslin cloth. There were five replications per treatment considering one larva per replication to avoid cannibalism among them. However, petri plates (150 mm × 20 mm) were used to evaluate insecticidal materials against *D. orientalis* and in this case, five fully matured ants having more or less uniform sizes (3-6 mm) were placed per replication with the help of a camel hairbrush. Cut potatoes were provided as food materials inside the cups/petri plates. Each rearing cup/petri plate was examined daily and clean water was sprinkled to keep the soil moist. Data on the mortality of the test insects were recorded at 24 hours intervals.

**2.1.3 Evaluation of insecticidal mixtures against the test insects**

Based on the performance of 14 individual insecticidal materials against the test insects, 11 insecticidal materials were selected and 3 materials (cow dung powder, lime powder and rock phosphate) were discarded. From 11 insecticidal materials, 15 mixtures (Mixture I-XV) were prepared by following the "Trial and Error" method (Table 2). There were 5 ingredients per mixture and an equal quantity (5 g) of each ingredient was taken to prepare the mixtures that yielded 25 g per mixture, out of which 5 g was taken and mixed with 50 g of sterilized soil in a glass beaker (500 ml capacity) followed by immediate release of the *A. ipsilon* larva. There were five replications per mixture allowing one larva per replication. Plastic disposable cups (8 cm height × 7 cm diameter) and petri plates (150 mm × 20 mm) were used in case of *L. mansueta* (one larva/replication) and *D. orientalis* (five red ants/petri plate). Cut potatoes were provided as feeding material to the test insects. Data on the mortality of the test insects were recorded at 24 hours intervals. Considering the efficacy of 15 insecticidal mixtures against the above-mentioned test insects, 5 superior insecticidal mixtures (Mixture-II, IV, VIII, XI and XIII) were selected.

**Table 2. Insecticidal mixture prepared based on laboratory efficacy of individual materials against targeted soil insect pests**

|  |  |  |
| --- | --- | --- |
| **Mixtures** | **Treatments considered as** | **Insecticidal Materials** |
| I | T1 | Mustard oil cake | Cow urine | Wood ash | Neem leaf powder | Find sand |
| II | T2 | Mustard oil cake | Cow urine | Wood ash | Neem leaf powder | Saw dust |
| III | T3 | Mustard oil cake | Cow urine | Wood ash | Neem leaf powder | Charcoal powder |
| IV | T4 | Mustard oil cake | Cow urine | Wood ash | Tobacco leaf powder | Find sand |
| V | T5 | Mustard oil cake | Cow urine | Wood ash | Tobacco leaf powder | Saw dust |
| VI | T6 | Mustard oil cake | Cow urine | Wood ash | Tobacco leaf powder | Charcoal powder |
| VII | T7 | Mustard oil cake | Cow urine | Wood ash | Jatropha leaf powder | Find sand |
| VIII | T8 | Mustard oil cake | Cow urine | Wood ash | Jatropha leaf powder | Saw dust |
| IX | T9 | Mustard oil cake | Cow urine | Wood ash | Jatropha leaf powder | Charcoal powder |
| X | T10 | Mustard oil cake | Cow urine | Wood ash | Pongamia seed powder | Find sand |
| XI | T11 | Mustard oil cake | Cow urine | Wood ash | Pongamia seed powder | Saw dust |
| XII | T12 | Mustard oil cake | Cow urine | Wood ash | Pongamia seed powder | Charcoal powder |
| XIII | T13 | Mustard oil cake | Cow urine | Wood ash | King chilli powder | Find sand |
| XIV | T14 | Mustard oil cake | Cow urine | Wood ash | King chilli powder | Saw dust |
| XV | T15 | Mustard oil cake | Cow urine | Wood ash | King chilli powder | Charcoal powder |

**2.2 Statistical analysis**

Data were analyzed by using SPSS (Statistical Package for the Social Sciences) software. For statistical significance, the difference between the treatment means was tested with an appropriate critical difference (CD) value at a 5% level of probability.

3. results and discussion

**3.1 Effectiveness of insecticidal materials against the test insects**

Data on the effectiveness of four groups of insecticidal materials (14 numbers) against *A. ipsilon* larvae, *L. mansueta* grubs and *D. orientalis* and their mean mortality (%) at different time intervals under laboratory conditions are presented in Table 3.

*A. ipsilon* larvae

When the per cent mortality was recorded treatment-wise and compared after 120 hours of exposure, the neem leaf powder, jatropha leaf powder, pongamia seed powder and tobacco leaf powder registered the highest mortality (13.3% each) and was found to be statistically at par with rest of the insecticidal materials (*P=.05*, CD=1.51). After 144 hours of exposure, neem leaf powder and pongamia seed powder recorded the maximum (33.3% each) mortality and were found to be statistically superior over the other materials except wood ash, cow urine, mustard oil cake, jatropha leaf powder, tobacco leaf powder and king chilli powder (*P=.05*, CD=1.97). Pongamia seed powder showed significantly highest mortality (46.6%) over other treatments except for mustard oil cake, neem leaf powder, jatropha leaf powder, tobacco leaf powder and king chili powder (*P=.05*, CD=2.24) after 168 hours of treatment. Highest mortality (60%) was obtained after 192 hours of exposure in regards to pongamia seed powder followed by neem leaf powder (46.6%) and mustard oil cake/ jatropha leaf powder/ tobacco leaf powder/ wood ash (33.3% each) was found to be statistically superior over all insecticidal materials including control (*P=.05*, CD=2.30). No mortality of cutworm larvae was recorded in cow dung powder, lime powder and rock phosphate treated soil even after 192 hours of exposure, and hence discarded (Table 3).

*L. mansueta* grubs

A perusal of data presented in Table 3 revealed that the neem leaf powder and pongamia seed powder recorded the highest mortality (13.3% each) after 120 hours and was found to be non-significant with the rest of the insecticidal materials. However, neem leaf powder and pongamia seed was found to be statistically superior over the other materials tested except jatropha leaf powder and tobacco leaf powder causing maximum mortality (33.3%) after 144 hours of exposure (*P=.05*, CD=1.74). Significantly highest mortality (46.6%) was registered in pongamia seed powder over other treatments except neem leaf powder, jatropha leaf powder and tobacco leaf powder (*P=.05*, CD=2.13) after 168 hours of experimentation. Nonetheless, pongamia seed powder registered the highest mortality (53.3%) and was found to be significantly superior to other insecticidal materials except neem leaf powder (46.66%), jatropha leaf powder (46.66%), mustard oil cake (33.3%), tobacco leaf powder (33.3%) and king chilli powder (33.3%) after 192 hours of exposure (*P=.05*, CD=2.30). After 192 hours, cow dung powder, lime powder and rock phosphate were discarded because of their inefficacy.

*D. orientalis*

Pongamia seed powder caused the highest (12%) mortality of D. orientalis and it was found to be at par with neem leaf powder (10.6%), jatropha leaf powder (9.3%) and tobacco leaf powder (8.0%) (*P=.05*, CD=0.68) and found significantly superior over rest of the materials after 24 hours of treatment. After 48 hours of the treatment, the pongamia seed powder registered significantly highest mortality (25.3%) over other treatments except neem leaf powder (21.3%), tobacco leaf powder (18.6%), jatropha leaf powder (18.6%) and king chilli powder (16.0%) (*P=.05*, CD=0.81). Significantly highest mortality (44.0% & 50.6%) was observed in pongamia seed powder at 72 (*P=.05*, CD=0.74) and 96 hours (*P=.05*, CD=0.51), respectively over other treatments. No mortality of the red ants was recorded in fine sand, sawdust, cow dung powder, lime powder and rock phosphate treated soil at different time intervals and hence discarded (Table 3).

**Table 3. Effectiveness of four groups of insecticidal materials against the tested insects under laboratory conditions**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Groups** | **Treatment** | ***Agrotis ipsilon* larvae** | ***Lepidiota mansueta* grubs** | ***Dorylus orientalis***  |
| **Mean mortality (%) at different time intervals** |
| **120 hours** | **144 hours** | **168 hours** | **192 hours** | **120 hours** | **144 hours** | **168 hours** | **192 hours** | **24 hours** | **48 hours** | **72 hours** | **96 hours** |
| Group IPhysical poisons | Fine sand | 0.0(1.00) | 0.0(1.00) | 6.6(1.60) | 13.3(2.21) | 0.0(1.00) | 0.0(1.00) | 6.6(1.60) | 6.6(1.60) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) |
| Wood ash | 0.0(1.00) | 20.0(2.81) | 20.0(2.81) | 26.6(3.41) | 0.0(1.00) | 13.3(2.21) | 13.3(2.21) | 20.0(2.81) | 0.0(1.00) | 4.0(1.72) | 14.6(3.10) | 26.6(4.41) |
| Saw dust | 0.0(1.00) | 0.0(1.00) | 20.0(2.81) | 20.0(2.81) | 0.0(1.00) | 0.0(1.00) | 13.3(2.21) | 20.0(2.81) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) |
| Group IIBiopesticides & bioenhancers | Cow dung powder | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) |
| Cow urine | 0.0(1.00) | 20.0(2.81) | 20.0(2.81) | 20.0(2.81) | 0.0(1.00) | 13.3(2.21) | 20.0(2.81) | 20.0(2.81) | 1.3(1.24) | 6.6(2.08) | 20.0(3.82) | 33.3(4.94) |
| Mustard oil cake | 0.0(1.00) | 20.0(2.81) | 26.6(3.41) | 33.3(4.02) | 0.0(1.00) | 13.3(2.21) | 20.0(2.81) | 33.3(4.02) | 4.0(1.72) | 12.0(3.03) | 21.3(3.94) | 37.3(5.22) |
| Group IIIBotanicals | Neem leaf powder | 13.3(2.21) | 33.3(4.02) | 40.0(4.62) | 46.6(5.22) | 13.3(2.21) | 33.3(4.02) | 33.3(4.02) | 46.6(5.22) | 10.6(2.79) | 21.3(3.78) | 37.3(5.02) | 45.3(5.72) |
| Jatropha leaf powder | 13.3(2.21) | 20.0(2.81) | 33.3(4.02) | 33.3(4.02) | 6.6(1.60) | 20.0(2.81) | 33.3(4.02) | 40.0(4.62) | 9.3(2.55) | 18.6(3.58) | 34.6(4.85) | 44.0(5.65) |
| Pongamia seed powder | 13.3(2.21) | 33.3(4.02) | 46.6(5.22) | 60.0(6.43) | 13.3(2.21) | 33.3(4.02) | 46.6(5.22) | 53.3(5.83) | 12.0(2.92) | 25.3(4.21) | 44.0(5.60) | 50.6(6.10) |
| Tobacco leaf powder | 13.3(2.21) | 20.0(2.81) | 33.3(4.02) | 33.3(4.02) | 6.6(1.60) | 20.0(2.81) | 33.3(4.02) | 33.3(4.02) | 8.0(2.43) | 18.6(3.73) | 33.3(4.88) | 41.3(5.45) |
| King chilli powder | 6.6(1.60) | 20.0(2.81) | 20.0(2.81) | 20.0(2.81) | 6.6(1.60) | 20.0(2.81) | 20.0(2.81) | 33.3(4.02) | 6.6(2.19) | 16.0(3.40) | 32.0(4.66) | 38.6(5.27) |
| Group IVMineral origin | Lime powder | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) |
| Charcoal powder | 0.0(1.00) | 0.0(1.00) | 6.6(1.60) | 20.0(2.81) | 0.0(1.00) | 0.0(1.00) | 6.6(1.60) | 20.0(2.81) | 0.0(1.00) | 6.6(2.19) | 16.0(3.37) | 22.6(4.07) |
| Rock phosphate | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) |
|  | Control | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) | 0.0(1.00) |
| S.Ed (±) | 0.58 | 1.00 | 1.13 | 1.17 | 0.54 | 0.88 | 1.08 | 1.16 |  0.35 | 0.41 | 0.38 |  0.26 |
| CD at 5% | 1.51 | 1.97 | 2.24 | 2.30 | N/A | 1.74 | 2.13 | 2.28 |  0.68 | 0.81 | 0.74 |  0.51 |

Dose: 5g material per 50 g soil, Data based on five replications, Data in the parentheses are square root transformation value, Feeding material provided: cut potato tuber, N/A – Not available

**3.2 Effectiveness of insecticidal mixtures against test insects under laboratory conditions**

A perusal of data presented in Figure 1 on the effectiveness of various insecticidal mixtures (15 numbers) against *A. ipsilon* under laboratory conditions, revealed the complete mortality (100%) of cutworm larvae in T2-Mixture-II, T4-Mixture-IV, T8-Mixture-VIII, T11-Mixture-XI and T13-Mixture-XIII and was significantly superior over rest of the mixtures after 144 hours of exposure (*P=.05*, CD=4.44). However, no significant differences were noticed in the mortality of the larvae among the mixtures at 96 and 120 hours of exposure. A similar trend of results was also obtained in case of *L. mansueta* grubs after 144 hours of exposure (*P=.05*, CD=4.25) (Fig. 2). Likewise, significant mortality (100%) of red ants was registered in T2-Mixture-II, T4-Mixture-IV, T8-Mixture-VIII, T11-Mixture-XI and T13-Mixture-XIII over the mixtures after 48 hours of exposure (*P=.05*, CD=17.42 (Fig. 3). Based on the efficacy of 15 insecticidal mixtures tested against three major soil dwelling insect pest species, 5 superior insecticidal mixtures (viz., mixture - II, IV, VIII, XI & XIII) were selected under laboratory conditions.

The effect of various naturally available insecticidal materials, alone or in combination had been attempted by earlier workers (Chander *et al.,* 2007; Sarma *et. al.,* 2016; Chowdhury *et al.,* 2023). Grain protectants like sawdust, sandy soil, dung cake ash, etc. were found significantly effective in suppressing egg-laying, adult emergence and seed damage caused by *Callosobruchus chinensis* on greengram seeds as compared to the untreated control after 35, 70 and 105 days of storage (Chander *et al.,* 2007). Diatomaceous earth and ash produced from rice husk, cow dung cake, maize cobs, wood, etc. were extensively used for safe and eco-friendly management of various insect pests of vegetables and storage (Mihale *et al.,* 2009; Barooah and Pathak, 2009; Kadam, 2012; Agrafioti *et al.,* 2023). Present findings are closure to the observation made during the study on the effect of 20 plant powders @ 2% against *Sitophilus oryzae* infesting paddy grains that recorded the highest mortalities (99.10%) in *Vitex negundo* followed by *Alpinia officinarum* (96.6%) and *Nelumbo speciosum* (94.4%) (Govindan and Nelson, 2009). Moreover, the efficacy of aqueous neem extract @ 1 kg/40 lit of water were registered against *Agrotis* sp. in potato from Sudan (Sidding *et al.,* 1993). An aqueous solution of azadirachtin (0.00045%) and cattle urine extract of tobacco dust (5 g/lit solution of cattle urine and water @1:5 ratio and kept for 24 hours) was also observed effective when drenched in the soil @ 25 ml/plant against red ants in potato (Joshi, 1998). Effectiveness of cow urine extracts (5ml/lit) of *Azadirachta indica*, *Sapindus mukorossi*, *Chrysanthemum cinerariaefolium*, *Nerium oleander*, *Jatropha curcas*, *Urtica dioica* and *V. negundo* was also recorded against *Brahmina coriacea* in potato (Rani *et al.,* 2009). Present findings also corroborate the findings of other workers who observed the efficacy of *Pongamia pinnata* seed extracts @ 5% against *Helicoverpa armigera* and recorded 1st instar larval mortality (>50%) along with feeding deterrence (>65%) of 3rd instar larvae (Reena *et al.,* 2012). Uses and efficiency of various minerals viz., charcoal, clay, common salt, red earth, calcium carbonate, river sand etc. were also documented against various insect pests (Baskaran and Narayanasamy, 1995).

The present investigation indicates that there could be an adequate improvement in terms of efficacy when the different insecticidal materials were applied in combination since the different organic substances used in the mixture have different modes of entry/action on insects and other targeted pests. Moreover, sometimes the sole application of insecticidal materials did not perform up to their potential to manage targeted insect pests. Previous research revealed that a mixture of cow urine + Neem Seed Kernal Extract (5%) + cow dung (5%) acted as an oviposition deterrent and antifeedant to *H. armigera* adults and larvae, respectively and thereby minimized the damage to matured pigeon pea pods (Sadawarte and Sarode, 1997). When neem, *J. curcas*, *Sapindus mukorossi*, *C. cinerariaefolium*, *E. globulus*, *V. negundo*, *N. oleander* and *U. dioica* were mixed with cow urine (9:1 parts) and applied against white grub, *B. coriacea* showed that NSKE in cow urine resulted in no egg-laying, minimum egg hatching (14-17%) and less survival (6-7%) and maximum mortality of 1st instar larvae (93-97%) over the untreated control (Kumari *et al.,* 2010). Spraying of neem extract, *S. mukorossi* or *J. curcas* and cow urine were also found effective to manage whitefly, *T. vaporariorum* and caused 82-98% mortality of the pest in potato (Kumari and Chandla, 2010). The present study has confirmed superiority of five insecticidal mixtures (II, IV, VIII, XI & XIII) against three major soil insect pests of potato under laboratory conditions. However, the application impact of those mixtures on physico-chemical & biological properties of soil, soil microbial biomass carbon and other soil inhabiting micro & macro arthropods needs to be assessed before recommending the best mixture for field use against the targeted insect pests.

**Fig. 1. Mean mortality (%) of *Agrotis ipsilon* larvae as affected by different insecticidal mixtures at different time intervals**

*h – hours*

*T1 to T15- Refer Table 2 for treatment details*

*T16: Untreated control*

**Fig. 2. Mean mortality (%) of *Lepidiota mansueta* grubs as affected by different insecticidal mixtures at different time intervals**

*h – hours*

*T1 to T15- Refer Table 2 for treatment details*

*T16: Untreated control*

**Fig. 3. Mean mortality (%) of *Dorylus orientalis* as affected by different insecticidal mixtures at different time interval**

*h – hours*

*T1 to T15- Refer Table 2 for treatment details*

*T16: Untreated control*

4. Conclusion

This research relates to the development of organic insecticidal mixtures by using naturally available eco-friendly insecticidal materials that were studied against the major insect pests of potato with an aim to address the insect pests problems in potato grown organically. However, these organic insecticidal mixtures will act as ‘bioenhancers’ favouring the multiplication of beneficial soil microbes and other micro-arthropods besides improving the physico-chemical properties of soil and might be used to replace the commonly used synthetic insecticides. This investigation will be helpful in addressing the multifaceted soil insect pests complex of potato. Exploration of these findings has enough scope for researchers to study the efficacy of these mixtures at field conditions against soil-dwelling insect pests with an aim to replace the commonly used synthetic insecticides. Moreover, this could open one of the income-generating avenues for start-up small-scale and cottage industries as well as for many bio-pesticide manufacturers in India.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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