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PLANT PROTECTION | ORIGINAL ARTICLE

Eco-Friendly Management of Potato Tuber Moth *(Phthorima operculella* Zeller) Under Storage and Field Condition in Dailekh, Nepal

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ABSTRACT

Potato tuber moth (PTM), (*Phthorima operculella* Zeller) is one of the most destructive pests of potato damaging the potato tuber in the field and storage condition leading to huge loss of potato tubers. An experiment was conducted to access the effect of different treatments for eco-friendly management of potato tuber moth in field and storage condition in Dailekh, Nepal. The experiment was conducted in Randomized Complete Block Design (RCBD) and Completely Randomized Design (CRD) in field and storage condition respectively with 10 different treatments and 3 replications. The treatments were T_1 (Control), T_2 (*Bacillus thuringiensis*), T_3 (*Artemisia vulgaris*), T_4 (Malathion) as check, T_5 (*Lantana camara*), T_6 (*Coriandrum sativum*), T_7 (*Curcuma longa*), T_8 (*Azadirachta indica* oil 5%EC), T_9 (*Justicia adhatoda*) and T_{10} (*Yucca* sp.). Among the different treatments, *Azadirachta indica* oil 5%EC showed the least foliage damage and severity which was statistically at par with Malathion and *Curcuma longa*. Similarly, pre-sowing treatment of tuber with Malathion had least infestation caused by PTM at tuber harvest which was at par with pre-sowing treatment with *Curcuma longa*, *Yucca* sp. and *Bacillus thuringiensis*. Tuber treated with Malathion before storage showed least infestation percentage and severity caused by PTM followed by *Coriandrum sativum, Curcuma longa* and *Lantana camara.* Tuber rot caused by PTM in the storage condition was found least in the tuber treated with Malathion, *Coriandrum sativum, Curcuma longa and Yucca* sp. Analyzing all the parameters, eco-friendly management of PTM can be done by successive spray of *Azadirachta indica* oil 5%EC and *Curcuma longa.* Likewise, pre-sowing treatment with *Curcuma longa*, *Yucca* sp. and *Bacillus thuringiensis* reduces the tuber infection at tuber harvest. Seed tuber when treated with different botanicals could protect tuber from PTM infestation during storage. The most potent powders were *Lantana camera*, *Coriandrum sativum* and *Curcuma longa* against PTM

1. Introduction

The potato tuber moth (PTM), *Phthorimaea operculella* (Zeller) which belongs to Gelechiidae class of order Lepidoptera, is an important storage pest of potato (*Solanum tuberosum* L.). Potato tuber moths are mainly associated with potatoes. However, they have been observed feeding on other plants such as tomatoes, eggplants (*Solanum melongena* L.), peppers (*Capsicum* spp.), tobacco, and wild solanaceous plants like Jimson weed or datura (*Datura stramonium* L.) (Aryal & Simkhada, 2020). Mostly infestation in the store starts through freshly harvested infested tubers or through moths entering the storage facilities. Larvae that come out from the eggs in tubers make them unsuitable for sale, consumption and cultivation. Damage increases rapidly when several generations develop during the storage period. Larvae are capable of causing damage to the crop either in the field or in the store (Sharaby&Fallatah, 2019). Low infestationby potato tuber moth in the field condition helps to keep infestation far in the storage condition as most of PTM gets into the storage through infested tuber in field (Hanafi, 1999).

Potato tuber moth becomes active during the period of February from the hibernating larvae of previous year (Chandel et. al., 2001). They prefer laying eggs on the leaf of the plant as the temperature gets rise above 17^0C. As the temperature increases, the infestation also increases adult female lays about 100-150 spherical, translucent white to yellow eggs. White eggs are hatched in 4-10 days and light brown colored larva starts mining in the leaves of

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the potato. As they move towards tuber, they bore into it from where they reach to the storage condition and become adult in 5-15 days (Giri et al., 2014). The adult has a narrow silver-grey body with grey-brown wings spanning 12mm speckled with small dark spots. Forewings have dark spots (two to three dots on males and a characteristic "X" pattern on females) (Chandel et. al., 2001). The population of potato tuber moth is found to be high in mid hills during the period of March to October (Giri et al., 2014).

Mostly adult PTM lays their eggs on underside of the leaves. As the eggs hatch, damage starts with first larval stage which creates mines in the leaves and stems causing weakening and break down. Finally, they move towards the tuber and enter through the tuber eye. First larval instars mine into the tuber causing the galleries in the field which moves into the storage along with the tuber leading to more survival and multiplication in the storage leading to 100% tuber loss if no any intervention is made (Tsedaley, 2015).

Different chemicals and bio-pesticides can be used in control of potato tuber moth especially in storage condition. Botanical insecticides have been used since long time in traditional pest management before the invention of chemical pesticides (Giri et al., 2013). *Bacillus thuringiensis* is found to be used in many parts of the world for control of potato tuber moth damage in the storage. Locally available plant products are being widely used in the control of potato tuber moth in the storage condition. PTM is also found to be controlled by the use of sex pheromone. The sex pheromone of this pest consists of two substances, first is *trans*-4, *cis*-7, tridecadien-1-ol acetate (also called PTM 1) and the second active substance is *trans*-4, *cis*-7, *cis*-10-tridecatrien-1-ol acetate (also called PTM 2) (Raman, 1988).The pull and push mechanism of different secondary metabolites found in the plants are responsible for the control of potato tuber moth by the mechanism that do not let PTM to lay egg on the plant (Ma & Xiam, 2013). *Lantana camara* is also being used widely which consists of triterpene acids lantadene A and B which is toxic to larva of potato tuber moth that may cause death if consumed (Sisay & Ibrabim, 2012). Other different botanical plants can also be used in the protection of tuber damage caused by PTM in storage and field condition. In field condition, many cultural practices can be followed for the control of PTM infection by avoiding infected tubers, crop rotation, deep sowing of the seed tubers, proper earthing up, regular irrigation and dehulming practices. Use of insecticides for the control of PTM in the field condition is done only in extreme cases. For storage protection of potato tubers against PTM, treatment with different botanicals and chemicals, sex pheromones, proper hygiene and proper sorting of infected tuber in the field can be done (Hanafi, 1999).

The infestation caused by PTM begins from the field though it causes no significance role in yield reduction. PTM is one of the most destructive pests of potato which leads to huge loss of potato tuber. Irrational use of chemical pesticide for control of PTM in potato leads to the increased concern regarding chemical residue, environment and health hazard and mainstreaming of organic agriculture in the Karnali province at policy level (Giri et al., 2014). There is an immediate need of eco- and human health- friendly solution for control of PTM and promotion of organic agriculture in the study region. This study will investigate eco-friendly and human health friendly alternatives for management of PTM resulting less tuber infection and loss in the storage and promotion of organic agriculture in Dailekh district. In Nepal, few studies have been carried out with respect to eco-friendly management of PTM using botanicals and entomo-pathogen in field condition where most of the research work has been concerned only in storage condition. Problem of insufficient research work and unavailability of modern methods for control of PTM in the study area is prevailing as a result of difficult land topography in mid hills and poor economic condition of farmers

2. Materials and Methods

2.1. Location of the site

The research experiment entitled "Eco-friendly management of potato tuber moth *Phthorima operculella*, Zeller under storage and field condition" was carried out at Mahabu rural municipality ward number 03, Dailekh district Nepal during 2021.

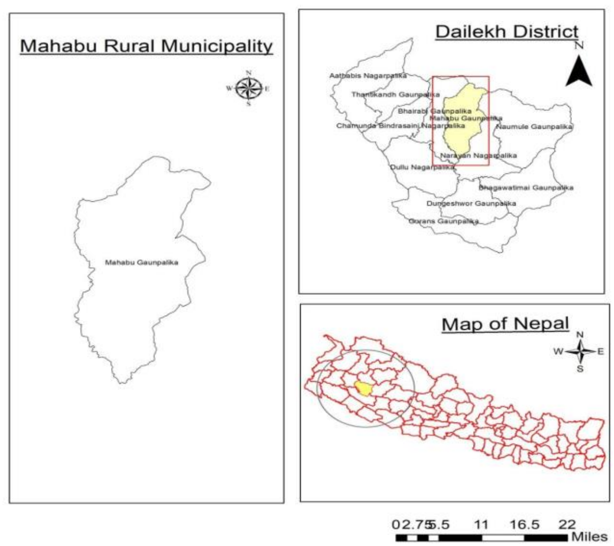

Figure 1. Map of Nepal showing research site

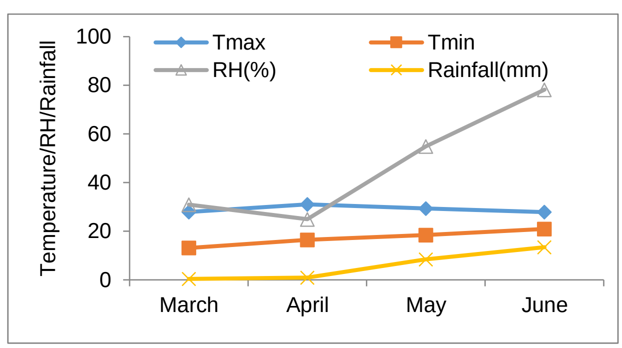

Figure 2. Meteorological data of the study site during the period of study (Source: POWER (Prediction of Worldwide Energy Resources) NASA https://power.larc.nasa.gov/data-access-viewer/)

The study site is located at 28°35' N to 29°80' N latitude and 81°25' E to 81°52' longitude at the elevation of 1450 masl. The meterological information of the study site is presented in Figure 2.

2.2. Site selection

An ordinary storage condition of a potato farmer and a healthy field suitable for the experiment was chosen prior to experimentation at Mahabu, Dailekh.

2.3. Collection and selection of seed tuber

Cardinal, Desiree and Local variety of potato are mostly grown by farmers in Dailekh district. So, Cardinal variety of potato grown by the farmers in the research site was used for study purpose. Tubers of medium size (35-50 grams) were weighted and selected for storage condition. While for field sowing, seed tubers were bought from the Agro-vet shop. Some tubers infected by PTM were also collected for plantation in the field to ensure PTM population in the field.

Table 1. List of treatments, formulations and doses

Treatments	Formulation	Treatment doses (not recommended doses)
T_1 (Control)		
T_2 (*Bacillus thuringiensis*)	Powder	25 gm kg^{-1} of potato tuber
T_3 (*Artemisiavulgaris*)	Powder	25 gm kg^{-1} of potato tuber
T_4 (Malathion) Check	Powder	25 gm kg^{-1} potato tuber seed (AITC, 2077)
T_5 (*Lantana camara*)	Powder	25 gm kg^{-1} of potato tuber seed
T_6 (*Coriandrum sativum*)	Powder	25 gm kg^{-1} of potato tuber seed.
T_7 (*Curcuma longa*)	Powder	25 gm kg^{-1} of potato tuber seed
T_8 (*Azadirachta indica* oil 5%EC)	Essential oil	2 ml lt^{-1} of water
T_9 (*Justicia adhatoda*)	Powder	25 gm kg^{-1} of potato tuber seed
T_{10} (*Yucca* sp.)	Powder	25 gm kg^{-1} of potato tuber seed

2.4. Date of sowing and storage

The sowing of seed tubers in the field and trail setup in storage was done in second week of March.

2.5. Treatment details and experimental design

Table 2. Experimental details included in management of potato tuber moth at field condition in Dailekh, Nepal, 2021

Particular	Trial details
Design	Randomized Complete Block Design (RCBD)
Replication (Blocks)	3
Treatments	10
Total Plot	30
Plots size	2 × 2 m^2
Spacing between plots	0.3 m
Number of plants per plot	16 (4 rows and 4 columns)
Total number of plants	480
Spacing	50 × 50 cm^2 (row to row and plant to plant respectively)
Sample plants	5 central plants

2.6. Experimental Procedure

2.6.1. Rearing potato tuber moth (Phthorimaea operculella Zeller)

Rearing of potato tuber moth was done on wooden cages with open top. The floor of the cage was covered with sand to provide a medium for pupation of potato tuber moth. Infected tuber from the farmer's storage condition was collected and placed in the cage and the activity of moth was monitored inside the cage.

2.6.2. Application of treatments

Matured leaves of botanicals and rhizomes of *Curcuma longa* were collected, dried and crushed into powder using traditional mill while Malathion powder and *Azadirachta indica* essential oil was bought from Agro-vet shop. Uniform distribution of powder over the potato tubers was ensured before storage and sowing in the field. For tubers treated with *Azadirachta indica* oil, tubers were soaked in solution for 15 minutes and air dried for 1 hour in shade.

Table 3. Experimental details included in management of potato tuber moth at storage condition in Dailekh, Nepal, 2021

Particular	Trial details
Design	Completely Randomized Design (CRD)
Replications	3
Treatments	10
Total Plot	30
Tuber per plot	1kg

Treated tubers were accordingly sown in the field as well as stored in ordinary storage placing in open plastic tray for easy entry and exit of PTM. For field condition, 10% tubers infected with PTM were incorporated to ensure PTM population in the field. Treatments were compounded after appearance of first foliage damage symptoms in field condition at the interval of 15 days.

2.6.3. Soil and Land preparation

For successful potato production, intensive soil preparation must be done. To make soil free from large soil clods and weeds, 2 deep ploughing followed by harrowing were done. The tubers were sown in flat bed to ensure enough moisture for germination of potatoes. Ridges and furrows were made during earthing up.

2.6.4. Manuring and fertilization

Potato needs heavy dose of fertilizer for its proper growth and development. The major essential nutrients of potato are nitrogen, phosphorus and potassium. The recommended doses of fertilizers for potato are: FYM: 15 kg ropani$^{-1,}$ Urea: 11 kg ropani^{-1}, DAP: 7 kg ropani^{-1}, MOP: 5 kg ropani^{-1} (AITC, 2077). All the fertilizer doses were incorporated into the field before sowing except nitrogen whose half dose was used as basal dose and half dose during earthing up.

2.6.5. Irrigation

Irrigation was done 10 days prior to the sowing by flood method and a single irrigation was applied after 25 days of sowing.

2.6.6. Harvesting

Cardinal variety of potato has maturity days of 90-100 days (AITC, 2077). So, the harvesting was done in 92 days after sowing.

2.6.7. Data collection and observation

For recording the observations on efficacy of entomopathogen, biological and chemical treatments on control of potato tuber moth, data were collected before and after each spray in the field. For storage conditions, data were collected in the interval of 15 days. Sample infested leaves from each sample plantwere picked out randomly and the number of larva in each leaf was counted from which average larva per leaf wascalculated. Five infested leaves from each sample plant were picked out randomly and the number of mining in each leaf was counted from which average mining per leaf was calculated.

The total number of tubers and the number of infested tubers in sample plants were counted. These data were collected following the destructive method that is the tubers were picked out of the plant for counting and the percentage of tuber infested was calculated. Sample infested seed from each sample plant was picked out randomly and the number of larva in each tuber will be counted from which average larva per fruit was calculated. Five infested tubers from each sample plants was picked out randomly and the number of mining in each fruit will be counted from which average mining per was calculated

Observation in field condition

A) Percentage of leaves infested by PTM

Percentage of leaves infected by PTM was observed and recorded in every 15 days after compounding treatments. For this 5 plants from each plot were selected randomly and observed.

% leaves infested $=\frac{Total\ number\ of\ leaves\ infected}{Total\ number\ of\ leaves}\times 100$

B) Severity of leaves infestation

Severity of leaves infection was calculated by using the following formula:

Infestation severity % =

$$\frac{Sum\ of\ numerical\ rating}{Total\ number\ of\ leaves\ observed * maximum\ rating}\times 100$$

Table 4. Severity scale used to score foliage damage caused by PTM (Fenemore 1980)

Score	Infestation Degree	Category
0	No symptoms on leaves	Clean
1	Small narrow mining covering 1% or less leaf area	Slight infestation
3	Small narrow mining covering 1-10% of leaf area	Slightly Moderate infestation
5	Wider mining covering 11-25% of the leaf area	Moderate infestation
7	Infestation causing rolling of the leaves	Severe infestation

C) Percentage of tuber infected by PTM

At harvest, percentage of tuber infected by PTM was observed. For this 5 tubers from each sample plant i.e. 25 tubers from each plot was observed.

Percentage of tuber infected =

$$\frac{Total\ number\ of\ infected\ tuber}{Total\ number\ of\ tuber}\times 100$$

D) Severity of tuber infection

Table 5. Severity scale used to score tuber damage caused by PTM (Fenemore 1980)

Score	**Infestation Degree**	**Category**
0	No sign of damage	Clean
1	1-2 mining holes	Slight infestation
3	3-4 mining holes	Moderate infestation
5	5 and more mining holes	Severe infestation

Infestation severity $=\frac{x1+x2+x3}{Total\ number\ of\ tubers}\times 3$ (Mohamed, Sharaby, &Fallatah, 2019)

Where x1=Slight infestation, x2= Moderate Infestation and x3=Severe Infestation

Observation in storage condition

A) Percentage of tuber infestation

Percentage of tuber infestation was calculated as:

Percentage of tuber infested = $\frac{Total\ number\ of\ infected\ tuber}{Total\ number\ of\ tubers} \times 100$

B) Infestation severity

Infestation severity = $\frac{x1+x2+x3}{Total\ number\ of\ tubers} \times 3$ (Mohamed, Sharaby, & Fallatah, 2019)

Where x1=Slight infestation, x2= Moderate Infestation and x3=Severe Infestation

C) Percentage of sprout infested

Percentage of sprout infested was calculated as:

Percentage of sprout infested = $\frac{Total\ number\ of\ infected\ sprout}{Total\ number\ of\ Sprouts} \times 100$

D) Percentage of rotten tuber

Percentage of rotten tuber was calculated as:

Percentage of rotten tuber = $\frac{Total\ number\ of\ rotten\ tubers}{Total\ number\ of\ tubers} \times 100$

2.7. Statistical analysis:

The collected data were systematically arranged and entered in MS Excel. Then the arranged data were analyzed using the software, R studio. The means were compared by using Duncan's Multiple Range Test (DMRT) at 5% level of significance (Gomez and Gomez). Effectiveness of treatments was studied based on above mentioned parameter.

3. Results

3.1. Field condition

3.1.1. Percentage of leaves infected

At 60 days after sowing and before treatment, leaves infection percentage was found higher in control plot (13.06%). Similarly, higher leaves infestation percentage was followed by *Bacillus thuringiensis* (8.10%) which was statistically at par with *Coriandrum sativum* (7.80%), *Artemisia vulgaris* (7.6%), *Justicia adhatoda*(7.37%), *Yucca* sp. (6.47%), *Curcuma longa* (5.90%) *and Lantana camara* (6.08%). Least infestation percentage was found in *Azadirachta indica* (4.71%) which was statistically at par with Malathion (4.73%).

At 75 days after sowing i.e. 15 days after first spray leaves infestation percentage was found higher in control plot (13.45%). Similarly, higher leaves infestation percentage was followed by plot sprayed with *Lantana camara* (6.77%) which was statistically at par with plot sprayed with *Justiciaadhatoda*(6.59%), *Coriandrum sativum* (26.46%), *Artemisia vulgaris* (6.46%), *Bacillus thuringiensis* (6.40%), *Yucca* sp.(5.57%) and *Curcuma longa* (4.56%). Least leaves infestation percentage was found in plot sprayed with Malathion (3.93%) which was statistically at par with plot sprayed with *Azadirachta indica* (3.93%).

At 90 days after sowing i.e. 15 days after second spray leaves infestation percentage was found higher in control plot (14.40%). Similarly, higher leaves infestation percentage was followed by the plot sprayed with *Bacillus thuringiensis* (7.14%) which was statistically at par with the plot sprayed with *Lantana camara* (4.67%), *Artemisia vulgaris* (7.05%), *Coriandrum sativum* (6.70%), *Yucca* sp.(6.46%), *Justicia adhatoda*(5.60%), C*urcuma longa* (4.67%) and Malathion (4.02%). Least leaves infestation was found in plot sprayed with *Azadirachta indica* (2.78%).

3.1.2. Leaves infestation severity

Statistically, there was no significance difference between the treatment in the severity caused by PTM in potato foliage before and 15 days after first spray. At 90 days after sowing i.e. 15 days after second spray leaves infestationseverity was found high in control plot (0.10%) which was statistically at par with plot sprayed with *Bacillus thuringiensis* (0.10%), *Lantana camara* (0.10%), *Coriandrum sativum* (0.10), *Curcuma longa* (0.10%), *Justicia adhatoda*(0.066%)and *Yucca* sp. (0.066%).Least infestations severity was found in the plot sprayed withMalathion (0.011%) which was statistically at par with plot sprayed with *Azadirachta indica* (0.033%).

3.1.3. Percentage of tuber infection

Statistically, higher percentage of tuber infestation was found in the tuber from control plot (52%) which was statistically at par with plot treated with *Coriandrum sativum* (41.33%), *Artemisia vulgaris* (41.33%), *Lantana camara* (41.33%) and*Azadirachta indica* (41.33%). Least percentage of tuber infestation was found in the plot treated with Malathion (25.33%).

3.1.4. Tuber infestationseverity

Statistically, higher tuber infestation severity was found in the control plot (5.43%) which was statistically at par with the plot treated with *Artemisia vulgaris* (3.66%)and *Curcuma longa* (3.83%). Least infestation severity was found in the tuber from the plot treated with *Justicia adhatoda*(2.16%)which was statistically at parwith *Bacillus thuringiensis* (2.17%),Malathion (2.46%),*Azadirachta indica* (2.96%), *Lantana camara* (2.93%)and *Yucca* sp.(3.03%).

Table 6. Effect of different treatments on damage incidence of potato tuber moth on foliage of potato in Dailekh, Nepal, 2021

Treatments	**Leaves infected (Percentage, %)**		
	60 DAS (BT)	**75 DAS (15 DAFS)**	**90 DAS (15 DASS)**
Control	13.06^{a}(3.68)	13.45^{a}(3.70)	14.40^{a}(3.82)
Bacillus thuringiensis	8.10^{b}(2.92)	6.40^{b}(2.62)	7.14^{b}(2.75)
Artemisia vulgaris	7.6^{b}(2.83)	5.53^{b}(2.63)	7.05^{b}(2.71)
Malathion (check)	4.73^{c}(2.28)	3.93^{c}(2.10)	4.02^{bc}(2.12)
Lantana camara	6.08^{bc}(2.55)	6.77^{b}(2.69)	7.02^{b}(2.72)
Coriandrum sativum	7.80^{b}(2.87)	6.46^{b}(2.63)	6.70^{b}(2.66)
Curcuma longa	5.90^{bc}(2.53)	4.56^{bc}(2.24)	4.67^{bc}(2.27)
Azadirachta indica oil 5% EC	4.71^{c}(2.27)	3.95^{c}(2.10)	2.78^{c}(1.81)
Justicia adhatoda	7.37^{b}(2.8)	6.59^{b}(2.66)	5.60^{b}(2.46)
Yucca sp.	6.47^{bc}(2.63)	5.57^{bc}(2.45)	6.46^{b}(2.61)
F -value	9.4898	8.55	6.90
P-value	8.364e-06 ***	6.664e-05 ***	0.0002693 ***
SEm(±)	0.096	0.11	0.149
LSD (p≤ 0.05)	0.3888692	0.46	0.60
CV (%)	8.27	10.48	13.47
Grand mean	2.73	2.58	2.59

Note: Same letter(s) within column in superscript indicate non-significant differences between the treatments based on Duncan's multiple range test (DMRT) at 5% level of significance. Figures in the parenthesis indicate leaves infection percentage in square root transformed values. Sem(±), standard error of mean; CV, coefficient of variation; LSD,least significant differences; DAS,days after sowing; BT, before treatment; DAFS, days after first spray; DASS, days after second spray ; ***, significance at 0.001 level of significance.

Table 7. Effect of different treatments on infestationseverity of potato tuber moth on foliage of potato in Dailekh, Nepal, 2021

Treatments	Leaves damage severity		
	60 DAS (BT)	75 DAS (15 DAFS)	90 DAS (15 DASS)
Control	0.133 (0.79)	0.10 (0.77)	0.10a(0.77)
Bacillus thuringiensis	0.033 (0.73)	0.066 (0.75)	0.10a(0.77)
Artemisia vulgaris	0.033 (0.73)	0.066 (0.75)	0.066ab(0.75)
Malathion (check)	0.066 (0.75)	0.10 (0.77)	0.011c(0.71)
Lantana camara	0.033 (0.73)	0.10 (0.77)	0.10a(0.77)
Coriandrum sativum	0.066 (0.75)	0.066 (0.75)	0.10a(0.77)
Curcuma longa	0.066(0.75)	0.10 (0.77)	0.033bc(0.73)
Azadirachta indica oil 5% EC	0.011(0.71)	0.011 (0.71)	0.011c(0.71)
Justicia adhatoda	0.066 (0.75)	0.033 (0.73)	0.10a(0.77)
Yucca sp.	0.22(0.84)	0.033 (0.73)	0.066ab(0.75)
F -value	1.79	2.32	4.82
P-value	0.51	0.06	0.009021 **
SEm(±)	0.02	0.029	0.035
LSD (p≤ 0.05)	0.07	0.11	0.033
CV (%)	9.14	9.19	2.62
Grand mean	0.75	0.75	0.75

Note: Same letter(s) within column in superscript indicate non-significant differences between the treatments based on Duncan's multiple range test (DMRT) at 5% level of significance. Figures in the parenthesis indicate damage severity in square root transformed value. SEM(±), standard error of mean; CV, coefficient of variation; LSD, least significant differences; DAS, days after sowing; BT, before treatment; DAFS, days after first spray; DASS, days after second spray ; **significance at 0.01 level of significance

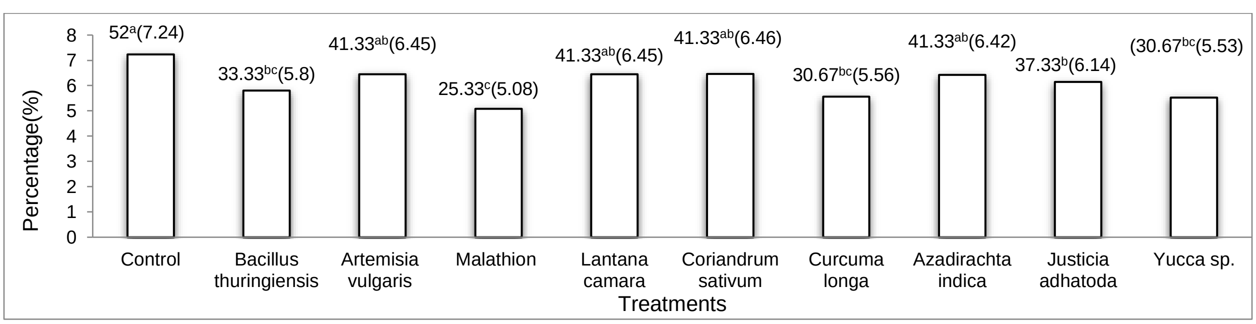

Figure 3. Effect of different treatments on percentage of tuber infected by PTM at field condition in Dailekh, Nepal, 2021

Table 8. Effect of different treatments on infestation severity of potato tuber moth in potato tubers in Dailekh, Nepal, 2021

Treatments	Tuber infestation severity
Control	5.433^{a}(2.42)
Bacillus thuringiensis	2.17^{c}(1.62)
Artemisia vulgaris	3.66^{abc}(2.03)
Malathion (check)	2.46^{bc}(1.71)
Lantana camara	2.93^{bc}(1.84)
Coriandrum sativum	3.2^{bc}(1.91)
Curcuma longa	3.83^{ab}(2.08)
Azadirachta indica oil 5%EC	2.96^{bc}(1.84)
Justicia adhatoda	2.16^{c}(1.61)
Yucca sp.	3.03^{bc}(1.87)
F-value	3.4571
P-value	0.01204 *
SEm(±)	0.36
LSD (p≤ 0.05)	0.096
CV (%)	13.79
Grand mean	1.89

Note: Same letter(s) within column in superscript indicate non-significant differences between the treatments based on Duncan's multiple range test (DMRT) at 5% level of significance. Figures in the parenthesis indicate infection severity in square root transformed value. Sem(±), standard error of mean; CV, coefficient of variation; LSD, least significant differences; *, significant at 0.05 level of significance

3.2. Storage condition

3.2.1. Percentage of tuber infestation

Statistically, there was no significant different between the treatments in the percentage of tuber infestation caused by potato tuber moth in 15 and 30 days after storage. At 45 days of storage, statistically higher infestation percentage was found in potato tuber from control (91.82%). Least infestation percentage of potato tubers caused by potato tuber moth was found in tubers treated with Malathion (35.28%) which was statistically at par with *Lantana camara* (49.39%), *Curcuma longa* (51.05%), *Coriandrum sativum* (52.9%),*Azadirachta indica* (55.42%), *Justicia adhatoda*(60.66%), *Yucca* sp. (60.93%), *Bacillus thuringiensis* (67.53%) and *Artemisia vulgaris* (68.51%).

At 60 days of storage, statistically higher infestation percentage was found in potato tuber with control (94.07%). Least infestation percentage of potato tubers caused by potato tuber moth was found in tubers treated with Malathion (33.28%) which was statistically at par with *Coriandrum sativum* (55.00%), *Lantana camara* (57.26%), *Curcuma longa* (59.45%), *Justicia adhatoda*(60.60%), *Yucca* sp. (60.99%), *Artemisia vulgaris* (68.51%),*Azadirachta indica* (68.31%) and *Bacillus thuringiensis* (71.46%).

At 75 days of storage, statistically higher infestation percentage was found in potato tuber with control (98.13%). Higher infection by potato tuber moth was followed by tubers treated with *Bacillus thuringiensis* (79.73%) which was statistically at par with tuber treated with *Artemisia vulgaris* (72.12%) and*Azadirachta indica* (68.31%). Least infestation percentage of potato tubers caused by potato tuber moth was found in tubers treated with Malathion (35.28%) which was statistically at par with *Coriandrum sativum* (55.00%), *Curcuma longa* (59.45%), *Lantana camara* (61.43%), *Yucca* sp.(64.95%) and *Justicia adhatoda*(65.00%).

At 90 days of storage, statistically higher infestation percentage was found in potato tuber with control (98.13%) which was statistically at par with tuber treated with *Bacillus thuringiensis* (89.30%), *Justicia adhatoda*(75.03%),*Azadirachta indica* (80.83%) and *Artemisia vulgaris* (79.62%). Least infestation percentage of potato tubers caused by potato tuber moth was found in tubers treated with Malathion (35.31%) which was statistically at par with *Coriandrum sativum* (55.00%), *Curcuma longa* (59.45%) and *Lantana camara* (63.28%).

3.2.2. Infestationseverity

At 15 and 30 days after storage there was no significant difference between the treatments on infestation severity caused by potato tuber moth in potato tuber in storage.

At 45 days after storage statistically, higher infestation severity was found on potato tubers with control (8.05%) which was statistically at par with the tubers treated with *Artemisia vulgaris* (5.27%), *Bacillus thuringiensis* (4.9%), *Justicia adhatoda*(4.75%)and*Curcuma longa* (3.95%). Least infestation severity was found in potato tubers treated with Malathion (1.41%) which was statistically at par with potato tubers treated with *Coriandrum sativum* (2.83%), *Lantana camara* (3.38%),*Azadirachta indica* (3.58%)and*Yucca* sp.(3.82%).

At 60 days after storage statistically, higher infestation severity was found on potato tubers with control (11.56%) which was statistically at par with the tubers treated with *Bacillus thuringiensis* (7.06%), *Artemisia vulgaris* (6.98%) *and Justicia adhatoda*(6.98%). Least infestation severity was found in potato tubers treated with Malathion (1.64%) which was statistically at par with potato tubers treated with *Coriandrum sativum* (4.10%), *Yucca* sp.(4.38%) and *Curcuma longa* (4.44%).

At 75 days after storage statistically, higher infestation severity was found on potato tubers with control (11.85%) which was statistically at par with the tubers treated with *Bacillus thuringiensis* (10.18%), *Artemisia vulgaris* (9.25%), *Justicia adhatoda*(7.38%) and *Azadirachta indica* (7.14%). Least infestation severity was found in potato tubers treated with Malathion (1.64%) which was statistically at par with potato tubers treated with *Coriandrum sativum* (4.23%), *Yucca* sp.(5.0%)and *Curcuma longa* (4.98%).

At 90 days after storage statistically, higher infestation severity was found on potato tubers with control (14.17%) which was statistically at par with the tubers treated with *Bacillus thuringiensis* (10.93%), *Artemisia vulgaris* (10.16%), *Justicia adhatoda*(8.99%), *Azadirachta indica* (9.6%), *Lantana camara* (6.42%) and *Yucca* sp.(7.90%). Least infestation severity was found in potato tubers treated with Malathion (5.55%) which was statistically at par with potato tubers treated with *Coriandrum sativum* (4.55%) and *Curcuma longa* (4.90%).

Table 9. Effect of different treatments on infestation incidence of potato tuber moth on potato tubers at storage in Dailekh, Nepal, 2021

Treatments	Tuber infested (percentage, %)					
	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Control	28.39 (32.17)	60.11 (50.83)	91.82[a] (76.31)	94.07[a] (78.48)	98.13[a] (85.40)	98.13[a] (85.40)
Bacillus thuringiensis	14.66 (21.43)	41.09 (39.85)	67.53[b] (55.55)	71.46[b] (58.54)	79.73[b] (64.40)	89.30[ab] (71.89)
Artemisia vulgaris	22.22 (26.90)	45.36 (42.29)	68.51[b] (55.98)	68.51[b] (55.98)	72.12[b] (58.23)	79.62[ab] (63.69)
Malathion (check)	19.60 (25.94)	27.44 (31.40)	35.28[b] (36.31)	33.28[b] (36.31)	35.28[c] (36.31)	35.31[c] (36.32)
Lantana camara	19.74 (25.41)	34.56 (35.76)	49.39[b] (44.76)	57.26[b] (49.72)	61.43[bc] (52.15)	63.28[bc] (53.67)
Coriandrum sativum	15 (22.22)	33.95 (35.58)	52.9[b] (46.67)	55[b] (47.88)	55.0[bc] (47.88)	55.00[bc] (47.88)
Curcuma longa	28.74 (32.15)	39.89 (38.89)	51.05[b] (45.50)	59.45[b] (50.46)	59.45[bc] (50.46)	59.45[bc] (50.46)
Azadirachta indica oil 5%EC	12 (15.64)	33.71 (35.24)	55.42[b] (48.18)	68.31[b] (56.34)	68.31[b] (56.34)	80.83[ab] (65.84)
Justicia adhatoda	29.56 (32.65)	45.11 (42.06)	60.66[b] (52.00)	60.6[b] (52.00)	65.00[bc] (54.54)	75.03[ab] (65.29)
Yucca sp.	28.86 (32.48)	44.92 (42.04)	60.93[b] (52.35)	60.99[b] (52.35)	64.95[bc] (54.61)	74.72[b] (60.38)
F-value	1.09	1.6	2.701	2.5998	4.6701	3.6761
P-value	0.41	0.1886	0.03477 *	0.04036 *	0.002657 **	0.009015 **
SEm(±)	4.08	3.15	4.75	4.87	4.34	5.3
LSD (p≤ 0.05)	16.41	12.68	19.06	19.58	17.42	21.3
CV (%)	35.84	18.77	21.62	21.21	18.11	20.66
Grand mean	26.7	39.39	51.38	53.8	56.06	60.08

Note: Same letter(s) within column in superscript indicate non-significant differences between the treatments based on Duncan's multiple range test (DMRT) at 5% level of significance. Figures in the parenthesis indicate percentage tuber infection in arcsine transformed value. Sem(±), standard error of mean; CV, coefficient of variation; LSD, least significant differences; DAS, days after storage; *, significant at 0.05 level of significance; **, significance at 0.01 level of significance

Table 10. Effect of different treatments on infestation severity of potato tuber moth in potato tubers at storage in Dailekh, Nepal, 2021

Treatments	Tuber infestation severity					
	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Control	1.64 (1.46)	5.76 (2.48)	8.056[a] (2.90)	11.56[a] (3.47)	11.85[a] (3.50)	14.17[a] (3.50)
Bacillus thuringiensis	0.53 (1.00)	3.60 (2.02)	4.9[ab] (2.31)	7.06[ab] (2.72)	10.18[ab] (3.24)	10.93[ab] (3.24)
Artemisia vulgaris	1.22 (1.27)	4.32 (2.16)	5.27[ab] (2.38)	6.98[ab] (2.72)	9.25[abc] (3.11)	10.16[abc] (3.11)
Malathion (check)	0.57 (1.03)	0.98 (1.21)	1.41[c] (1.37)	1.64[c] (1.44)	1.64[e] (1.44)	5.55[d] (1.44)
Lantana camara	1.20 (1.29)	2.21 (1.58)	3.38[bc] (1.90)	5.53[b] (2.41)	6.2[bcd] (2.55)	6.42[abc] (2.55)
Coriandrum sativum	0.57 (1.02)	1.07 (1.24)	2.83[bc] (1.79)	4.10[bc] (2.11)	4.23[de] (2.13)	4.55[cd] (2.13)
Curcuma longa	1.53 (1.42)	1.77 (1.51)	3.95[abc] (2.09)	4.44[bc] (2.21)	4.98[cd] (2.32)	4.90[bcd] (2.32)
Azadirachta indica oil 5%EC	0.51 (0.96)	2.62 (1.75)	3.58[bc] (1.99)	6.38[b] (2.59)	7.14[abcd] (2.72)	9.6[abc] (2.72)
Justicia adhatoda	1.51 (1.38)	3.21 (1.82)	4.75[ab] (2.24)	6.98[ab] (2.67)	7.38[abcd] (2.74)	8.99[abc] (2.74)
Yucca sp.	1.23 (1.31)	2.43 (1.65)	3.82[bc] (2.03)	4.38[bc] (2.17)	5.0[bcd] (2.48)	7.90[abc] (2.48)
F-value	1.7	2.2	2.5799	3.9608	4.7227	3.0026
P-value	0.15	0.073	0.04157 *	0.006259 **	0.002501 **	0.02252 *
SEm(±)	0.11	0.2	0.19	0.2	0.2	0.23
LSD (p≤ 0.05)	0.45	0.8	0.75	0.79	0.81	0.91
CV (%)	21.39	26.78	20.69	18.78	18.02	20.19
Grand mean	1.22	1.74	2.1	2.45	2.63	2.63

Note: Same letter(s) within column in superscript indicate non-significant differences between the treatments based on Duncan's multiple range test (DMRT) at 5% level of significance. Figures in the parenthesis indicate infection severity in arcsine transformed value.SEM(±), standard error of mean; CV, coefficient of variation; LSD, least significant differences; DAS, days after storage; *, significant at 0.05 level of significance; **, significance at 0.01 level of significance

Table 11. Effect of different treatments on sprout damage caused by potato tuber moth at storage in Dailekh, Nepal, 2021

Treatments	Sprout damage (percentage, %)	
	75 DAS	90 DAS
Control	36.88^{a}(6.24)	62.43^{a}(7.92)
Bacillus thuringiensis	31.10^{a}(5.53)	52.21^{ab}(7.23)
Artemisia vulgaris	27.40^{a}(5.24)	45.99^{abc}(6.73)
Malathion (check)	8.52^{bc}(2.17)	10.25^{d}(2.77)
Lantana camara	22.26^{ab}(4.24)	24.47^{cd}(4.90)
Coriandrum sativum	16.11^{ab}(4.07)	22.67^{cd}(4.74)
Curcuma longa	1.33^{c}(1.18)	25.63^{bc}(5.08)
Azadirachta indica oil 5%EC	16.66^{abc}(3.87)	21.66^{cd}(4.59)
Justicia adhatoda	15.55^{abc}(3.75)	22.61^{cd}(4.55)
Yucca sp.	25.04^{a}(5.02)	25.99^{abc}(5.94)
F-value	3.2273	4.7722
P-value	0.01646 *	0.002362 **
SEm(±)	0.63	0.52
LSD (p≤ 0.05)	2.51	2.06
CV (%)	35.49	22.14
Grand mean	4.12	5.44

Note: Same letter(s) within column in superscript indicate non-significant differences between the treatments based on Duncan's multiple range test (DMRT) at 5% level of significance. Figures in the parenthesis indicate sprout damage percentage in square root transformed value.SEM(±), standard error of mean; CV, coefficient of variation; LSD, least significant differences; NS, non significant; DAS, days after storage; *, significant at 0.05 level of significance; **, significance at 0.01 level of significance

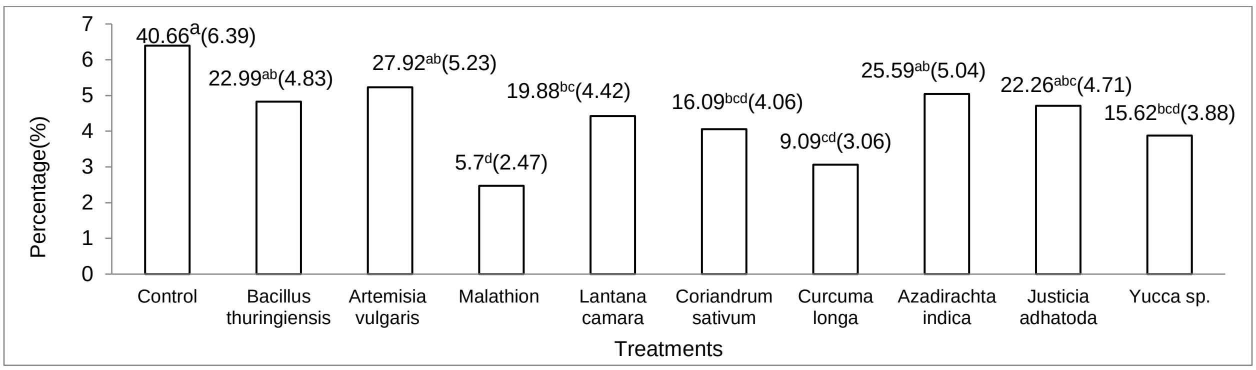

Figure 4. Effect of different treatment on percentage of rotten tuber caused by potato tuber moth at storage condition in Dailekh, Nepal, 2021

3.2.3. Sprout damage

Sprout damage caused by potato tuber moth in storage was statistically high in the potato tubers with control (36.88%) which was statistically at par with the tubers treated with *Bacillus thuringiensis* (31.10%), *Artemisia vulgaris* (27.40%), *Yucca* sp.(25.04%), *Lantana camara* (22.26%),*Azadirachta indica* (16.66%)and*Justicia adhatoda*(15.55%). Least sprout damage was found in the tubers treated with *Curcuma longa* (1.33%) which was statistically at par with Malathion (8.52%) at 75 days after storage.

At 90 days after treatment, statistically higher sprout damage was found in tuber with control (62.43%) which was statistically at par with the tubers treated with *Bacillus thuringiensis* (52.21%), *Artemisia vulgaris* (45.99%) and *Yucca* sp.(25.99%). Least sprout damage was found in the tubers treated with Malathion (10.25%) which was statistically at par with *Justicia adhatoda* (22.61%),*Azadirachta indica* (21.66%),*Coriandrum sativum* (22.67%), *Lantana camara* (24.47%) and *Curcuma longa* (25.63%).

3.2.4. Percentage of rotten tuber

Percentage of rotten potato tubers caused by potato tuber moth in storage was found statistically high in the control (40.66%) which was statistically at par with tubers treated with *Artemisia vulgaris* (27.92%),*Azadirachta indica*(25.59%), *Bacillus thuringiensis* (22.99%) *and Justicia adhatoda*(22.26%). Least percentage of rotten tubers was found in potato tubers treated with Malathion (5.7%) which was at par with rotten tuber treated with *Curcuma longa* (9.09%), *Yucca* sp.(15.62%)and *Coriandrum sativum* (16.09%).

4. Discussion

Among different treatments, *Azadirachta indica* oil 5% EC and Malathion powder showed better effect in minimizing the foliage damage caused by PTM in the field condition. Control in damage caused by PTM might be the result of oviposition deterrent effect of neem oil in PTM (Erdogen& Yilmaz, 2018).

Malathion which inhibits the acetylcholinesterases (AChE) that breaks down acetylcholine, a chemical essential in transmitting nerve impulses across junctions between nerves which finally leads to the death might be the cause beside the less damage percentage (Kumari, 2012). Above ground damage caused by PTM was also found least by (El-Salam & Teixeira da Silva, 2010) on successive spray of neem oil in their experiment. Recently, numerous studies indicated that many wild medicinal and ornamental plants have pesticidal properties, which show anti-feedant, repellent, growth regulator effects, and toxic activities on PTM (A, Rahman, & S, 2002). Otieno (2019) has suggested spraying the plants with neem leaf extracts and botanicals for control of PTM in field condition.Tsedaley (2015) has suggested the use of organosulphateinsectiside only in the case when the PTM population exceed the appropriate action threshold.

Stored potatoes treated with *Coriandrum sativum*, *Curcuma longa* and *Lantana camara* had same level of control over damage caused by potato tuber moth as compared with potato tubers treated with Malathion powder. Malik (2017) has also suggested use of Malathion for seed tuber storage. Present finding was also supported by the experiment of (KV & RH, 1986), who found less infection of potato tuber moth in tuber covered with coriander, turmeric and other botanicals. Low egg deposition because of olfactory and contact chemo receptors located on the ovipositor, tarsus, and antennae were repelled by the odor of volatile or chemical constituents of the plant powder leading to small number of destructive generation of PTM (A, Rahman, & S, 2002).Application of *Bacillus thuringiensis* shows not much great effect as it inactivated by ultraviolet sunlight within few days of application (Usta, 2013)

Less damage percentage of tubers was also reported in experiment of (Lal, 1987) in the tubers covered with Lantana camera. Applications of powder formulation are found to be more effective as a result of trachea and spiracle blockage during respiration (KA & BB, 2013). (Mishra & Agrawal, 2008) had also suggested the use of Malathion for seed tuber storage.

In the sprout induction of potato tubers, no any effect was found through the use of various treatments. Sprouts started bursting after 60 days i.e., 8 weeks after storage. No effect of treatments on sprout induction was also reported by (Sharaby, Gesraha, &Fallatah, 2020). Least sprout damage was found in the tubers treated with Malathion, Justicia adhatoda, *Azadirachta indica*, *Coriandrum sativum*, *Lantana camara* and *Curcuma longa*. Less attack of PTM on sprout of potato tuber could be due to plant odor which acts as feeding deterrents to a wide variety of insect pests (Sharaby& Baker, 2019). The similar result was also obtained by (Lal, 1987) in his experiment where potato tubers were covered with *Lantana camera*. Less sprout damage caused by potato tuber moth in potato tubers treated with *Coriandrum sativum* was also found in the experiment of (Sharaby& Baker, 2019). The result of protection of potato tuber from the infection caused by PTM is their photochemical constituents and secondary metabolites of active ingredients (Sharaby, 2020).

The excrement in the tunnels attracts fungal and bacterial growth leading to further infections and damages. The holes created provide secondary infection- entry points for pathogens. The pathogens entering through the holes mined by PTM leads to the rotting of tuber in the storage (Arthurs et al., 2008). Least percentage of rotten tubers was found in tubers treated with Malathion, *Curcuma longa, Yucca* sp*.* and *Coriandrum sativum.* The antifungal and antioxidant properties of *Coriandrum sativum*, *Yucca sp*. and *Curcuma longa* might lead to the prevention of rot in the potato tubers in storage (Gurdip et al.,2007).

5. Conclusion

The study has concluded some information on ecofriendly management of potato tuber moth**.** Among the treatments, two foliar spray of *Curcuma longa* and *Azadirachtaindica* oil 5% EC at the rate of 2 ml ltr^{-1} at 15 days interval was found most effective to reduce the above ground damage and severity caused by potato tuber moth under field condition which has same effect as that of Malathion.Pre sowing seed tuber treatment with *Justicia adhatoda*, *Yucca* sp. and *Curcuma longa* powder at the rate of 25 gm kg^{-1} was found promising and equally effective in reducing tuber infection and severity at tuber harvest. Seed tuber when treated with different botanicals could protect tuber from potato tuber moth infestation during storage. The most potent powders were *Lantana camera*, *Coriandrumsativum* and *Curcuma longa*. In nutshell, our study generated evidences of the effectiveness of botanical based pesticides for the effective and eco-friendly management of potato tuber moth.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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