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A Comprehensive Approach to Manage *Eriophyes prosopidis* Mite induced Flower Galls in *Prosopis cineraria* (L.) Druce

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Authors' contributions

This work was carried out in collaboration among all authors. Author SB and SS performed the conceptualization, formal analysis, investigation and methodology. Author NS, AUK and BK did the data collection of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The Khejri tree (*Prosopis cineraria*), is a vital resource in the Thar Desert. Sangri, the name of its pods, is the key ingredient in the Rajasthani vegetable dishes Panchkutta and Trikuta. There is severe gall formation and significant pod reduction in *P. cineraria* caused by the eriophyid mite *Eriophyes prosopidis*. The gall-infested trees look unwell because they have a lot of disorganized and deformed green galls hanging from them. During the field trials of the present study, we found that the infestation of this mite can be managed by an integrated management approach. The mechanical removal of dried galls fallen on surface and lopping at an interval of one year can reduce the infestation considerably. Treatment with botanicals *Putranjiva roxburgii* (10%) leaf extract, *Balanites aegyptiaca* (10%) leaf extract, spray of *Metarhizium anisopliae* 2.5 x 10^7 conidia /ml and chemicals Abamectin 1.9% EC @1ml/L and Diafenthiuron 25% WW + Pyriproxyfen 5% WW @ 2ml/L can be utilized for effective management of flower galls of *P. cineraria*.

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Keywords: Prosopis cineraria; Eriophyes prosopidis; botanicals; entomopathogens and chemicals.

1. INTRODUCTION

Prosopis cineraria (Khejri), a common and naturally occurring tree, is a leguminous multipurpose tree. It is sometimes referred to as the "Wonder Tree" of the Thar Desert or the "Golden Tree." It is crucial to the socioeconomic advancement of farmers in India's desert regions. Khejri plays a significant function as a drought-resistant food in desert regions where cultivating vegetables is challenging [17]. It is indigenous to India, and in certain places it is even regarded as a tree of worship [2,3]. In the dry regions of western Rajasthan*, P.* cineraria (Khejri) pods are the most prized food and top feed agroforestry species. It offers green leaves known as loong to the livestock in the desert which is considered extremely palatable and nourishing forage feed [4-6]. The indigenous populace uses green (sangri) and dried pods (kho-kha) as famine food [7]. In agricultural landscapes, tree development typically harms crop productivity and vegetative biomass under and around the tree. However, beneath its shade, kheiri is believed to improve crop or vegetation productivity. Sangri, has a variety of medical applications, including the treatment of pain, excessive cholesterol, diabetes, anemia, renal, and hepatic conditions, chronic diseases including cancer and atherosclerosis [8].

Recently severe insect and disease attacks have drastically decreased the ability of *P. cineraria* to produce pods. According to [9,10] bruchids and flower galls are to blame for the decrease in seed and pod yield. Usually in healthy trees, 4-5 kg of pods per plant can be obtained but due to flower gall formation, pod yield is immensely decreased [11].

According to [12-14], plant galls are irregular growths brought on by nematodes, fungi, bacteria, mites, insects, etc. stimulating plant cells. Galls can develop on the roots, in the lamina and petioles of leaves, twigs, buds, or flowers. Each form of gall-producer is unique to a single plant species. The gall is a particular instance of a plant-pest connection that results in negative effects including hypertrophies and tumorous (neoplasmic) outgrowths as well as positive effects for the plants by assisting bacteria, actinomycetes, and blue-green algae in fixing nitrogen. [15] reported that in *P. cineraria,* galls inhibit vegetative growth and seed production. *Prosopis* sp. are just a few of the host plants that are seriously harmed by damage from plant galls [16-18, 9, 6]. Four different forms of galls have been described in *P. cineraria* [9,15,17].

Galls of the khejri inflorescence are caused by *Eriophyes prosopidis*, an eriophyid mite and are a frequent occurrence in arid regions that hinders flower development and reduce pod yield (Fig. 1). In the experimental field between 1999 and 2000, [17] evaluated the seasonal fluctuation in the population of *E. prosopidis* Saxena, which causes inflorescence gall in young and mature tree stands of *P. cineraria*. [19] discovered the floral organ implicated in gall development and its effects on pod development in *P. cineraria* trees. These gall-forming insects are attracted to flowers during the flowering season and inhibit the production of pods and seeds by converting ovarian tissues into galls. According to [20,21] when an insect interacts with its host tissues an intricate material of nucleic acid and protein is formed which helps in the development of galls. Additionally, the insect secretions and actively expanding ovarian cells in *P. cineraria* create aberrant growths in the form of galls.

The *Prosopis* tree stem, branches, rachis, leaflets, and flowers are all affected by galls.

Fig. 1. Flower galls infested khejri

Damage from flower galls lowers the trees aesthetic appeal but also lowers the yield of pods, which raises the cost per kilogram of pods. Reviewing the aforementioned studies undertaken by various researchers, scanty information pertaining to an integrated management strategy to address the flower gall of Khejri was available. To assess a competent management plan against the flower gall inducer, the current study was carried out.

2. MATERIALS AND METHODS

To assess the efficiency of different management measures against *Eriophyes prosopidis*, field trials at five different locations in Rajasthan viz., Phalodi, Lohawat, Osian, Baori and Pipar were conducted. Each treatment was replicated thrice and data was recorded on an average number of flower galls and pods formed on the marked branches of the tree post-treatment. The field trial was conducted from 2018-2022. The first spray was done at the budding stage (of flowering) and the second after 15 days on the marked trees. The following measures were adopted:

1) Mechanical measures: The removal of the dried khejri flower galls' fallen on the ground.
2) Lopping of trees: An experiment involving lopping was carried out in the months of October-December at intervals of one year (T_1), two years (T_2), and three years (T_3). Each treatment was replicated thrice. The level of incidence of flower gall was assessed in succeeding seasons.
3) Chemical, botanical and Entomopathogens: Effects of different botanicals entomopathogens and pesticides were recorded viz., *Beauveria bassiana, Hirsutella Thompsonii, Paecilomyces fumosoroseus, Metarhizium anisopliae* and *Lecanicillium lecanii* (entomopathogens); *Putranjiva roxburgii, Balanites aegyptiaca, Calotropis procera, Murraya koenigii, Eucalyptus, Annona squamosa,* Javik kheti Azadirachtin (botanicals); Abamection, Imidacloprid, Diafenthiuron 25% WW + Pyriproxyfen 5% WW, Spiromesifen, chlorfenapyr (different insecticides) and control. The first spray was done at the bud initiation and the second after 15 days interval on marked trees. The average number of galls per inflorescence and an average number of pods per inflorescence post-treatment were recorded.

3. RESULTS

3.1 Removal of Fallen Dried Flower Galls of Khejri

Eriophyes prosopidis causes flower gall and leaf gall of the khejri. Mites puncture the plant's outermost cells and cause the unopened flower bud to turn into a gall. Additionally, it was discovered that the eryiophid mites responsible for floral gall of khejri emerge on the outer surface of the mature galls and resemble rust which can be seen under a microscope. After the dried mature gall falls to the ground, these mites look for shelter close to the tree, in nooks and crannies, underneath the bark, and in other locations. They then infest freshly developed buds in the next season from February to March. Therefore the dried mature galls that fell on the ground were collected and removed as shown in Fig.2.This practice helped to eliminate overwintering stages of mite thereby decreasing their population and checked the infestation in subsequent season.

According to [22] as buds break in the spring, overwintering females of mites emerge from protective locations to lay eggs and graze on new foliage. The best opportunity for applying insecticides is now to keep the mite population from causing economic harm. Therefore, dried flower galls that have fallen to the ground must be mechanically removed to stop overwintering females from laying eggs on the new foliage at the time of bud initiation.

3.2 Lopping of Trees for the Management of Khejri Flower Galls

Khejri is traditionally pruned in November and December in Rajasthan. The flowering behaviour in khejri is influenced by the pruning techniques. In the un-lopped khejri trees, the first growth flush occurs in the spring, from February to March, and it coincides with flowering. When the pods reach full maturity in June, the second growth begins, and it continues as the monsoon and rainy seasons begin. Using this as a base, study, three different looping treatments were given: one at a one-year interval (T_1), two at a two-year interval (T_2), and three at three years (T_3).

The first lopping was done in Oct. 2018 (Fig. 3). The level of incidence of flower gall was assessed after lopping in different treatments along with control at all five selected sites (Tables 1 & 2; Figs. 4 to 7). The data in March-April 2019 revealed that there was no flowering and fruiting in the lopped khejri trees and the average galls per inflorescence and average number of pods per inflorescence in control was 15.99 and 5.3 respectively. Our results are in agreement with those of [23], who claimed due to the new shoots

Fig. 2. Removal of fallen dried flower galls of khejri

Fig. 3. Lopped khejri tree

immaturity during the khejri flowering season, pruned trees do not produce flowers from February to March, and as a result, no pods are produced.

In treatment T_1, the average number of pods per inflorescence was 5.16 in 2018, rising to 10.7 in 2020 and 10.79 in 2022, while the average number of galls per inflorescence was 15.22 in 2018, falling to 5.15 in 2020 and 4.93 in 2022. In treatment T_2, the average number of pods per inflorescence was 5.17 in 2018, rising to 10.41 in 2020 and reducing to 7.87 in 2021, while the average number of galls per inflorescence was 15.52 in 2018, falling to 5.19 in 2020 and 7.08 in 2021. In treatment T_3, the average number of pods per inflorescence was 5.14 in 2018, rising to 10.50 in 2020 and reducing to 7.86 in

2021 & 5.62 in 2022 while the average number of galls per inflorescence was 15.26 in 2018, falling to 5.18 in 2020, 7.09 in 2021 and 13.13 in 2022. Whereas in control the average number of pods per inflorescence was 5.30 in 2018, 5.39 in 2019, 5.19 in 2020, 5.175 in 2021 and 5.44 in 2022, while the average number of galls per inflorescence was 15.99 in 2018, 15.01 in 2019, 14.95 in 2020, 16.29 in 2021 and 14.60 in 2022. The results reflect that the gall formation was highest in control and least in T_1 where lopping was done at an interval of 1 year (Figs. 4, 5, 6 & 7) also pod per inflorescence was maximum in T_1 and least in control. In all the three treatments T_1 (looping at a one-year interval) performed the best when compared to the control, followed by T_2 (looping at a two-year interval).

Thus lopping at an interval of one year is recommended as it reduces the average number of gall formation.

Fig. 4. Pod & galls in control

Fig. 5. Pod & galls in lopping at 3 year interval

Fig. 6. Pod &galls in lopping at 2 year interval

Fig. 7. Pod & galls in lopping at 1 year interval

Table 1. Effect of lopping on average number of galls per inflorescence at different sites

Treatment/ Interval	Sites	Average No galls per inflorescence under different lopping treatments (Yearly)				
		2018	2019	2020	2021	2022
T1(1 year)	Phalodi	14.90	No flowering and fruiting in Feb-March as new flush starts after first lopping	5.24	No flowering and fruiting in Feb-March as new flush starts after second lopping	5.03
	Lohawat	15.70		5.15		4.99
	Osian	14.60		5.14		4.97
	Pipar	15.40		5.12		4.85
	Baori	15.50		5.08		4.80
	Average	15.22		5.15		4.93
T2(2 year)	Phalodi	15.30		5.26	7.27	No flowering and fruiting in Feb-March as new flush starts after second lopping
	Lohawat	16.10		5.21	7.19	
	Osian	15.40		5.25	7.08	
	Pipar	15.40		5.12	6.95	
	Baori	15.40		5.08	6.92	
	Average	15.52		5.19	7.08	
T3(3 year)	Phalodi	15.00		5.22	7.37	13.33
	Lohawat	15.60		5.17	7.22	13.23
	Osian	15.80		5.18	7.1	13.19
	Pipar	14.50		5.18	6.91	13.01
	Baori	15.40		5.13	6.84	12.89
	Average	15.26	-	5.18	7.09	13.13
Control		15.99	15.01	14.95	16.29	14.60

Table 2. Effect of lopping on average number of pods per inflorescence at different sites.

Treatment/ Interval	Sites	Pods per inflorescence under different lopping treatments (Yearly)				
		2018	**2019**	**2020**	**2021**	**2022**
T1(1 year)	Phalodi	5.40	No flowering and fruiting in Feb-March as new flush starts after first lopping	10.82	No flowering and fruiting in Feb-March as new flush starts after second lopping	11.29
	Lohawat	5.17		10.72		10.75
	Osian	5.13		10.65		10.66
	Pipar	5.07		10.63		10.62
	Baori	5.03		10.68		10.62
	Average	5.16		10.70		10.79
T2(2 year)	Phalodi	5.27		10.45	7.93	No flowering and fruiting in Feb-March as new flush starts after second lopping
	Lohawat	5.27		10.40	7.88	
	Osian	5.13		10.38	7.84	
	Pipar	5.1		10.38	7.82	
	Baori	5.1		10.43	7.88	
	Average	5.17		10.41	7.87	
T3(3 year)	Phalodi	5.23		10.80	7.92	5.64
	Lohawat	5.17		10.48	7.86	5.65
	Osian	5.1		10.43	7.8	5.61
	Pipar	5.07		10.39	7.82	5.59
	Baori	5.13		10.41	7.88	5.63
	Average	5.14		10.50	7.86	5.62
Control		5.30	5.39	5.19	5.17	5.44

3.3 Chemical, Botanicals and Entomopathogens

Based on data collected it was found that 5.84 average no. of galls per inflorescence were observed in treatment with *Putranjiva roxburgii* (10%), 5.78 average no. of galls per inflorescence in *Balanites aegyptiaca* (10%), 7.15 average no. of galls per inflorescence in *Metarhizium anisopliae* 2.5 x 10^7 conidia/ml; 4.77 average no. of galls per inflorescence in abamectin 1.9% EC @1ml/L and 5.2 average no. of galls per inflorescence in treatment with diafenthiuron 25% WW + Pyriproxyfen 5% WW @ 2 ml/L in comparison to control where the average no. of galls per inflorescence was 14.99 (Table 3; Fig. 8). Average no. of pods per inflorecence in treament with *Putranjiva roxburgii* (10%) was at par with average no. of pods per inflorecence in treatment with *Balanites aegyptiaca* (10%) i.e 10.10 & 10.14 respectively; 8.26 average no. of pods per inflorescence in treatment with *Metarhizium anisopliae* 2.5 x 10^7 conidia /ml; 11.08 average no. of pods per inflorescence in treatment with abamectin 1.9% EC @1ml/L and 10.24 average no. of pods per inflorescence in treatment with diafenthiuron 25% WW + pyriproxyfen 5% WW @ 2 ml/L in comparison to control where the average no. of pods per inflorescence was 4.44 (Table 4; Fig. 9).

4. DISCUSSION

Our results are supported by finding of [23] who reported that regular tree pruning and annual pruning led to the lowest possible long yield and no sangri production. Trees lopped in alternate years and in rotations for long produced the maximum yield. In another study [16,17] concluded that gall formation was 49.5% of the inflorescence in unlopped trees, which resulted in a pod production as low as 3.37%. In contrast, gall formation was greatly decreased (5.56%) in trees that had been lopped, and as a result, pod production was 13.3% greater. These findings also support the present findings which reveal that the practice of lopping after one year checks the population's build-up of khejri flower gall mite and reduces the flower gall formation. The results were found to be in line with [24] who reported that better control of *Aceria pallida* Keifer causing galls in goji berry *Lycium barbarum* L. was accomplished with artificial defoliation than pesticides. According to published accounts of *P. glandulosa*, pruning has been shown to promote increased tree growth [25]. According to the results of the current study, lopping at intervals of one year is beneficial for increasing the pods per inflorescence and decreasing the flower galls per inflorescence.

Several plant extracts have been reported to exhibit antimicrobial and pesticidal properties [26,27]. Plant metabolites and plant-based insecticides are known to have a low environmental impact and offer no harm to consumers when compared to synthetic pesticides [28].

In the present work, *Balanites aegyptiaca* and *Putranjiva roxburgii* leaf extracts were found effective in the management of flower galls of khejri which is in line with the other researchers who reported that different plant parts from *Balanites aegyptiaca* (L.) Del can be utilized as a botanical insecticide since they have promising findings for their botanical and insecticidal actions against a variety of pests. *Balanites aegyptiaca* fruit kernel was found to be effective against mosquito larvae of *Aedes aegypti, Aedes arabiensis* and *Culex quinquefasciatus* [29]. Additionally, [20,31] reported pesticidal and repellency activity of *Balanites aegyptiaca* acetone leaf extract against cowpea bruchid *Callosobruchus maculates*, *Castaneum tribolium* and *Trogoderma granarium*. When tested against the insect *Bruchus pisorum*, *Putranjiva* seed oil has shown great repellence in a small dosage of 0.02 ml, in contrast to other oils that failed to demonstrate the same repellence in the same amount. Due to its high toxicity insects, *P. roxburghii* oil protected the peanut seeds for six months [32].

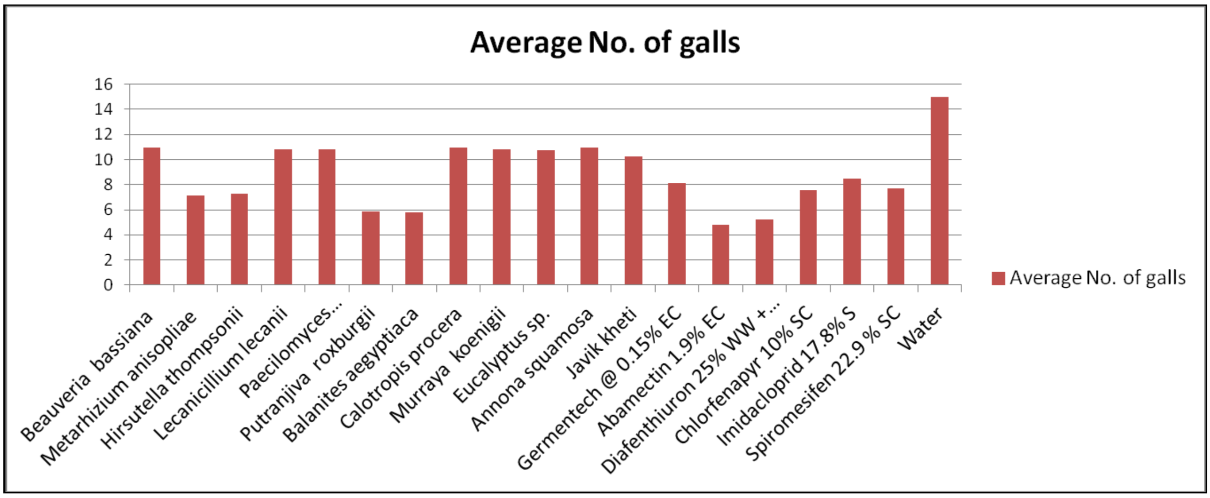

Fig. 8. Average No. of galls formed per inflorescence in different treatments

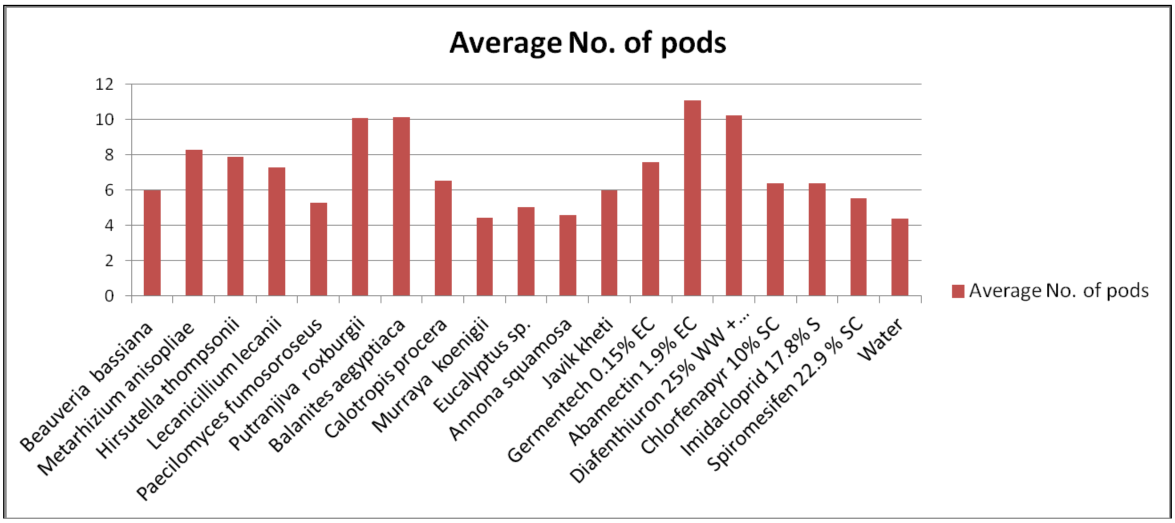

Fig. 9. Average No. of pods formed per inflorescence in different treatments

Table 3. Efficacy of different treatments against Khejri flower gall (Average No. of galls per inflorescence)

Treatment/ Interval		Doses	2018-19	2019-20	2020-21	2021-22	Average
			Average No. of galls	Average No. of galls	Average No. of galls	Average No. of galls	
T1 Entomopathogens	*Beauveria bassiana* 2.5 x 10^7 conidia /ml	2g/lit	10.92	10.92	11.15	10.83	10.95±0.06
	Metarhizium anisopliae 2.5 x 10^7 conidia /ml	2g/lit	7.18	7.11	7.25	7.07	7.15±0.03
	Hirsutella thompsonii 2 x10^8 conidia /ml	2g/lit	7.28	7.26	7.31	7.18	7.26±0.02
	Lecanicillium lecanii 1x10^7 conidia /ml	2g/lit	10.82	10.79	10.92	10.77	10.83±0.03
	Paecilomyces fumosoroseus 1.5x 10^8 conidia /ml	2g/lit	11.25	10.47	11.27	10.28	10.82±0.25
T2 Botanicals /biopesticides	*Putranjiva roxburgii*	10%	5.97	5.82	5.834	5.754	5.84± 0.04
	Balanites aegyptiaca	10%	5.94	5.75	5.72	5.71	5.78± 0.05
	Calotropis procera	10%	10.99	10.88	11.24	10.78	10.97±0.09
	Murraya koenigii	10%	11.19	10.71	11.22	10.25	10.84±0.22
	Eucalyptus sp.	10%	11.16	10.61	11.21	9.89	10.72± 0.3
	Annona squamosa	10%	11.23	11.00	11.26	10.39	10.97± 0.2
	Javik kheti	1.5 ml/lit.	10.35	10.21	10.41	10.10	10.27± 0.06
	Germentech (Azadirachtin) @ 0.15% EC	5 ml/ lit.	8.09	7.89	8.76	7.75	8.12±0.22
T3 Pesticides	Abamectin 1.9% EC	1 ml/lit.	4.984	4.74	4.99	4.38	4.77±0.14
	Diafenthiuron 25% WW + Pyriproxyfen 5% WW	2 ml/lit.	5.34	4.98	5.63	4.85	5.2±0.17
	Chlorfenapyr 10% SC	1.5 ml/lit.	7.65	7.48	7.76	7.37	7.57±0.08
	Imidacloprid 17.8% S	1 ml/lit.	8.49	8.46	8.62	8.31	8.47±0.06
	Spiromesifen 22.9 % SC	1 ml/lit.	7.71	7.64	7.79	7.54	7.67±0.05
Control	Water		15.52	14.31	15.89	14.26	14.99±0.41

Table 4. Efficacy of different treatments against Khejri flower gall (Average no. of pods)

Treatment/ Interval		Doses	2018-19 Average No. of pods	2019-20 Average No. of pods	2020-21 Average No. of pods	2021-22 Average No. of pods	Average
T1 Entomopathogens	*Beauveria bassiana* 2.5 x 10^7 conidia /ml	2g/lit.	5.86	6.02	5.88	6.1	5.97±0.05
	Metarhizium anisopliae 2.5 x 10^7 conidia /ml	2g/lit.	8.22	8.22	8.22	8.38	8.26±0.04
	Hirsutella thompsonii 2 x10^8 conidia /ml	2g/lit.	7.86	7.82	7.82	8.08	7.89±0.06
	Lecanicillium lecanii 1x10^7 conidia /ml	2g/lit.	7.3	7.28	7.24	7.34	7.29±0.02
	Paecilomyces fumosoroseus 1.5x 10^8 conidia /ml	2g/lit.	5.24	5.26	5.26	5.4	5.29±0.03
T2 Botanicals /biopesticides	*Putranjiva roxburgii*	10%	10.02	10.16	9.94	10.26	10.10±0.07
	Balanites aegyptiaca	10%	10.06	10.14	10.02	10.32	10.14±0.06
	Calotropis procera	10%	6.42	6.64	6.42	6.64	6.53±0.06
	Murraya koenigii	10%	4.4	4.44	4.36	4.56	4.44±0.04
	Eucalyptus sp.	10%	4.88	5.12	4.86	5.16	5.01±0.07
	Annona squamosa	10%	4.54	4.6	4.52	4.6	4.57±0.02
	Javik kheti	1.5 ml/lit.	5.88	6.04	5.86	6.16	5.99±0.07
	Germentech (Azadirachtin) @ 0.15% EC	5 ml/ lit.	7.46	7.66	7.48	7.64	7.56±0.05
T3 Pesticides	Abamectin 1.9% EC	1 ml/lit.	11.08	11.22	10.58	11.44	11.08±0.08
	Diafenthiuron 25% WW + Pyriproxyfen 5% WW	2 ml/lit.	10.12	10.26	10.14	10.42	10.24±0.06
	Chlorfenapyr 10% SC	1.5 ml/lit.	6.34	6.44	6.28	6.44	6.38±0.03
	Imidacloprid 17.8% S	1 ml/ lit.	6.32	6.38	6.28	6.46	6.36±0.03
	Spiromesifen 22.9 % SC	1 ml/ lit.	5.46	5.64	5.34	5.6	5.51±0.06
Control	Water		4.16	4.40	4.18	5.04	4.44±0.18

Furthermore, numerous reports are available on the field effectiveness of the mitosporic entomopathogenic fungus *Metarhizium anisopliae* against Acari. In actuality, entomopathogenic fungi (EPF) are being evaluated as a rational alternative to mite management through biological means [33,34]. According to [35] *M. anisopliae* has a high level of effectiveness against the eriophyoid mite, *Phyllocoptes gracilis*, which significantly reduces the yield of organic raspberries in Europe. [8] has reported high efficacy of *M. anisopliae* against *Tetranychus urticae* a pest of common bean plants in field conditions. Our findings also concludes the efficacy of *Metarhizium anisopliae* against flower gall of Khejri.

According to [36] Abamectin alone or in combination with mineral oil, sulfur, hexythiazox, and fenpyroximate is highly effective against *A. litchi.* [37] reported abamectin as the most effective tested miticide. According to [38-40] Diafenthiuron 25% + Pyriproxyfen 5% SE was found to be more efficient against sucking insect pests such as aphids, leafhoppers, whiteflies, and thrips in Bt cotton. Our finding also reports the efficacy of Abamectin 1.9% EC and Diafenthiuron 25% WW + Pyriproxyfen 5% WW for the effective management of khejri flower gall problem.

5. CONCLUSIONS

Eriophyes prosopidis induced flower galls are responsible for the loss of pods and seed production in *P. cineraria.* The gall-infested trees look unwell because they have a lot of disorganized and deformed green galls hanging from them. During the field trials of the present study, we found that the infestation of this mite can be managed by an integrated management approach. The mechanical removal of dried galls fallen on surface and lopping at an interval of one year can reduce the infestation considerably. Treatment with botanicals *Putranjiva roxburgii* (10%) leaf extract, *Balanites aegyptiaca* (10%) leaf extract, spray of *Metarhizium anisopliae* 2.5 x 10^7 conidia /ml and chemicals Abamectin 1.9% EC @1 ml/L and Diafenthiuron 25% WW + Pyriproxyfen 5% WW @ 2ml/L can be utilized for effective management of flower galls of *P. cineraria*.

DATA AVAILABILITY STATEMENT

The data presented in this study are available in article.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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