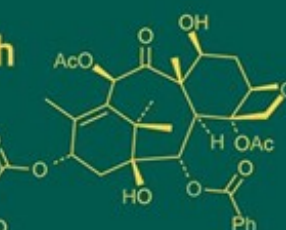
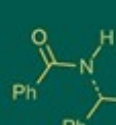


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Management of major insect pests of Ashwagandha, *Withania somnifera* (L.) Dunal using biorationals and their impact on natural enemies

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ABSTRACT

Ashwagandha, *Withania somnifera* (L.) Dunal, is an important medicinal crop widely cultivated in India and extensively used in traditional systems of medicine to treat skin conditions, lung inflammation, arthritis, etc. However, its production is constrained by several insect pests. The present investigation was undertaken to evaluate the effectiveness of selected botanical (neem oil, datura leaf extract and tobacco leaf extract) and biodynamic (Neemastra, Brahmastra, and Agniastra) products against major insect pests of Ashwagandha and their impact on the associated natural enemies. Among the treatments, neem oil exhibited the highest efficacy against cotton aphid, whereas Agniastra was the most effective treatment against hadda beetle, brown-winged green stink bug and fruit borer, whereas all the evaluated treatments were found safe to ladybird beetles, indicating their compatibility with biological control agents and their potential integration into eco-friendly pest management programmes. Agniastra exhibited the maximum yield increase (4.20 q/ha) and the highest incremental cost-benefit ratio (ICBR of 1:19.50). Overall, the findings demonstrated that biorationals can provide effective, economical, and environmentally compatible management of major insect pests in Ashwagandha. Their use may reduce dependence on synthetic insecticides and support safer production of medicinal plant material with minimal risk of pesticide residues and adverse effects on beneficial arthropods.

Keywords: Ashwagandha, Medicinal, Biorationals, Pests, Management

1. Introduction

Withania somnifera (L.) Dunal, commonly known as Ashwagandha, Asgandh, Indian ginseng or Indian Winter Cherry, belongs to the family Solanaceae, and is commonly grown as an annual herb (Farooqi *et al.*, 1991) [9]. It is extensively exploited in Indian traditional systems of medicine, Ayurveda, Siddha and Unani for over 3000 years (Sharma *et al.*, 2011) [27], and widely recognized as Queen of Ayurveda (Widodo *et al.*, 2010) [31]. In India, ashwagandha cultivation spans an estimated 10,780 hectares, with primary production concentrated across the states of Madhya Pradesh, Gujarat, Haryana, Maharashtra, Punjab, Rajasthan, and Uttar Pradesh. In Madhya Pradesh alone, it is grown in more than 5,000 ha of area (Kedar *et al.*, 2025) [13]. The pharmacological property of ashwagandha is attributed to the presence of several alkaloids, mainly 'Withanine' (antibacterial and anti-tumor properties) and 'Somniferine'. The paste made from its leaves is used to treat tubercular gland irritation, and of roots is utilized in treating skin conditions, bronchitis, tuberculosis, arthritis and ulcers. Furthermore, the fruits and seeds exhibit distinct diuretic properties (Bhattacharjee, 1998) [2]. Ashwagandha possesses adaptogenic, immune-modulator, rejuvenating, and anti-stress properties (Chadha, 2001) [4]. It also increases haemoglobin level, recovers anaemia, and reduces the greying of hairs (Kumari *et al.*, 2026) [17].

Ashwagandha is a crucial medicinal crop; however, it is devastated by an array of insect pests. Among these, cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae) (Chaudhary, 2013; Kedar *et al.*, 2024) [5], brown-winged green stink bug, *Plautia crossota* (Dallas) (Hemiptera: Pentatomidae) (Annual report ICFRE, 2011; Kedar *et al.*, 2024) [1, 12], fruit borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) and hadda beetle, *Henosepilachna vigintioctopunctata* (Fabricius) (Coleoptera: Coccinellidae) (Kumar *et al.*, 2009; Chaudhary, 2013; Kedar *et al.*, 2024) [15, 5, 12] are the major insect pests attacking Ashwagandha. Furthermore, several natural enemies of these insect pests have been documented in association with ashwagandha, prominent among which is the six-spotted zigzag ladybird beetle, *Cheilomenes sexmaculata* (Fabricius) (Coleoptera: Coccinellidae) (Kedar *et al.*, 2024) [12]. Infestation by these insect pests results in extensive defoliation and arrested plant growth, negatively influencing both the yield and quality of therapeutic phytochemicals of Ashwagandha. Considering its commercial value and medicinal significance, implementing Integrated Pest Management (IPM) practices is imperative to mitigate pest pressure while ensuring sustainable production.

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Although chemical intervention has historically been utilized for insect pest suppression, its deployment on medicinal crops like Ashwagandha is strictly limited due to the risks of persistent chemical residues, ecological degradation, non-target toxicity, and the acceleration of pest resistance. Because ashwagandha derivatives such as foliage and root powders are directly consumed for therapeutic purposes, synthetic pesticide residues severely compromise the safety, quality, and regulatory compliance of raw herbal materials. Consequently, the rapid expansion of the pharmaceutical industry demands an immediate shift towards eco-friendly alternatives. The integration of organic and biorational inputs should be preferred *viz.*, botanical extracts (e.g. *Datura* and tobacco leaf extracts) and biodynamic products (Cow-based by-products *i.e.*, Brahmasra, Neemasra, Agniastra, etc.) as they offer a cost-effective, sustainable, and residue-free strategy to mitigate yield losses while aligning with increasing global food safety and environmental standards.

2. Materials and Methods

2.1. Site of experiment: The experiment was conducted at the field of All India Coordinated Research Project (Medicinal, Aromatic Plants and Betel vine) of Department of Plant Physiology, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur during *Rabi*, 2024-25 and *Rabi*, 2025-26.

2.2. Layout and design of Experiment: The field experiment was laid out in a simple randomized block design (RBD), the variety being Jawahar Ashwagandha 20 (JA-20), with seven treatments and each replicated thrice in the plot of size 3 m x 3 m keeping row to row and plant to plant spacing of 30 cm and 20 cm, respectively. The details of treatments along with their doses (in Litre or Kg per hectare) are as follows: T₁ - 5% v/v Neem oil (25), T₂ - 5% w/v *Datura* leaf extract (25), T₃ - 5% w/v Tobacco leaf extract (25), T₄ - 3% w/v Neemasra (15), T₅ - 3% w/v Brahmasra (15), T₆ - 3% w/v Agniastra (15), and T₇ - Untreated control.

2.3. Methodology of preparation of biorationals

Following the recommendations of NITI Aayog [20] and Nayak (2022) [19], the treatment doses were established, and the botanical and biodynamic preparations were executed using the methodology described below:

- 1.
2. Neemasra - 5 L of cow urine, 1 kg of cow dung, and 5 kg of fine neem leaf paste were dissolved in 100 L of water within a drum. The solution was agitated clockwise using a wooden rod, covered with a gunny bag, and kept in shade for 48 hours to prevent exposure to sunlight and rain. During the two-day period, the mixture was stirred clockwise every morning and evening before final filtration through a muslin cloth.
3. Brahmasra - 20 L of cow urine and 2 kg each of fine leaf pastes from neem, karanj, custard apple, and *datura* were boiled for 15 min in an aluminium vessel. The mixture was stirred in a clockwise direction, covered with a lid, and allowed to cool. After 48 h, it was filtered through a muslin cloth and stored in a plastic container under shade.
4. Agniastra - A formulation was prepared by combining 20 L of cow urine, 2 kg each of neem leaf paste and tobacco powder, 500 g of chilli paste, 250 g of garlic paste, and 200 g of turmeric powder into 200 L of water in a plastic drum. The mixture was boiled for 30 min, filtered through a muslin cloth, and stored in a plastic drum under shade for future application.

2.4. Spray schedule

The initial spray was applied when the pest populations were sufficiently established. Subsequent second and third applications were administered at 21-day intervals using a knapsack sprayer (Kumari, 2022) [16].

2.5. Observations: Pre-treatment observations of major insect pests and natural enemies were recorded one day before spray and post-treatment observations were taken at 3, 7 and 14 days after each spray on ten randomly selected plants per plot/treatment (Vinyas *et al.*, 2022) [30]. In case of cotton aphids, the population was recorded by counting the number of nymphs and adults/six leaves/plant *i.e.*, 2 leaves from each top, middle and bottom of randomly selected plants (Chouhan, 2021) [7]. For the observation of hadda beetles (grubs and adults) (Yadav *et al.*, 2017) [32], brown-winged green stink bugs (nymphs and adults) (Parija *et al.*, 2023) [21], fruit borers (caterpillars) (Chopade *et al.*, 2020) [6] and zig-zag ladybirds (grubs and adults) (Pradhan *et al.*, 2020) [23], the plants were selected randomly and population was recorded on per plant basis. After harvest, root yield of ashwagandha was recorded treatment-wise and subsequently converted to a per-hectare equivalent. The bio-efficacy of the biorationals and the economics of each treatment were then calculated.

2.6. Interpretation of data

Bio-efficacy of the treatments was computed and the cost-benefit ratio of all the treatments was worked out as suggested by Gomez *et al.* (1984) [10]. The percent reduction in insect population over the untreated control was determined for each treatment using the Henderson *et al.* (1955) [11] corrected reduction method as follows:

$$\text{Reduction over control (\%)} = \left[1 - \frac{T_a \times C_b}{T_b \times C_a} \right] \times 100$$

where,

T_a = insect population in treated plot after treatment

T_b = insect population in treated plot before treatment

C_a = insect population in untreated control after treatment

C_b = insect population in untreated control before treatment

Population counts of insect pests and natural enemies were subjected to analysis of variance (ANOVA) following square root transformation ($\sqrt{x+0.5}$). Percentage data for reduction over control (ROC) were normalized using angular (arc-sine) transformation. To determine the significance of the biorational treatments, Duncan's Multiple Range Test (DMRT) was applied as described by Thumar *et al.* (2020) [29].

3. Results

The effectiveness of different biorationals against insect pest populations was evaluated under field conditions by comparing the treatments on the basis of percent reduction in pest populations at different intervals after spraying. A total of three sprays were administered on the crop during *Rabi*, 2024-25 and *Rabi*, 2025-26. Initial pre-treatment observations identified cotton aphid and hadda beetle as the primary insect pests. Prior to the second application, the major pests included cotton aphid, hadda beetle, brown-winged green stink bug and fruit borer. During the pre-treatment observation of the third application, only brown-winged green stink bug and fruit borer persisted as major insect pests. The impact of biorationals on natural enemies (mainly the six-spotted zigzag ladybird beetle) of insect pests on Ashwagandha was monitored during all three sprays.

3.1. Bio-efficacy of biorationals against cotton aphid (*Aphis gossypii*) on Ashwagandha

The pooled data (*Rabi*, 2024-25 and *Rabi*, 2025-26) of the overall mean of two sprays (1st and 2nd sprays) presented in Table 1 and Fig. 6 revealed that all the biorational treatments were found significantly superior than untreated control against cotton aphids (nymphs and adults) (Fig. 1).

Among the treatments, Neem oil (5% v/v) (T₁) was significantly proved to be the most effective, recording the lowest population of cotton aphids (61.85 aphids/six leaves/plant), and it was significantly at par with Brahmasra (3% w/v) (T₅) (70.32 aphids/six leaves/plant) which was further at par with Agniastra (3% w/v) (T₆), Tobacco leaf extract (5% w/v) (T₃), Neemasra (3% w/v) (T₄) and *Datura* leaf ex

tract (T₂) with 77.54, 85.32, 93.11 and 100.01 aphids/six leaves/plant, respectively. Whereas, the highest aphid population was recorded in the untreated control (T₇) with 146.18 aphids/six leaves/plant.

The maximum percent reduction in aphid population was recorded in T₁ - Neem oil (59.06 %) over the untreated control, followed by T₅ - Brahmasra (52.82 %), T₆ - Agniastra (47.81 %), T₃ - Tobacco leaf extract (41.95 %), T₄ - Neemastra (36.00 %) and T₂ - Datura leaf extract (31.16 %). All the biorational treatments were found to be significantly different from each other.



Figure 1. Cotton aphid infesting Ashwagandha

3.2. Bio-efficacy of biorationals against hadda beetle (*Henosepilachna vigintioctopunctata*) on Ashwagandha

As shown in Table 2 and Fig. 7, the pooled data of the overall mean of two sprays (1st and 2nd sprays) across Rabi, 2024-25 and Rabi, 2025-26 depicted that all biorational treatments were significantly more effective against hadda beetles (grubs and adults) (Fig. 2) than the untreated control.

Among the treatments, Agniastra (3% w/v) (T₆) was significantly found to be the most effective, recording the lowest population of hadda beetles (1.36 beetles/plant), and it was significantly at par with Neem oil (5% v/v) (T₁) (1.52 beetles/plant) which was further at par with Tobacco leaf extract (5% w/v) (T₃), Brahmasra (3% w/v) (T₅), Neemastra (3% w/v) (T₄) and Datura leaf extract (T₂) with 1.70, 1.84, 1.97 and 2.06 beetles/plant, respectively. Whereas, the highest population was recorded in the untreated control (T₇) with 3.16 beetles/plant.

The maximum percent reduction in hadda beetle population was recorded in T₆ - Agniastra (56.14 %) over the untreated control, followed by T₁ - Neem oil (50.46 %), T₃ - Tobacco leaf extract (45.81 %), T₅ - Brahmasra (40.56 %), T₄ - Neemastra (37.18 %) and T₂ - Datura leaf extract (33.62 %). A statistically significant difference was observed among the biorational treatments in their efficacy.

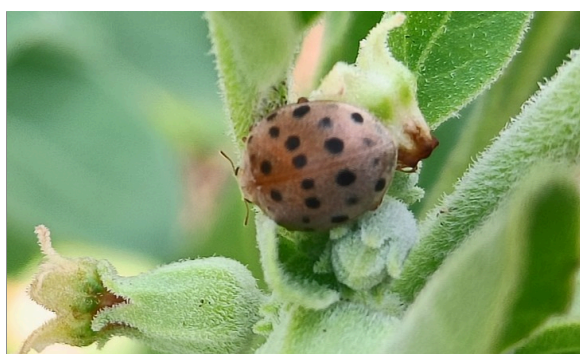


Figure 2. Hadda beetle infesting Ashwagandha

3.3. Bio-efficacy of biorationals against brown-winged green stink bug (*Plautia crossota*) on Ashwagandha

The pooled data (Rabi, 2024-25 and Rabi, 2025-26) representing the overall mean of 2nd and 3rd sprays (presented in Table 3 and Fig. 8) showed that every biorational treatment performed significantly better than the untreated control in managing brown-winged green stink bugs (nymphs and adults) (Fig. 3).

Among the treatments, Agniastra (3% w/v) (T₆) was significantly proved to be the most effective, recording the lowest population of stink bugs (1.84 bugs/plant), and it was significantly at par with Neem oil (5% v/v) (T₁) (2.03 bugs/plant) which was further at par with Brahmasra (3% w/v) (T₅), Tobacco leaf extract (5% w/v) (T₃), Neemastra (3% w/v) (T₄) and Datura leaf extract (T₂) with 2.21, 2.41, 2.59 and 2.78 bugs/plant, respectively. Whereas, the highest stink bug population was recorded in the untreated control (T₇) with 4.16 bugs/plant.

The maximum percent reduction in bug population was observed in T₆ - Agniastra (53.92 %) over the untreated control, followed by T₁ - Neem oil (49.62 %), T₅ - Brahmasra (45.81 %), T₃ - Tobacco leaf extract (41.25 %), T₄ - Neemastra (36.94 %) and T₂ - Datura leaf extract (33.08 %). All the biorational treatments were found to be significantly different from each other.



Figure 3. Brown-winged green stink bug infesting Ashwagandha

3.4. Bio-efficacy of biorationals against fruit borer (*Helicoverpa armigera*) on Ashwagandha

The analysis of the pooled data (Rabi, 2024-25 and Rabi, 2025-26) of the overall mean of two sprays (2nd and 3rd sprays) presented in Table 4 and Fig. 9 revealed that all the biorational treatments were found significantly superior than untreated control against fruit borers (caterpillars) (Fig. 4).

Among the treatments, Agniastra (3% w/v) (T₆) was significantly found to be the most effective, recording the lowest population of fruit borers (1.08 borers/plant), and it was significantly at par with Brahmasra (3% w/v) (T₅) (1.22 borers/plant) which was further at par with Neem oil (5% v/v) (T₁), Tobacco leaf extract (5% w/v) (T₃), Neemastra (3% w/v) (T₄) and Datura leaf extract (T₂) with 1.37, 1.47, 1.58 and 1.70 borers/plant, respectively. Whereas, the highest population was recorded in the untreated control (T₇) with 2.46 borers/plant. The maximum percent reduction in fruit borer population was recorded in T₆ - Agniastra (54.45 %) over the untreated control, followed by T₅ - Brahmasra (49.89 %), T₁ - Neem oil (44.40 %), T₃ - Tobacco leaf extract (39.88 %), T₄ - Neemastra (34.81 %) and T₂ - Datura leaf extract (30.54 %). A statistically significant difference was observed among the biorational treatments in their efficacy.



Figure 4. Fruit borer infesting Ashwagandha

3.5. Impact of biorationals on natural enemies (six-spotted zigzag ladybird beetle, *Cheilomenes sexmaculata*) of insect pests on Ashwagandha

The pooled data (*Rabi*, 2024-25 and *Rabi*, 2025-26) of overall mean of all three sprays presented in Table 5 and Fig. 10 depicted that the population of ladybird beetle (Fig. 5) was evenly distributed in the field and ranged from 4.03 to 4.17 grub and adult/plant which was found to be statistically non-significant difference among the different biorational treatments.



Figure 5. Six-spotted zigzag ladybird beetle on Ashwagandha

3.6. Bio-efficacy of biorationals on root yield of Ashwagandha

In the present investigation (Table 6 and Fig. 11), all the plots treated with biorationals gave significantly higher root yield over T_7 - untreated control (3.01 q/ha). The maximum root yield was obtained in T_6 - Agniastra (3% w/v) (7.21 q/ha), followed by T_1 - Neem oil (5% v/v) (7.10 q/ha), T_5 - Brahmastra (3% w/v) (6.24 q/ha), T_3 - Tobacco leaf extract (5% w/v) (5.14 q/ha), T_4 - Neemastra (3% w/v) (4.87 q/ha), and T_2 - Datura leaf extract (5% w/v) (3.92 q/ha). All the biorational treatments were found to be significantly different from each other.

The pooled data presented in Table 6 showed that the highest increase in yield over control was recorded in Agniastra (4.20 q/ha), followed by Neem oil (4.09 q/ha) and Brahmastra (3.23 q/ha). The next highest yield increases were in Tobacco leaf extract (2.13 q/ha) and Neemastra (1.86 q/ha). The lowest yield increase was recorded in Datura leaf extract (0.92 q/ha).

The data presented in Table 6 and Fig. 12 clearly showed that among the different biorational treatments, the maximum net return of 1,19,806 ₹/ha was obtained in Agniastra, followed by Neem oil (1,06,194 ₹/ha), Brahmastra (85,828 ₹/ha), Tobacco leaf extract (56,928 ₹/ha), and Neemastra (49,867 ₹/ha), whereas minimum was in Datura leaf extract (21,198 ₹/ha). Although, the highest incremen-

tal cost-benefit ratio (ICBR) was observed in Agniastra (1:19.50), followed by Neemastra (1:8.27), Tobacco leaf extract (1:8.17), Brahmastra (1:7.68), Neem oil (1:6.43), and the lowest ratio was found in Datura leaf extract (1:3.39).

4. Discussion

All the treatments were found significantly more effective than untreated control. Among different treatments, Neem oil was found to be most effective against cotton aphid, *Aphis gossypii* Glover, followed by Brahmastra and Agniastra. The results of the present study are in accordance with the findings of Ranila *et al.* (2020) [25] who observed that neem oil (0.3%) managed the aphid, *A. gossypii* on coriander effectively. Similarly, Borad *et al.* (2019) [3] evaluated different botanicals, among which Neem oil was found most effective against aphid (*Aphis craccivora* Koch) on cowpea. In addition, Patel *et al.* (2017) [22] reported that Brahmastra (20 %) was found highly effective in suppressing the sucking pests of cotton viz., aphid (*A. gossypii*), followed by Agniastra and Neemastra at 20 %. Among the different botanical treatments, Agniastra was found to be most effective against hadda beetle, *Henosepilachna vigintioctopunctata* (Fabricius), followed by Neem oil and Tobacco leaf extract. In support of the present findings, Kumari *et al.* (2026) [17] recently found the effectiveness of azadirachtin 0.03 EC, followed by Neem oil and NSKE 5% against hadda beetle, *H. vigintioctopunctata*. Similarly, Rajendran *et al.* (1998) [24] examined that Neem oil (4%) reduced the fecundity of *H. vigintioctopunctata* on brinjal by 62.8 % over control. In addition, Kodandaram *et al.* (2014) [14] found that neem oil was the most effective treatment for controlling hadda beetle on vegetable cowpea.

In the present study, Agniastra was found to be most effective against brown-winged green stink bug, *Plautia crossota* (Dallas), followed by Neem oil and Brahmastra. The findings of this study closely align with those of Lozano *et al.* (2024) [18], who demonstrated that botanical formulations derived from garlic (Natualho®), neem (azadirachtin), and various *Piperaceae* species disrupt feeding behaviors, stunt growth, and inhibit reproduction in stink bugs.

In case of fruit borer, *Helicoverpa armigera* (Hübner), Agniastra was found to be most effective, followed by Brahmastra and Neem oil. In support to the present findings, Rehaman *et al.* (2016) [26] depicted that the highest mean per cent reduction of *H. armigera* infestation on fruits of ashwagandha was recorded with Ha NPV @ 250 LE, which was on par with nimbecidine @ 3ml/L, followed by NSKE 5 % and neem oil 5 ml/L over control.

All the treatments were found to be safe for natural enemies. The highest yield was observed in Agniastra, followed by Neem oil and Brahmastra. The highest incremental cost-benefit ratio was observed in Agniastra, followed by Neemastra, Tobacco leaf extract, Brahmastra, Neem oil, and Datura leaf extract. Present findings are in accordance with Subha *et al.* (2025) [28] who found that all biodynamics and botanicals were safe on natural enemies of insect pests as they were statistically non-significant over control, and also revealed that the maximum yield of summer green gram was recorded in Neem oil 5%, followed by NSKE 5% and Brahmastra 5%, although the highest cost-benefit ratio was found in Brahmastra 5% (1:8.34), followed by Agniastra 5% (1:7.18) and Neemastra 5% (1:6.03). Similar findings have been reported by Nayak (2022) [19] who observed that the highest yield of black gram was obtained from the plots treated with NSKE 5%, followed by Neem oil and Brahmastra, whereas Brahmastra was found to have highest ICBR. In addition, Dubey (2024) [8] also revealed that all the biodynamic treatments were found safe for natural enemies on the mustard crop, and the highest yield increases and cost-benefit ratio were observed in Agneyastra @ 60 ml/litre, followed by Dasparni ark @ 60 ml/litre and Brahmastra @ 60 ml/litre.

Table 1. Bio-efficacy of biorationals against cotton aphid on Ashwagandha (after 1st and 2nd sprays)

Treatment	Dose (L or Kg per ha)	Rabi, 2024-25		Rabi, 2025-26		Pooled (Rabi, 2024-25 and 2025-26)	
		Mean population	ROC (%)	Mean population	ROC (%)	Mean population	ROC (%)
T ₁ -Neem oil (5% v/v)	25	69.25 (8.35) ^f	58.66 (49.99) ^a	54.45 (7.41) ^g	59.18 (50.29) ^a	61.85 (7.89) ^g	59.06 (50.22) ^a
T ₂ -Datura leaf extract (5% w/v)	25	113.37 (10.67) ^b	29.68 (32.97) ^f	86.64 (9.33) ^b	32.79 (34.93) ^f	100.01 (10.02) ^b	31.16 (33.92) ^f
T ₃ -Tobacco leaf extract (5% w/v)	25	97.62 (9.90) ^c	40.48 (39.49) ^d	73.03 (8.57) ^d	43.70 (41.38) ^d	85.32 (9.26) ^d	41.95 (40.36) ^d
T ₄ -Neemastra (3% w/v)	15	106.13 (10.32) ^b	34.86 (36.15) ^e	80.08 (8.97) ^c	37.32 (37.65) ^e	93.11 (9.67) ^c	36.00 (36.85) ^e
T ₅ -Brahmastra (3% w/v)	15	78.85 (8.90) ^e	52.16 (46.24) ^b	61.79 (7.89) ^f	53.41 (46.95) ^b	70.32 (8.41) ^f	52.82 (46.62) ^b
T ₆ -Agniastra (3% w/v)	15	87.12 (9.36) ^d	47.31 (43.46) ^c	67.96 (8.27) ^e	48.17 (43.95) ^c	77.54 (8.83) ^e	47.81 (43.74) ^c
T ₇ -Untreated control	-	162.42 (12.76) ^a	-	129.93 (11.42) ^a	-	146.18 (12.11) ^a	-
<i>SE_m</i> ±		0.12	0.65	0.06	0.38	0.07	0.44
CD at 5%		0.37	2.04	0.18	1.21	0.22	1.38

NS = Non-significant, Figures in parentheses are square root transformed values;

ROC = Reduction over control, Figures in parentheses are Arc sin or angular transformed values;

Within column means followed by different letters are significantly different at 5% level of DMRT test

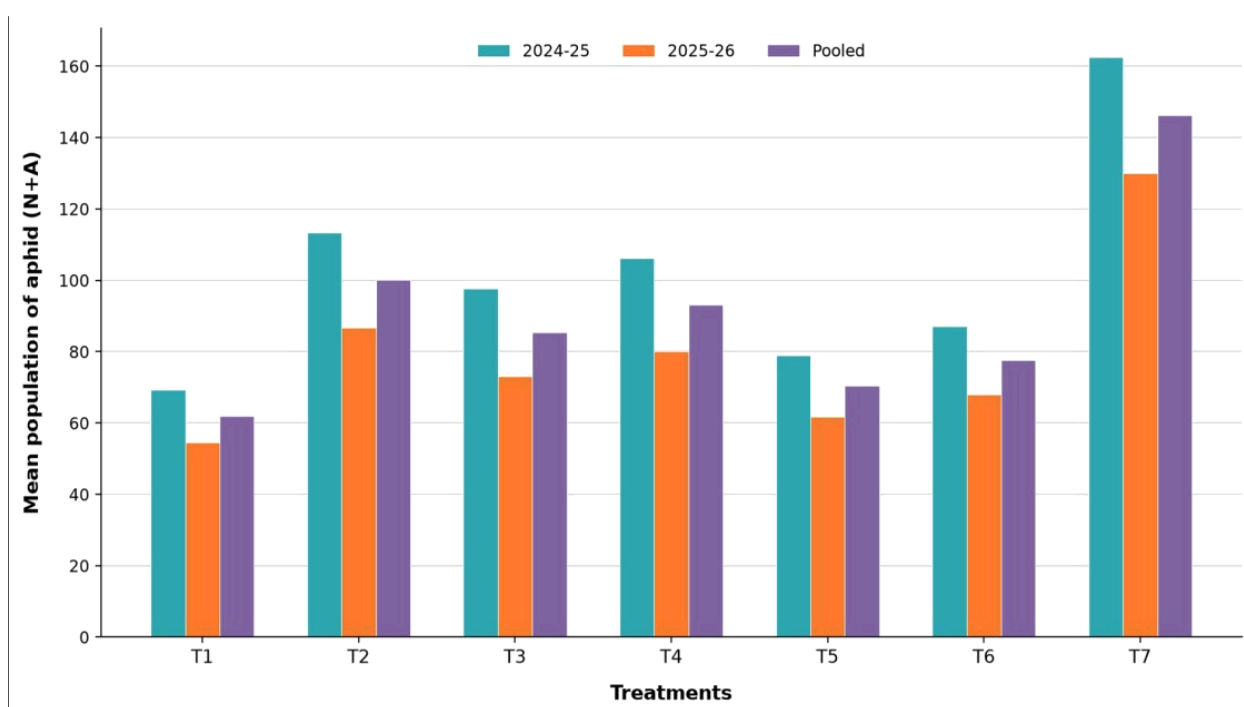
**Figure 6.** Comparison of bio-efficacy of biorationals against cotton aphid on Ashwagandha

Table 2. Bio-efficacy of biorationals against hadda beetle on Ashwagandha (after 1st and 2nd sprays)

Treatment	Dose (L or Kg per ha)	Rabi, 2024-25		Rabi, 2025-26		Pooled (Rabi, 2024-25 and 2025-26)	
		Mean population	ROC (%)	Mean population	ROC (%)	Mean population	ROC (%)
T ₁ -Neem oil (5% v/v)	25	1.68 (1.48) ^f	49.32 (44.61) ^b	1.36 (1.36) ^e	51.61 (45.92) ^b	1.52 (1.42) ^f	50.46 (45.26) ^b
T ₂ -Datura leaf extract (5% w/v)	25	2.27 (1.66) ^b	33.76 (35.52) ^f	1.85 (1.53) ^b	33.06 (35.10) ^f	2.06 (1.60) ^b	33.62 (35.44) ^f
T ₃ -Tobacco leaf extract (5% w/v)	25	1.87 (1.54) ^e	45.27 (42.29) ^c	1.53 (1.43) ^d	46.20 (42.82) ^c	1.70 (1.48) ^e	45.81 (42.60) ^c
T ₄ -Neemastra (3% w/v)	15	2.14 (1.62) ^c	37.34 (37.66) ^e	1.79 (1.51) ^b	36.69 (37.28) ^e	1.97 (1.57) ^c	37.18 (37.57) ^e
T ₅ -Brahmastra (3% w/v)	15	2.02 (1.59) ^d	40.73 (39.66) ^d	1.66 (1.47) ^c	40.09 (39.28) ^d	1.84 (1.53) ^d	40.56 (39.56) ^d
T ₆ -Agniasta (3% w/v)	15	1.51 (1.42) ^g	55.45 (48.14) ^a	1.21 (1.31) ^f	56.84 (48.93) ^a	1.36 (1.36) ^g	56.14 (48.53) ^a
T ₇ -Untreated control	-	3.42 (1.98) ^a	-	2.89 (1.84) ^a	-	3.16 (1.91) ^a	-
<i>SE_m</i> ±		0.01	0.50	0.01	0.54	0.00	0.25
CD at 5%		0.02	1.57	0.02	1.70	0.01	0.79

NS = Non-significant, Figures in parentheses are square root transformed values;

ROC = Reduction over control, Figures in parentheses are Arc sin or angular transformed values;

Within column means followed by different letters are significantly different at 5% level of DMRT test

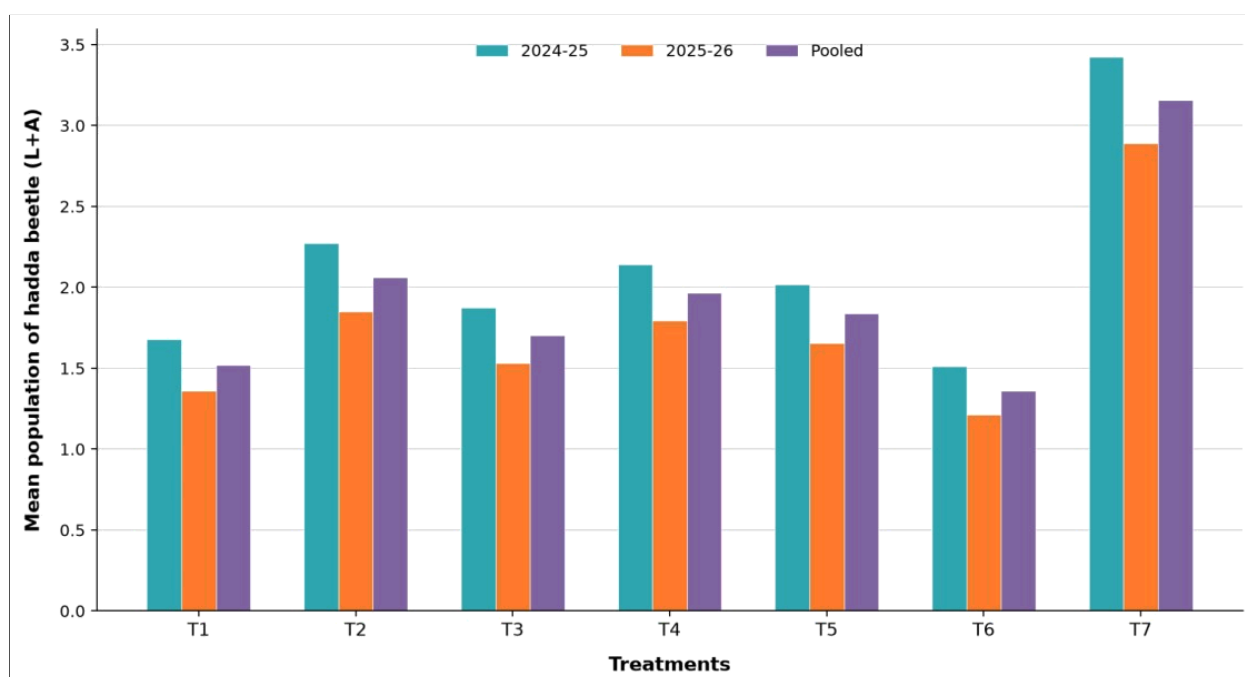
**Figure 7.** Comparison of bio-efficacy of biorationals against hadda beetle on Ashwagandha

Table 3. Bio-efficacy of biorationals against brown-winged green stink bug on Ashwagandha (after 2nd and 3rd sprays)

Treatment	Dose (L or Kg per ha)	Rabi, 2024-25		Rabi, 2025-26		Pooled (Rabi, 2024-25 and 2025-26)	
		Mean population	ROC (%)	Mean population	ROC (%)	Mean population	ROC (%)
T ₁ -Neem oil (5% v/v)	25	2.06 (1.60) ^f	49.16 (44.52) ^a	1.99 (1.58) ^f	50.10 (45.06) ^b	2.03 (1.59) ^f	49.62 (44.78) ^b
T ₂ -Datura leaf extract (5% w/v)	25	2.77 (1.81) ^b	33.66 (35.46) ^c	2.80 (1.82) ^b	32.51 (34.75) ^d	2.78 (1.81) ^b	33.08 (35.11) ^f
T ₃ -Tobacco leaf extract (5% w/v)	25	2.44 (1.71) ^d	41.77 (40.25) ^b	2.39 (1.70) ^d	40.46 (39.50) ^c	2.41 (1.71) ^d	41.25 (39.96) ^d
T ₄ -Neemastra (3% w/v)	15	2.57 (1.75) ^c	36.64 (37.25) ^c	2.60 (1.76) ^c	37.30 (37.64) ^c	2.59 (1.76) ^c	36.94 (37.43) ^c
T ₅ -Brahmastra (3% w/v)	15	2.24 (1.66) ^e	44.97 (42.11) ^b	2.18 (1.64) ^e	46.71 (43.11) ^b	2.21 (1.65) ^e	45.81 (42.59) ^c
T ₆ -Agniastra (3% w/v)	15	1.87 (1.54) ^g	52.74 (46.57) ^a	1.82 (1.52) ^g	55.14 (47.95) ^a	1.84 (1.53) ^g	53.92 (47.25) ^a
T ₇ -Untreated control	-	4.23 (2.17) ^a	-	4.08 (2.14) ^a	-	4.16 (2.16) ^a	-
<i>SE_m</i> ±		0.00	0.65	0.00	0.68	0.00	0.56
CD at 5%		0.01	2.06	0.01	2.13	0.01	1.76

NS = Non-significant, Figures in parentheses are square root transformed values;

ROC = Reduction over control, Figures in parentheses are Arc sin or angular transformed values;

Within column means followed by different letters are significantly different at 5% level of DMRT test

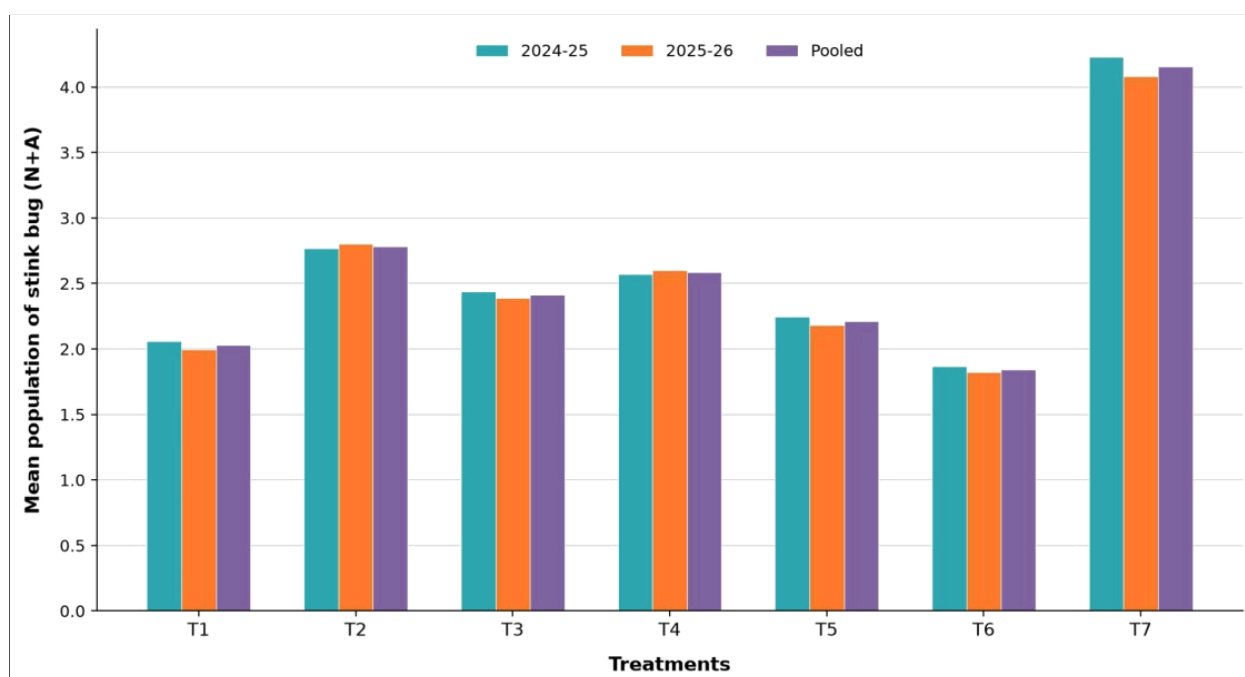
**Figure 8.** Comparison of bio-efficacy of biorationals against brown-winged green stink bug on Ashwagandha

Table 4. Bio-efficacy of biorationals against fruit borer on Ashwagandha (after 2nd and 3rd sprays)

Treatment	Dose (L or Kg per ha)	Rabi, 2024-25		Rabi, 2025-26		Pooled (Rabi, 2024-25 and 2025-26)	
		Mean population	ROC (%)	Mean population	ROC (%)	Mean population	ROC (%)
T ₁ -Neem oil (5% v/v)	25	1.50 (1.41) ^e	43.72 (41.39) ^c	1.23 (1.32) ^e	44.89 (42.06) ^b	1.37 (1.37) ^e	44.40 (41.78) ^c
T ₂ -Datura leaf extract (5% w/v)	25	1.84 (1.53) ^b	30.52 (33.53) ^f	1.56 (1.44) ^b	30.06 (33.25) ^e	1.70 (1.48) ^b	30.54 (33.55) ^f
T ₃ -Tobacco leaf extract (5% w/v)	25	1.60 (1.45) ^d	39.61 (38.99) ^d	1.34 (1.36) ^d	39.73 (39.06) ^c	1.47 (1.40) ^d	39.88 (39.16) ^d
T ₄ -Neemastra (3% w/v)	15	1.71 (1.48) ^c	34.09 (35.70) ^e	1.45 (1.40) ^c	34.85 (36.16) ^d	1.58 (1.44) ^c	34.81 (36.16) ^e
T ₅ -Brahmastra (3% w/v)	15	1.35 (1.36) ^f	49.51 (44.72) ^b	1.09 (1.26) ^f	50.04 (45.02) ^a	1.22 (1.31) ^f	49.89 (44.93) ^b
T ₆ -Agniastra (3% w/v)	15	1.17 (1.29) ^g	54.98 (47.86) ^a	0.98 (1.22) ^g	53.63 (47.08) ^a	1.08 (1.25) ^g	54.45 (47.55) ^a
T ₇ -Untreated control	-	2.67 (1.78) ^a	-	2.25 (1.66) ^a	-	2.46 (1.72) ^a	-
<i>SE_m</i> ±		0.00	0.58	0.01	0.77	0.00	0.55
CD at 5%		0.01	1.82	0.02	2.42	0.01	1.72

NS = Non-significant, Figures in parentheses are square root transformed values;

ROC = Reduction over control, Figures in parentheses are Arc sin or angular transformed values;

Within column means followed by different letters are significantly different at 5% level of DMRT test

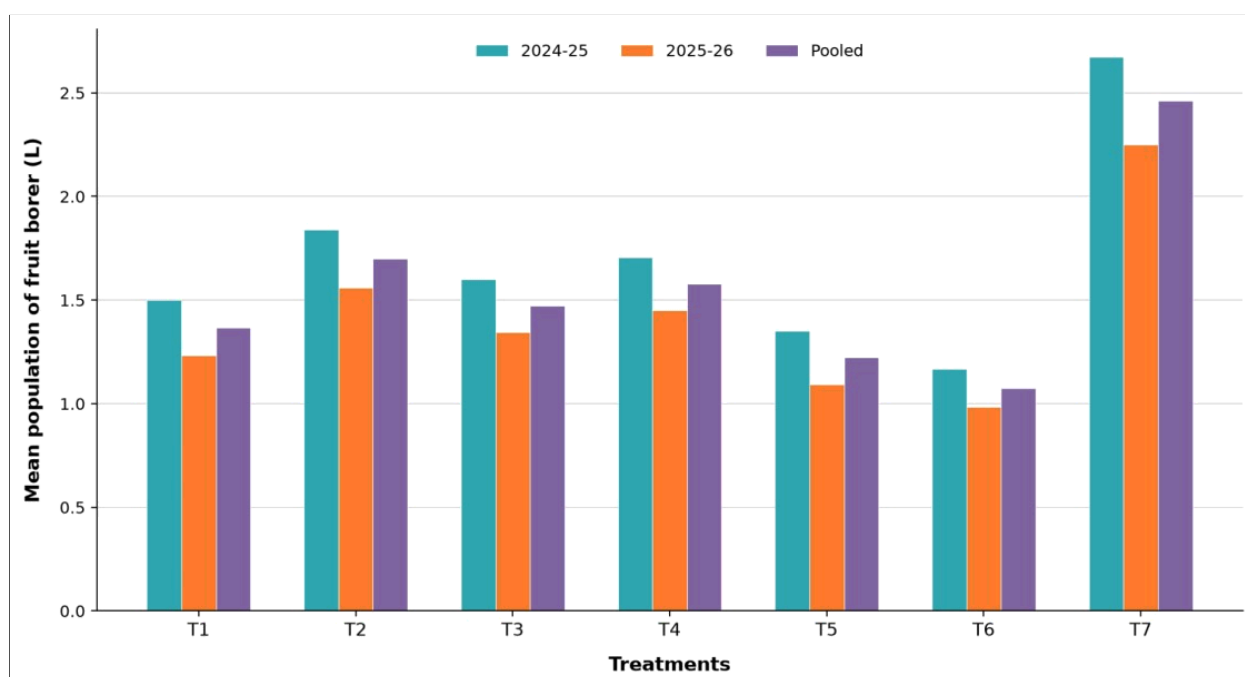
**Figure 9.** Comparison of bio-efficacy of biorationals against fruit borer on Ashwagandha

Table 5. Impact of biorationals on six-spotted zigzag ladybird beetle on Ashwagandha (after 1st, 2nd and 3rd sprays)

Treatment	Dose (L or Kg per ha)	Rabi, 2024-25		Rabi, 2025-26		Pooled (Rabi, 2024-25 and 2025-26)	
		Mean population	ROC (%)	Mean population	ROC (%)	Mean population	ROC (%)
T ₁ -Neem oil (5% v/v)	25	3.36 (1.96)	-	4.82 (2.31)	-	4.09 (2.14)	-
T ₂ -Datura leaf extract (5% w/v)	25	3.35 (1.96)	-	4.78 (2.30)	-	4.07 (2.14)	-
T ₃ -Tobacco leaf extract (5% w/v)	25	3.36 (1.96)	-	4.73 (2.29)	-	4.04 (2.13)	-
T ₄ -Neemastra (3% w/v)	15	3.41 (1.98)	-	4.88 (2.32)	-	4.15 (2.16)	-
T ₅ -Brahmastra (3% w/v)	15	3.42 (1.98)	-	4.63 (2.26)	-	4.03 (2.13)	-
T ₆ -Agniastra (3% w/v)	15	3.33 (1.96)	-	4.81 (2.31)	-	4.07 (2.14)	-
T ₇ -Untreated control	-	3.53 (2.01)	-	4.82 (2.31)	-	4.17 (2.16)	-
$SE_{m\pm}$		0.02	-	0.02	-	0.01	-
CD at 5%		NS	-	NS	-	NS	-

NS = Non-significant, Figures in parentheses are square root transformed values

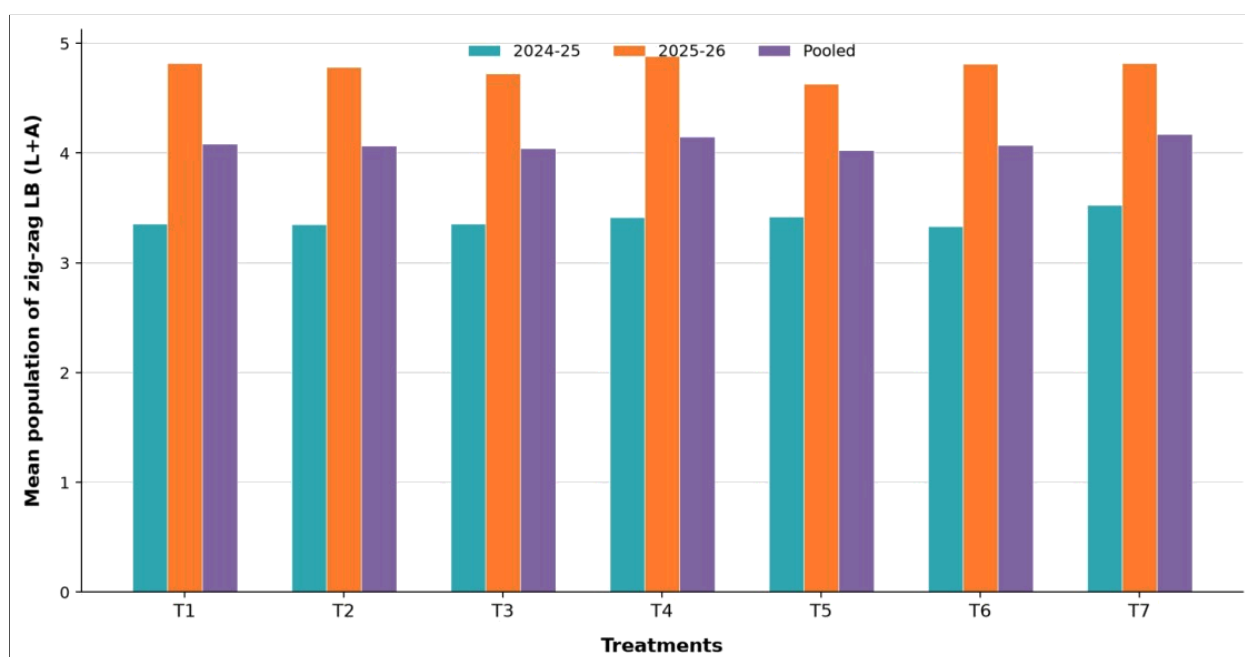
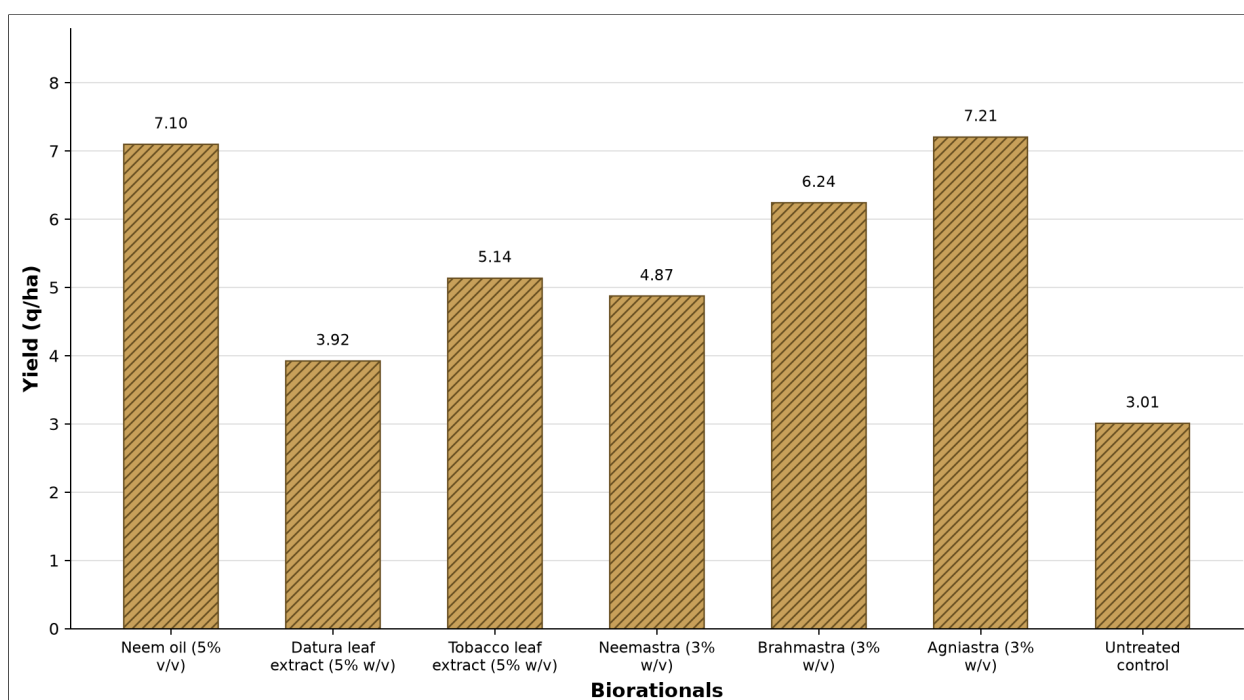
**Figure 10.** Comparison of impact of biorationals on six-spotted zigzag ladybird beetle on Ashwagandha

Table 6. Economics of biorational treatments in management of major insect pests on Ashwagandha during *Rabi*, 2024-25 and *Rabi*, 2025-26 (pooled)

Treatments	Yield (q/ha)	Increase in yield over control (q/ha)	Cost of treatment of one spray			Cost of 3 sprays (₹/ha)	Gross return due to treatment (₹/ha)	Net return due to treatment (₹/ha) (8-7)	ICBR (9/7)
			Cost of treatment (₹/ha)	Labour charge/spray (₹/ha)	Total cost (₹/ha) (4+5)				
1	2	3	4	5	6	7	8	9	10
T ₁ -Neem oil (5% v/v)	7.10 ^b	4.09	4,500	1,002	5,502	16,506	1,22,700	1,06,194	1:6.43
T ₂ -Datura leaf extract (5% w/v)	3.92 ^f	0.92	1,082	1,002	2,084	6,252	27,450	21,198	1:3.39
T ₃ -Tobacco leaf extract (5% w/v)	5.14 ^d	2.13	1,322	1,002	2,324	6,972	63,900	56,928	1:8.17
T ₄ -Neemastra (3% w/v)	4.87 ^e	1.86	1,009	1,002	2,011	6,033	55,900	49,867	1:8.27
T ₅ -Brahmastra (3% w/v)	6.24 ^c	3.23	2,722	1,002	3,724	11,172	97,000	85,828	1:7.68
T ₆ -Agniastra (3% w/v)	7.21 ^a	4.20	1,046	1,002	2,048	6,144	1,25,950	1,19,806	1:19.50
T ₇ -Untreated control	3.01 ^g	-	-	-	-	-	-	-	-
SE(m)±	0.01	-	-	-	-	-	-	-	-
CD at 5%	0.04	-	-	-	-	-	-	-	-

Means followed by different letters are significantly different at 5% level of DMRT test

**Figure 11.** Root yield of Ashwagandha as influenced by application of biorationals in management of major insect pests during *Rabi*, 2024-25 and *Rabi*, 2025-26 (pooled)

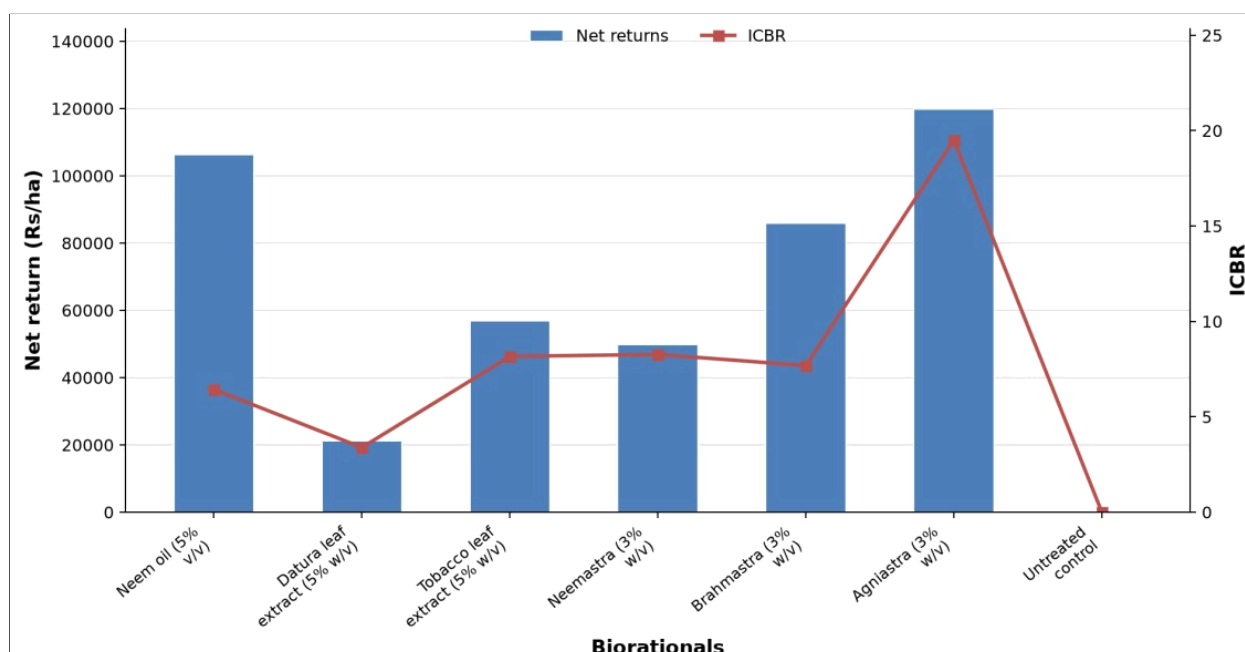


Figure 12. Net return and ICBR of different biorationals in management of major insect pests on Ashwagandha during *Rabi*, 2024-25 and *Rabi*, 2025-26 (pooled)

5. Conclusion

The bio-efficacy of different botanicals revealed that among the treatments, Neem oil was found to be most effective against cotton aphid, whereas Agniastara was found to be most effective against hadda beetle, brown-winged green stink bug and fruit borer. All the treatments were found effective and safe for natural enemies (ladybird beetles), proving their compatibility with eco-friendly pest management. The highest yield increases were observed in Agniastara (4.20 q/ ha), followed by Neem oil (4.09 q/ ha), Brahmastra (3.23 q/ ha), Tobacco leaf extract (2.13 q/ ha) and Neemastra (1.86 q/ ha), while the lowest yield increase was recorded in Datura leaf extract (0.92 q/ ha). The highest incremental cost-benefit ratio (ICBR) was observed in Agniastara (1:19.50), followed by Neemastra (1:8.27), Tobacco leaf extract (1:8.17), Brahmastra (1:7.68), Neem oil (1:6.43), and the lowest ratio was found in Datura leaf extract (1:3.39).

The present study revealed that the botanical-based management approach on Ashwagandha resulted in strategic pest management as farmers can deploy Neem oil for targeted control of aphid outbreaks, and switch to Agniastara as a powerful broad-spectrum solution for complex infestations (stink bugs, borers, and beetles). It optimized both productivity and profitability by providing a massive cost-to-benefit return alongside high yield increase, ensuring farmers get maximum financial returns for a low input cost. Unlike synthetic chemical pesticides, all tested botanicals were found safe for ladybird beetles which preserves local biodiversity and allows natural predators to continue controlling pests biologically. Also, utilizing natural extracts and bio-dynamic products is highly beneficial for Ashwagandha, as it is a high-value medicinal plant where purity should be strictly monitored for pharmaceutical and export markets.

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