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BIO EFFICACY OF INSECTICIDES AGAINST LEPIDOPTERAN PESTS AND THEIR IMPACT ON NATURAL ENEMIES IN THE MAIZE CROP

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ABSTRACT

Maize is one of the most important crops in India after rice and wheat. The maize crop is attacked by major lepidopteran pests. Therefore, the present investigation was carried out to evaluate the bio-efficacy of different insecticides against lepidopteran pests and their impact on natural enemies. The insecticides evaluated were Indoxacarb 20% + Emamectin benzoate 5% EC, Indoxacarb 14.5 SC, Emamectin benzoate 5% SG, Chlorantraniliprole 18.5 SG, and Emamectin 5% + Lufenuron 40% WG, along with an untreated control.

Field experiments were conducted during the *kharif* and *rabi* seasons of 2023. The results revealed that Indoxacarb 20% + Emamectin benzoate 5% EC at a higher dose (187.5 ml/ha) consistently recorded the lowest fall armyworm (*Spodoptera frugiperda*) larval population (0.61 and 0.37 larvae/plant in *kharif*; 0.40 and 0.23 larvae/plant in *rabi* after the first and second sprays, respectively) and minimum leaf damage, resulting in a 78–89% reduction over the untreated control. This was followed by Indoxacarb 20% + Emamectin benzoate 5% EC (150 ml/ha) and Emamectin 5% + Lufenuron 40% WG (80 g/ha). Similarly, stem borer–induced dead heart incidence was lowest at this dose (0.21 and 0.27% in *kharif*; 0.26 and 0.22% in *rabi*), with an 82–90% reduction over the control. The treatment at 187.5 ml/ha remained statistically at par with the lower dose (150 ml/ha), which also provided substantial suppression of pest infestation. Untreated plots recorded the highest larval population, leaf damage, and dead heart incidence in both seasons. The results further revealed that the application of insecticides did not exert any significant adverse effect on the potent natural enemy - spider population. No significant differences were observed among treatments at pre-treatment, 7, and 14 days after both sprays in either season.

Indoxacarb 20% + Emamectin benzoate 5% EC significantly enhanced maize yield and profitability during both seasons. The higher dose (187.5 ml/ha) recorded the maximum grain yield (4014 and 4059 kg/ha in *kharif* and *rabi*, respectively) along with higher C:B ratios (1:3.27 and 1:3.31), remaining statistically at par with 150 ml/ha.
Keywords **:** *Spodoptera frugiperda*, Bio efficacy, lepidopteran pests, stem borer and natural enemy-spider.

Introduction

Maize (*Zea mays* L.) is an important cereal crop next to rice and wheat, grown across a wide range of geographical and environmental conditions in India compared to other cereal crops (Kumar *et al*., 2013). Known as the “Queen of Cereals,” it is globally important due to its high production potential (Parihar *et al*., 2011). In India, maize serves multiple purposes, including human consumption, cattle and poultry feed, and as a raw material for food processing and industrial extraction of starch, dextrose, corn syrup, and oil (Mallapur *et al*., 2018). Maize grains possess high nutritional value, containing approximately 72% starch, 10% protein, 4.8% oil, 8.5% fiber, 3.0% sugar, and 1.7% ash (Huma *et al*., 2019).

Globally, maize is cultivated over 208.23 million ha, producing 1126.32 million metric tonnes (mmt) with an average yield of 5.96 mt/ha (FAOSTAT, 2023). India ranks among the major maize-producing countries, with 10.74 million ha under cultivation, producing 34.55 mmt and achieving a productivity of 3.54 mt/ha in 2023 (FAOSTAT, 2023). In Madhya

Pradesh, maize occupies 1.40 million ha with a production of 4.61 mmt and productivity of 3.29 mt/ha (Anonymous, 2023). Specifically, Jabalpur district recorded 0.28 million ha area, 813.68 thousand tonnes production, and 2,843 kg/ha productivity during 2022–23 (Anonymous, 2022).

Maize production and productivity are constrained by both abiotic and biotic factors. Abiotic stresses such as drought, salinity, and extreme temperatures (Ahuja *et al*., 2010; Gong *et al*., 2014), along with biotic stresses caused by fungi, bacteria, viruses (Jeffers, 2004; Subedi, 2015), and insect pests (De Groote, 2002; Kfir *et al*., 2002), adversely affect crop growth, development, and yield (Pratt *et al*., 2017).

Among the biotic factors, insect pests cause substantial yield losses. Approximately 141 insect species are reported to damage maize at various growth stages, from sowing to harvest (Reddy and Trivedi, 2008). Major insect pests of maize include aphids, shoot bugs, cutworms, stem borers, white grubs, chaffer beetles, armyworms, gram pod borers, wireworms, and hairy caterpillars (Arifie *et al*., 2019).

The recent invasion of fall armyworm, *S. frugiperda* (J.E. Smith), has become a serious concern for maize cultivation due to its polyphagous nature and destructive feeding behavior. The pest was first reported in West Africa in late 2016 (Goergen *et al*., 2016) and rapidly spread across sub-Saharan Africa by early 2017. In India, it was first reported on maize in Shivamogga district of Karnataka during May–June 2018 (Sharanabasappa *et al*., 2018), and subsequently spread to most maize-growing regions of the country (Rakshit *et al*., 2019). In Madhya Pradesh, its occurrence was first recorded in 2020 (Vishwakarma *et al*., 2020). The larvae feed on leaves, whorls, cobs, and husks, sometimes causing complete crop loss. Early instars scrape leaf surfaces, whereas later instars cause severe defoliation and characteristic windowing symptoms (Goergen *et al*., 2016).

The pink stem borer, *Sesamia inferens* Walker, is another major insect pest of maize, particularly during the *rabi* season in peninsular India. Similarly, *Chilo partellus* Swinhoe is a serious maize stem borer in India (Nagarjuna *et al*., 2015). These pests cause foliage damage, stem tunneling, dead heart formation, stem breakage, lodging, ear damage, and tassel damage. Among these, foliage damage, stem tunneling, and dead heart formation are the most destructive, leading to significant yield losses (Chatterji *et al*., 1969; Attri and Sharma, 1968; Mathur *et al*., 1981). The pests are widely distributed across Andhra Pradesh, Karnataka, Tamil Nadu, Madhya Pradesh, Maharashtra, Odisha, West Bengal, Bihar, Assam, Uttar Pradesh, Delhi, and Punjab (Reddy *et al*., 2003).

Effective pest management has therefore become a major concern for maize farmers. Multidisciplinary research and the adoption of innovative Integrated Pest Management (IPM) strategies are essential for ensuring sustainable pest control (Vasileiadis *et al*., 2011).

Since the introduction of fall armyworm in India, several insecticides have been evaluated for its management in maize (Kumar, 2019; Mallapur *et al*., 2019; Birhanu Sisay *et al*., 2019; Suthar *et al*., 2020; Thumar *et al*., 2020). However, the extensive use of conventional insecticides has led to issues such as resistance development, adverse effects on non-target organisms, including natural enemies, and environmental concerns (Rezende-Teixeira *et al*., 2022).

Therefore, the present study was undertaken to evaluate the bio-efficacy of novel insecticides against major lepidopteran pests and their impact on natural enemies in the maize ecosystem. The study focuses on assessing their effectiveness and suitability for integration into existing pest management practices. The findings are expected to contribute toward developing more sustainable and efficient pest management strategies for maize cultivation.

Materials and Methods

The present investigation was conducted at the Research Field of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.), during the *kharif* and *rabi* seasons of 2023. The study aimed to evaluate the bio-efficacy of insecticides against lepidopteran pests and to assess their impact on natural enemies.

Design and layout

The experiment was laid out in a Randomized Block Design (RBD) comprising eight treatments replicated thrice. Each plot measured 25 m², with a spacing of 60 × 20 cm between rows and plants. The replications were separated by a 1 m gap to facilitate irrigation channels. The maize crop was raised following the recommended package of practices, except for plant protection measures.

The maize variety JM-218 was sown on 10 July 2023 during the *kharif* season and on 02 November 2023 during the *rabi* season.

Treatment Details:

Table 1 : Treatments details and insecticide dose

Tr. No.	Treatment details	Dose	
		Active (gm a.i./ha)	Formulation (gm or ml/ha)
T_1	Indoxacarb 20% + Emamectin benzoate 5% EC	22.5+4.5	112.5
T_2	Indoxacarb 20% + Emamectin benzoate 5% EC	30+6	150
T_3	Indoxacarb 20% + Emamectin benzoate 5% EC	37.5+7.5	187.5
T_4	Indoxacarb 14.50 SC	40	266
T_5	Emamectin benzoate 5% SG	10	200
T_6	Chlorantraniliprole 18.5 SG	40	200
T_7	Emamectin 5 % + Lufenuron 40 % WG	4+32	80
T_8	Untreated Control	-	-

Time and Method of application

Sprays were applied using a knapsack sprayer fitted with a hollow cone nozzle during the evening hours. Each treatment plot was sprayed with the respective insecticide, ensuring uniform coverage (Table 1). The treatments were imposed when the incidence of fall armyworm and stem borer crossed the Economic Threshold Level (ETL). Two sprays were applied in each season at an interval of 14 days.

During the *kharif* season, the first spray was applied on 27 August 2023 and the second spray on 10 September 2023. During the *rabi* season, the first spray was applied on 22 December 2023 and the second spray on 05 January 2024.

Observations methodology

Fall Army Worm (*S. frugiperda*)

The mean number of larvae per plant (recorded through visual observation) and percent leaf damage (assessed using a visual rating scale) were recorded from ten randomly selected plants per plot. Observations were taken one day before treatment (pre-treatment) and at 3, 7, 10, and 14 days after each spray (Table 2).

Table 2 : Visual rating scales for leaf damage assessment cause by fall armyworm

Scale	Description
0	No visible leaf damage
1	Only pinhole damage on leaves
2	Pinhole and shot hole damage to leaf
3	Small elongated lesions (5–10 mm) on 1–3 leaves
4	Midsized lesions (10–30 mm) on 4–7 leaves
5	Large elongated lesions (>30 mm) or small portions eaten on 3–5 leaves
6	Elongated lesions (>30 mm) and large portions eaten on 3–5 leaves
7	Elongated lesions (>30 cm) and 50% of leaf eaten
8	Elongated lesions (30 cm) and large portions eaten on 70% of leaves
9	Most leaves with long lesions and complete defoliation observed

* As per visual guide of Davis Scale (Source: Davis and Williams, 1992)

Stem borer (*Chilo partellus*): *C. partellus* is considered a minor pest of maize in Jabalpur. Its occurrence is infrequent and generally does not cause significant economic damage. The bio-efficacy of all treatments against stem borer was assessed in terms of percent dead heart. Observations were recorded from ten randomly selected plants per plot at one day before treatment (pre-treatment) and at 3, 7, 10, and 14 days after each spray.

Natural Enemies:

The population of natural enemies, particularly spiders, was recorded in each treatment at pre-treatment (0 day), and at 7 and 14 days after each spray.

Yield:

To record yield data, the crop was harvested replication-wise, and the grain yield per plot was recorded and expressed in kg/plot. The yield was subsequently converted and expressed as kg/ha**.**

Statistical analysis

The experimental data were subjected to statistical analyzed using analysis of variance (ANOVA) appropriate for a Randomized Block Design (RBD). The percentage data were subjected to arc sine transformation before analysis to normalize the distribution. The larval population data were transformed using square root transformation, wherever necessary to stabilize variance. The significance of treatment differences was tested at the 5% level of probability (P = 0.05).

Results and Discussion

The study was conducted during the *kharif* season (July 2023 to October 2023) and the *rabi* season (November 2023 to February 2024) at the College of Agriculture, JNKVV, Jabalpur. Fall armyworm (*S. frugiperda*) and stem borer were observed as the major insect pest of the maize crop during both seasons. In both seasons, insecticidal sprays were initiated when the pest population crossed the Economic Threshold Level (ETL).

Fall armyworm (FAW)

Kharif, 2023

Larval population

The data presented in Table 3 on the larval population of FAW revealed that the lowest population (0.61 and 0.37 larva/plant) was recorded in T3 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha), with the highest reduction (80.32% and 88.49%) in larval population over control after 14 days of the 1st and 2nd sprays, respectively, which was at par with T2 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha) with 0.65 and 0.42 larva/plant and 79.03% and 86.94% reduction in larval population over control (T8). These were followed by T7 (0.88 and 0.65 larva/plant), T5 (0.94 and 0.69 larva/plant), T1 (0.99 and 0.71 larva/plant), T6 (1.53 and 0.84 larva/plant), and T4 (1.58 and 0.96 larva/plant), whereas 3.10 and 3.22 larvae/plant were recorded in the untreated check (T8 control) after 14 days of the 1st and 2nd sprays, respectively.

The findings of the present study are in close agreement with earlier reports. Kumari *et al*. (2020) and Charitha and Kumar (2023) documented the effectiveness of Indoxacarb 14.5 SC in reducing FAW larval population in maize. Similarly, Chandar and Tayde (2023) observed significantly lower larval populations with Emamectin benzoate 5 SG and Indoxacarb formulations. The present results also corroborate the findings of Deshmukh *et al*. (2020) and Bharadwaj *et al*. (2020), who reported significant reductions in larval population with emamectin benzoate. Ahir *et al*. (2021) further reported that Emamectin benzoate 5 SG effectively reduced larval population and leaf damage. Mian *et al*. (2022) also demonstrated the efficacy of emamectin benzoate against third instar larvae of fall armyworm.

Leaf damage

The data presented in Table 5 revealed significant differences among treatments with respect to percent leaf damage caused by fall armyworm. Among the treatments, T3 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha) recorded the lowest leaf damage (8.97% and 7.37% per plant) after 14 days of the first and second sprays, respectively. This treatment also achieved the highest reduction in leaf damage over control (79.94% and 86.87%). It was found to be statistically at par with T2 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha), which recorded 9.21% and 7.93% leaf damage per plant, with 79.40% and 85.87% reduction over control after the first and second sprays, respectively. These treatments were followed by T7 (10.23% and 11.63%), T5 (11.61% and 12.84%), T1 (12.43% and 13.91%), T6 (13.67% and 14.53%), and T4 (14.56% and 16.56%) leaf damage per plant after 14 days of the first and second sprays, respectively. In contrast, the untreated control recorded the highest leaf damage (44.71% and 56.12%) after 14 days of the first and second sprays, respectively.

The findings of the present study are in agreement with Narayan (2020), who reported that Emamectin benzoate 5% SG @ 4 g/10 L and Indoxacarb 14.5 SC @ 10 ml/10 L significantly reduced fall armyworm infestation and associated leaf damage in maize.

Rabi, 2023

Larval population

The data presented in Table 4 revealed significant differences among treatments in reducing the larval population of fall armyworm during the *rabi* season. Among all treatments, T3 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha) recorded the lowest larval population (0.40 and 0.23 larva/plant) after 14 days of the first and second sprays, respectively. This treatment also resulted in the highest reduction over control (78.26% and 89.78%). It was statistically at par with T2 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha), which recorded 0.42 and 0.29 larva/plant with 77.17% and 87.11% reduction over control after the first and second sprays, respectively. These treatments were followed by T7 (0.71 and 0.50 larva/plant), T5 (0.74 and 0.57 larva/plant), T1 (0.77 and 0.61 larva/plant), T6 (1.07 and 0.89 larva/plant), and T4 (1.19 and 0.91 larva/plant). In contrast, the untreated control recorded the highest larval population (1.84 and 2.25 larvae/plant) after 14 days of the first and second sprays, respectively.

The present findings are in agreement with Sangle *et al*. (2020), who reported that Emamectin benzoate 5 SG recorded the minimum larval population of fall armyworm, followed by Indoxacarb 14.5 SC. Their findings also demonstrated that both insecticides effectively reduced the number of larvae per plant of fall armyworm.

Leaf damage

The data presented in Table 6 revealed significant differences among treatments in reducing percent leaf damage caused by fall armyworm. Among the treatments, T3 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha) recorded the lowest leaf damage (8.14% and 7.19% per plant) after 14 days of the first and second sprays, respectively. This treatment also achieved the highest reduction over control (80.75% and 86.27%) following the first and second sprays. It was statistically at par with T2 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha), which recorded 8.27% and 7.47% leaf damage per plant, with 80.44% and 85.74% reduction over control, respectively. These treatments were followed by T7 (10.45% and 9.96%), T5 (11.23% and 10.81%), T1 (12.33% and 11.22%), T6 (15.82% and 12.69%), and T4 (17.54% and 12.93%) leaf damage per plant after 14 days of the first and second sprays, respectively. In contrast, the untreated control recorded the highest leaf damage (42.29% and 52.37%) after 14 days of the first and second sprays, respectively.

Table 3: Effect of treatments on larval population of fall army worm in Maize crop during *Kharif*, 2023.

Tr. code	Treatments	Dose (ml/ ha)	Mean larval population /plant at different DA1 & 2 S*										
			BS	1st Spray				% ROC At 14 DA1S	2nd Spray				% ROC At 14 DA2S
				3	7	10	14		3	7	10	14	
T_1	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	2.38 (1.70)	1.71 (1.49)	1.29 (1.34)	0.80 (1.14)	0.99 (1.22)	68.06	0.63 (1.06)	0.59 (1.04)	0.61 (1.05)	0.71 (1.10)	77.92
T_2	Indoxacarb 20% + Emamectin benzoate 5% EC	150	2.46 (1.72)	1.27 (1.33)	0.96 (1.21)	0.51 (1.00)	0.65 (1.07)	79.03	0.33 (0.91)	0.22 (0.85)	0.21 (0.84)	0.42 (0.96)	86.94
T_3	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	2.50 (1.73)	1.02 (1.23)	0.87 (1.17)	0.49 (0.99)	0.61 (1.05)	80.32	0.31 (0.90)	0.20 (0.84)	0.18 (0.82)	0.37 (0.93)	88.49
T_4	Indoxacarb 14.50 SC	266	2.43 (1.71)	1.95 (1.56)	1.43 (1.39)	1.46 (1.40)	1.58 (1.44)	49.03	0.79 (1.14)	0.72 (1.10)	0.88 (1.17)	0.96 (1.21)	70.14
T_5	Emamectin benzoate 5% SG	200	2.42 (1.71)	1.62 (1.46)	1.25 (1.32)	0.77 (1.13)	0.94 (1.20)	69.68	0.57 (1.03)	0.47 (0.98)	0.45 (0.97)	0.69 (1.09)	78.54
T_6	Chlorantraniliprole 18.5 SG	200	2.52 (1.74)	1.88 (1.54)	1.37 (1.37)	1.41 (1.38)	1.53 (1.42)	50.65	0.68 (1.09)	0.65 (1.07)	0.70 (1.10)	0.84 (1.16)	73.87
T_7	Emamectin 5 % + Lufenuron 40 % WG	80	2.41 (1.70)	1.56 (1.44)	1.22 (1.32)	0.75 (1.12)	0.88 (1.17)	71.61	0.55 (1.02)	0.45 (0.97)	0.41 (0.95)	0.65 (1.07)	79.78
T_8	Untreated Control	-	2.48 (1.73)	2.70 (1.79)	2.82 (1.82)	2.92 (1.85)	3.10 (1.90)	0.00	3.16 (1.91)	3.24 (1.93)	3.28 (1.94)	3.22 (1.93)	0.00
	SEM ±		0.03	0.08	0.08	0.07	0.07	-	0.07	0.07	0.06	0.06	-
	CD (P = 0.05)		NS	0.25	0.23	0.22	0.21	-	0.20	0.21	0.19	0.18	-

BS- Before spray; DA1 & 2 S- Days after first and second spray; * Values in the parentheses are square root transformed values
ROC- Reduction over Control

Table 4: Effect of treatments on larval population of fall army worm in Maize crop during *Rabi*, 2023

Tr. code	Treatments	Dose (ml/ ha)	Mean larval population /plant at different DA1 & 2 S*										
			BS	1st Spray				% ROC At 14 DA1S**	2nd Spray				% ROC At 14 DA2S**
				3	7	10	14		3	7	10	14	
T_1	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	1.57 (1.44)	0.99 (1.22)	0.79 (1.14)	0.68 (1.09)	0.77 (1.13)	58.15	0.61 (1.05)	0.55 (1.02)	0.49 (0.99)	0.61 (1.05)	72.89
T_2	Indoxacarb 20% + Emamectin benzoate 5% EC	150	1.60 (1.45)	0.61 (1.05)	0.50 (1.00)	0.38 (0.94)	0.42 (0.96)	77.17	0.32 (0.91)	0.26 (0.87)	0.19 (0.83)	0.29 (0.89)	87.11
T_3	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	1.61 (1.45)	0.53 (1.01)	0.41 (0.95)	0.33 (0.91)	0.40 (0.95)	78.26	0.29 (0.89)	0.22 (0.85)	0.14 (0.80)	0.23 (0.85)	89.78
T_4	Indoxacarb 14.50 SC	266	1.60 (1.45)	1.12 (1.27)	0.85 (1.16)	0.97 (1.21)	1.19 (1.30)	35.33	0.75 (1.12)	0.69 (1.09)	0.78 (1.13)	0.91 (1.19)	59.56
T_5	Emamectin benzoate 5% SG	200	1.57 (1.44)	0.97 (1.21)	0.77 (1.13)	0.65 (1.07)	0.74 (1.11)	59.78	0.59 (1.04)	0.52 (1.01)	0.46 (0.98)	0.57 (1.03)	74.67
T_6	Chlorantraniliprole 18.5 SG	200	1.59 (1.45)	1.08 (1.26)	0.81 (1.14)	0.92 (1.19)	1.07 (1.25)	41.85	0.67 (1.08)	0.61 (1.05)	0.73 (1.11)	0.89 (1.18)	60.44

T$_7$	Emamectin 5 % + Lufenuron 40 % WG	80	1.60 (1.45)	0.90 (1.18)	0.75 (1.12)	0.63 (1.06)	0.71 (1.10)	61.41	0.57 (1.03)	0.50 (1.00)	0.42 (0.96)	0.50 (1.00)	77.78
T$_8$	Untreated Control	-	1.56 (1.43)	1.60 (1.45)	1.66 (1.47)	1.79 (1.51)	1.84 (1.53)	0.00	1.96 (1.57)	2.11 (1.62)	2.20 (1.64)	2.25 (1.66)	0.00
	SEM ±	**-**	0.03	0.09	0.08	0.08	0.07	-	0.08	0.07	0.07	0.06	-
	CD (P = 0.05)	**-**	NS	0.27	0.24	0.23	0.21	-	0.24	0.22	0.21	0.19	-

BS- Before spray; DA1 & 2 S- Days after first and second spray;
* Values in the parentheses are square root transformed values
ROC- Reduction over Control;

Table 5: Effect of treatments on foliage damage caused by fall armyworm in Maize crop during *Kharif*, 2023

Tr. code	Treatments	Dose (ml/ ha)	Percent leaf damage /plant at different DA1 & 2 S*										
			BS	1st Spray				% ROC At 14 DA1S	2nd Spray				% ROC At 14 DA2S
				3	7	10	14		3	7	10	14	
T$_1$	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	20.83 (27.15)	13.87 (21.87)	11.14 (19.50)	9.98 (18.42)	12.43 (20.64)	72.20	11.63 (19.94)	9.36 (17.81)	8.13 (16.57)	13.91 (21.90)	75.21
T$_2$	Indoxacarb 20% + Emamectin benzoate 5% EC	150	21.11 (27.35)	11.73 (20.03)	8.31 (16.75)	7.52 (15.92)	9.21 (17.67)	79.40	8.71 (17.17)	7.87 (16.29)	6.94 (15.27)	7.93 (16.36)	85.87
T$_3$	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	20.73 (27.08)	11.57 (19.89)	8.23 (16.67)	7.35 (15.73)	8.97 (17.43)	79.94	8.47 (16.92)	7.65 (16.06)	6.57 (14.85)	7.37 (15.75)	86.87
T$_4$	Indoxacarb 14.50 SC	266	20.77 (27.11)	14.51 (22.39)	12.22 (20.46)	12.37 (20.59)	14.56 (22.43)	67.43	13.51 (21.57)	11.68 (19.98)	12.37 (20.59)	16.56 (24.01)	70.49
T$_5$	Emamectin benzoate 5% SG	200	20.94 (27.23)	12.96 (21.10)	9.71 (18.16)	8.87 (17.33)	11.61 (19.92)	74.03	10.14 (18.57)	9.53 (17.98)	8.97 (17.43)	12.84 (21.00)	77.12
T$_6$	Chlorantraniliprole 18.5 SG	200	21.23 (27.44)	12.99 (21.13)	11.83 (20.12)	11.97 (20.24)	13.67 (21.70)	69.43	12.47 (20.68)	10.14 (18.57)	11.81 (20.10)	14.53 (22.41)	74.11
T$_7$	Emamectin 5 % + Lufenuron 40 % WG	80	20.87 (27.18)	12.81 (20.97)	9.25 (17.71)	8.48 (16.93)	10.23 (18.65)	77.12	9.81 (18.25)	8.97 (17.43)	8.61 (17.06)	11.63 (19.94)	79.28
T$_8$	Untreated Control	-	21.27 (27.46)	26.51 (30.99)	33.45 (35.34)	39.67 (39.04)	44.71 (41.96)	0.00	46.34 (42.90)	49.23 (44.56)	54.43 (47.54)	56.12 (48.52)	0.00
	SEM ±	**-**	0.08	0.32	0.30	0.29	0.30	-	0.33	0.32	0.41	0.45	-
	CD (P = 0.05)	**-**	NS	0.97	0.89	0.88	0.91	-	1.00	0.97	1.22	1.34	-

BS- Before spray; DA1 & 2 S- Days after first and second spray; ROC- Reduction over Control;
* Values in the parentheses are arcsine transformed value

Table 6: Effect of treatments on foliage damage caused by fall armyworm in Maize crop during *Rabi*, 2023

Tr. code	Treatments	Dose (ml/ ha)	Percent leaf damage /plant at different DA1 & 2 S*										
			BS	1st Spray				% ROC At 14 DA1S	2nd Spray				% ROC At 14 DA2S
				3	7	10	14		3	7	10	14	
T$_1$	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	19.39 (26.13)	16.71 (24.13)	16.34 (23.84)	11.71 (20.01)	12.33 (20.56)	70.84	9.96 (18.40)	9.10 (17.56)	8.71 (17.17)	11.22 (19.57)	78.58
T$_2$	Indoxacarb 20% + Emamectin benzoate 5% EC	150	18.67 (25.60)	10.82 (19.20)	8.41 (16.86)	7.49 (15.88)	8.27 (16.71)	80.44	7.27 (15.64)	6.24 (14.47)	5.97 (14.14)	7.47 (15.86)	85.74
T$_3$	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	18.84 (25.72)	10.14 (18.57)	7.87 (16.29)	6.19 (14.41)	8.14 (16.58)	80.75	7.12 (15.48)	6.16 (14.37)	5.84 (13.98)	7.19 (15.55)	86.27
T$_4$	Indoxacarb 14.50 SC	266	19.21 (25.99)	17.43 (24.68)	14.08 (22.04)	15.55 (23.22)	17.54 (24.76)	58.52	10.53 (18.94)	9.18 (17.64)	10.92 (19.30)	12.93 (21.07)	75.31

T_5	Emamectin benzoate 5% SG	200	18.75 (25.66)	14.65 (22.50)	13.10 (21.22)	10.46 (18.87)	11.23 (19.58)	73.45	9.82 (18.26)	8.58 (17.03)	8.27 (16.71)	10.81 (19.20)	79.36
T_6	Chlorantraniliprole 18.5 SG	200	19.25 (26.02)	13.96 (21.94)	12.15 (20.40)	12.88 (21.03)	15.82 (23.44)	62.59	9.91 (18.35)	9.16 (17.62)	10.81 (19.20)	12.69 (20.87)	75.77
T_7	Emamectin 5 % + Lufenuron 40 % WG	80	18.91 (25.78)	13.24 (21.34)	10.65 (19.05)	9.75 (18.19)	10.45 (18.86)	75.29	9.52 (17.97)	8.37 (16.82)	8.18 (16.62)	9.96 (18.40)	80.98
T_8	Untreated Control	-	19.11 (25.92)	24.27 (29.51)	31.35 (34.05)	38.47 (38.33)	42.29 (40.56)	0.00	44.43 (41.80)	49.31 (44.60)	51.64 (45.94)	52.37 (46.36)	0.00
	SEM ±	**-**	0.09	0.78	0.70	0.71	0.71	-	0.73	0.70	0.73	0.79	-
	CD (P = 0.05)	**-**	NS	2.34	2.1	2.12	2.14	-	2.2	2.11	2.18	2.36	-

BS- Before spray; DA1 & 2 S- Days after first and second spray; ROC- Reduction over Control;
* Values in the parentheses are arcsine transformed value

Stem borer:

Dead Heart:

***Kharif*, 2023:**

The observations presented in Table 7 revealed significant differences among treatments in reducing percent dead heart caused by stem borer during the *kharif* season. Among all treatments, T3 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha) recorded the lowest dead heart incidence (0.21% and 0.27%) after 14 days of the first and second sprays, respectively. This treatment also achieved the highest reduction over control (84.89% and 87.50%) following the first and second sprays. It was found to be statistically at par with T2 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha), which recorded 0.25% and 0.34% dead heart incidence, with 82.01% and 84.26% reduction over control after the first and second sprays, respectively. These treatments were followed by T7 (0.42% and 0.52%), T5 (0.48% and 0.57%), T1 (0.58% and 0.62%), T6 (0.61% and 0.67%), and T4 (0.69% and 0.91%) dead heart incidence after 14 days of the first and second sprays, respectively. In contrast, the untreated control recorded the highest dead heart incidence (1.39% and 2.16%) after 14 days of the first and second sprays, respectively.

The present findings are in agreement with Narayan (2020), who reported that Emamectin benzoate 5% SG @ 4 g/10 L and Indoxacarb 14.5 SC @ 10 ml/10 L were effective in reducing stem borer infestation. Choudhary (2019) also reported that Emamectin benzoate 5 SG was effective against maize stem borer. Similarly, Sidar *et al*. (2017) observed the minimum percent dead heart damage with Emamectin benzoate 50% against stem borer.

***Rabi*, 2023**

The observations presented in Table 8 revealed significant differences among treatments in reducing percent dead heart caused by stem borer during the *rabi* season. Among the treatments, T3 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha) recorded the lowest dead heart incidence (0.26% and 0.22%) after 14 days of the first and second sprays, respectively. This treatment also achieved the highest reduction over control (82.31% and 89.57%) following the first and second sprays. It was statistically at par with T2 (Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha), which recorded 0.31% and 0.29% dead heart incidence, with 78.91% and 86.26% reduction over control after the first and second sprays, respectively. These treatments were followed by T7 (0.47% and 0.49%), T5 (0.54% and 0.54%), T1 (0.57% and 0.59%), T6 (0.60% and 0.61%), and T4 (0.74% and 0.91%) dead heart incidence after 14 days of the first and second sprays, respectively. In contrast, the untreated control recorded the highest dead heart incidence (1.47% and 2.11%) after 14 days of the first and second sprays, respectively.

The present findings are in agreement with Devananda *et al*. (2018), who reported that Indoxacarb 15.8 EC @ 0.015% was highly effective in reducing dead heart incidence. The results are also in partial conformity with Kulkarni *et al*. (2016), who found Emamectin benzoate 5 SG to be highly effective and economical in reducing stem borer damage in maize. Kumar and Kumar (2017) reported that Indoxacarb 14.5 SC effectively reduced stem borer infestation in maize. Similarly, Siddalingappa *et al*. (2010) observed higher efficacy of Indoxacarb 0.0145% in suppressing stem borer. Rathod *et al*. (2020) reported that Emamectin benzoate 5% SG @ 4 g/10 L and Indoxacarb 14.5 SC @ 10 ml/10 L were significantly effective in reducing stem borer infestation in maize. Ramesh *et al*. (2012) also reported that Emamectin benzoate (0.002%) significantly reduced damage caused by *C. partellus*. Furthermore, Chouraddi and Mallapur (2017) observed that Emamectin benzoate 5 SG significantly reduced dead heart incidence caused by maize stem borer.

Table 7: Effect of treatments on dead heart caused by stem borer on Maize crop during (*Kharif*, 2023).

Treatments	Doses / Ha	Percent dead heart during *Kharif*, 2023										
			Days after 1st Spray				%	Days after 2nd Spray				%
	Form. (ml)	BS	3	7	10	14	ROC At 14 DA1S	3	7	10	14	ROC At 14 DA2S
T1- Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	0.76 (5.00)	0.55 (4.25)	0.47 (3.93)	0.52 (4.14)	0.58 (4.37)	58.27	0.41 (3.67)	0.39 (3.58)	0.47 (3.93)	0.62 (4.52)	71.30
T2- Indoxacarb 20% + Emamectin benzoate 5% EC	150	0.72 (4.87)	0.35 3.39)	0.25 (2.87)	0.21 (2.63)	0.25 (2.87)	82.01	0.21 (2.63)	0.18 (2.43)	0.15 (2.22)	0.34 (3.34)	84.26
T3- Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	0.68 (4.73)	0.32 (3.24)	0.22 (2.69)	0.19 (2.50)	0.21 (2.63)	84.89	0.19 (2.50)	0.15 (2.22)	0.11 (1.90)	0.27 (2.98)	87.50
T4- Indoxacarb 14.50 SC	266	0.68 (4.73)	0.62 (4.52)	0.58 (4.37)	0.62 (4.52)	0.69 (4.76)	50.36	0.49 (4.01)	0.45 (3.85)	0.64 (4.59)	0.91 (5.47)	57.87
T5- Emamectin benzoate 5% SG	200	0.67 (4.70)	0.49 (4.01)	0.42 (3.72)	0.44 (3.80)	0.48 (3.97)	65.47	0.39 (3.58)	0.36 (3.44)	0.41 (3.67)	0.57 (4.33)	73.61
T6- Chlorantraniliprole 18.5 SG	200	0.76 (5.00)	0.57 (4.33)	0.49 (4.01)	0.55 (4.25)	0.61 (4.48)	56.12	0.45 (3.85)	0.41 (3.67)	0.53 (4.17)	0.67 (4.70)	68.98
T7- Emamectin 5 % + Lufenuron 40 % WG	80	0.72 (4.87)	0.45 (3.85)	0.39 (3.58)	0.36 (3.44)	0.42 (3.72)	69.78	0.34 (3.34)	0.32 (3.24)	0.36 (3.44)	0.52 (4.14)	75.93
T8- Untreated Control	-	0.74 (4.93)	0.87 (5.35)	0.99 (5.71)	1.21 (6.32)	1.39 (6.77)	0.00	1.65 (7.38)	1.81 (7.73)	2.11 (8.35)	2.16 (8.45)	0.00
SEM ±		0.02	0.03	0.04	0.05	0.05		0.04	0.04	0.05	0.05	
CD (P = 0.05)		NS	0.09	0.12	0.14	0.15		0.11	0.12	0.14	0.16	

BS- Before spray; DAS- Days after spray, ROC- Reduction over Control; Values in the parentheses are arcsine transformed values.

Table 8: Effect of treatments on dead heart caused by stem borer on Maize crop during (*Rabi*, 2023).

Treatments	Doses / Ha	Percent dead heart during *Rabi*, 2023										
			Days after 1st Spray				%	Days after 2nd Spray				%
	Form. (ml)	BS	3	7	10	14	ROC At 14 DA1S	3	7	10	14	ROC At 14 DA2S
T1- Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	0.70 (4.80)	0.57 (4.33)	0.47 (3.93)	0.55 (4.25)	0.57 (4.33)	61.22	0.45 (3.85)	0.41 (3.67)	0.48 (3.97)	0.59 (4.41)	72.04
T2- Indoxacarb 20% + Emamectin benzoate 5% EC	150	0.70 (4.80)	0.41 (3.67)	0.31 (3.19)	0.29 (3.09)	0.31 (3.19)	78.91	0.22 (2.69)	0.19 (2.50)	0.12 (1.99)	0.29 (3.09)	86.26
T3- Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	0.71 (4.83)	0.37 (3.49)	0.29 (3.09)	0.22 (2.69)	0.26 (2.92)	82.31	0.20 (2.56)	0.16 (2.29)	0.10 (1.81)	0.22 (2.69)	89.57
T4- Indoxacarb 14.50 SC	266	0.72 (4.87)	0.64 (4.59)	0.62 (4.52)	0.66 (4.66)	0.74 (4.93)	49.66	0.54 (4.21)	0.52 (4.14)	0.70 (4.80)	0.91 (5.47)	56.87
T5- Emamectin benzoate 5% SG	200	0.70 (4.80)	0.54 (4.21)	0.45 (3.85)	0.49 (4.01)	0.54 (4.21)	63.27	0.41 (3.67)	0.36 (3.44)	0.42 (3.72)	0.54 (4.21)	74.41
T6- Chlorantraniliprole 18.5 SG	200	0.71 (4.83)	0.59 (4.41)	0.52 (4.14)	0.59 (4.41)	0.60 (4.44)	59.18	0.52 (4.14)	0.50 (4.05)	0.53 (4.17)	0.61 (4.48)	71.09
T7- Emamectin 5 % + Lufenuron 40 % WG	80	0.70 (4.80)	0.51 (4.10)	0.43 (3.76)	0.45 (3.85)	0.47 (3.93)	68.03	0.37 (3.49)	0.31 (3.19)	0.33 (3.29)	0.49 (4.01)	76.78
T8- Untreated Control	-	0.72 (4.87)	0.91 (5.47)	1.11 (6.05)	1.35 (6.67)	1.47 (6.96)	0.00	1.62 (7.31)	1.74 (7.58)	1.97 (8.07)	2.11 (8.35)	0.00
SEM ±		0.02	0.03	0.03	0.04	0.04		0.04	0.03	0.04	0.05	
CD (P = 0.05)		NS	0.08	0.01	0.12	0.13		0.12	0.1	0.13	0.15	

BS- Before spray; DAS- Days after spray, ROC- Reduction over Control; Values in the parentheses are arcsine transformed values.

Population of natural enemy-Spider

***Kharif*, 2023**: The observations recorded on the population of spiders during the *kharif* season revealed that there were no significant differences among the treatments at pre-treatment, and at 7 and 14 days after both sprays. The results clearly indicate that the application of Indoxacarb 20% + Emamectin benzoate 5% EC at different test concentrations did not exert any adverse effects on the spider population. The mean population of spiders per plant ranged from 1.02 to 1.27 and 0.90 to 1.27 after 14 days of the first and second sprays, respectively (Table 9), indicating that the treatments were relatively safe to natural enemy-spider under field conditions.

***Rabi*, 2023:** Similarly, during the *rabi* season, no significant differences were observed among treatments with respect to spider population at pre-treatment, and at 7 and 14 days after spraying. The mean spider population per plant ranged from 0.95 to 1.13 and 0.90 to 1.27 after 14 days of the first and second sprays, respectively (Table 10).

The present findings are in agreement with Rathod *et al*. (2020), who reported that newer insecticides had a non-significant impact on the population of natural enemies.

Table 9: Effect of treatments on population of natural enemy - spider on Maize crop during *Kharif*, 2023

Tr. code	Treatments	Dose (ml/ ha)	Spider population /plant at different DA1 & 2 S*						
			1st Spray				2nd Spray		
			BS	7	14	Mean	7	14	Mean
T_1	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	0.94 (1.20)	1.06 (1.25)	1.06 (1.25)	1.02	0.80 (1.14)	1.00 (1.22)	0.90
T_2	Indoxacarb 20% + Emamectin benzoate 5% EC	150	1.14 (1.28)	1.06 (1.25)	1.14 (1.28)	1.11	0.94 (1.20)	1.00 (1.22)	0.97
T_3	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	1.06 (1.25)	1.00 (1.22)	1.20 (1.30)	1.09	0.94 (1.20)	0.94 (1.20)	0.94
T_4	Indoxacarb 14.50 SC	266	0.94 (1.20)	1.06 (1.25)	1.20 (1.30)	1.07	1.00 (1.22)	1.00 (1.22)	1.00
T_5	Emamectin benzoate 5% SG	200	1.06 (1.25)	1.00 (1.22)	1.06 (1.25)	1.04	0.94 (1.20)	1.00 (1.22)	0.97
T_6	Chlorantraniliprole 18.5 SG	200	1.20 (1.30)	1.00 (1.22)	1.14 (1.28)	1.11	0.86 (1.17)	0.94 (1.20)	0.90
T_7	Emamectin 5 % + Lufenuron 40 % WG	80	1.26 (1.33)	1.06 (1.25)	1.14 (1.28)	1.15	0.94 (1.20)	1.06 (1.25)	1.00
T_8	Untreated Control	-	1.06 (1.25)	1.40 (1.38)	1.34 (1.36)	1.27	1.20 (1.30)	1.34 (1.36)	1.27
	SEM ±		0.02	0.03	0.02	-	0.03	0.02	-
	CD (P = 0.05)		NS	NS	NS	-	NS	NS	-

BS- Before spray; DA1 & 2 S- Days after first and second spray;
* Values in the parentheses are square root transformed values

Table 10: Effect of treatments on population of natural enemy - spider on Maize crop during *Rabi*, 2023

Tr. code	Treatments	Dose (ml/ ha)	Spider population /plant at different DA1 & 2 S*						
			1st Spray				2nd Spray		
			BS	7	14	Mean	7	14	Mean
T_1	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	0.86 (1.17)	1.06 (1.25)	1.14 (1.28)	1.02	1.00 (1.22)	1.06 (1.25)	1.03
T_2	Indoxacarb 20% + Emamectin benzoate 5% EC	150	0.80 (1.14)	1.00 (1.22)	1.06 (1.25)	0.95	0.94 (1.20)	1.00 (1.22)	0.97
T_3	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	0.94 (1.20)	1.00 (1.22)	1.06 (1.25)	1.00	0.94 (1.20)	1.00 (1.22)	0.97
T_4	Indoxacarb 14.50 SC	266	0.94 (1.20)	1.06 (1.25)	1.20 (1.30)	1.07	1.06 (1.25)	1.14 (1.28)	1.10
T_5	Emamectin benzoate 5% SG	200	0.86 (1.17)	1.00 (1.22)	1.14 (1.28)	1.00	0.94 (1.20)	1.00 (1.22)	0.97
T_6	Chlorantraniliprole 18.5 SG	200	0.86 (1.17)	1.06 (1.25)	1.14 (1.28)	1.02	0.86 (1.17)	0.94 (1.20)	0.90
T_7	Emamectin 5 % + Lufenuron 40 % WG	80	0.94 (1.20)	1.06 (1.25)	1.14 (1.28)	1.05	0.94 (1.20)	1.06 (1.25)	1.00
T_8	Untreated Control	-	0.94 (1.20)	1.26 (1.33)	1.20 (1.30)	1.13	1.34 (1.36)	1.20 (1.30)	1.27
	SEM ±		0.02	0.03	0.02	-	0.02	0.02	-
	CD (P = 0.05)		NS	NS	NS	-	NS	NS	-

BS- Before spray; DA1 & 2 S- Days after first and second spray;
* Values in the parentheses are square root transformed values

Crop yield and C:B ratio:

Kharif, 2023:

During the *kharif* season, significant differences in grain yield were observed among the treatments (Table 11). The highest grain yield (4014 kg/ha) was recorded in Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha, along with a higher cost–benefit (C: B) ratio of 1:3.277. This treatment was statistically at par with Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha, which recorded a grain yield of 3999 kg/ha and a C:B ratio of 1:3.278.

Rabi, 2023

A similar trend was observed during the *rabi* season (Table 12). The highest grain yield (4059 kg/ha) was recorded in Indoxacarb 20% + Emamectin benzoate 5% EC @ 187.5 ml/ha, along with the highest C:B ratio (1:3.313). This treatment was statistically at par with Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha, which yielded 4045 kg/ha and recorded a C:B ratio of 1:3.316.

Table 11: Assessment of crop yield and C:B ratio in maize during *Kharif*, 2023

Tr. code	Treatments	Dose (ml/ ha)	Grain yield (Kg/ha)	ICBR
T_1	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	3765.00	1:3.099
T_2	Indoxacarb 20% + Emamectin benzoate 5% EC	150	3999.00	1:3.278
T_3	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	4014.00	1:3.277
T_4	Indoxacarb 14.50 SC	266	3574.00	1:2.935
T_5	Emamectin benzoate 5% SG	200	3771.00	1:3.078
T_6	Chlorantraniliprole 18.5 SG	200	3645.00	1:2.988
T_7	Emamectin 5 % + Lufenuron 40 % WG	80	3785.00	1:3.124
T_8	Untreated Control	-	1885.00	1:1.571
	SEM ±	-	65.31	-
	CD (P = 0.05)	-	196.00	-

ICBR- Increased cost benefit ratio

Table 12: Assessment of crop yield and C:B ratio in maize during *Rabi*, 2023

Tr. code	Treatments	Dose (ml/ ha)	Grain yield (Kg/ha)	ICBR
T_1	Indoxacarb 20% + Emamectin benzoate 5% EC	112.5	3811.00	1:3.137
T_2	Indoxacarb 20% + Emamectin benzoate 5% EC	150	4045.00	1:3.316
T_3	Indoxacarb 20% + Emamectin benzoate 5% EC	187.5	4059.00	1:3.313
T_4	Indoxacarb 14.50 SC	266	3618.00	1:2.971
T_5	Emamectin benzoate 5% SG	200	3815.00	1:3.113
T_6	Chlorantraniliprole 18.5 SG	200	3691.00	1:3.025
T_7	Emamectin 5 % + Lufenuron 40 % WG	80	3829.00	1:3.160
T_8	Untreated Control	-	1932.00	1:1.610
	SEM ±	-	68.14	-
	CD (P = 0.05)	-	204.45	-

ICBR- Increased cost benefit ratio

Conclusion

Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha was found to be effective in controlling fall armyworm (*S. frugiperda*) and recorded a significantly higher grain yield and cost–benefit (C: B) ratio. The treatment was also found to be safe for natural enemy-spider, with no phytotoxicity symptoms observed on the maize crop during both the *kharif* 2023 and *rabi* 2023–24 seasons. Therefore, Indoxacarb 20% + Emamectin benzoate 5% EC @ 150 ml/ha may be recommended for the management of fall armyworm in maize. The treatment showed no significant adverse effect on spider populations, indicating its safety to beneficial arthropods. Overall, the combination proved effective, economical, and compatible with integrated pest management strategies.

Authors' Contributions

This work was carried out in collaboration among all authors. Authors Manish Gadekar and S. B. Das designed the study, performed the statistical analysis, developed the protocol, and wrote the first draft of the manuscript. Authors S. B. Das, Subhashree Patnaik and Kailash Choukikar managed the analyses of the study. Authors Manish Gadekar, Subhashree Patnaik and S.

B. Das, conducted the literature review. All authors read and approved the final manuscript.

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