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Pesticide use and residue management in brinjal crop *Solanum melongena* (Lin.)

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Abstract
The crop of brinjal is vulnerable to several pests, illnesses, and insects. The growers of eggplants employ fungicides and chemical insecticides in a combination of two to three. Insect resistance to pesticides and residual issues arise from the continuous and careless application of insecticides. The health risks associated with pesticide residues in food, whether short- or long-term, are dose-dependent. The amount of pesticide consumed per kilogram of body weight determines whether or not there may be health risks. The Food Safety and Standards Authority of India sets the maximum residue limits (MRLs) values for various pesticides in various crops in our nation (FSSAI). Using more recent pesticides is safer in terms of toxicity to non-targets, safer for the environment, and also prevents the target pest from developing resistance. Integrated pest management, or IPM, is one of the most important and environmentally safe solutions to boost crop yield in the nation while ensuring the sustainability of the brinjal crop. Farmers must decide which pesticide to use and how to apply it correctly. Each pesticide label that comes with the formulation package details the amount to be used, when and how to apply it, as well as any necessary precautions to take both during and after application. Teaching farmers to use pesticides safely is the biggest challenge. Building robust and efficient networks amongst farmers, extension agents, and research organizations is necessary to provide healthy food, minimize the use of pesticides, and save the environment.

Keywords: Brinjal, pesticide, residue, maximum residue limits and integrated pest management

Introduction

The most popular, common, and important vegetable crop farmed in India is brinjal. Because of its great productivity, adaptability, and ease of availability, this crop is known as the "poor man's crop." Its fruits provide a decent supply of iron, calcium, phosphorus, and vitamins, especially the B group. Due to the increased concentration of poly unsaturated fatty acids in the pulp and seeds, brinjal has the ability to lower cholesterol.

Approximately 19.63 lakh ha (48.51 lakh acres) of land were planted with brinjal in the world throughout 2021–2022, yielding 29893 kg/ha (12097 kg/acre) and producing 58.68 lakh tonnes. After tobacco, tomato, potato, and pepper, it is now the fifth-most important solanaceous crop in terms of economic importance (FAO, 2021). The top five producers are Egypt (1.2 million tons), Turkey (0.83 million tons), Indonesia (0.67 million tons), China (37.45 million tons; 63.83% of global total), and India (12.87 million tons; 21.9% of world total). Eggplant is one of the top five most important vegetable crops in Asia and the Mediterranean.

In 2022–2023, India's Bhrindabal area amounted to 6.77 lakh hectares (16.72 lakh acres), with a production of 127.79 lakh tonnes. West Bengal, Orissa, Bihar, Gujarat, Maharashtra, Karnataka, Uttar Pradesh, Telangana, and Andhra Pradesh are the states that produce the most brinjal. In Telangana, 2995 acres were covered in brinjal during the Yasangi (Rabi) season of 2022–2023. Telangana's principal areas for the production of brinjal include 393 acres in Rangareddy, 299 acres in Vikarabad, 204 acres in Medchal-Malkajgiri, 143 acres in Asifabad, 134 acres in Sangareddy, 100 acres in Kotthagudem, 63 acres in Medak, and 39 acres in Jangoan (Anonymous, 2023) [2].

The crop is vulnerable to a range of pests, illnesses, and insects, albeit the extent of each infestation varies greatly. The fruit and shoot borer, jassids, mites, beetles, aphids, and mealy bugs are a few of the significant insects. Numerous diseases can infect the roots, leaves, stems, and fruits of brinjal plants. Leucinodes orbonalis, the Fruit and Shoot Borer (FSB), is a common pest in all states that produce brinjal. Its primary food source is brinjal. Because of its enormous capacity for reproduction, it presents a significant risk. Fruits and fragile shoots are borrated by FSB larvae, which stunts plant growth and renders the fruits unfit for commercial or human consumption. There have been reports of losses of up to 70% and fruit damage of up to 95% in commercial crops. *Sclerotium rolfsii*, a polyphagous and common fungus, causes wilt, also known as collar rot, on a variety of vegetables produced in tropical, subtropical, and temperate climates, including brinjal, tomato, chilli, and cucurbits. In cases of severe infection, it can account for over 50% of crop loss due to 30-90% seedling mortality.

In India, the average hectare-wise pesticide usage grew from 3.2 gm in 1954–1955 to 570 gm in 1996 (Bami, 1996) [4]. According to Kumarasamy (2008) [7], India currently uses 480 grams of pesticides per hectare, which is much less than Taiwan's 17 kg/ha, Japan's 16.5 kg/ha, and the US's 4.5 kg/ha. The data regarding the consumption of chemical pesticides, which was projected to reach 70668 metric tons in 2020–21 (MoA&FW, 2021) [8], clearly illustrates the rising need for chemical pesticides. After chili, eggplant receives the most pesticide spraying out of the 13–14% of vegetables in India (Kodandaram *et al*., 2013) [6]. However, its careless use has detrimental effects on the environment and the economy. To keep pests out of their crop, eggplant growers utilized fungicides and chemical pesticides in combinations of two to three. The majority of the chemical pesticides utilized by the producers belonged to the organophosphate group and were either contact or systemic in nature. The most popular chemical pesticide for controlling pests in eggplant crops was chlorpyriphos. Nonetheless, a concerning proportion of the respondents who grew eggplants applied pesticides in excess of the prescribed dosage and at the wrong times for their crop's growth. According to the pesticide usage history on eggplant, farmers in the Dharmapuri area sprayed 22.6 times (5.4 insecticides), followed by 21.6 times (8.9 insecticides) in the Raichur and Guntur area and 21.4 times (7.9 insecticides). Insecticides were applied either not at all or very little to the L. orbonalis that was gathered from the mountainous regions of Pune and Almora. Insect resistance to insecticides and resistance issues are caused by continuous and careless use of pesticides, which increases selection pressure (Kariyanna *et al*., 2020) [5]. Chemical insecticides can lead to a return of the targeted insect pests by eliminating their natural enemies. In addition to increasing agricultural losses dramatically, pests develop resistance to chemical insecticides. Pesticides require frequent application and do not offer long-term control. Pesticide use over time causes substantial levels of hazardous residues to accumulate in food, ground water, and the atmosphere.

There are currently few viable options available to farmers for avoiding the usage of synthetic pesticides. To reduce pesticide residual issues and ensure safe vegetable production, available pesticides must be applied judiciously in accordance with label claims and scientific advice. As of June 1, 2023, 330 pesticides and insecticide products were registered in India to address illnesses and insect pests (CIBRC, India). A small number of these insecticides with low doses and minimal mammalian toxicity are also available for sale.

Pesticide recommendations to use in Brinjal crop

The registrant company specifies the usage of the pesticide in the label claim during the registration process. Based on bioefficacy data from trials carried out by SAUs, ICAR institutes, or other accredited laboratories, the crop(s) and application rate(s) indicated in the label claim are chosen. The actual pesticide usage guidelines are created based on assessments conducted against the target species in the field and in laboratories. In order to establish an appropriate dosage regimen that lowers danger to users and non-target species, these studies also address the metabolism, persistence, and degradation of the pesticides. There have been concerns raised all throughout the nation regarding the lack of awareness of pesticide label claims and their application, with a significant percentage of pesticide use occurring without authorized label claims. This results in the residues of those pesticides being present, which are not permitted to be used on specific crops. A list of the most effective ways to use pesticides was approved by the Registration Committee, which was established by the Indian government. The following table provides recommendations for the usage of approved pesticides in India for the brinjal crop (Anonymous, 2023a) [3].

Table 1: Approved pesticides on brinjal crop

Fungicides/ insecticides	Pest common name	Dosage / ha			Waiting period (in days) between the last application and harvest.
		a. i. (g)	Formulation (g/ml) /%	Dilution in water (L)	
Captan 75% WP	Damping off (Nursery)	0.25%	2500 gm	1000 Soil drench in the nursery	NA
Carbendazim 50%WP	Leafspot	150 gm	300 gm	600	-
	Fruitrot	150 gm	300 gm	600	-
Zineb 75%WP	Blight	1.125- 1.5KG	1.5-2KG	750-1000 Lt	
Afidopyropen 50 g/L DC	Whitefly, Leafhopper	50	1000	500 – 750	01
Broflanilide 300 g/l SC	Shoot and fruit borer	12.6-18.6	42-62	500	1
Broflanilide 20% SC	Shoot and fruit borer, Thrips & Leafhopper	25	125	500	1
Carbofuran 03% CG	Root knot nematode, Reni form nematode	2000	66600	-	-
Carbosulfan 25% EC	Fruit and Shoot borer	312.5	1250	500	5
Chlorantraniliprole 18.50% SC	Shoot & Fruit borer	40	200	500 –750	22

Chlorpyrifos 20% EC	Shoot & fruit borer	200	1000	500 –1000	-
Cypermethrin 00.25% DP	Fruit & shoot borer	50 – 60	20000 – 24000	-	03
Cypermethrin 10% EC	Fruit & shoot borer	50 – 70	550 – 760	150 – 400	03
Cypermethrin 25% EC	Shoot & fruit borer, Leafhoppers, Epilachna grub	37 – 50	150 – 200	500	01
Deltamethrin 02.80% EC	Shoot & Fruit Borer	10 – 12.5	400 – 500	500	03
Dicofol 18.50% EC	Yellow mite	500 – 1000	2700 – 5400	500 – 1000	15-20
Diafenthiuron 50% WP	Whitefly	300	600	500 – 750	03
Dimethoate 30% EC	Leafhopper	600	1980	500 – 1000	-
	Shoot borer	200	660	500 – 1000	-
Emamectin benzoate 05% SG	Fruit and Shoot borer	10	200	500	03
Etoxazole 10% SC	Red spider mite	40	400	400 – 500	05
Fenazaquin 10% EC	Red spider mite	125	1250	500	07
Fenazaquin 18.3% SC	Red spider mite	114.375	625	400 – 500	10
Fenpropathrin 30% EC	Whitefly, Shoot and Fruit borer, Mites	75 – 100	250 – 340	750 – 1000	10
Fenvalerate 20% EC	Shoot & fruit borer,Aphids	75 – 100	375 – 500	600 – 800	05
Flonicamid 50% WG	Aphids), Leafhoppers, White fly	100	200	500	15
Flubendiamide 39.35% w/w SC	Shoot and fruit borer	72 – 90	150 – 187.5	500	05
Flumite 20% SC / Flufenzine 20% SC	Mite	80 – 100	400-500	500 – 1000	05
Fluxametamide 10% w/w EC	Leaf hopper, Thrips, Fruit and Shoot Borer	40	400	500	5
Hexythiazox 05.45% w/w EC	Red spider mite	25	500	500	07
Isocycloseram 9.2% W/W Dc (10% W/V) DC	Leafhoppers and Red Spider mite	20	200	500	5
Lambda-cyhalothrin 04.90% CS	Shoot & fruit borer	15	300	500	05
Lambda-cyhalothrin 05% E	Shoot & fruit borer	15	300	400 - 600	04
Malathion 50.00% EC	Mites	750	1500	500 - 1000	-
Phosalone 35% EC	Fruit borer	500	1428	500 - 1000	-
Propargite 57% EC	Two spotted spidermite	570	1000	400	06
Pyriproxyfen 10% EC	White fly & Leafhoppers	50	500	300	07
Spinosad 45% SC	Fruit & Shoot borer	73 – 84	162 – 187	500	03
Spiromesifen 22.90% SC	Red spider mite	96	400	500	05
Thiacloprid 21.70% SC	Shoot & fruit borer	180	750	500	05
Thiodicarb 75% W	Shoot & Fruit borer	470 – 750	625 – 1000	500	06
Thiamethoxam 25% WG	Whitefly	50	200	500	03
Beta-cyfluthrin 08.49% + Imidacloprid 19.81% w/w OD	Aphids, Leafhopper s, Shoot & fruit borer	15.75 + 36.75- 18 + 42	175 – 200	500	07
Cypermethrin 3% + Quinalphos 20% EC	Shoot & Fruit borer	-	350 – 400	500 – 600	07
Chlorpyrifos 50% + Cypermethrin 05% EC	Shoot & Fruit Borer	500+50	1000	500	7
Clothianidin 3.5%+Pyriproxyfen 8% SE	Whitefly, Leafhopper, Thrips and Aphids	44+100	1250	500	3
Pyriproxyfen 05% + Fenpropathrin 15% EC	Whitefly, Shoot & fruit borer	25 + 75 -37.5 + 112.5	500 -750	500 – 750	07
Pyriproxyfen 8% + Dinotefuran 5% + Diafenthiuron 18% SC	Whitefly, Leafhopper, Thrips and Aphids	48+30+108 to 66+41.25+148.5	600-825	500	8-10
Spirotetramat 11.01% + Imidacloprid 11.01% w/w SC	Whitefly, Red spidermites	60 + 60	500	500	05
Chlorantraniliprole 09.30% + Lambda-cyhalothrin 04.60% ZC	Shoot and fruit borer,Jassids	28	200	500	05
Azadirachtin 01.00% EC (10000 PPM) Min. Neem Based	Shoot & fruit borer	-	1000-1500	500	03
Azadirachtin 00.03% WSP (300 PPM) Neem Oil Based	Shoot & Fruit borer, beetles	-	2500-5000	500-1000	07
Metarhizium anisopliae 1.0% WP (1x108 CFU/gm min)	Shoot & Fruit borer	-	2.5-5.0	500-750	-

Strain No. IPL/KC/44 (Own R & D Isolate), Accession No. 6895.		
Pseudomonas fluorescens 1.0% WP (Strain No. IIHR-PF-2 Accession No. ITCCB0034)	Wilt	Before transplanting, treat the seed with *Pseudomonas fluorescens* 1.0% WP @ 20 gm/kg of seeds, treat the nursery beds with *Pseudomonas fluorescens* 1.0% WP @ 50 gm/sq.m, and enrich the soil with FYM* at 5 tons/ha by applying *Pseudomonas fluorescens* 1.0% WP @ 5 kg/ha.
Trichoderma harzianum 1.0% WP (Strain No. IIHR-TH-2 Accessions No. ITCC6888)	Wilt	Add Trichoderma harzianum to the seed. Apply 1.0% WP at 20 g/kg of seeds and use Trichoderma harzianum to treat the nursery beds. Before transplanting, treat the soil with Trichoderma harzianum 1.0% WP @ 5kg/ha enriched FYM*@5tons/ha and 1.0% WP @ 50 gm/sq.m.
Trichoderma viride 1.5% WP (Strain No. IIHR-TV-5, Accession No. ITCC 6889)	Wilt	Apply Trichoderma viride 1.5% WP @ 5 kg/ha enriched FYM*@5tons/ha to the soil prior to transplantation. Treat the seeds with Trichoderma viride 1.5% WP @ 20 gm/kg of seeds and the nursery beds with 50 gm/sq.m.
Trichoderma viride 1.0% WP(IPL/VT/101)	Root Rot/ Wilt/ Damping off	5 grams per kilogram of seeds Seed Treatment: Prior to sowing, make a thin paste of the necessary amount of Trichoderma viride 1.0% WP with the least amount of water, coat the seeds evenly, and let the seeds dry in a shade of 16 before planting. 10 grams per water liter Brinjal seedling roots should be dipped in a solution containing 10 grams of Trichoderma viride 1.0% WP per liter of water for a duration of 15 minutes.
Pseudomonas fluorescens 1.0% WP (Strain No. IIHR-PF-2, Accession No. ITCC-B0034)	Root-knot nematodes	Apply *Pseudomonas fluorescens* 1.0% WP (@ 5 kg/ha enriched FYM* @ 5 tons/ha) to the soil prior to transplantation. Treat the seed with *Pseudomonas fluorescens* 1.0% WP @ 20 gm/kg of seeds. Treat the nursery beds with *Pseudomonas fluorescens* 1.0% WP @ 50 gm/sq.m.
Trichoderma harzianum 1.0% WP (Strain No. IIHR-TH-2 Accessions No. ITCC 6888)	Root-knot nematodes	Before transplanting, treat the seeds with 20 gm/kg of Trichoderma harzianum 1.0% WP and the nursery beds with 50 gm/sq.m. Additionally, treat the soil with 5 kg/ha of enriched FYM* at 5 tons/ha of Trichoderma harzianum 1.0% WP.
Trichoderma harzianum 1.5% WP (Strain No. IIHR-TV-5 Accessions No. ITCC 6889)	Root-knot nematodes	Before transplanting, treat the seed with 20 gm/kg of Trichoderma harzianum 1.5% WP and the nursery beds with 50 gm/sq.m. Additionally, treat the soil with 5 kg/ha of enriched FYM* at 5 tons/ha of Trichoderma harzianum 1.5% WP.
Trichoderma viride 1.5% WP (Strain No. IIHR-TV-5 Accessions No. ITCC 6889)	Root-knot nematodes	Before transplanting, treat the seeds with Trichoderma viride l.5% WP @ 20 gm/kg of seeds and the nursery beds with Trichoderma viride l.5% WP @ 50 gm/sq.m. Additionally, treat the soil with Trichoderma viride 1.5% WP (@ 5 kg/ha enriched FYM* @ 5 tons/ha).
Verticillium chlamydosporium 1.0% WP, (2x106 CFU/gm min) Strain – IIHR-VC-3 Accession No – ITCC-6898	Root-knot nematodes	Before transplanting, treat the seeds with Verticillium chlamydosporium 1.0% WP @ 20 gm/kg of seeds and the nursery beds with Verticillium chlamydosporium 1.0% WP @ 50 gm/sq.m. Additionally, add to the soil 5 tons/ha of enriched FYM* with Verticillium chlamydosporium 1.0% WP @ 5 kg/ha.
Paecilomyces lilacinus 01.15% WP (Accession No. MTCC No. 5175, T-Stanes PI-1 Strain)	Root Knot Nematode	To 500 kg of organic fertilizer or manure, add 03.00 kg of bioagent.

Pesticide residue definition

According to the World Health Organization (WHO), a pesticide residue is "Any substance or mixture of substances in food for man or animals resulting from the use of a pesticide and includes any specified derivaties, such as degradation and conversion products, metabolites, reaction products, and impurities that are considered to be of toxicological significance."

Important safety guidelines for pesticide residues

The health risks associated with pesticide residues in food, whether short- or long-term, are dose-dependent. The amount of pesticide consumed per kilogram of body weight determines whether or not there may be health risks. "Acceptable Daily Intake" (ADI) is the highest level of pesticide residues that a person can consume on a daily basis for the rest of their life without experiencing a significant danger. The ADI is designed to identify a threshold beyond which no adverse effects would be anticipated. It is based on scientific assessment of all available information at the time of evaluation. The milligrams of substance per kilogram of body weight is the unit used to measure ADIs. The hundredth of the highest dose of the pesticide that is fed to test animals without having any negative effects on the most vulnerable test species is the value for the adverse drug impact coefficient, or ADI. The factor one hundredth results from the precautionary presumptions that warm-blooded animals are not as sensitive as humans are, and that humans with the highest levels of sensitivity are ten times more sensitive than the average. In certain circumstances, the short-term consumption of residues may surpass the ADI, but not the long-term intake. Then, when evaluating the hazards associated with short-term intake, the acute reference dose (ARfD), which is generated from a no-observed adverse effect level (NOAEL) in short-term feeding studies, is taken into consideration. As a result, the risk resulting from pesticide consumption is ascertained by contrasting dietary exposure with insecticide ADI and ARfD. In order to evaluate the dangers associated with short-term intake, studies on feeding are taken into consideration. As a result, the risk resulting from pesticide consumption is ascertained by contrasting dietary exposure with insecticide ADI and ARfD. Internationally recognized organizations, such as the United Nations Codex Alimentarius Commission MRLs, can be consulted for guidance in the absence of national or regional MRLs. The FSSAI determines the MRL values for a number of pesticides in various crops across our nation. In order to guarantee the availability of healthy and safe food for human consumption, the Food Safety and Standards Authority of India (FSSAI) was founded under the Food Safety and Standards Act of 2006 to establish science-based standards for food articles and to regulate their manufacture, storage, distribution, sale, and import.

Table 2: Maximum residual limits (MRLs) established by the Food Safety and Standards Authority of India (FSSAI) for various pesticides in the brinjal crop

Sl. No.	Pesticide name	MRL (mg/ kg)
1.	Beta cyfluthrin	0.01
2.	Chlorantraniliprole	0.03*
3.	Chlormequat chloride (CCC)	0.1
4.	Cypermethrin	0.2
5.	Deltamethrin	0.3
6.	Diafenthiuron	1.0
7.	Zineb as CS2	0.01**
8.	Etoxazole	0.2
9.	Fenazaquin	0.01
10.	Fenpropathrin	0.2
11.	Fenvalerate	2.0
12.	Flubendiamide	0.1
13.	Fluchloralin	0.01**
14.	Imidacloprid	0.01
15.	Lambda cyhalothrin	0.2
16.	Propargite	2.0
17.	Pyriproxyfen	0.02
18.	Spiromesifen	0.5
19.	Tebuconazole	0.3
20.	Thiodicarb	0.05
21.	Thiamethoxam	0.3

*MRL set at LOQ; ** Insecticides are registered under the 1968 Insecticide Act (46 of 1968), but the commodity's label claims are unfixed, hence the MRL is set at LOQ

Monitoring of pesticide residues in India

The Indian government has implemented a number of initiatives to ensure that farmers in the nation handle pesticides appropriately. Under the central sector program "Monitoring of Pesticide Residues at National Level," which was started in 2005–06, the Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture, and 25 participating laboratories representing the Ministry of Agriculture, Indian Council of Agricultural Research, Ministry of Health and Family Welfare, Ministry of Environment and Forest, Council of Scientific and Industrial Research, Ministry of Chemical and Fertilizer, Ministry of Commerce, and State Agricultural Universities, regularly monitor the pesticide residues in food commodities and environmental samples. Samples of food commodities are collected by participating laboratories from public distribution systems, farm gates, and other marketplaces run by the Agriculture Produce Marketing Committee. Additionally, soil and drinkable water samples are gathered from farms throughout the nation. The samples are examined to determine whether any potential pesticide residues can be found in a variety of food items, including fish, meat, tea, vegetables, fruits, cereals, spices, pulses, milk, and butter. In order to raise awareness among farmers and start corrective action for the prudent and appropriate use of pesticides on crops using an Integrated Pest Management approach, the pesticide residue data generated under the aforementioned scheme is shared with State Governments and relevant Ministries/Organizations.

Brindal samples were gathered from three vegetable markets in Telangana state: Jangaon, Raghunathpally, and Hanmakonda. Six organophosphate and four synthetic pyrethroid insecticides were found to have residues in the samples. Ethion, dimethoate, chlorpyriphos, profenophos, quinalphos, and malathion were the organophosphate insecticides that were found. According to Priyadarshini *et al*. (2017) [9], the synthetic pyrethroids that were found in any of the three marketplaces included lambda cyhalothrin, cypermethrin, deltamethrin, and fenvalerate.

The "waiting period (WP)" or "pre-harvest interval (PHI)" is the length of time between the application of pesticides and the harvesting date. WPs for the most often used pesticides have been established at ICAR-IIHR.

Table 3: The IIHR investigated the waiting intervals for a few common insecticides used on brinjal

Recommended Insecticides	Target Pests	Dose in a.i. /ha	Waiting Period in days	MRL in (mg/kg) (source)
Acephate 75 SP	Aphids, leafhoppers, Whitefly	500 g	10	0.01(EU)
Chlorantraniliprole 18.5 SC	BSFB	40 g	1	2.0 (FAO / WHO
Chlorpyrifos 20EC	BSFB	200 g	15	0.5 (EU)
Lambda cyhalothrin 5EC	BSFB, Thrips, Mite, leafhoppers	15 g	7	0.2 (FAO/ WHO)
*Triazophos	BSFB	500 g	15	0.01 (EU)
Quinalphos 25 EC	BFSB	375 g	4	0.05 (EU)

* Crops grown in polyhouse, WP= Waiting period, PHI = Pre harvest interval, BSFB = Brinjal shoot and fruit borer

Important approaches for pest management to minimise residues in brinjal

Nematodes, diseases, and insect pests are the main obstacles preventing brinjal from reaching its maximum yield potential. The indiscriminate application of chemical pesticides has led to the development of resistance in pests, residual issues with food and drinking water, and ecological imbalance from the loss of beneficial insects and microbes. Thus, in order to ensure the sustainability of the brinjal crop, these biotic stresses must be controlled using environmentally friendly methods complemented by the prudent and need-based application of pesticides to produce significant financial gains without upsetting the peace and balance of the ecosystem. One of the most important, environmentally safe, and commercially feasible ways to boost the nation's brinjal yield is integrated pest management, or IPM. The following list includes some of the crucial elements of IPM procedures for brinjal.

- Using resistant genotypes, hybrids, and varieties (host plant resistance).
- Utilizing wholesome seeds procured from a dependable vendor.
- Rotating crops, intercropping, trap/barrier crops, and so forth.
- The best times to sow and harvest.
- Use of botanicals, biofumigants, and biocontrol agents, among others.
- Application of safer and labeled chemical pesticides based on need.

Host Plant Resistance
Considering the variety and severity of pests in a given area, choosing resistant or less sensitive varieties, hybrids, or genotypes is a good approach to pest management. Host plant resistance fits in nicely with all the other elements and is fully safe. In contrast to cereals, very few resistant or less sensitive genotypes have been produced for the management of insect pests in brinjal. Sucking pests can be more effectively controlled by developing resistant kinds and genotypes. Similar to this, certain genotypes have also been found to be associated with the treatment of illnesses in Indian brinjal.

Table 4: Tolerant genotypes of brinjal crop against major insect Pests and diseases

S. No.	Pest(s)	Genotype(s)
1.	Shoot and fruit borer	ARV 2-C, Pusa Purple Round, Punjab Neelam, Kalyanpur-2, Narendra Hybrid Brinjal-2, SM 17-4, PBr 129-5 Punjab Barsati
2.	Leafhopper	Doli 5, Pusa Purple, Chaklasi Doli,
3.	Little leaf disease	Junagadh Oblong, Pusa Purple Round, Narendra Hybrid Brinjal-1
4.	Bacterial wilt	Alka Keshav, Arka Nidhi, Utkal Tarini, Surya, BB-64, Swarna Abhilamb, Pusa Purple Cluster, Utakal tarini, Pant Brinjal Hybrid- 1, Swarna Pratibha, Swarna Shyamali, Swarna Shree,
5.	*Phomopsis* blight and bacterial Wilt	Swarna Ajay, Pant Samrat
6.	Root knot and *Reniform* nematode	Co-1
7.	*Fusarium* wilt	Utkal Keshari, Utkal Madhuri
8.	*Phomopsis* blight, little leaf disease and wilt	JC-1
9.	Little leaf and *Phomopsis* blight	Narendra Hybrid Brinjal-2, Azad B-1
10.	Root knot nematode	Black beauty, Banaras Giant, Pusa Long Purple

Intercropping
This technique disrupts traditional monoculture by growing crops with different plant geometries alongside insect pests, hence reducing pest infestation. Because of their diversity, plants prevent adults from laying eggs and also discourage adult insects from harming crops by releasing volatile allelo-chemicals from a specific crop. Every planting combination of this kind also increases the activity of parasites and predators.

S.No	Crop combination	Target pest
1.	Brinjal + Coriander /Fennel	Fruit and shoot borer

Using insecticides safely to reduce their residue in brinjal
Farmers in brinjal rely on the use of synthetic insecticides because there aren't enough non-chemical options for managing insect pests. It is necessary to switch from the traditional method to the safer synthetic alternatives in order to prevent the risk associated with hazardous pesticides.

Pesticides with low toxicity and low dose
Conventional pesticides are applied at very high rates—often more than one kilogram per hectare. However, as newer generation insecticides take their place, their use is trending downward. Imidacloprid, a common pesticide, is used at a rate of 21–45 g/ha to fruits and vegetables; rates for milbemectin and emmemactin-benzoate are even lower. In terms of toxicity to non-targets, the majority of recently released insecticides are less hazardous. Modern pesticides with registration in our nation, including flubendiamide and chlorantraniliprole, are not very harmful to mammals. Most of them don't stay in the environment for very long. In the near future, these safer pesticides will most likely replace all of the traditional ones, providing complete crop protection without compromising biodiversity.

Newer modes of action for pesticides to counteract resistance
Many insecticides have caused insect pests to become resistant to them. The pesticide is metabolized by the resistant insects, which lowers its concentration inside the insect to an ineffective level. Farmers must switch to insecticides with distinct modes of action in order to prevent this issue. The only known modes of action for pesticides in the past were organophosphates and carbamates, which worked by inhibiting the nervous system's acetyl choline esterase (ACHE) enzyme. Organochlorines and pyrethroids functioned by either blocking normal chloride channel function at the GABA receptor-ionophore complex of the nervous system or by opening up sodium ion channels in neurons, causing hyperactivity of the nerves. Neonicotnoid insecticides are among the many novel groups of pesticides that have been created recently. These pesticides work by binding to several post-synaptic nicotinic acetylcholine receptors in the central nervous system. Benzoylureas prevent insects from producing chitin, diamides paralyze muscles by activating ryanodine receptors, and insecticides like propargite and diafenthiuron block the mitochondrial enzyme that produces ATP, among other effects. A large number of these new pesticides with their unique mechanisms of action are less persistent and more polar, which makes them less harmful to the environment. Additionally, using pesticides with various modes of action prevents the target pest from developing a resistance to any chemical.

Using botanicals as insecticides and developing new ones
Plants are an abundant supply of bioactive organic molecules, which have been effectively extracted to produce substances that protect plants. The physostigmine, or esserine, a deadly molecule found in African calabar plants, provides the basis for the chemistry used to create organo carbamate pesticides. The insecticidal qualities of a number of African and Asian species of *Chrysanthemum* were well recognized. *Chrysanthemum* blooms contain six naturally occurring terpenoid esters that together are referred to as pyrethrins, and they have a very effective knockdown effect on a variety of insects. However, because natural compounds are photolabile in the presence of sunshine, they are not highly active in outdoor environments. Many photostable pyrethrin-like compounds, collectively referred to as "synthetic pyrethroids," were produced as a result of chemical synthesis altering the structures of natural

pyrethrins. Azadirachtin, a potent antifeedant found in neem seed kernels, is used to protect plants. Due of its photosensitivity and short half-life, azadirachtin proved to be challenging to use at first. Sunscreen was added to the formulation to remedy the issue, and it is now a crucial component of the integrated pest management program. Animal-derived metabolites have also been used, either directly or indirectly, as insecticides. For example, nereistoxin analogues were created from the lead chemical nereistoxin, which was extracted from the marine annelid *Lumbriconereis heteropoda*. All of the analogues have substantially lower mammalian toxicities than their original chemical, nereistoxin. By using underutilized or unused microorganisms, plants, and animals, novel lead compounds can be discovered. The manufacture of novel compounds with low dosage (high potency), minimal mammalian toxicity, and environmental safety could be facilitated by these bioactive natural ingredients.

Bio-pesticides

Utilizing live insect pathogens for biological control of insects is a sustainable and environmentally benign method of managing insects. Although these formulations of living organisms have various limits, once a component of this method is installed in the agricultural field, a constant pressure builds upon the target insect to keep its number below the economic threshold level. Examples of these biocontrol agents include nuclear polyhedrosis virus (NPV), some formulations of *Bacillus thuringiensis* bacteria, and others. These agents are typically crucial elements of integrated pest management programs.

The choice of pesticide, the amount applied, and the application technique

Farmers must explore the region to determine the level of insect damage before selecting the pesticide and the appropriate application technique. Each pesticide label that comes with the formulation package details the amount to be used, when and how to apply it, as well as any necessary precautions to take both during and after application. It is necessary to regularly inspect and maintain spray nozzles, hoses, gauges, and tanks. Applying pesticides at precise rates requires proper sprayer calibration. The consistent application of pesticides is ensured by using high-quality calibrated sprayers. It is most likely for strong rains to wash pesticides away from target sites in the early hours following application. Consequently, if there is a chance of significant rain, pesticide application should be avoided. Drift from pesticide application is influenced by temperature, humidity, and wind speed. Lowering boom heights and utilizing nozzles that generate large-sized droplets can help prevent drift.

Farmer Education

Currently, producers may minimize the danger associated with pesticides by managing insect pests of fruits and vegetables using a variety of non-chemical approaches. Teaching farmers to use pesticides safely is the biggest challenge. The uptake of safer knowledge by users is critical to the development of such knowledge. Each and every system stakeholder is responsible for the change. Building robust and efficient networks amongst farmers, extension agents, and research organizations is necessary to provide healthy food, minimize the use of pesticides, and save the environment.

Conclusion

For sustainability of brinjal crop, One of the most important, ecologically safe, and commercially feasible solutions for raising crop yield in the nation is integrated pest management, or IPM. Using resistant varieties, hybrids, and genotypes; using healthy seeds from a reputable source; crop rotations; intercropping; using trap and barrier crops; determining the best times to plant and harvest; using biocontrol agents; using botanicals; and applying safer, label-claimed chemical pesticides only when necessary are some of the crucial elements of integrated pest management (IPM) techniques for brinjal. Farmers must decide which pesticide to use and how to apply it correctly. Each pesticide label that comes with the formulation package details the amount to be used, when and how to apply it, as well as any necessary precautions to take both during and after application. Teaching farmers to use pesticides safely is the biggest challenge. Building robust and efficient networks amongst farmers, extension agents, and research organizations is necessary to provide healthy food, minimize the use of pesticides, and save the environment.

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