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Field efficacy of imidacloprid 17.8% SL against Green Apple Aphid, *Aphis pomi* De Geer (Homoptera: *Aphididae*) on apple in mid-hill Himalayas of Kashmir

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Abstract
The green apple aphid, *Aphis pomi* De Geer (Hemiptera: *Aphididae*), is a major pest affecting apple cultivation, causing significant yield losses. Neonicotinoids, particularly imidacloprid, are commonly used worldwide for aphid control. This study evaluated the field efficacy of various concentrations of imidacloprid 17.8% SL against *A. pomi* under open-field conditions in Kashmir. All tested concentrations significantly suppressed aphid populations compared to the standard check (Chlorpyrifos 20EC) and the untreated control. The highest reductions were observed at 0.5 and 0.6 ml/L concentrations of imidacloprid, achieving 93.65% and 95.99% control in the first year, and 90.71% and 93.24% in the second year, respectively, at 21 days post-application. In contrast, Chlorpyrifos 20EC showed only 5.63% reduction, indicating markedly lower efficacy. These results confirm that imidacloprid 17.8% SL is highly effective against *A. pomi* and should be considered a reliable component of integrated pest management (IPM) strategies for apple orchards in Kashmir and other temperate apple-growing regions of India.

Keywords: *Aphis pomi*, apple, efficacy, imidacloprid

Introduction
Crop protection remains one of the cornerstones of global agricultural productivity. The damage caused by pests, diseases, and weeds can significantly reduce crop yields, with losses often ranging from 10% to 50% (Pimentel *et al*., 1992; Beddington, 2010) [6, 30]. Among the many insect pests affecting crops, aphids are among the most destructive. These tiny sap-sucking insects are notorious worldwide for their capacity to damage a wide range of cultivated plants (Bakroune *et al*., 2023; Zahida *et al*., 2023) [4]. Globally, more than 5,500 aphid species have been recorded, grouped into over 700 genera and 30 subfamilies (Favret, 2018) [13]. Aphids are remarkable for their adaptability, often forming dense populations across various spatial and temporal scales (Kindlmann and Dixon, 1993; Dixon, 1998; Borges *et al*., 2006) [9, 11, 21]. Their biological diversity and ecological interactions make them a valuable model for studying a range of important biological phenomena, including virus transmission, reproductive polymorphism, symbiosis, phenotypic plasticity, insecticide resistance, and plant-insect dynamics (Bass *et al*., 2014) [5].
In the temperate region of Kashmir, apple cultivation holds immense economic and cultural significance. As the most extensively cultivated fruit crop in the region, apples from Kashmir contribute around 65% of the total apple production in India (Khursheed *et al*., 2024) [19]. However, the productivity and quality of apple crops in the region are increasingly threatened by the green apple aphid, *Aphis pomi*. This species is considered the most serious sap-feeding pest in apple orchards of Kashmir (Khursheed *et al*., 2021) [20]. Originally native to Europe (Borbely *et al*., 2023) [8], *A. pomi* is now established in nearly all apple growing regions of the world. It follows a monoecious, holocyclic life cycle, completing all its developmental stages on apple and related *Maloideae* species (Blackman and Eastop, 1994; Holman, 2009) [7, 16]. Winged females emerge with the onset of summer and disperse across orchards, colonizing fresh apple shoots (Baker and Turner, 1916). Under warm summer conditions, the aphid can complete its life cycle in just one week, leading to rapid and exponential population growth.
A. pomi typically overwinters as eggs that hatch at the silver tip stage of apple bud development, with population build-up accelerating from late May to early June as the shoots elongate. Parthenogenetic reproduction allows females to produce live offspring without mating, giving the species a considerable advantage in increasing its numbers rapidly. It primarily targets the tender, growing shoot tips where it causes characteristic rolling and curling of leaves, an adaptation that protects the aphid colonies from predators, environmental stress, and even pesticides. Beyond the visible damage to foliage, this pest negatively impacts fruit development by reducing size (Filajdic *et al*., 1995) [14], deforming fruit shapes (Hulle *et al*., 2006) [17], and even causing premature fruit drop (Van Emden *et al*., 1969) [37]. The sticky, sugary excretion known as honeydew not only blemishes fruit but also supports the growth of sooty mold and attracts ants, which tend to the aphids and protect them from natural enemies (Khursheed *et al*., 2021; Arshid *et al*., 2024) [20].
In response to such threats, chemical pesticides have become an integral part of modern farming practices, contributing to nearly one-third of the world's agricultural output (Tudi *et al*., 2021) [36]. However, despite the widespread application of synthetic insecticides such as organophosphates, effective management of *A. pomi* remains elusive in Kashmir. The repeated use of such chemicals has led to environmental concerns and the emergence of resistance in aphid populations (Peris and Kiptoo, 2017) [29]. This resistance underscores the urgent need to explore alternative control strategies.
Among the newer insecticidal options, imidacloprid, a neonicotinoid compound, has shown considerable potential due to its systemic action and targeted mode of interference

with insect nervous systems. Its use in other agricultural systems against sucking pests has yielded promising results, raising interest in its potential effectiveness against *A. pomi*. Assessing its efficacy under real field conditions in apple orchards can provide vital information on its utility in integrated pest management (IPM) frameworks.

Recognizing the economic importance of apple cultivation and the challenges posed by ineffective pest control, the present study was undertaken to evaluate the field performance of imidacloprid against *Aphis pomi* in Kashmir. The results aim to contribute to the development of more effective, sustainable pest control strategies and offer practical benefits for apple growers in the region.

Materials and Methods

Study Site and Experimental Design

The field trials were conducted during the 2022 and 2023 growing seasons at the Ambi Apple Research Centre Experimental Farm, Pahnoo, Shopian, Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K). The site is located at an altitude of 1953 meters above mean sea level, with geographical coordinates of 33°44′ N latitude and 74°51′ E longitude. The apple cultivar *Red Delicious* was selected for the study due to its commercial significance and widespread cultivation across temperate regions of India (Khursheed *et al*., 2024) [19].

The experimental layout consisted of 18 uniformly grown apple trees arranged in a Randomized Block Design (RBD), with each treatment replicated three times. Each replicate comprised one tree. To ensure representativeness, nine twigs of approximately 5 cm length were randomly selected from all four canopy directions (north, south, east, and west) of each tree, with a total of 27 twigs per treatment. A buffer row of trees was maintained between treatments to prevent cross contamination, and three trees were left as untreated controls, sprayed only with water. All experimental trees were tagged and marked with white paint for identification throughout the study.

Insecticide Treatments and Application

The study evaluated the efficacy of four concentrations of imidacloprid 17.8% SL (0.3, 0.4, 0.5, and 0.6 ml per liter of water) against *Aphis pomi*, and included a standard insecticide check using chlorpyrifos 20% EC at 1 ml per litre. Treatments were applied during the walnut-size fruit stage in June, coinciding with the period when aphid populations reached the economic threshold level and honeydew secretion was visible.

A petrol-operated Honda power sprayer fitted with an Aspee HTP pump and a 30-liter capacity was used to apply treatments. Each tree received 15 liters of spray solution, with a total of 45 liters used per treatment. A hollow cone nozzle was employed to ensure thorough coverage of the canopy, including the undersides of leaves and the trunk. Sprays were conducted in the morning when ambient temperatures ranged between 15°C and 25°C, optimizing insecticide performance.

Apart from a single pre-season application of dormant horticultural mineral oil before the green tip stage (targeting San Jose scale and European red mite), no other insecticides were used in the orchard. Other cultural operations—fertilization, irrigation, fungicide sprays, and weeding were conducted as per SKUAST-K's recommended practices for temperate fruit crops. The orchard had a spacing of 5.49 m between trees and rows, with seven trees per row and a planting density of approximately 250 trees per hectare.

Aphid Monitoring and Fruit Assessment

To assess aphid population dynamics, counts were made on the pre-selected twigs one day prior to treatment application. Post-treatment observations were recorded at 1, 3, 7, 15, and 21 days after spraying across all treatments and control. At harvest, fruit yield from each experimental tree was collected, and 100 fruits were randomly sampled per tree to evaluate infestation resulting from aphid secreted honeydew. The percentage of fruit infestation was calculated using the formula:

$$\text{Fruit infestation (\%)} = \frac{\text{Number of fruits infested}}{\text{Total number of fruits selected}} \times 100$$

Efficacy Evaluation

The effectiveness of treatments in reducing aphid populations was estimated using the Henderson and Tilton (1955) [15] formula, which accounts for both pre- and post-treatment population levels in treatment and control plots:

$$\text{Pest population reduction (\%)} = 1 - \left(\frac{Ta \times Cb}{Tb \times Ca}\right) \times 100$$

Where:

Ta = Number of aphids in treatment after application
Tb = Number of aphids in treatment before application
Ca = Number of aphids in control after application
Cb = Number of aphids in control before application

Statistical Analysis

All data were subjected to analysis of variance (ANOVA) using SPSS version 16. Prior to statistical evaluation, data were transformed using OP-Stat software to meet the assumptions of normality. Means were separated using Duncan's Multiple Range Test (DMRT) at a significance level of $p \leq 0.05$. Observations from each interval were analyzed independently, and seasonal data for both years were treated and presented separately.

Results

During the 2022 growing season, observations revealed that the initial population of *Aphis pomi* ranged from approximately 78 to 104 individuals per 5 cm twig across all experimental treatments, including the untreated control plots. Following the application of insecticidal treatments, a noticeable and statistically significant reduction in aphid populations was recorded in all treated trees when compared to the control. This trend was consistent across all observation intervals, 1, 3, 7, 15, and 21 days after spraying (table 1).

Table 1: Efficacy of Imidacloprid 17.8% SL against Green Apple Aphid, *Aphis pomi* at AARC, Pahnoo, Shopian during 2022.

Treatments	Dosage (ml/liter of water)	*Aphid population/5cm twig 1DBS	**Mean percent reduction in aphid population over pre-treatment					**Honeydew infested fruits (%)
			1DAS	3DAS	7DAS	15DAS	21DAS	
Imidacloprid 17.8% SL	0.3	91.33 (9.39)	13.91 (21.83)	40.86 (39.71)	62.65 (52.32)	72.93 (58.59)	71.31 (67.56)	18.67 (25.57)
Imidacloprid 17.8% SL	0.4	84.33 (9.23)	18.17 (25.20)	58.85 (50.10)	70.34 (56.98	82.37 (65.24)	81.29 (68.86)	9.33 (17.74)
Imidacloprid 17.8% SL	0.5	80.00 (9.01)	29.27 (32.68)	(63.35 (52.83)	86.24 (68.95)	89.58 (72.78)	93.65 (83.03)	3.33 (10.34)
Imidacloprid 17.8% SL	0.6	94.00 (9.73)	32.53 (34.67)	74.74 (59.82)	92.66 (77.62)	94.38 (82.20)	95.19 (82.99)	2.00 (7.94)
Chlorpyriphos 20EC	1.00	104.33 (10.26)	15.13 (22.65)	20.80 (26.95)	23.76 (29.09)	20.23 (26.38)	10.53 (18.87)	63.33 (52.78)
Control	water	78.33 (9.11)	0.0 (0.0)	0.0 (10.45)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	91.33 (73.50)
CD (P=0.05)		NS	5.01	10.45	7.23	7.33	3.50	7.86

* Figures in the parentheses are square root transformed values **Figures in the parentheses are arc sine transformed values DAS=days after spray

Among the various treatments tested, imidacloprid 17.8% SL consistently demonstrated superior performance in suppressing aphid populations. All concentrations of imidacloprid used in the trial led to marked reductions in pest density, but the most pronounced effects were observed at application rates of 0.5 and 0.6 ml per litre of water. These two doses were particularly effective, achieving mean population reductions of 93.65% and 95.19%, respectively. Both concentrations were statistically at par throughout the study period, indicating their equal potential in managing *A. pomi* under field conditions. The treatment with imidacloprid at 0.4 ml/litre also produced a notable decline in aphid numbers, though it was slightly less effective than the higher doses. Importantly, imidacloprid exhibited a residual effect lasting up to 21 days post-application, after which a gradual resurgence in the pest population was observed.

In contrast, the standard insecticidal check chlorpyrifos 20% EC proved to be far less effective. While it showed a brief reduction in aphid numbers, with a maximum decline of 23.76% observed seven days after application, its impact diminished rapidly thereafter. The pest population rebounded quickly, suggesting that chlorpyrifos lacked both the efficacy and the residual activity needed to provide long term control under field conditions.

A similar pattern was observed during the 2023 season. The pre-treatment aphid population was higher this year, with counts ranging from 100 to 137 individuals per 5 cm twig. Nevertheless, the general response to the treatments mirrored the previous year. imidacloprid 17.8% SL again demonstrated the highest level of efficacy. The 0.5 and 0.6 ml/litre treatments were particularly effective, leading to pest reductions of 90.71% and 93.24%, respectively, by 21 days after application. These two concentrations remained statistically equivalent throughout all observational intervals, including 1, 7, and 15 days after treatment, reaffirming their strong and consistent performance. The 0.4 ml/litre treatment, while slightly less potent, still maintained notable pest suppression. Chlorpyrifos, on the other hand, offered only temporary relief, achieving its highest pest reduction (26.46%) on the 7th day, with population levels increasing sharply thereafter (table 2).

Table 2: Efficacy of Imidacloprid 17.8% SL against Green Apple Aphid, *Aphis pomi* at AARC, Pahnoo, Shopian during 2023.

Treatments	Dosage (ml/liter of water)	*Aphid population/5cm twig 1DBS	**Mean percent reduction in aphid population over pre-treatment					**Honeydew infested fruits (%)
			1DAS	3DAS	7DAS	15DAS	21DAS	
Imidacloprid 17.8% SL	0.3	110.33 (10.53)	13.78 (21.62)	29.35 (32.76)	47.69 (43.65)	68.87 (56.23)	70.96 (61.40)	21.67 (27.68)
Imidacloprid 17.8% SL	0.4	116.00 (1081)	17.21 (24.16)	38.09 (38.08)	60.02 (50.87)	76.00 (60.99)	81.55 (68.09)	12.00 (20.55)
Imidacloprid 17.8% SL	0.5	106.00 (10.28)	30.20 (33.26)	53.83 (47.21)	84.53 (66.83)	89.17 (71.61)	90.71 (79.07)	6.00 (14.14)
Imidacloprid 17.8% SL	0.6	137.33 (11.75)	35.13 (36.26)	73.08 (58.85)	92.29 (74.14)	95.07 (79.48)	93.24 (87.10)	3.33 (10.34)
Chlorpyriphos 20EC	1.00	109.00 (10.48)	11.65 (19.75)	20.97 (27.15)	26.46 (30.94)	12.93 (20.75)	5.63 (11.24)	75.33 (60.27)
Control	water	100.00 (10.07)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.00 (0.0)	0.0 (0.0)	90.67 (72.47)
CD (P=0.05)		NS	8.71	11.62	10.44	12.04	8.54	5.72

* Figures in the parentheses are square root transformed values **Figures in the parentheses are arc sine transformed values
DAS=days after spray

Fruit infestation

Beyond aphid population suppression, the treatments also significantly influenced the extent of fruit infestation caused by honeydew excreted by *A. pomi*. In 2022, the proportion of fruit showing signs of infestation varied considerably among treatments, ranging from just 2.00% in the most effective treatments to as high as 91.33% in the untreated controls. The lowest infestation levels were observed in trees treated with imidacloprid at 0.5 and 0.6 ml/litre, with values of 3.33% and 2.00%, respectively. These results were in sharp contrast to the chlorpyrifos-treated trees, where 63.33% of the fruits showed infestation symptoms, and the untreated control plots, which exhibited the highest damage (table 1).

The 2023 season confirmed this trend, with fruit infestation levels ranging from 3.33% to 90.67%. Once again, the trees treated with imidacloprid at 0.5 and 0.6 ml/litre recorded the lowest fruit infestation, at 6.00% and 3.33%, respectively. Meanwhile, the highest levels of fruit infestation were recorded in chlorpyrifos treated (75.33%) and untreated trees (90.67%) (table 2).

Collectively, the results from both years strongly support the conclusion that imidacloprid 17.8% SL, particularly at 0.5 and 0.6 ml/litre concentrations, offers highly effective and sustained control of *Aphis pomi* in apple orchards. It not only significantly reduces pest populations but also minimizes fruit infestation, making it a superior choice over chlorpyrifos for managing this economically important pest in temperate apple growing regions like Kashmir.

Discussion

The present investigation into the efficacy of insecticides against *A. pomi* clearly highlights the superior performance of imidacloprid 17.8% SL over the standard check chlorpyrifos 20% EC across two consecutive growing seasons. While chlorpyrifos exhibited a brief and limited suppressive effect, achieving less than 30% population reduction at 7 days after treatment and declining to below 15% by the 15th day, its efficacy had nearly vanished by the 21st day post-application. In stark contrast, imidacloprid maintained over 70% efficacy at all tested concentrations throughout the same duration in both years, demonstrating consistent and prolonged effectiveness.

These findings align with earlier studies by Aheer *et al*. (2000) [2], Afzal *et al*. (2001) [1], Shah *et al*. (2007) [34], and Solangi and Lohar (2007) [35], who all reported imidacloprid as the most effective insecticide for aphid control in a range of cropping systems. The performance of imidacloprid in the present study reinforces the growing body of evidence that neonicotinoid insecticides serve as reliable alternatives to traditional chemical classes such as organophosphates and carbamates, whose efficacy has been increasingly compromised by resistance development.

Neonicotinoids, including imidacloprid, thiamethoxam, and clothianidin, have been structurally optimized to enhance their activity against both chewing and piercing-sucking insects (Maienfisch *et al*., 2001) [23]. Their mode of action involves targeting the nicotinic acetylcholine receptors in the insect nervous system, resulting in rapid feeding cessation and mortality (Elbert *et al*., 2008) [12]. This mechanism is particularly effective against aphids, which rely heavily on sustained phloem feeding.

Further support for the effectiveness of neonicotinoids comes from studies showing strong anti-feeding responses to sublethal concentrations of imidacloprid on various aphid species. Nauen (1995) [26] reported significant behavioral disruptions in *Myzus persicae*, while Nauen and Elbert (1997) [27] and Nauen *et al*. (1998) [28] observed similar responses in *M. nicotinanae* and *Bemisia tabaci*, respectively. These sublethal effects not only reduce immediate pest pressure but also inhibit reproduction and long-term population growth. For instance, Miao *et al*. (2014) [24] found that in *Sitobion avenae*, neonicotinoid-treated plants exhibited higher incidences of non-probing behavior and shorter phloem ingestion phases, thereby significantly impairing the insect's feeding success.

Moreover, neonicotinoids have been shown to influence life-table parameters that directly affect pest population dynamics. Reductions in daily fecundity, developmental duration, and intrinsic rates of increase have all been documented in various studies (Daniels *et al*., 2009; Lashkari *et al*., 2007) [10, 22]. However, Miao *et al*. (2014) [24] noted that while sublethal concentrations (LC_{10}) of imidacloprid, dinotefuran, thiacloprid, and thiamethoxam had limited effects on the longevity and fertility of *S. avenae*, significant reductions were observed at LC_{50} levels, indicating that dosage plays a critical role in population suppression.

From an economic standpoint, the cost-effectiveness of neonicotinoids further adds to their appeal. Raghuraman and Gupta (2006) emphasized the favorable cost-benefit ratio of neonicotinoids in managing sucking pests, a conclusion supported by similar findings from Saha *et al*. (2011) [33] and Kencharaddi and Balikai (2012) [18], who demonstrated high returns per unit cost when neonicotinoids were integrated into pest management programs.

Aphid-infested shoots

Aphid-infested shoots

Honeydew infested fruits

Conclusions

The findings of this study clearly demonstrate the superior efficacy of imidacloprid 17.8% SL in managing *A. pomi* populations under field conditions. Its consistent performance across different concentrations and observation periods suggests that neonicotinoid compounds, particularly imidacloprid, serve as effective alternatives to conventional insecticides that have shown declining efficacy due to resistance development. Given its systemic action and prolonged residual activity, imidacloprid holds strong potential as a key component in integrated pest management (IPM) strategies targeting aphid pests in apple orchards, not only in Kashmir but also in other temperate fruit-growing regions of India.

However, the long-term success of imidacloprid in pest management depends on its judicious use. Continuous application without rotation may lead to the development of resistance in aphid populations. Therefore, it is crucial to incorporate imidacloprid into a broader IPM framework that includes monitoring, resistance management, and integration with biological and cultural control practices to ensure sustainable and effective pest suppression.

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