




Outbreaks of green apple aphid, *Aphis pomi* (De Geer) in apple orchards of Kashmir, India: Grower-Adopted management tactics and their implications for cultivation costs

Mohd Abas Shah ^{*} , Sheikh Aafreen Rehman, Hafsa Ajaz Trambo, Rifat Rasool, Wasim Hassan Raja, Sajad Un Nabi, Geetika Malik, Javid Iqbal Mir, Om Chand Sharma, Mahendra Kumar Verma

ICAR-Central Institute of Temperate Horticulture, Rangreth, 190007, Srinagar, Jammu and Kashmir, India

ARTICLE INFO

Keywords:

Apples
Cost of cultivation
Cost of spray
Growers' perception survey
Insecticide resistance
Sooty mold

ABSTRACT

Green apple aphid (GAA), *Aphis pomi* has assumed the status of a major pest in the last few years in Jammu and Kashmir (India) with continuous seasonal outbreaks. Based on a grower perception survey conducted in ten major apple-growing districts, we assessed the reported incidence of GAA, the management practices adopted by growers, and the perceived economic losses incurred. We found that the high incidence of GAA is widespread in all apple growing districts and on all the major commercial varieties under cultivation (Delicious group) including newly introduced varieties in the Gala group. Up to four additional insecticide sprays are needed for the management of GAA. The type of insecticides sprayed is dominated by the old chemistry insecticides like dimethoate, chlorpyrifos and cypermethrin. Higher number of sprays is needed if these insecticides are included in the spray regimes, and these insecticides are responsible for control failures. The cost of insecticide treatments can lead to 13.13 % increase in cost of cultivation in case of traditional orchards, and up to 18.58 % in case of high-density orchards, and 4.37 %–11.67 % increase in cost of post-harvest operations owing to incidence of sooty mold on harvested fruit. It is concluded that GAA has a significant economic impact on the apple production system in India. The probability of insecticide resistance development seems to be the major reason for GAA outbreaks in the recent years. Therefore, the use of new chemistry insecticides, and laying off the traditional insecticides is necessary and efforts at educating the growers about the best management practices are imperative.

1. Introduction

India is the 5th largest producer of apples, *Malus domestica* Borkh. (Rosales: Rosaceae) in the world with 2.589 MMt fruit harvested from an area of 0.31 Mha (FAO, 2024). In India, Jammu and Kashmir (J&K) is the leading apple growing region with production of 1.88 MMt contributing 77.71 % to the total production (Ministry of Agriculture and Farmers' Welfare, 2018). Emphasis is being given to shift the traditional orchards to high density plantations (HDP) to harness the maximum potential of orchards and to increase the farmers' income (DoH Kashmir, 2021). In India, the apples are infested by various insect and mite pests for which regime of insecticide sprays is recommended (SKUAST-K 2018). The presence of the green apple aphid (GAA), *Aphis pomi* (De Geer) (Hemiptera: Aphididae), on apple trees has been

documented for a long time across various parts of India (Menon and Pawar, 1958; Behura, 1963; Rishi, 1979; Bhagat et al., 1988). However, in recent years, its incidence has escalated to outbreak levels, particularly in all major apple-growing regions of Kashmir, indicating a significant shift in its pest status in the region.

The green apple aphid is one of the most abundant and widespread herbivore pests in apple orchards of Europe, North America, and the Middle East (Blackman and Eastop, 2000; Rakauskas et al., 2015; Alford, 2016). Infestation with *A. pomi* can stunt plant growth and stimulate lateral shoot growth, especially on young, non-bearing plants (Cutright, 1930; Arbab et al., 2006; Whitaker et al., 2006; Stoeckli et al., 2008). Mature trees are mostly affected by the honeydew production of the aphids dripping onto foliage and fruit. Honeydew stimulates sooty mold growth, which hinders key leaf functions and fruit ripening (Cutright,

* Corresponding author.

E-mail address: mabas.shah@icar.org.in (M.A. Shah).

<https://doi.org/10.1016/j.cropro.2025.107328>

Received 6 February 2025; Received in revised form 23 June 2025; Accepted 1 July 2025

Available online 3 July 2025

0261-2194/© 2025 Elsevier Ltd. All rights reserved, including those for text and data mining, AI training, and similar technologies.

1930; Stoeckli et al., 2008). The incidence of GAA starts from the third week of March (green tip stage) as occasional colonies hatching from the overwintering eggs. The incidence continues as wingless viviparous females for one generation and by the 2nd to 3rd week of April (petal fall), the production of winged spring migrants starts. The winged morphs spread to most of the apple plants and subsequently the aphid population increases exponentially within 2–3 generations. The aphid population peaks during mid-June and is accompanied by the accumulation of honey dew on leaves and subsequently on fruits (fruit development stage III). The GAA population subsequently decreases towards the third week of August. Thereafter, the population maintains a steady state till the 1st week of October (fruit harvest) when it enters the sexual phase, marked by the production of oviparae and males.

Other than the quantitative and qualitative losses in apple production; general weakening of the apple plants and incidence of sooty mold on harvested fruit is a wide spread phenomenon now. The economic costs of the GAA incidence are associated with the additional number of insecticide sprays needed and the additional cleaning/washing treatments of the harvested fruit to get rid of the blackening due to sooty mold on apples.

The objective of this study is to evaluate the extent of green apple aphid (GAA) infestation and to quantify the associated economic losses incurred in apple production. The collected information will help to devise specific and efficient management modules for GAA. Based on a grower perception survey conducted across all major apple-growing districts of Jammu and Kashmir, we present a descriptive analysis of the extent and severity of GAA colony incidence, associated damage symptoms such as sooty mold on leaves and fruits, induction of lateral growth in terminal shoots, and the presence of GAA eggs, along with the factors perceived to influence these patterns. We also characterise the general management practices adopted by the growers and the associated issue of control failures and the phenomenon of re-infestation by GAA. In addition, we provide estimates of the economic impact of GAA incidence on apple production in India mainly in terms of increase in cost of cultivation due to additional insecticide sprays needed for the management of GAA and increase in cost of sorting and grading of the harvested fruit to get rid of blackening due to incidence of sooty mold on fruits. In the next section, we provide relevant background information on the apple fruit production scenario in India with emphasis on the study area. The relevant factors associated with the incidence of GAA are also discussed.

2. Background

The study location – Kashmir division of Jammu and Kashmir (J&K) is a valley bound by the Pir Panjal range in the south-west and the Greater Himalayan range in the north-east (Supplementary material S1). The topography of the valley on the whole is gentle, but for the miniature plateaux constituted of the *Karewas*. The plain valleys have an altitude of 1560 m masl, which rises to 1950 m in low altitude *Karewas* in mid belts, and 2400–3000 m in the upper belts (Akhtar and Kirk, 2024). Based on such landscape factors and subsequent crop husbandry and tree growth characteristics, it is plausible to assume that orchard location might affect the incidence parameters of GAA. The average annual rainfall of Kashmir valley is 670 mm (IMD, 2014). The apple orchards exhibit a mix of rainfed and irrigated areas, with a significant dependence on rainfall for cultivation (Awasthi and Kamal, 2005). Irrigation in apple orchards is primarily sourced from canals and applied using the flood or basin method, although newly established high-density (HD) orchards are equipped with drip irrigation systems. Assured and consistent irrigation promotes continuous vegetative growth, creating favourable conditions for GAA proliferation. Consequently, orchards with reliable irrigation are more likely to experience higher levels of GAA infestation.

The varietal genetic base is narrow with delicious group of varieties dominating the production system (Red Delicious, Golden Delicious and

Royal Delicious) (Awasthi and Kamal, 2005; Verma and Kumar 2005). Most of the existing orchards consist of plants of seedling origin or on seedling rootstocks, large in size and very old (>30 years). The training system adopted is mostly the standard tree type trained to modified central leader or a mixture of various traditional systems (Ananda and Chandel, 2005; Awasthi and Mehta, 2005). Training systems have a direct bearing on the extent of vegetative growth of plants and hence their susceptibility to the incidence of GAA (Brown and Welker, 1992; Paulson et al., 2005). The orchards are established without regular plant to plant and row to row arrangement, with average spacing of 5 m, accommodating close to 400 trees per ha (SKUAST-K 2018). The average holding size (orchard size) for the whole of J&K is 0.6 ha (Economic Survey, 2023). Traditional apple orchards use wider spacing and vigorous seedling rootstocks, resulting in large trees with delayed bearing. High-density orchards use closer spacing (1–3 m), dwarfing rootstocks like M9, and precocious, high-yielding varieties. High-density orchards use slender spindle or vertical axis systems.

As for the management of major insect and mite pests infesting apples orchards, the state agricultural university (Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar-190,025, Srinagar, J&K) in collaboration with development department (Directorate of Horticulture, Kashmir, Department of Horticulture, Government of J&K) brings out an annual schedule of pesticide sprays, mostly consisting of calendar-based applications and some based on economic threshold levels (ETLs). The spray schedule consists of an essential spray of horticulture mineral oil (HMO) at delayed dormant stage, followed by up to three essential sprays at different phenological stages and some optional sprays if the economic thresholds are crossed for the management of insects and mites. The recommended list of insecticides includes chemicals mostly from the organophosphate group (dimethoate, chlorpyrifos, quinalphos, ethion), synthetic pyrethroids (cypermethrin), neonicotinoids (thiacloprid), and a range of acaricides (hexythiazox, spiromesifen, fenazaquin, cyenopyrafen, propargite etc.). Most of these chemicals have been in use for at least one to two decades (Directorate of Horticulture, 2015, 2020, 2024). Previously, endosulfan and dicofol were the pesticides of choice for a wide array of insect and mite pests (Bhardwaj and Bhardwaj, 2005).

3. Materials and methods

3.1. Survey design and distribution

The survey was conducted using an online questionnaire developed on ‘Google Forms’ tool and distributed to the growers via email links wherever available and mainly through ‘WhatsApp’ messenger application. The survey was further advertised at various growers’ meetings, training programs and farmer field visits. The survey was developed together with experts from fruit science, entomology, extension agencies and some progressive farmers. The links were shared initial in February 2023 and subsequently shared to other groups over the period till June 2024. A printable. pdf version of the survey questionnaire is available as Supplementary Material (S2).

The survey consisted of five sections and an introduction. The total number of questions was 38. It was a mixture of demography questions, multiple-choice questions, rating scale questions, open-end questions, qualitative questions, quantitative questions, frequency and likelihood questions. The first section collected respondents’ contact information and orchard locations. The second section addressed orchard characteristics, including size, planting density, tree age, training systems, and cultivated varieties. The third and fourth sections focused on GAA incidence and management, asking about sooty mold on leaves and fruits, infested trees’ appearance, lateral growth of shoots, and GAA eggs on apple shoots. Growers detailed their insecticide use, including frequency and recurrence of GAA infestations post-spray. The final section asked growers to rate GAA incidence’s importance, identify knowledge gaps, and speculate on causes of high incidence. The survey concluded

with a consent statement for follow-up and a thank-you note. Responses were analyzed using descriptive statistics, with variations in summary statistics due to missing values or relevance. All analyses were conducted in R version 4.3.1 (R Core Team, 2023).

The influence of orchard and crop management attributes on GAA incidence and damage symptoms was assessed using Chi-square tests. Variables such as holding size, location, growth stage, planting density, training system, and irrigation source were tested for association with response variables including GAA incidence duration, sooty mold presence, fruit cleaning needs, lateral shoot growth, egg presence, and plant discoloration (details in Supplementary Table 1). Associations were tested at a significance level of $p \leq 0.05$. Post-hoc analysis of significant results was performed using the “*chisq.posthoc.test*” function following Beasley and Schumacker (1995).

3.2. Association of insecticides sprayed with the incidence and effective control of GAA

Delayed dormant HMO spray can kill overwintering GAA eggs or emerging nymphs, potentially reducing early population build-up. Orchards receiving such sprays may experience delayed GAA build-up, necessitating fewer insecticide sprays during the main season. A Chi-square test was used to assess the association between delayed dormant HMO sprays, timing of GAA incidence, and the number of additional sprays required.

A Chi-square test examined the association between insecticide types and spray frequency. The insecticide spray regimes were classified in to three categories: A) in case organophosphates and/or synthetic pyrethroids only were sprayed, B) in case neonicotinoids and synthetic pyrethroids only were sprayed, and C) where any combination of insecticides from group A and B were sprayed.

Insecticides that are not completely effective against GAA result in shorter intervals between sprays and re-infestation. A Chi-square test analyzed the association between insecticide types and re-infestation intervals. Post-hoc analysis based on residuals of Pearson’s Chi-squared test for count data was conducted using the “*chisq.posthoc.test*” function in R 4.3.1 (R Core Team, 2023), as given by Beasley and Schumacker (1995).

3.3. Estimation of cost of spray

Based on the survey responses, 1 to more than 3 additional insecticide sprays were needed (weighted mean 2.16) for the effective control of GAA. The most commonly used rotations included any combination of those chemicals. With this background, the cost per treatment was calculated using standard costing procedures.

The costs of additional insecticide applications were broken down to cost of insecticide material and cost of application. The cost of insecticides was taken as the average of the lowest bulk price available in the market (FOR basis, as on 01-06-2024 in Srinagar (J&K)). The currency exchange rate is taken as \$1 USD = Indian Rupees INR 83.45 as on 01-06-2024. Most doses are stated as amount per 100 L of water. Reference doses were taken from insecticide labels the Package of Practices for Fruits and various advisories issued by SKAUST-K, Shalimar (SKAUST-K 2018b). Volume of spray solution needed per plant was adjusted for plant age, plant spacing and canopy size depending on the rootstock. The fixed cost included depreciation, interest on investment, taxes, insurance and housing costs. Power sprayer 6.5 HP, including 200 ft spray pipe, spray gun and nozzles was the most commonly used equipment for pesticide spray. Assuming an economic life of 10 years and a salvage value of 10 % of the initial investment cost of the machinery, the depreciation was calculated by straight line method. Assuming a 13 % rate of interest on investment, and 5 % inflation rate (base year 2011–12), the adjusted or “real” interest rate was taken as 8 %. The charges for taxes, insurance and housing (TIH) were taken as 3 % per year of the average cost of the machine.

The variable costs of application include repairs and maintenance, fuel, lubrication, and operator labour. The repair and maintenance costs for sprayers was calculated as 10 percent of the initial cost of the machine per year, and for 6.5 HP sprayer with petrol engine, the hourly fuel consumption was taken as 1.5 L per hour with total lubrication costs as 15 % of fuel costs. The actual labour cost per ha of an orchard ranged from INR 3500.0 (\$41.94) for traditional orchards to INR 5600.0 (\$67.11) for high density orchards, assuming a wage rate of INR 700 (\$8.39) per day. Total fixed and variable costs were added to determine the combined total cost per hour of operating the machine, and the total cost per hour was divided by the hourly work rate in ha to get the estimated cost of each spray treatment. The increase in cost of cultivation was calculated based on estimates provided by Kireeti et al. (2014); Naqash et al. (2019); Hassan et al. (2020); Wani et al. (2021a,b), and personal communication with the growers.

3.4. Estimation of additional cost of post-harvest cleaning of fruit

The cost of additional cleaning operations (wiping with dry or wet cloth/washing) of the harvested fruit was estimated as drop in the sorting and grading operations performance as compared to the performance achievable in the absence of infestation/blackening of the fruit by sooty mold.

The cost of sorting, grading and packing operation (the three steps happening in tandem) consists of labour, use of utilities and packaging material. Based on grower responses, the average cost of the sorting, grading and packing operation comes out as INR 6.5 (\$0.08) per Kg (INR 115 (\$1.38) per box, box of 18 Kg), and the share of labour cost comes out as 35 % of the total cost for these operations. Therefore, the cost of sorting, grading, and packing of the harvested fruit was taken as INR 1,95,000 (\$2336.80) for the harvest fruit of one ha in traditional orchards which includes INR 68,250 (\$817.88) as labour cost. For high density orchards, the respective figures were taken as INR 3,90,000 (\$4673.60) including INR 1,36,500 (\$1635.76) as labour cost. The estimate of increase in cost was calculated on 50 % of the yield with 20–40 % drop in performance of the labour alone owing to additional cleaning operations.

4. Results

A total of 275 growers participated in the survey (response rate 34.94 %, $n = 787$), from all 10 apple growing districts of the Kashmir valley of Jammu and Kashmir, India (Table 1). The participant-share was more or less proportionate to the percent production share of the respective apple growing districts.

Table 1
Participation of surveyed apple growers across districts of Jammu and Kashmir, India.

Sl. No.	District	Number of Tehsils	Number of villages	Participants		% Production share ^a
				Number	%	
1.	Anantnag	10	42	49	17.82	11.55
2.	Budgam	05	15	15	5.45	7.00
3.	Bandipora	03	06	06	2.18	2.75
4.	Baramulla	7	30	33	12.00	25.73
5.	Kulgam	06	32	41	14.91	11.64
6.	Kupwara	04	08	08	2.91	10.46
7.	Shopian	07	56	84	30.55	15.41
8.	Srinagar	01	02	02	0.73	1.09
9.	Ganderbal	03	06	07	2.55	4.71
10.	Pulwama	06	25	30	10.91	9.65
Total		52	222	275	100	100

^a Based on annual agricultural statistical figures published by the state government, see Ministry of Agriculture & Farmers’ Welfare (2018).

4.1. Orchard characteristics

The percent response share of the various orchard characteristics is indicated in Fig. 1. The average holding of most respondents was less than 0.5 ha (56.70 %, n = 156), with 32.0 % respondents having orchard of 0.5–1 ha and mere 11.3 % having >1 ha area under apple orchard. Based on the location of the orchards, majority of the orchards are located in the lowland area (40.7 %, n = 112) while as the remaining orchards are almost equally distributed in the upland areas (25.1 %, n = 69) and plain areas (29.5 %, n = 81). The most grown varieties are Red Delicious (31.08 %, n = 198), Royal Delicious (22.76 %, n = 145) and Golden Delicious (Delicious) (18.36 %, n = 117). In addition, numerous other varieties are also grown on smaller scale now (27.78 %, n = 177); these include American Apirouge, Shinico Gala Red, King Roat, Scarlet Spur, Gala Mast, Star Krimson, Gala Redlum, and Silver Spur. Majority of the orchards were in full bearing stage (68.0 %, n = 187).

Most of the respondents have traditional orchards (73.8 %, n = 203), while as 20.3 % have established orchards with medium density and 5.5 % have established high density plantations of apple. The open centre system of training is most adopted by the growers (36.0 %, n = 99) followed by modified central leader (24.4 %, n = 67) and central leader system (10.5 %, n = 29). The tall spindle system, commonly used in high- and medium-density orchards, was reported in 9.1 % of the responses. A sizeable number of respondents (20 %, n = 55) reported that the training system prevailing in their orchards does not conform to any one system of the training system. Irrigation canals dominate as the source of irrigation water (68.0 %, n = 187) followed by tube wells (6.2 %, n = 17). A sizeable number of orchards are rainfed (21.1 %, n = 58) with possibly one life saving irrigation through water tankers etc.

Results of Chi-square analysis results examining the association between orchard characteristics and the incidence/severity of GAA are given in Supplementary Table 2. A significant association was found between the number of years GAA was reported and the training system, with open centre systems showing longer infestation periods (χ^2 (8, N = 251) = 15.62, $p \leq 0.04$). Sooty mold incidence on fruits was linked to orchard size, location, growth stage, and planting density, with higher occurrence in medium/large holdings, upland sites, full-bearing orchards, and traditional plantings. The need for additional fruit cleaning due to mold was similarly associated with growth stage and planting density, and more prevalent in full-bearing, traditional orchards.

Greater cleaning needs were also reported for early-bearing and rainfed orchards (χ^2 values ranging from 5.57 to 15.88, $p \leq 0.01$ – 0.03). Lateral growth on terminal shoots correlated with training system (χ^2 (8, N = 275) = 21.05, $p \leq 0.001$), while GAA egg incidence was linked to orchard location and training system, with higher incidence in upland and structured orchards (χ^2 values up to 14.50, $p \leq 0.001$). Lastly, the blackish appearance of trees was significantly more common in upland orchards (χ^2 (2, N = 262) = 6.43, $p \leq 0.03$).

4.2. Scenario of *Aphis pomi* incidence and management

Most respondents reported that they noticed significant incidence of GAA for the previous one or more seasons (91.3 %, n = 251) (Fig. 2). All the major varieties grown by the respondents have been reported to be infested by GAA.

Majority of the growers reported the incidence of sooty mold on leaves (84 %, n = 231) and fruits (69.5 %, n = 191). In addition, 72.7 % (n = 200) reported that the general appearance of the trees turned blackish due to the sooty mold. 16.7 % (n = 46) respondents reported that more than 50 % of the foliage had sooty mold on it (Fig. 2). In case of harvested fruits, 69.8 % respondents reported that the fruit with sooty mold needed additional cleaning or washing treatment. 6.2 % (n = 17) reported that almost all the harvested fruit had sooty mold blackening and needed cleaning while 23.3 % (n = 64) reported that most of fruit needed cleaning treatments to get rid of sooty mold (Fig. 2). Regarding the induction of lateral growth of the terminal shoots induced by feeding and devitalization of apical bud by GAA, 78.9 % (n = 217) respondents observed at least some instances of the phenomenon in their orchards. Only one half of the respondents reported observing eggs of GAA on apple shoots in their orchards (50.5 %, n = 139).

Majority of the respondents sprayed the recommended delayed dormancy HMO in their orchards (76.0 %, n = 209) while 24 % (n = 66) respondents reported that they do not spray the recommended HMO at delayed dormancy stage. A wide array of responses was obtained about the timing of the incidence of GAA in apple orchards. Majority reported incidence from June onwards (45.1 %, n = 124). A small fraction reported incidence from July (13.8 %, n = 38) and August (5.8 %, n = 16) (Fig. 2).

About the number of insecticide sprays needed for the management of GAA during the last season, the growers provided varying responses

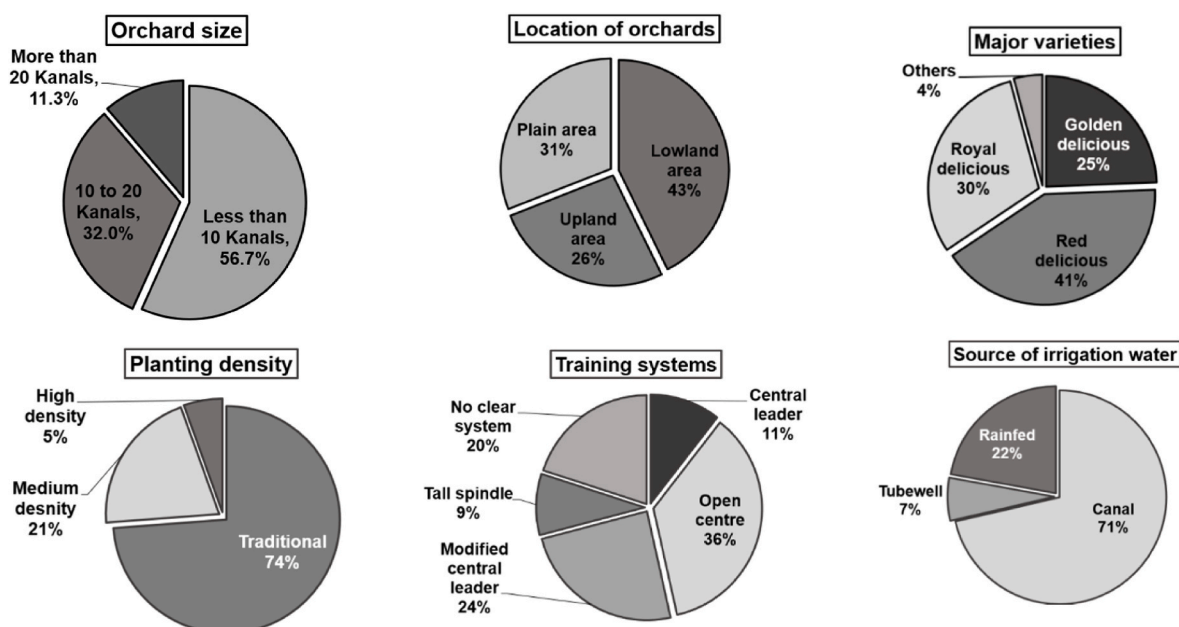


Fig. 1. Summary statistics of orchard characteristics.

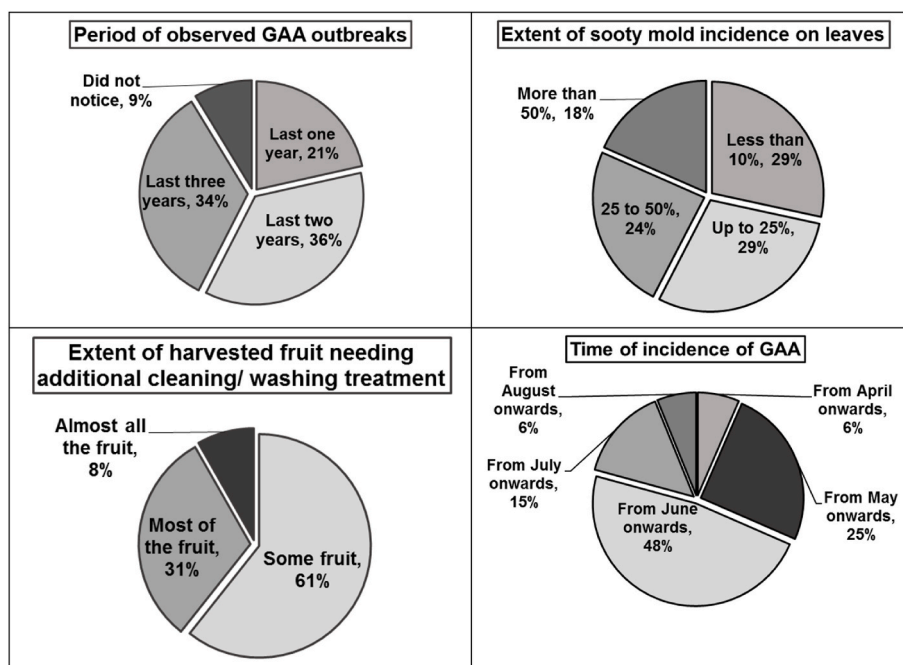


Fig. 2. Per cent response share regarding incidence and damage symptoms of *Aphis pomi*.

ranging from one to more than three additional sprays needed specifically for the management of GAA (94.9 %, n = 261). Majority of growers needed 2 additional sprays (46.5 %, n = 128) while as 21.1 % (n = 58) and 18.2 % (n = 50) needed one or three additional sprays, respectively. Some growers indicated that more than three additional sprays were needed for the effective management of GAA (9.1 %, n = 25) (Fig. 3). The list of commonly sprayed insecticides against GAA by

the growers is given in Fig. 3. During the main season, growers used various insecticides, including organophosphates, synthetic pyrethroids and neonicotinoids. The spray regimes included one or more sprays of the following insecticides or any combination thereof: chlorpyrifos 50 % + cypermethrin 5 % EC, thiacloprid 240 SC, chlorpyrifos 20 EC, thiamethoxam 25 WG, lambda cyhalothrin 9.5 % + thiamethoxam 12.6 % ZC, dimethoate 30 EC, imidacloprid 17.8 SL, and imidacloprid 6 % +

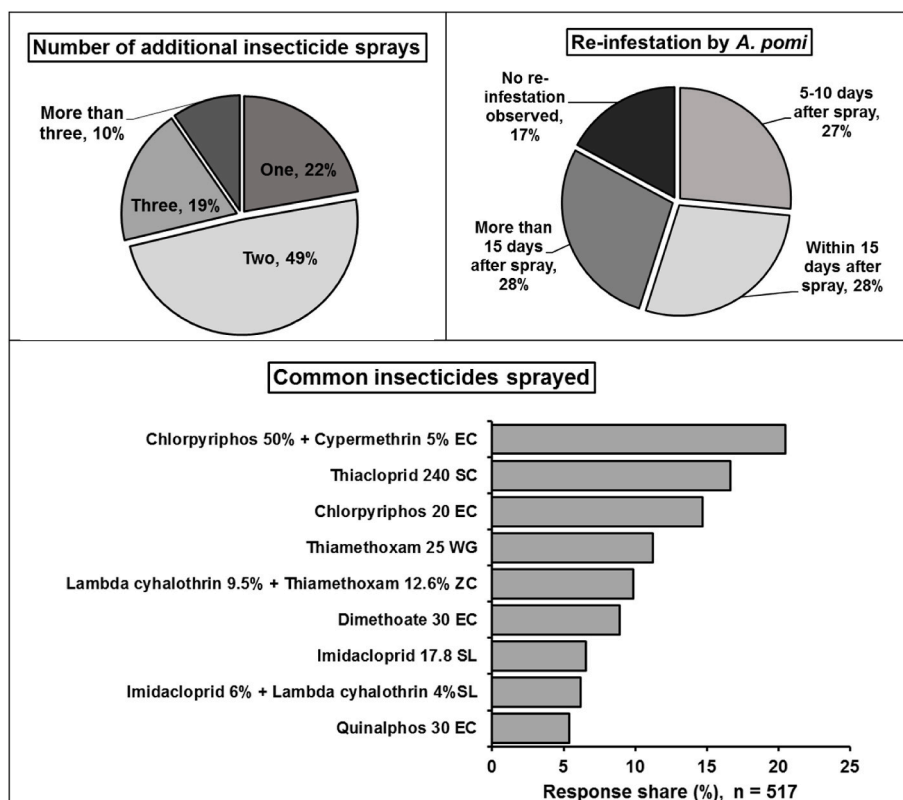


Fig. 3. Per cent response share regarding various management factors for *Aphis pomi*.

lambda cyhalothrin 4 % SL. The phenomenon of re-infestation of GAA after spray was commonly noted by the growers. In extreme case, re-infestation was noted by the growers within 5–10 days of spray (26.5 %, n = 73). In 56.4 % (n = 155) cases, re-infestation was noted within 15 days or more than 15 days after spray. In 17.1 % (n = 47) cases, no re-infestation was noted (Fig. 3).

4.3. Knowledge gaps

The respondents were asked to rate the importance of GAA incidence and its management as not important to very important. Most of the growers rated the GAA pest problem as very important (77.1 %, n = 212) while as 18.2 % (n = 50) rated the problem as somewhat important. When asked about what was most worrisome about the incidence of GAA, the top two reasons were about the failure of insecticides to control the aphid pest and lack of clear insecticide recommendations by the authorities. The knowledge gap about the pest biology and management emerged at number three. Among the possible reasons for high incidence of GAA in the recent years, majority of the growers believe that the outbreak situation was related to weather conditions (hot and dry) and weather conditions promoting luxuriant growth of apple plants. The other responses included excess use of nitrogenous fertilizers, new varieties of apple, imported planting material, intensive management of orchards and lack of proper spray of HMO. Only two respondents believed that the aphid has developed resistance to commonly used insecticides.

4.4. Association of pesticides sprayed with incidence and effective control of GAA

The delayed dormancy HMO spray was not significantly associated with the timing of incidence of GAA ($\chi^2_{(4, N=257)} = 7.92, p \leq 0.09$). The fact that delayed dormant HMO spray was applied or not did not affect the timing of the GAA incidence. Similarly, delayed dormant HMO spray was not significantly associated with number of insecticide sprays needed for the management of GAA during the main season ($\chi^2_{(3, N=258)} = 2.52, p \leq 0.47$).

In Table 2, we represent the results of Chi-square analysis undertaken for testing the association of type of insecticides sprayed with the

Table 2
Association of type of insecticides sprayed on the number of insecticide sprays and the re-infestation pattern of *Aphis pomi*^a.

i) Number of extra insecticide sprays						
Category of insecticides sprayed	One	Two	Three	More than three	Chi-square d. f., N)	p-value
A	7 10.82	35 37.43	12 14.01	20 11.70	57.51 (6, N = 253)	0.01
B	26 12.72	53 44.01	6 16.50	2 13.75		
C	4 13.45	40 46.54	60 17.45	18 14.54		
ii) Interval of re-infestation						
Category of insecticides sprayed	5–10 days after spray	15 days after spray	More than 15 days after spray	Chi-square (d. f., N)	p-value	
A	22 22.80	26 24.43	24 24.76	10.01 (4, N = 221)	0.04	
B	14 20.58	20 22.05	31 22.35			
C	34 26.60	29 28.50	21 28.88			

^a Contingency table of observed and expected frequencies. Significantly different categories are indicated in bold face.

number of insecticides sprayed, and the re-infestation pattern of GAA. The number of insecticide sprays needed for the management of GAA during main season was significantly associated with the type or category of insecticides sprayed ($\chi^2_{(6, N=253)} = 57.51, p \leq 0.01$). For “A” category of insecticide spray regimes, higher number of sprays was needed and for “B” category of insecticide spray regimes, lower number of sprays was needed. For “C” category of insecticide spray regimes, the observed frequency of “three” sprays is significantly higher than expected indicating that a higher number of sprays is needed if “C” group of insecticides is sprayed. Therefore, the results clearly indicate that higher number of sprays is needed if the insecticides belonging to organophosphates and/or synthetic pyrethroids are included in the spray regimes. The interval of re-infestation (recurrence) by GAA after last spray was significantly associated with the type or category of insecticides sprayed ($\chi^2_{(4, N=221)} = 10.01, p \leq 0.04$). For “B” category of insecticide spray regimes, the longest interval of re-infestation was recorded.

4.5. Estimated cost of spray treatments

The cost of one spray treatment was worked for full bearing traditional orchards (10–20 years age), and high density plantations (5 years age), with standard spray conditions. The lowest cost of one insecticide spray was estimated as INR 12,394.8 (\$148.53) per ha (2.58 % increase in cost of cultivation) and highest estimated cost per spray was INR 15,754.8 (\$188.80) per ha (3.28 % increase) in case of traditional orchards (Table 3). In case of high density orchards, the respective costs came out as INR 23,778.0 (\$284.95) per ha (3.80 % increase) as lowest and INR 29,028.0 (\$338.45) per ha (4.64 % increase) as highest (Table 3). As the average number of additional insecticide sprays was 2 (weighted mean of 2.16 based on response share), the estimated cost of spray treatments worked out as INR 24,790 (\$289.04) to 31,510 (\$367.39) per ha (5.08 %–6.56 % increase) for traditional orchards, and INR 47,556.0 (\$554.48) to 58,056.0 (\$676.90) per ha (7.61–9.29 % increase) in case of high density orchards. In occasional instances where more than 3 additional sprays were needed (say 4 sprays), the cost of insecticide treatments can go as high as INR 63,019.0 (\$734.77) per ha (13.13 % increase) in case of traditional orchards, and INR 1,16,112.0

Table 3
Estimate cost (INR/USD) of one insecticide spray per ha for traditional and high density apple orchards.

S. No.	Insecticides	IRAC ^a MoA Group	Traditional orchards (10–20 yrs)	High density orchards (2–5 yrs)
1.	Dimethoate 30 EC	Group 1 B (Organophosphate)	12394.8/ 144.52	23778.0/ 277.24
2.	Chlorpyrifos 20 EC	Group 1 B (Organophosphate)	13194.8/ 153.84	25028.0/ 291.81
3.	Quinalphos 25 EC	Group 1 B (Organophosphate)	14794.8/ 172.50	27528.0/ 320.96
4.	Thiacloprid 240 SC	Group 4 A (Neonicotinoid)	14500.4/ 169.07	27068.0/ 315.60
5.	Imidacloprid 17.8 SL	Group 4 A (Neonicotinoid)	13898.8/ 162.05	26128.0/ 304.64
6.	Thiamethoxam 25 WG	Group 4 A (Neonicotinoid)	12554.8/ 146.38	24028.0/ 280.15
7.	Chlorpyrifos 50 % Cypermethrin 5 % EC	Group 1 B + 3 A (Organophosphate + Pyrethroid)	15754.8/ 183.69	29028.0/ 338.45
8.	Thiamethoxam 12.6 % lambda cyhalothrin 9.5 % ZC	Group 4 A + 3 A (Organophosphate + Pyrethroid)	13322.8/ 155.34	25228.0/ 294.15
9.	Imidacloprid 6 % + lambda cyhalothrin 4 % SL	Group 4 A + 3 A (Organophosphate + Pyrethroid)	13354.8/ 155.71	25278.0/ 294.73

^a IRAC = Insecticide Resistance Action Committee.

(\$1353.81) per ha (18.58 % increase) in case of high density orchards.

The percent increase in cost of cultivation was calculated based on cost of cultivation of 1 ha of traditional orchard (10–20 years age, 400 plants per ha, average production of 30 tons) as INR 4,80,000.0 (\$5596.56) and for high density orchard (5 years age, 3333 plants per ha, average production of 60 tons) as INR 6,25,000.0 (\$7287.19) summarised from grower responses.

4.6. Estimated increase in cost of post-harvest operations

Based on survey response share, 48.71 % (weighted mean) of the harvested fruit needed additional cleaning. Based on the intensity of the sooty mold on fruits, the operational efficiency of the labour engaged in sorting, grading and packing decreased by 20–40 % (private communication with growers). The estimated cost assuming 20 % decrease in efficiency of sorting, grading and packing owing to additional cleaning of infested fruit (for 50 % of the total yield) came out as INR 2,03,531.25 (\$2373.07) and INR 2,17,750 (\$2538.86) assuming 40 % decrease in efficiency in case of traditional orchards. For high density plantations, the respective figures came out as INR 4,07,062.5 (\$4746.15) and INR 4,35,500.0 (\$5077.71), respectively. In both the orchard systems (traditional and high density), the cost of sorting, grading and packing operation increased by 4.37 % assuming 20 % decrease in operational efficacy, and 11.67 % in case of 40 % decrease in operational efficiency owing to incidence of sooty mold on harvested fruit (Fig. 4).

5. Discussion

We performed a survey in J&K, the major contributor of apple production in India to document the scenario of the incidence of green apple aphids in outbreak situation and its associated factors. We found that the high incidence of GAA was widespread in all apple growing districts, on all the major commercial varieties under cultivation including newly introduced varieties in the Gala group, for the last three or more seasons. The pest incidence is recorded in both traditional and high density orchards. The incidence of GAA is associated with its characteristic damage symptoms including sooty mold on leaves and fruits, and induction of lateral growth of terminal shoots.

As a rule, 2–3 additional insecticide sprays are needed for the management of GAA and occasionally more than three sprays are needed. The types of insecticides sprayed continue to be dominated by the old chemistry insecticides like dimethoate, chlorpyrifos, quinalphos and cypermethrin (alone or in combination). New chemistry insecticides like imidacloprid, thiamethoxam, thiacloprid, lambda cyhalothrin (alone or

in combination) are being adopted as well. The phenomenon of re-infestation by GAA quickly after last spray is a wide spread phenomenon. We found that the major reason for requirement of numerous sprays of insecticides is associated with potential failure of insecticides like organophosphates and synthetic pyrethroids to control the pest population pointing at possible development of insecticide resistance in the aphid populations. Preliminary bioassays suggest GAA populations exhibit resistance to organophosphates and synthetic pyrethroids (data not shown), potentially leading to control failures and increased sprays. Lowery et al. (2006) and Smirle et al. (2010) summarised the account of insecticides generally recommended in the North American region for the management of GAA. These include dimethoate, imidacloprid, and pirimicarb. The earlier used insecticides included endosulfan, carbaryl, and pyrethroids such as lambda-cyhalothrin (Smith et al., 2005). Currently recommended insecticides include acetamiprid, clothianidin, flonicamid, spirotetramat and thiamethoxam (Alston et al., 2010 from Utah State University Extension); dormant HMO, spirotetramat, acetamiprid, clothianidin and imidacloprid (Beers et al., 2015 for University of California IPM); and flonicamid, acetamiprid and spirotetramat (NIAB, 2024, for European region).

The severity of symptoms of damage by GAA is generally higher in case of traditional orchards, and orchards located in upland locations and rainfed. Similarly, higher severity of damage symptoms was noticed in medium and large size orchards. Comparatively higher severity was also noticed in orchards in early and full bearing stage. In general, the newly established high-density orchards tend to be more intensively managed as the cost of establishment and maintenance is much higher. Therefore, higher severity of incidence and damage symptoms is expected in the former cases. By the same logic, the orchards located in upland locations, which are mostly rainfed, also suffer more due to poor crop husbandry. The possibility of higher incidence in case of traditional orchards with standard tree type of training systems in comparison to the plants in high density orchards with new tall spindle type of training system is also to be expected as the former tend to retain a large quantum of vegetative growth (Awasthi and Mehta, 2005). In general, growers managing large farms are associated with lower additional costs due to pest incidence as large farms are negatively associated with such additional costs (Möhrling et al., 2020; Knapp et al., 2021). However, the reverse trend was noted in the current study possibly due to sample size effect or resolution of the data collected.

Horticultural mineral oils alone (Beers et al., 2015) or in combination with an insecticide (Alston et al., 2010) at delayed dormant stage are recommended with the belief that it will kill most of the eggs and hatching nymphs. However, the significant effect of the HMO spray

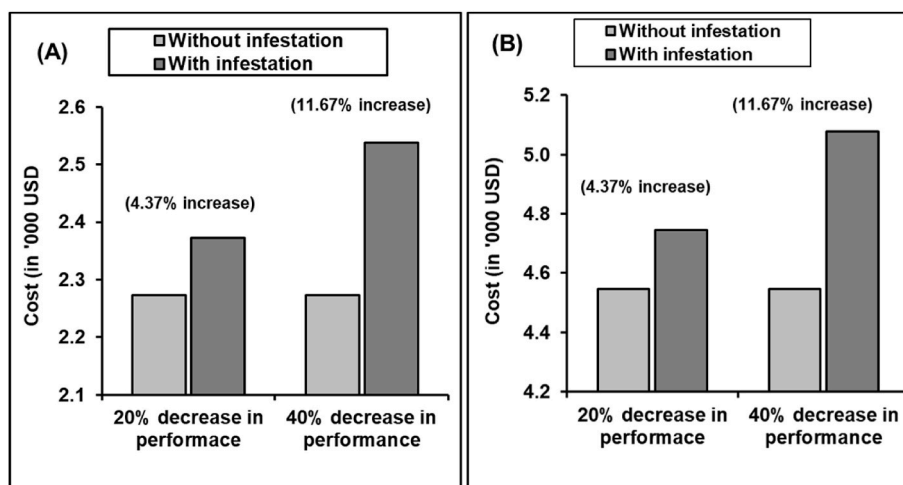


Fig. 4. Estimated increase in cost (USD) of post-harvest operations due to incidence of sooty mold on harvested fruit in case of A) traditional and B) high density apple orchards.

could not be detected in the current study possibly due to sample size effect or resolution of the data collected. The results clearly indicate that higher number of sprays is needed if the insecticides belonging to organophosphates and/or synthetic pyrethroids are included in the spray regimes, and these insecticides are responsible for control failures. There is high probability of development of insecticide resistance in GAA populations with wide distribution due to continuous exposure of the apple pests to these classes of insecticides over the last couple of decades. Numerous cases of insecticide resistance in GAA have been reported across multiple countries against organophosphates, carbamates and synthetic pyrethroids (Hogmire et al., 1990, 1992; Qin et al., 2002; Tamas et al., 2015; Erdogan et al., 2023). The cases of resistance reported are for the insecticides that have been applied over the years for the management of GAA and other pests of apple e.g., chlorpyrifos, diazinin, primicarb, parathion, beta-cyfluthrin etc (Erdogan et al., 2023; Mota-Sanchez and Wise, 2024). Other than the possible development of resistance, general decline in the number of natural enemies associated with the aphids could also contribute to the pest resurgence.

The additional cost associated with chemical control of the GAA incidence was estimated in the range of 2.58 %–3.28 % over the total production cost in case of traditional orchards for each additional spray, and in the range of 3.80 %–4.64 % increase in case of high density orchards. In cases requiring more than three additional sprays, costs increased by up to 13.13 % for traditional orchards and 18.58 % for high-density orchards. This is the first estimate of GAA-related production cost increases in Indian apple orchards. The production costs increase not only due to additional need of insecticidal sprays but also due to increased effort at post-harvest processing. Sorting, grading, and packing costs rose by 4.37 % with a 20 % efficiency drop and 11.67 % with a 40 % drop due to sooty mold on harvested fruit. Similar phenomenon is known in case of berries (strawberries and raspberries) infested by *Drosophila suzukii* Matsumura (Diptera: Drosophilidae), harvesting costs rise because additional effort is needed to identify and remove infested fruits (Ioriatti et al., 2012, as cited in Mazzi et al., 2017).

There are important caveats to cost estimation analyses; the spray schedule includes all sprays for the entire season and addresses multiple pests, not only GAA specifically. Although every care was taken to include only those insecticide sprays specifically targeted at managing GAA, the possibility of multiple target pests remains. Further, baseline calculations presented in the cost estimation are an upper bound estimated of the insecticide sprays needed as it assumes all acreage is affected. However, infestation over all acreage is almost never the case, despite widespread incidence of GAA. Further, the heterogeneity of extent of incidence from orchard to orchard and location to location cannot be incorporated in the current study. Revenue losses due to decreased yields, decrease in general vigour of the plants over seasons, and qualitative losses due to decrease in fruit quality (reduced fruit size and incidence of sooty molds resulting in down grading of the fruits to 'B' or 'C' class and consequent reduction in market price) and increased costs due to monitoring have not been included in this study.

Growers rated their lack of knowledge about pest biology and management as very important. Awareness of HMO's role in managing overwintering stages of GAA and other pests was limited. Indiscriminate insecticide spraying was also a significant issue. Over 50 % of growers reported not spotting GAA eggs on apple trees. Shah et al. (2017) found that 56 % of apple growers in Pulwama lacked knowledge of key plant protection measures, while Yousuf et al. (2024) reported that only 35 % of growers in Baramulla had proper knowledge of the recommended spray schedule, with few following it.

Conclusion: This is the first descriptive report on incidence and severity of *Aphis pomi* in major apple growing region of India based on growers' perception survey. We found that *A. pomi* has assumed the status of a major pest of apples across all apple growing regions. There are considerable knowledge gaps among the growers about the pest biology and its management. The costs associated with insecticide

sprays needed for the management of GAA have led to significant increase in the cost of cultivation of apples. Further, the cost of post-harvest processing of apples infested by sooty molds is also significant. Frequent pest control failures are associated with the commonly sprayed insecticides in the organophosphate and synthetic pyrethroids groups. Therefore, there is urgent need to switch over to new chemistry insecticides for the efficient control of GAA.

CRediT authorship contribution statement

Mohd Abas Shah: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Sheikh Aafreen Rehman:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Hafsa Ajaz Trambo:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Rifat Rasool:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Wasim Hassan Raja:** Writing – review & editing, Writing – original draft, Conceptualization. **Sajad Un Nabi:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Geetika Malik:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Javid Iqbal Mir:** Writing – review & editing, Writing – original draft, Conceptualization. **Om Chand Sharma:** Writing – review & editing, Writing – original draft, Visualization, Conceptualization. **Mahendra Kumar Verma:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Consent to participate

Not applicable.

The consent of participants in research

Not Applicable.

Ethics approval

Not Applicable.

Consent for publication

All authors give their consent for publication.

Code availability

Not applicable.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

No Generative AI and AI-assisted technologies were used in the writing process.

Funding

This work was funded by Department of Science Technology (DST), Government of India under Scheme for Young Scientists and Technologists SYST wide grant number SP/YO/2021/1644.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was funded by Department of Science and Technology (DST), Government of India under Scheme for Young Scientists and Technologists (SYST) vide grant number SP/YO/2021/1644. The authors would like to thank Dr. Aabid H. Lone, Dr. Mumtaz A. Ganie, Dr. Imtiyaz A. Lone, Dr. Shoaib N. Kirmani and numerous other scientists and extension workers for mobilising the growers to participate in the survey. And above all, we thank all the growers for sparing their time to participate in the survey.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cropro.2025.107328>.

References

- Akhtar, R., Kirk, W., 2024. Jammu and Kashmir. Encyclopedia Britannica (2024). <https://www.britannica.com/place/Jammu-and-Kashmir>. Accessed 24 December 2024.
- Alford, D., 2016. Pests of Fruit Crops: a Colorful Handbook, second ed. CRC Press, Boca Raton, FL.
- Alston, D., Reding, M., Murray, M., 2010. Apple Aphids - Utah Pests Factsheet. ENT-143-98. Published by Utah State University Extension and Utah Plant Pest Diagnostic Laboratory, 2010. <https://extension.usu.edu/planthealth/upddl/files/factsheet/aphids-apple.pdf>. (Accessed 24 December 2024).
- Ananda, S.A., Chandel, J.S., 2005. Rootstocks. In: Chadha, K.L., Awasthi, R.P. (Eds.), The Apple: Improvement, Production and Post-harvest Management. Malhotra Publishing House, New Delhi, pp. 137–154.
- Arbab, A., Kontodimas, D.C., Sahragard, A., 2006. Estimating development of *Aphis pomi* (DeGeer) (Homoptera: Aphididae) using linear and nonlinear models. *Environ. Entomol.* 35 (5), 1208–1215. <https://doi.org/10.1093/ee/35.5.1208>.
- Awasthi, R.P., Kamal, M.Y., 2005. History, challenges and future prospects. In: Chadha, K.L., Awasthi, R.P. (Eds.), The Apple: Improvement, Production and Post-harvest Management. Malhotra Publishing House, New Delhi, pp. 1–15.
- Awasthi, R.P., Mehta, K., 2005. Training and pruning. In: Chadha, K.L., Awasthi, R.P. (Eds.), The Apple: Improvement, Production and Post-harvest Management. Malhotra Publishing House, New Delhi, pp. 182–201.
- Beasley, T.M., Schumacker, R.E., 1995. Multiple regression approach to analyzing contingency tables: post hoc and planned comparison procedures. *J. Exp. Educ.* 64 (1), 79–93. <https://doi.org/10.1080/00220973.1995.9943797>.
- Beers, E.H., Hoyt, H.C., Willett, M.J., 2015. Apple Aphid and Spirea Aphid, UC IPM Pest Management Guidelines: Apple, 3432. UC ANR Publication. <https://treefruit.wsu.edu/crop-protection/opm/apple-aphid-and-spirea-aphid/>. (Accessed 24 December 2024).
- Behura, B.K., 1963. Aphids of India- survey of published information. Proceedings of the First Summer School on Recent Advances in Zoology, Held at Shimla, India, 1961. Govt. of India Publication, pp. 25–78.
- Bhagat, K.C., Masoodi, M.A., Koul, V.K., 1988. Some observations on the incidence of arthropod natural enemies of *Aphis pomi* de Geer (Homoptera: Aphididae) occurring in apple orchard ecosystem. *J. Aphidol.* 2, 80–89, 1, 2.
- Bhardwaj, S.P., Bhardwaj, S., 2005. Insect and mite pests. In: Chadha, K.L., Awasthi, R.P. (Eds.), The Apple: Improvement, Production and Post-harvest Management. Malhotra Publishing House, New Delhi, pp. 346–396.
- Blackman, R.L., Eastop, V.F., 2000. Aphids on the World's Crops-An Identification Guide, third ed. Wiley, Chichester. J.
- Brown, M.W., Welker, W.V., 1992. Development of phytophagous arthropod communities on apple as affected by orchard management. *Environ. Entomol.* 21, 458–492.
- Cutright, C.R., 1930. Additional notes on *Aphis pomi* deg. *J. Econ. Entomol.* 23, 738–741. <https://doi.org/10.1093/jee/23.4.738>.
- Directorate of Horticulture, 2015. Plant Protection Schedule for the Management of Insect Pests and Diseases of Apple- Session 2015, Issued by Directorate of Horticulture, Kashmir.
- Directorate of Horticulture, 2020. Plant protection advisory-2020. Plant Protection Schedule for the Management of Insect Pests and Diseases of Apple. Issued by Directorate of Horticulture, Kashmir.
- Directorate of Horticulture, 2024. Management Guide for Apple Orchards in Kashmir-2024. Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar, Srinagar. Issued through Directorate of Horticulture, Kashmir.
- Economic Survey, 2023. Economic Survey 2022-23, Jammu and Kashmir Government. Directorate of Economics and Statistics, Planning, Development and Monitoring Department, p. 327. J&K.
- Erdogan, C., Ozdem, A., Alpkent, Y.N., Demiroz, D., 2023. Resistance to common insecticides and mechanisms of resistance in *Aphis pomi* de Geer (Hemiptera: Aphididae), in apple orchards in Turkey. *Phytoparasitica* 51 (2), 323–335. <https://doi.org/10.1007/s12600-022-01042-x>.
- FAO, 2024. FAOSTAT database. In: Food and Agricultural Organization (FAO) of the United Nations. Rome, Italy (2024). <https://www.fao.org/faostat/en/#home>. (Accessed 18 December 2024).
- Hassan, B., Bhattacharjee, M., Wani, S., 2020. Economics of high-density apple orchards: a comparative analysis of Jammu and Kashmir, India and Trentino-Alto-Adige, Italy. *Global J. Hum. Soc. Sci.* 20 (9), 27–36.
- Hogmire, H.W., Brown, M.W., Crim, V.L., 1990. Toxicity of slide dip application of five insecticides to Apple aphid and spirea aphid (Homoptera: Aphididae). *J. Entomol. Sci.* 25 (1), 10–15. <https://doi.org/10.18474/0749-8004-25.1.10>.
- Hogmire, H.W., Brown, M.W., Schmitt, J.J., Winfield, T.M., 1992. Population development and insecticide susceptibility of Apple aphid and spirea aphid (Homoptera: Aphididae) on apple. *J. Entomol. Sci.* 27 (2), 113–119. <https://doi.org/10.18474/0749-8004-27.2.113>.
- IMD, 2014. Climate of Jammu and Kashmir, climatological summaries of states series - No. 20. Additional Director General of Meteorology (Research), India Meteorological Department, India. Shivajinagar, Pune 411 005.
- Ioriatti, C., Frontuto, A., Grassi, A., Anfora, G., Simoni, S., 2012. *Drosophila suzukii* (Matsumura), una nuova specie invasiva dannosa alle colture di piccoli frutti. *Atti dell'Accademia dei Georgofili* 2012 VIII, 69–80 (In Italian).
- Kashmir, DoH, 2021. Modified high density plantation scheme-An initiative for doubling farmers income. Govt. Jammu Kashmir, Dep. Horticulture, Kashmir 20p. <https://www.hortikashmir.gov.in/DATA/tenders/Government%20Order%20425%20JK%20APD%20%20dtd%2027%2012%202022%20merged.pdf>. (Accessed 24 December 2024).
- Kireeti, K., Guleria, C., Mukherjee, D.N., Sharma, L.R., 2014. A study of the cost of production of apples in Shimla district of Himachal Pradesh. *Prog. Res.* 9, 866–870.
- Knapp, L., Mazzi, D., Finger, R., 2021. The economic impact of *Drosophila suzukii*: perceived costs and revenue losses of Swiss cherry, plum and grape growers. *Pest Manag. Sci.* 77 (2), 978–1000. <https://doi.org/10.1002/ps.6110>.
- Lowery, D.T., Smirle, M.J., Footitt, R.G., Beers, E.H., 2006. Susceptibilities of Apple aphid and spirea aphid collected from apple in the Pacific Northwest to selected insecticides. *J. Econ. Entomol.* 99 (4), 1369–1374. <https://doi.org/10.1093/jee/99.4.1369>.
- Mazzi, D., Bravin, E., Meraner, M., Finger, R., Kuske, S., 2017. Economic impact of the introduction and establishment of *Drosophila suzukii* on sweet cherry production in Switzerland. *Insects* 8 (1), 18. <https://doi.org/10.3390/insects8010018>.
- Menon, M.G., Pawar, J.G., 1958. Taxonomic studies of Indian Aphididae I. Addition to the aphid fauna of Delhi. *Proc. 45th Ind. Sci. Cong. part 3*, 348.
- Ministry of Agriculture & Farmers' Welfare, 2018. Horticultural statistics at a glance-2018. Horticulture Statistics Division. Department of Agriculture, Cooperation & Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare, Government of India, New Delhi, p. 490.
- Möhrling, N., Wüpper, D., Musa, T., Finger, R., 2020. Why farmers deviate from recommended pesticide timing: the role of uncertainty and information. *Pest Manag. Sci.* 76, 2787–2798. <https://doi.org/10.1002/ps.5826>.
- Mota-Sanchez, D., Wise, J., 2024. The Arthropod Pesticide Resistance Database. Michigan State University, 2020. <http://www.pesticideresistance.org>. (Accessed 24 December 2024).
- Naqash, F., Wani, S.A., Mir, S.A., Wani, W.M., Baba, S.H., Malik, H.A., 2019. Economics of pesticide use in the apple producing areas of Kashmir valley. *Int. J. Adv. Res. Innov. Ideas Edu.* 5 (4), 68–80.
- NIAB, 2024. Green apple aphid (*Aphis pomi* DeGeer). National Institute of Agricultural Botany (NIAB), 93 Lawrence Weaver Road Cambridge CB3 0LE, UK (2024). <https://www.niab.com/green-apple-aphid-aphis-pomi-degeer>. Accessed 24 December 2024.
- Paulson, G.S., Hull, L.A., Biddinger, D.J., 2005. Effect of a plant growth regulator prohexadione-calcium on insect pests of apple and pear. *J. Econ. Entomol.* 98 (2), 423–431.
- Qin, X., Jiucui, H., Shanxi, T., 2002. Resistance monitoring of *Aphis pomi* DeGeer from Shanxi province to pyrethroids. *J. Shanxi Agric. Univ. (Soc. Sci. Ed.)* 22 (1), 39–41.
- R Core Team, 2023. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Rakauskas, R., Basilova, J., Bernotienė, R., 2015. *Aphis pomi* and *Aphis spiraeola* (Hemiptera: Sternorrhyncha: Aphididae) in Europe - new information on their distribution, molecular and morphological peculiarities. *Eur. J. Entomol.* 112, 270–280. <https://doi.org/10.14411/eje.2015.043>.
- Rishi, N.D., 1979. Additional records of aphid fauna (Homoptera: Aphididae) from Jammu and Kashmir (India). Symposium on Recent Trends in Aphidological Studies, Bhubaneswar. Abstract.
- Shah, Z.A., Matoo, J.M., Mir, R., Dar, M.A., Beigh, M.A., 2017. Knowledge level of recommended cultivation practices of apple growers in district Pulwama of J&K. *J. Pharmacogn. Phytochem.* 6 (5), 2472–2474.
- Skuast, K., 2018. Temperate fruits- package of practices (manual). Directorate of Extension, SKUAST-K, Shalimar 1, 123.
- Smirle, M.J., Zurowski, C.L., Lowery, T.D., Footitt, R.G., 2010. Relationship of insecticide tolerance to esterase enzyme activity in *Aphis pomi* and *Aphis spiraeola* (Hemiptera: Aphididae). *J. Econ. Entomol.* 103 (2), 74–378. <https://doi.org/10.1603/EC09275>.
- Smith, T.J., Dunley, J., Beers, E.H., Brunner, J.F., Grove, G.G., Xiao, C.L., Elfving, D., Peryea, F., Parker, R., Bush, M., et al., 2005. Crop Protection Guide for Tree Fruits in Washington. Ext. Bull. EB0419. Washington State University, Pullman, WA.

- Stoeckli, S., Mody, K., Dorn, S., 2008. *Aphis pomi* (Hemiptera: Aphididae) population development, shoot characteristics, and antibiosis resistance in different apple genotypes. *J. Econ. Entomol.* 101 (4), 341–348. <https://doi.org/10.1093/jee/101.4.1341>.
- Tamas, N., Dojnov, B., Margetic, A., Vujcic, M., Spirovic, B., Miletic, N., Stevic, M., Vujcic, Z., 2015. Resistance to common organophosphate and carbamate insecticides in *Aphis pomi* (Hemiptera: Aphididae). *Fruits* 70 (3), 135–142. <https://doi.org/10.1051/fruits/2015005>.
- Verma, H.S., Kumar, J., 2005. Varieties. In: Chadha, K.L., Awasthi, R.P. (Eds.), *The Apple: Improvement, Production and Post-harvest Management*. Malhotra Publishing House, New Delhi, pp. 61–82.
- Wani, M.H., Bhat, A., Baba, S.H., 2021a. Economic evaluation of high density apple (ex-ante) in Kashmir. *Int. J. Fruit Sci.* 21 (1), 706–711. <https://doi.org/10.1080/15538362.2021.1926393>.
- Wani, S.A., Kumar, S., Naqash, F., Shaheen, F.A., Wani, F.J., Rehman, H.U., 2021b. Potential of apple cultivation in doubling farmer's income through technological and market interventions: an empirical study in Jammu & Kashmir. *Indian J. Agric. Econ.* 76 (2), 278–291.
- Whitaker, P.M., Mahr, D.L., Clayton, M., 2006. Verification and extension of a sampling plan for apple aphid, *Aphis pomi* DeGeer (Hemiptera: Aphididae). *Environ. Entomol.* 35 (2), 488–496. <https://doi.org/10.1603/0046-225X-35.2.488>.
- Yousuf, D., Ali, L., Shah, Z.A., Bhat, S.H., War, W.A., Bhat, M.I., 2024. Knowledge assessment of farmers regarding pesticides and pesticide practices in insect-pest/disease management process of apple. *Int. J. Agric. Ext. Soc. Dev.* 7 (11), 78–83.