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Evaluation of the Susceptibility of Some Eggplant Cultivars to Green Peach Aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae)

Zienab Raeyat [1], Jabraiel Razmjou [1,*], Bahram Naseri [1], Asgar Ebadollahi [2] and Patcharin Krutmuang [3,4,*]

[1] Department of Plant Protection, Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Ardabil 5697194781, Iran; hastam.z26664@gmail.com (Z.R.); bnaseri@uma.ac.ir (B.N.)
[2] Department of Plant Sciences, Moghan College of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Ardabil 5697194781, Iran; ebadollahi@uma.ac.ir
[3] Department of Entomology and Plant Pathology, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand
[4] Innovative Agriculture Research Center, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand
* Correspondence: razmjou@uma.ac.ir (J.R.); patcharink26@gmail.com (P.K.)

Abstract: Due to the detrimental side-effects of synthetic pesticides, the use of nonchemical strategies in the management of insect pests is necessary. In the present study, the susceptibility of fourteen eggplant cultivars to green peach aphid (*M. persicae*) were investigated. According to preliminary screening tests, 'Long-Green', 'Ravaya' and 'Red-Round' as relatively resistant, and 'White-Casper' and 'Pearl-Round' as susceptible cultivars were recognized. In the antixenosis tests, the highest hosting preference was documented for 'White-Casper'. Population growth parameters were used for evaluation of antibiosis. The highest and lowest developmental time (d) was observed on 'Long-Green' (4.33 d) and 'White-Casper' (3.26 d), respectively. The highest and lowest intrinsic rates of population increase (r_m) were on 'White-Casper' (0.384 d^{-1}) and 'Long-Green' (0.265 d^{-1}), respectively. Significant differences were observed in the height and fresh and dry weight of infested and noninfected plants. Plant resistance index (PRI), as a simplified way to assess all resistance mechanisms, provides a particular value to determine the proper resistant cultivar. The greatest PRI value was observed on 'Long-Green'. In general, the 'Long-Green' showed the least, and the 'White-Casper' displayed the most susceptibility among tested cultivars infested by *M. persicae*, which might be useful in integrated management of this pest.

Keywords: antibiosis; antixenosis; tolerance; eggplant cultivars; green peach aphid

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1. Introduction

Green peach aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), is one of the most damaging insect pests throughout the world, with more than 800 host plant species [1]. Its feeding on the sap leads to chlorosis and necrosis spots, honeydew production, and a dramatic reduction in the marketability of crops [2]. Along with direct losses due to nutritional activities, *M. persicae* can indirectly impair the host plants by the transmission of pathogenic viruses as an efficient vector [3,4]. As a holocyclic species, *M. persicae* can produce both the sexual population with the ability of genetic adaptation against environmental pressures and asexual generations to create large populations [5]. These characteristics have made *M. persicae* a very harmful pest on a wide range of crops, orchards, and greenhouses [6].

Although the chemical control is the main method in the management of aphids, overuse of synthetic insecticides has led to various side effects, including insecticide resistance, the outbreak of secondary pests, negative effects on beneficial organisms, and dangerous residues on foods [7–9]. Therefore, the application of chemical insecticides must be replaced by eco-friendly and efficient methods, such as resistant host plants [10].

The use of resistant plants, as one of the most prominent pest management tools, is an effective way to reduce the utilization of chemical pesticides [11,12]. Due to differences in food quality, morphological characteristics, and other host-dependent factors, the performance of aphids may change on plant cultivars (CVS) [13–15]. In general, the plant resistance is classified into three categories, including tolerance, antibiosis, and antixenosis. Tolerance is defined as the ability of a plant to diminish or to recover from herbivore damage. Tolerance mechanisms may be associated with increases in photosynthesis, compensatory growth, and utilization of stored materials [16,17]. For instance, in the study of Nampeera et al. [2], the production of large leaves and/or the repair of leaves of *Amaranthus* sp. were considered as tolerance mechanism evidence against *M. persicae* damage. Antixenosis, as an insect-preferred reaction, is the genetic resistance of a plant. Antixenosis represents specific morphological and chemical characteristics of the host plant that adversely affect the behavior of the insect, and lead to the selection of another host by the pest [18–20]. Antibiosis resistance is formed in plants based on biological traits of insects, such as survival, longevity, and fertility. It pronounces the inefficiency of a plant as a host, leading to select another host plant by the pests [21]. The importance of host plant resistance in integrated pest management strategies has led many researchers to study its categories in different crops for various insect pests, including aphids [22–24]. For example, resistance of seven cabbage CVS and six potato CVS against *M. persicae* was documented [25,26].

Eggplant, *Solanum melongena* L. (Solanaceae), with great morphological and genetic diversity is renowned as an economically important vegetable crop, especially in Asia and the Mediterranean regions [27]. After potato and tomato, eggplant is the third-largest crop of the Solanaceae family [28]. In terms of nutritional value, eggplant is one of the valuable vegetables for human health due to its high content of vitamins, minerals, and biologically active compounds [29–31]. Due to the economic importance of eggplant and detrimental side effects caused by the use of synthetic insecticides, it is necessary to introduce its resistant CVS against pests. Therefore, the main objective of the present study was a) to identify possible resistance and susceptibility of eggplant cultivars and b) to determine the type of possible resistance categories, including antixenosis, antibiosis, and tolerance, against *Myzus persicae*. Hence, the results of the present study may provide useful information for the integrated management of *M. persicae* on eggplant.

2. Materials and Methods

2.1. Collecting and Breeding Aphid Colonies

About two-hundred apterous female adults of aphids were collected from the research greenhouse of the Faculty of Agriculture and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran. After collection, apterous female adults of aphids were transferred to the four-leaf stage of the pepper (*Capsicum annum* L.: 'California wonder' cultivar (CV.)). Aphids was reared for three generations on all fourteen CVS of eggplant and pots were kept in the greenhouse at 25 ± 5 °C, 60 ± 10% Relative Humidity (RH), and a natural photoperiod.

2.2. Cultivation of Eggplant Cultivars

Seeds of 14 eggplant cultivars, including 'Bianca-Tonda', 'Black-Beauty', 'Calliope', 'Florida-Market', 'Long-Green', 'Green-Oblong', 'Pearl-Round', 'Purple-Violetta', 'Purple-Panter', 'Ravaya', 'Red-Round', 'Rosa-Bianca', 'White-Casper' and 'White-Eggplant' were obtained from Johnny's seeds, (Larosa, Reimerseeds Company, Maryland, USA). Before planting, the seeds were soaked for 12 h in the paper towel. The seeds were then planted in the cultivated tray with coco peat and perlite in equal proportions as a growing medium. When seedlings reached the two-leaf stage, they were transferred to plastic pots (20 cm diameter and 14 cm height) with a mixture of soil, sand, and manure (1:1:2). The pots were kept in the greenhouse at 25 ± 5 °C, 60 ± 10% RH, and a natural photoperiod.

2.3. Screening Test

Fourteen eggplant CVS were cultivated in four replications in plastic pots (20 cm diameter and 14 cm height) wrapped with 50 mesh cloth to prevent the escape the aphids and contamination with other pests. After germination of seeds, only one seedling was kept in each pot, and the others were removed. Each plant in the five to six leaf growth stage was infested with four aphids and the number of aphids on each plant was recorded after 14 days. Finally, two CVS with the highest ('Pearl-Round' and 'White-Casper') and three CVS with the lowest ('Long-Green', 'Ravaya' and 'Red-Round') mean number of aphids were selected for antixenosis, antibiosis, and tolerance experiments.

2.4. Antixenosis Test

Three eggplant CVS, including 'Long-Green', 'Ravaya' and 'Red-Round' as relatively resistant, and two relatively susceptible CVS, including 'White-Casper' and 'Pearl-Round', were selected for the antixenosis experiment based on the screening test results. Antixenosis test or host preference experiment was performed based on Webster's method [32]. Same height eggplants in the four-leaf stage were randomly selected and arranged in a circle. A circular paper was adjusted to fit the pot and located in its middle so that each plant was out of the paper from the stem. Then, 50 aphids were placed in the center of the paper, and the number of aphids on each CV. was counted after 24, 48, and 72 h. The experiment was conducted in a completely randomized design with five replications for each cultivar in the growth chamber at 25 ± 5 °C, 60 ± 10% RH, and 16: 8 Light: Dark (L:D) photoperiod. Therefore, in total we used 25 plants in the experiments.

2.5. Antibiosis Test

Female adults of aphids were randomly selected from the colony and placed on the leaves of above mentioned CVS. Each aphid was placed inside the leaf cage (5 cm diameter and 1 cm height) to prevent escape or injury by other insects. After 24 h, the adult aphids and all nymphs were removed from the leaf cage, excluding a first-instar nymph. These nymphs were monitored daily to evaluate the survival and developmental time on each CV. After determining developmental time (d), the number of nymphs produced by each female adult was daily recorded and removed from the plant. This experiment performed with 30 aphids for each cultivar in a growth chamber at 25 ± 2 °C, 60 ± 5% RH, and 16:8 (L:D) photoperiod. In total, 150 aphids were used in the experiment. This experiment continued as long as developmental time (d), and mortality was also recorded during this period [23]. The intrinsic rate of population increase (r_m) for aphids in different CVS were calculated using the following Equation (1) [33]:

$$\mathrm{rm} = 0.738\frac{\ln \mathrm{Md}}{\mathrm{d}} \quad (1)$$

In the formula, d is the developmental time (from the nymph' first-stage to the beginning of adult reproduction), M_d is nymphs produced per female during the period equal with d, and 0.738 is the correction factor.

2.6. Tolerance Test

The eggplant CVS studied in the antixenosis and antibiosis tests were also used for the tolerance test. The seeds were planted in a cultivated tray again, and after germination in the two-leaf stage, the seedlings were transferred to plastic pots (20 cm diameter and 14 cm height). When the seedlings reached the four-leaf stage, 10 female adults were positioned on each CV. surrounded with 50 mesh cloths to prevent the entrance of other pests. The nymphs produced on each plant were removed every 24 h. When the number of female adults of aphids was decreased, more aphids were added so their number reached ten again. The experiment was performed with six replications for each cultivar along with the control groups without aphids' contamination. The experiment lasted 14 days under the same conditions [32]. To calculate the dry weight, the seedlings were dried in an oven at 60 °C for three days. The plant height from the soil surface and fresh and dry weight of each CV. were measured according to the following Formulas (2)–(4) [34].

$$\text{Reduction in the height of the infested plant (\%)} = \text{the height of the control plant} - \text{height of the infested plant/height of the control plant} \times 100 \quad (2)$$

$$\text{Reduction in the fresh weight of the infested plant (\%)} = \text{fresh weight of the control plant} - \text{the fresh weight of the infested plant/fresh weight of the control plant} \times 100 \quad (3)$$

$$\text{Reduction in the dry weight of the infested plant (\%)} = \text{dry weight of the control plant} - \text{the dry weight of the infested plant/dry weight of the control plant} \times 100 \quad (4)$$

2.7. Resistance Index Calculation

A plant resistance index (PRI) was used to compare different tested eggplant CVS [35]. The PRI for each CV. was calculated by dividing the value of any categories (antixenosis, antibiosis, and tolerance) by its highest mean in all studied CVS at a replication. The number one represents the lowest value for the considered mechanism in a CV. The mean number of aphids attracted within 5 days for antixenosis (X), the mean intrinsic rate of population increase (r_m) of aphids on each CV. for antibiosis (Y), and the reduction rate in each CV. compared to the control groups for tolerance mechanism (Z) were calculated. Therefore, normalized indices for X, Y, and Z values were used to estimate PRI in the following Formula (5):

$$\text{PRI} = 1/\text{XYZ} \quad (5)$$

2.8. Statistical Analysis

All obtained data from above-mentioned tests were analyzed using one-way ANOVA by Minitab 18 software (Minitab Inc. 1994, Philadelphia, PA, USA), and the comparison of means was performed using Tukey's test at $p < 0.05$.

3. Results

3.1. Screening Test

Significant differences were observed for the number of adult aphids grown on the 14 eggplant CVS examined (F (Fisher: F-distribution) = 3.22; df (degrees of freedom) = 13, 34; $p < 0.05$). The order of eggplant CVS, based on the number of grown aphids, was 'White-Casper', 'Pearl-Round', 'Florida-Market', 'Purple-Violetta', 'Rosa-Bianca', 'Black-Beauty', 'Bianca-Tonda', 'Calliope', 'Purple-Panter', 'White-Eggplant', 'Green-Oblong', 'Ravaya', 'Red-Round' and 'Long-Green' CVS, respectively (Table 1).

Table 1. Mean number (±Standard Error (SE)) of *Myzus persicae* on fourteen eggplant cultivars for screening the test in the greenhouse conditions.

Eggplant Cultivars	Adult Aphids
'White-Casper'	1006 ± 25.90 [a]
'Pearl-Round'	987 ± 17.77 [a]
'Florida-Market'	855 ± 71.54 [a,b]
'Purple-Violetta'	788.3 ± 11.60 [b]
'Rosa-Bianca'	746.7 ± 8.42 [b]
'Black-Beauty'	741 ± 20.19 [b]
'Bianca-Tonda'	460 ± 13.60 [b]

Table 1. *Cont.*

Eggplant Cultivars	Adult Aphids
'Calliope'	404.5 ± 9.69 [b]
'Purple-Panter'	404 ± 15.87 [b]
'White-Eggplant'	357 ± 20.42 [c,b]
'Green-Oblong'	320.5 ± 11.66 [c,b]
'Ravaya'	299 ± 10.73 [c,b]
'Red-Round'	283.5 ± 10.60 [c,b]
'Long-Green'	138.3 ± 30.42 [c]

Different letters in column indicate significant differences between eggplant cultivars (Tukey's test, $p < 0.05$).

3.2. Antixenosis Test

Antixenosis data analysis revealed that the number of aphids was significantly affected by tested eggplant CVS within 24, 48, and 72 h ($F = 1.21$; $df = 4, 20$; $p < 0.05$), ($F = 4.78$; $df = 4, 20$; $p < 0.05$), ($F = 6.21$; $df = 4, 20$; $p < 0.05$). After 72 h, the highest number of aphids was recorded on CV. 'White-Casper', while the lowest was on CVS 'Long-Green' and 'Ravaya' (Table 2).

Table 2. Mean number (± SE) of *Myzus persicae* on five eggplant cultivars for antixenosis test after 24, 48, and 72 h.

Eggplant Cultivars	Aphid Numbers after 24 h	Aphid Numbersafter 48 h	Aphid Numbers after 72 h
'Ravaya'	8.00 ± 2.58 [a]	4.60 ± 1.02 [b]	3.40 ± 0.60 [b]
'Long-Green'	6.20 ± 2.26 [a]	1.80 ± 0.79 [b]	1.00 ± 0.59 [b]
'White-Casper'	11.40 ± 1.12 [a]	22.20 ± 6.44 [a]	30.60 ± 2.03 [a]
'Pearl-Round'	9.60 ± 1.28 [a]	13.80 ± 4.46 [a,b]	17.00 ± 1.38 [a,b]
'Red-Round'	10.80 ± 1.95 [a]	14.20 ± 2.65 [a,b]	17.20 ± 1.16 [a,b]

Different letters in each column indicate a significant difference between eggplant cultivars (Tukey's test, $p < 0.05$).

3.3. Antibiosis Test

The intrinsic rate of *M. persicae* population increase (r_m) values were affected by eggplant CVS ($F = 11.07$, $df = 4,140$, $p < 0.05$). The highest r_m value was observed on CV. 'White-Casper' (0.384 d^{-1}), while the lowest value was on CV. 'Long-Green' (0.265 d^{-1}) (Table 3).

Table 3. Mean (± SE) of intrinsic rate of population increase (r_m) and developmental time (d) of *Myzus persicae* on five eggplant cultivars in the greenhouse conditions.

Eggplant Cultivars	r_m (d^{-1})	d (d)
'Ravaya'	0.3060 ± 0.09 [b,c]	3.92 ± 0.94 [a,b]
'Long-Green'	0.2650 ± 0.07 [c]	4.33 ± 0.78 [a]
'White-Casper'	0.3836 ± 0.06 [a]	3.26 ± 0.44 [c]
'Pearl-Round'	0.3593 ± 0.05 [a,b]	3.56 ± 0.77b [c]
'Red-Round'	0.3413 ± 0.07 [a,b]	3.50 ± 0.77b [c]

Different letters in each column indicate a significant difference between eggplant cultivars (Tukey's test, $p < 0.05$).

The cultivars also significantly changed the developmental time (d) of the aphid ($F = 8.54$; $df = 4, 140$; $p < 0.05$). The lowest and highest amount of developmental time were observed on CVS 'White-Casper' (3.26 d) and 'Long-Green' (4.33 d), respectively (Table 3).

3.4. Tolerance Test

M. persicae had significant effects on the decreases in plant height (F = 7.92; df = 4, 20; $p < 0.05$), the fresh weight (F = 3.42; df = 4, 20; $p < 0.05$), and the dry weight (F = 6.52, df = 4, 20; $p < 0.05$) of the aphid-infested CVS examined. The largest reduction percentages in the height and dry weight occurred on CVS 'White-Casper' and 'Pearl-Round', while the lowest reduction percentages for both parameters were seen on CV. 'Long-Green'. Meanwhile, the highest and the lowest reduction percentages were observed on CVS 'White-Casper' and 'Long-Green', respectively (Table 4).

Table 4. Mean (± SE) reduction percentage of the growth parameters of five eggplant cultivars against *Myzus persicae* in the greenhouse conditions.

Eggplant Cultivars	Height Reduction (%)	Weight Loss (%)	Dry Weight Loss (%)
'Ravaya'	17.26 ± 6.59 ^{b,c}	31.74 ± 6.76 ^{a,b}	34.33 ± 5.08 ^{a,b}
'Long-Green'	12.00 ± 2.28 ^{c}	22.19 ± 6.89 ^{b}	7.48 ± 4.65 ^{b}
'White-Casper'	39.76 ± 3.29 ^{a}	61.61 ± 8.17 ^{a}	57.51 ± 3.77 ^{a}
'Red Round'	32.74 ± 3.77 ^{a,b}	32.27 ± 9.01 ^{a,b}	37.40 ± 11.89 ^{a,b}
'Pearl-Round'	37.57 ± 4.84 ^{a}	41.59 ± 9.20 ^{a,b}	29.74 ± 6.50 ^{a}

Different letters in each column indicate a significant difference between eggplant cultivars (Tukey's test, $p < 0.05$).

3.5. Plant Resistance Index (PRI)

The plant resistance index (PRI) of tested eggplant CVS against aphids are shown in Table 5. The greatest PRI value was observed on cv. 'Long-Green' (7.75), followed by 'Ravaya' (3.32). On the contrary, 'White-Casper' was highlighted with the lowest PRI value (1.00) (Table 5).

Table 5. Plant Resistance Indices (PRI) related to five eggplant cultivars infested by *Myzus persicae*.

Eggplant Cultivars	Antixenosis Index (X)	Antibiosis Index (Y)	Tolerance Index (Z)	XYZ	PRI
'White-Casper'	1.00	1.00	1.00	1.00	1.00
'Pearl-Round'	1.00	0.89	1.00	0.89	1.12
'Red-Round'	1.00	0.92	0.86	0.791	1.26
'Ravaya'	0.42	0.78	0.92	0.301	3.32
'Long-Green'	0.19	0.68	1.00	0.129	7.75

4. Discussion

The quantity and type of the resistance of common eggplant CVS with three resistance categories, including antixenosis, antibiosis, and tolerance, were investigated to *Myzus persicae* in the present study. Experiments originated with fourteen eggplant CVS in the screening test to arrange resistant categories. Screening tests save time and increase the accuracy in the main experiments. Based on the obtained results from the screening test, three relatively resistant ('Long-Green', 'Ravaya' and 'Red-Round') and two susceptible CVS ('White-Casper' and 'Pearl-Round') were selected. Singh et al. [36] found that seven eggplant CVS had diverse resistance and susceptibility to *Tetranychus urticae* (Koch). Also, according to the screening tests, 23 CVS of eggplant were classified into four resistant, relatively resistant, relatively susceptible, and susceptible groups against *Leucinodes orbonalis* Guenee [37].

Our results also showed, in general, there was a significant difference in the performance of *M. persicae* among the five tested eggplant CVS. Based on our findings from the screening test, 'Long-Green' was the most resistant cv. to the *M. persicae*, which was confirmed in all antixenosis, antibiosis, and tolerance experiments. Although there was not significant difference in the antixenosis test between tested CVS after 24 h, *M. persicae* preferred CV. 'White-Casper' and had less host preference over 'Long-Green' and 'Ravaya' CVS after 24 and 48 h. The host preference of *M. persicae*, like other insect pests, varies according to different plant species [38]. The antixenosis resistance of eight potato [38] and seven cabbage CVS [39] were reported to *M. persicae*. Ahmed et al. [39] declared that chemical and olfactory compounds of CVS caused the attraction of aphids to the preferred hosts. Therefore, differences in host preference of insect pests for the plant species CVS could be due to variations in their chemical and morphological parameters. Although our experiments did not investigate the mechanisms of antixenosis and antibiosis, these compounds may be the main factors in susceptible eggplant CVS for attracting *M. persicae*.

The antibiosis resistance of eggplant CVS, measured as significant effects on the growth, survival, and reproduction of *M. persicae*, was also obtained in the present study. It was used to assess variations in the resistance of different CVS of a plant and to predict the population of pests [40–42]. In the present study, the developmental time (d) of *M. persicae* on the cv. 'Long-Green' with a mean of 4.33 d was significantly longer than other CVS. Furthermore, the highest and lowest intrinsic rates of population increase (r_m) were seen on the most susceptible CV. 'White-Casper' (0.383 d^{-1} for) and the most resistant CV. 'Long-Green' (0.265 d^{-1}), respectively. In the study of Ahmed et al. [25], the intrinsic rate of population increase (r_m) and the developmental time (d) of *M. persicae* had a significant difference for seven cabbage CVS. Along with antixenosis resistance, the significantly different r_m value of *M. persicae* was also documented on six commonly produced potato cultivars by Mottaghinia et al. [43]. In general, the quality of the host plant can be the main reason to prefer different CVS by aphids and an important factor in the antibiosis resistance [44,45].

In the evaluation of the tolerance category, tested eggplant CVS showed significantly different reactions, based on plant growth parameters containing height and fresh and dry weight, after twenty-one days of infestation by *M. persicae*. Some of them, such as 'Long-Green', indicated significant tolerance, whereas some others, such as 'White-Casper', had less ability to compensate for aphid damage. During the genetic-based phenomena tolerance, plants can continue to grow despite the presence of a specific population and damage of the pest [12,21]. The tolerance existed in some eggplant CVS based on significant differences in their growth parameters. The eggplant tolerance was also investigated by Khan and Singh [46], in which 38 genotypes from 192 tested genotypes were tolerant against *L. orbonalis.*

In the present study, significant differences were supposed between resistant mechanisms of fourteen eggplant CVS against *M. persicae*. According to our observations, CV. 'Long-Green', which presented high resistance against *M. persicae*, had a smaller leaf area than others. Several morphological traits, including plant surface trichrome or epidermal tissue stiffness, may influence host acceptance by aphids [47]. For example, morphological characteristics of eight eggplant CVS had significant effects on the preference of silver whitefly, *Bemisia tabaci* (Gennadius) [48]. Therefore, such characteristics may be the reason why *M. persicae* did not prefer CV. 'Long-Green'.

5. Conclusions

According to the plant resistance index (PRI), eggplant CV. 'White-Casper' with lowest PRI value (1.00) had higher susceptibility to *M. persicae* than the other tested CVS. The 'Red-Round' and 'Pearl-Round' CVS with PRI values of 1.12 and 1.26, respectively, were also more susceptible than 'Ravaya', which is an early maturing, high yielding, and popular variety for the fresh export market [49], with a PRI value of 3.32. Finally, the 'Long-Green', with the highest PRI value compared to other CVS (7.75), can be introduced as the most resistant CV. for application in integrated management of *M. persicae*. In general, the green eggplant CVS that are early maturing, with high tolerance to bacterial wilt and attractive fruit shape and color had high consumer preference [50]. However, these CVS should be tested in the field conditions to determine the yield of the infested plant in natural conditions. Furthermore, it is necessary to conduct additional research on the mechanisms of resistance or susceptibility of the CVS.

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