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RELATIONSHIP OF THE ROSE VARIETIES INFESTATION LEVEL BY SPIDER MITE WITH THE BUSH STRUCTURAL ELEMENTS UNDER THE *Phytoseiulus persimilis* APPLICATION IN GREENHOUSES

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Abstract

Varieties of roses grown for cutting differ in the degree of costs for protection against pests, primarily from the two-spotted spider mite *Tetranychus urticae* Koch. To control this pest, from 6-8 to 25 or more treatments with acaricides are required. The predatory mite phytoseiulus *Phytoseiulus persimilis* A.-H. can be used as an alternative or addition to chemical treatments. Here, we report on a long-term monitoring of the spider mite abundance in commercial rose greenhouses. The observation allows us, for the first time, to assess a relationship between two *Rosa hybrida* variety-specific morphometric parameters, the area of a compound leaf segment and the total leaf area per bush, and an abundance of the spider mite in a triotrophic system, i.e., rose plant—spider mite—predatory mite. From this data, we obtained the equations to predict the development of the pest and determined the predatory mite number effective on a certain variety. This work aimed i) to assess the two-spotted spider mite infestation in a set of rose varieties, ii) to establish the relationship of the spider mite infestation level with the bush structure elements, and iii) to choose mathematical models for prediction of the pest infestation levels and the number of the predatory mite phytoseiulus necessary to use for the control of the pest. Observations on the two-spotted spider mite development were carried out in a block glass greenhouse of ZAO Agroleader (Vyborgsky District, Leningrad Province) on rose plants (*Rosa* sp., hybrid tea group) of 18 varieties. The area of the greenhouse was 45,000 m^2. A scoring system was used to assess the infestation levels of roses by spider mites. The greenhouse was divided into plots. Each plot was a 3.95 m long (8.02 m^2 in area) segment of a double row of rose bushes. The survey consisted of a visual inspection of plants and assignment of the infestation level score from 1 to 5. Surveys were carried out twice a month, the total number of counts per year was at least 24. The dynamics of rose plant infestation by spider mites was assessed over 8 years (2011-2018). Since 2011, on particular varieties, and since 2012, on the entire area of the rose greenhouse, the predatory mite *Ph. persimilis*, introduced continuously or into the infestation foci, was used to control the two-spotted spider mite. Continuous application from 3 to 10 individuals/m^2 over the entire area of the greenhouse was carried out 1-1.5 times a month; from 10 to 60 individuals per bush were introduced into foci weekly until new significant foci of the pest continued to appear. Acaricides were used only in cases where the *T. urticae* infestation level exceeded 2.5 points. Seven days after the first treatment the second treatment was carried out. We determined the number of stems in the upper part of the bush (crown) and on the whole bush, the productive stem length, the number of lobes of the complicated leaf, the number of leaves on the entire stem and on 10 centimeters of the stem, the number of leaves in the bush crown and on the entire bush, the surface areas of the lobule and the entire leaf, the area of the leaves surface in the crown and in the entire bush. Correlation analysis was used to assess the relationship between the occupancy of individual varieties of roses and the structural elements of their bushes, and regression analysis was used to describe it mathematically (rectilinear regression equations). To establish the relationship between the parameters of individual elements of the structure of rose bushes and the infestation level of spider mites, a two-factor ANOVA was used. When comparing the parameters of regression models built from sample data, the least squares method was used. In the most contrasting varieties Brazil and Aqua, the average long-term level of infection differed by 17.8 times. The remaining varieties could be divided into 6-8 groups, of which the most contrasting ones differed by 5.0 times. The rose varieties differed significantly in the average values of individual elements of the bushes structure. These were the number of stems per crown and per entire bush; the number of lobules of the compound leaf; the number of leaves per entire stem and per 10 cm of the stem; the number of leaves per crown and per entire bush; the productive stem length; the areas of the leaf lobule and the entire leaf; the leaf surface per bush and per its crown. Of the 12 indicators of the rose bush structure, a significant relationship with the infestation level of varieties by spider mites in the presence of phytoseiulus was found only for four indicators. These were the number of lobules in a compound leaf ($r = 0.49 \pm 0.218$, $0.95 < P < 0.99$), the area of the leaf lobule ($r = -0.52 \pm 0.214$, $0.95 < P < 0.99$), the leaf area of the bush crown ($r = -0.70 \pm 0.179$, $P > 0.998$), the leaf area of the entire bush ($r = -0.65 \pm 0.189$, $P > 0.995$). A very close relationship was found between the pest infestation of rose varieties and the multiplication of the leaf lobule area by the area of leaves per entire bush ($r = -0.89 \pm 0.134$, $P > 0.99999$) or by the leaf area per crown ($r = -0.94 \pm 0.096$, $P > 0.999999$). Rectilinear regression equations were chosen for predicting the level of rose variety average infestation by *T. urticae*. It was $y_p = 2.57 - 0.073xz$ (with an error of 0.102±0.0154 points) for the first year of phytoseiulus application and $y_p = 2.89 - 0.127xz$ (with an error of 0.081±0.0156 points) for continuous use of phytoseiulus. For predicting the required releases of predatory mites, it was $y_{ph} = 345 - 11.3xz$ (an error of 22.0±5.52 individuals per 1 m^2 per year) for the first year and $y_{ph} = 278 - 11.1xz$ (the error of which is 9.8±1.36 individuals per 1 m^2 per year) for continuous use. In the equations, y_p is the level of a particular rose variety average infestation by the two-spotted spider mite, points; y_{ph} is the number of *Ph. persimilis* required for releases in order to protect this variety from spider mites during a year, individuals per m^2; x is the average area of a leaf segment (lobule) of a given rose variety, cm^2; z is the average area of a bush crown leaves of a given rose variety, m^2. These equations are recommended for use in the biological control of two-spotted spider mite on roses using *Ph. persimilis*.

Keywords: *Rosa hybrida*, rose varieties, bush, structure elements, commercial greenhouses, *Tetranychus urticae*, pest infestation level, *Phytoseiulus persimilis*, correlation analysis, regression analysis, forecasting models, rectilinear regression equations

The cut rose cultvaion is characterized by a significant, ever-increasing number of varieties which differ not only in the decorative properties of the flower, but also in the structural elements and architecture of the bush [1]. Varieties differ in the degree of costs for protection from pests, primarily from the common spider mite *Tetranychus urticae* Koch., to combat which some varieties require 25 or more acaricide treatments, while others require only 6-8 [2-4].

Colonization by phytophages can be influenced by plant height [5], leaf surface area [6, 7], structural complexity [8] and their relationship (leaf contact) [9], number of leaves on the plant [1, 10], leaf area and thickness, their morphological structure (pubescence, density of trichomes, their types) [11-14]. Elements of plant structure determine the presence of shelters for phytophages, distribution [16] and abundance of phytophages [17], and also indirectly influence natural enemies due to the spatial distribution of prey [18, 19]. In addition, plant structure affects the choice of the host plant by natural enemies [20], their movement and survival [18, 21], other features of the behavior of predators and parasites [22], for example, the predatory activity of acarifages, their reproductive behavior, dispersal, and search ability [23-25].

Rose varietal properties affecting the phytophage *T. urticae* were assessed mainly in turms of biochemical traits (terpene content, tannins, essential oils) and leaf morphological traits (trichomes, glands, leaf thickness) [26, 27]. Interaction between the plant, *T. urticae* and its predator *Phytoseiulus persimilis* A.-H. on rose varieties with different resistance to the phytophage has not been enough studied [28]. In addition, little is known about the influence of plant architectural features on their infestation by spider mites and the effectiveness of *Phytoseiulus* [29), although this is of scientific interest and necessary for successful, cost-effective crop protection from the pest. Identification of the elements of the rose bush structure that determine the development of the phytophage and its predator will make it possible to predict the protective measures on cultivated and new varieties.

Previously, we established significant differences in varieties of roses grown for cutting in the degree of their infestation by spider mites, both under conditions of acaricide use and when using phytoseiulus [2, 3].

In this work, the elements of the rose bush structure that determine the development of the phytophage *T. urticae* and its predator *Ph. persimilis* have been identified for the first time, and equations were suggested to predict protective measures on different varieties of *Rosa hybrida* grown in greenhouses for cutting.

The goal of the work was a long-term assessment of the infestation of various rose varieties by the common spider mite, establishing its connection with the parameters of individual elements of the bush structure and to develop math models to predict the infestation rate for this pest and the number of the predatory phytoseiulus mite to combat it.

Materials and methods. Observations on the development of the common spider mite were carried out in a 45,000 m^2 block glass greenhouse (Agroleader LLC, Leningrad Province, Vyborg District) on rose (*Rosa hybrida*) varieties Aqua, Avalanche, Peach Avalanche, Wow, Dark Wow, Grand Prix, Miss Piggy , Penny Lane, Jumilia, Taleya, Myrna, Brazil, Heaven, Dolomiti, Hot Shot, Red Naomi, Deep Water, Fiesta.

Roses were grown using low-volume hydroponics with Grodan mineral wool (Grodan B.V., the Netherlands) as a substrate. The microclimate in the greenhouses was regulated, drip irrigation, artificial lighting (4500 lux), and curtains were used. During lighting (from 4.00 to 0.00), the temperature was maintained at least +20 °C and relative air humidity 60-65%, without lighting, the parameter were at least +16 °C and 70-75%, respectively (an automatic mode).

A scoring system was used to assess the infestation of roses with spider mites. The entire greenhouse was divided into sections. Each plot was a section of a double row of rose bushes. The length of the segment was 3.95 m, its area was 8.02 m^2. The number of bushes per site was on average 60 at the rate of 7-8 bushes/m^2. The number of plots varied among different varieties, since the area under them was not the same. The minimum area and number of plots (76 in total) were for the Fiesta variety, the maximum (988 plots) for the Grand Prix variety. In a survey, the plants were visually inspected to assign an infestation score for each area on the following scale: 1 — spider mites are found in a part of the bush formed by bending shoots down to increase photosynthesis; 2 — the spider mite is found in the crown (the productive part of the bush, consisting of marketable shoots, peduncles, and shoots for bending), moves to the middle and upper tiers of productive stems but does not yet reach the bud (dozens of individuals on infested leaves); 3 — appearance of the first mites and cobwebs on the buds (hundreds of individuals per site plant); 4 — cobwebs have appeared on more than 50% of the leaves, "caps" of cobwebs appear on the buds (thousands of individuals per site plant); 5 — the entire plant in a web, accumulations of phytophage on the buds and tips of leaves, cessation of shoot growth and their deformation, drying out and falling of leaves (this situation is not allowed in greenhouses) [2-4]. After each survey, the average pest infestation score was determined for each variety on the recording date. Surveys were carried out 2 times a month, the total number of surveys per year was at least 24. The dynamics of the spider mite population was assessed over 8 years (2011-2018). For each variety, the total number of surveys varied, since during the study period some varieties were removed from production and new ones were introduced. The average long-term population was also estimated for each variety. As a result, the minimum number of surveys (48 in total) was carried out on the Brazil variety, and the maximum (195 surveys) on the Deep Water variety. The average number of surveys for all varieties over 8 years was 137.5±11.21. Based on the survey results, a decision was made to carry out protective measures.

Since 2011 on some varieties, and since 2012 on the entire area of the enterprise, the predatory phytoseiulus mite *Phytoseiulus persimilis* introduced by continuous and local (to the pest foci) methods was used to combat the common spider mite. A continuous application of 3 to 10 mites/m^2 over the entire area of the greenhouses was carried out 1-1.5 times a month, in the foci from 10 to 60 mites per bush weekly [30] until new significant foci of the pest continued to appear. With such an introduction, as a rule, the required predator-to-prey ratio of 1:10-1:20 is created [30, 31]. If the presence of acarifage was detected in the foci (1-5 mites/leaf), its additional application was canceled. Acaricides were used only in cases where the *T. urticae* infestation of roses exceeded 2.5 points. The treatments were paired, i.e., the second treatment was 7 days after the first treatment.

To study the influence of elements of the bush structure on the development of the common spider mite and the effectiveness of phytoseiulus, the morphometric parameters assessed in all 18 varieties of roses were as follows. The productive stem number in the crown and in the bending part was counted in 30 randomly selected bushes of each variety, the sum of the crown stems and the bending stems gave the total number of stems per bush, then the average number of stems per bush was calculated for each variety. The length of productive stems was measured. The number of segments of a compound leaf and leaves on the entire stem were assessed by counting on 30 randomly selected stems of each variety (the quotient of dividing the number of leaves on the entire stem by its length multiplied by 10 gave the number of leaves per 10 cm of stem). The number of leaves in the crown of the bush and on the entire bush was calculated by multiplying the average number of leaves per entire stem by the average number of stems in the crown and in the entire bush. The area of a lobule (simple leaf) was calculated by the formula for an ellipse using the length and width of 30 compound leaves of each variety (the number of measurements varied from 140 to 173, since the number of leaf lobules, deviating from the standard five, varied among varieties). The leaf surface area per bush or per its crown was calculated by multiplying the average area of a compound leaf by the number of leaves per entire bush or its crown.

Statistical data processing was carried out using the SPSS program (https://www.ibm.com/products/spss-statistics) and Microsoft Excel. For each variety, the mean (*M*) colonization score for the entire observation period, the mean values of the bush structure parameters and the standard errors of the means (±SEM) were calculated. The significance of differences was assessed by Student's *t*-test. Correlation analysis was used to evaluate the relationship between the infestation of the rose variety and its bush structural elements, and regression analysis (linear regression equations) was used to describe it mathematically. To reveal the relationship between the element of bush structure of the variety and the degree of its infestation, two-factor analysis of variance was used [32]. When comparing parameters of regression models built from sample data, the least squares method was applied [33]. The errors of the regression equations were calculated by averaging the deviations of the actual values of the average long-term degrees of infestation by spider mites for all studied varieties or the nimber of phytoseiulus released from those expected according to the estimated mathematical model.

Results. Increasing the number of varieties and combining the results over several years made it possible to identify a wider composition of groups compared to previous studies [2, 3], differing in traits that affect the development of the common spider mite when phytoseiulus is released (Fig. 1). Thus, two varieties with the smallest (Aqua, No. 1) and the highest (Brazil, No. 18) pest infestation highly significantly ($p < 0.001$) differed from the others and from each other (by 17.8 times), and should be considered the most contrasting.

The second most infestead (Grand Prix, No. 17) and penultimate (Deep Water, No. 2) varieties also differed statistically significantly ($p < 0.001$) from all the others and 5-fold between themselves, therefore, they should be considered representatives of two more groups. The fifth group with a relatively low mite population density was represented by the varieties Jumilia, Peach Avalanch, Avalanche, Taleya (Nos. 3-6) (see Fig. 1), which did not differ significantly in this trait (with sample sizes from 72 to 168). The varieties Taleya, Wow, Fiesta, Dark Wow, Hot Shot, Myrna, Red Naomi (Nos. 6-12) which showed moderaate colonization (0.61-1.19 points), represented several groups, since each of them did not differ significantly from the previous one, but differed (mainly at $p < 0.05$) from the variety with a number two units less. Finally, one or two more groups were represented by the varieties Heaven, Dolomiti, Miss Piggy, Penny Lane (Nos. 13-16), among which only the varieties Heaven (No. 13) and Pany Lane (No. 16) differed significantly ($p < 0.05$) in the rate of spider mite infestation in the presence of phytoseiulus.

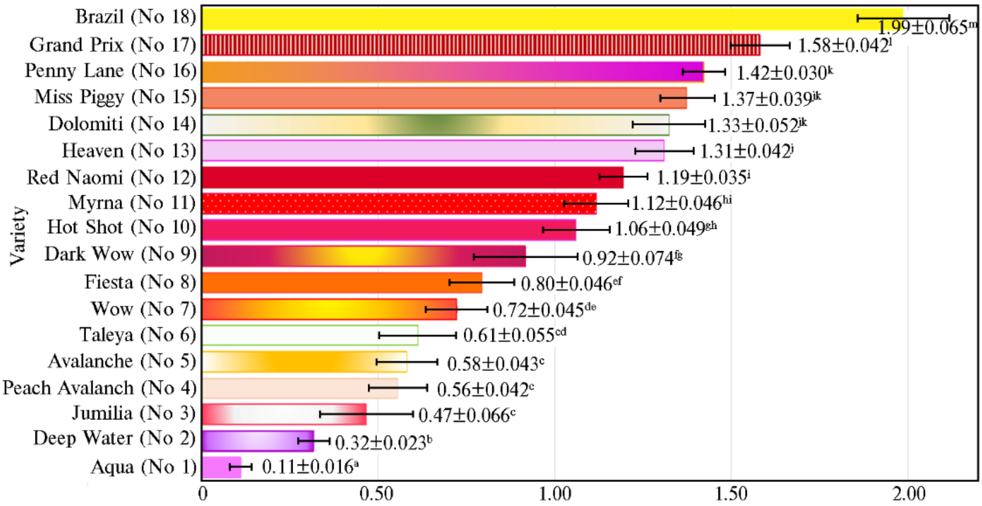

Fig. 1. Average long-term infestation (points) **of different rose (*Rosa* sp.) varieties of the hybrid tea group by the common spider mite *Tetranychus urticae* Koch. during releases of the predatory mite *Phytoseiulus persimilis* A.-H. (**M±SEM, experience in greenhouses, OOO Agroleader, Leningrad Province, 2011-2018). Error bars indicate confidence intervals for a probability of 0.95; the same letters indicate values that do not differ significantly ($p > 0.05$) according to Student's *t*-test.

Analysis of the elements of the structure of rose bushes showed significant intervarietal variability [29]. Between the most contrasting varieties, the differences were highly significant ($p < 0.001$) for all studied parameters. However, in absolute value they turned out to be not as high as in *T. urticae* colonization. Thus, the fewest stems in the crown of the bush and on the entire bush was in Brazil variety (3.6±0.14 and 6.2±0.21), and the largest values were characteristic of Peach Avalanch (9.5±0.43 and 13.9±0.62). The longest stems were found in the Grand Prix variety (74.1±1.49 cm), the shortest in Heaven (60.4±0.98 cm). Aqua had the fewest segments in a complex leaf (4.7±0.14), and in Heaven the leaf segment number is the largest (5.7±0.17).

1. Leaf surface parameters in 18 rose (*Rosa* sp.) varieties of the hybrid tea group ($M\pm$SEM, greenhouse tests, OOO Agroleader, Leningrad Province, 2011-2018)

Variety	Leaf area			
	whole leaf, cm^2 (n = 30)	leaf segments, cm ^{2} (n from 140 to 173)	bush crown, m^2 (n = 30)	whole bush, m^2 (n = 30)
Aqua	115.7 ± 3.81^{efg}	24.8 ± 1.00^{kl}	0.79 ± 0.050^{qr}	$1.16\pm0.077^{\alpha-\delta}$
Deep Water	129.4 ± 4.05^{bc}	25.4 ± 0.98^{kl}	0.79 ± 0.040^{qr}	$1.16\pm0.057^{\alpha\beta\gamma}$
Jumilia	172.5 ± 7.60^{a}	35.2 ± 1.35^{i}	$0.61\pm0.091^{s-v}$	$0.91\pm0.066^{\zeta\eta}$
Peach Avalanch	110.9 ± 4.13^{fgh}	20.5 ± 0.57^{no}	0.94 ± 0.040^{q}	$1.37\pm0.097^{\alpha}$
Avalanche	112.8 ± 4.43^{fgh}	20.9 ± 0.68^{no}	0.95 ± 0.066^{q}	$1.40\pm0.125^{\alpha\beta}$
Taleya	128.2 ± 4.18^{bcd}	24.3 ± 0.70^{l}	0.81 ± 0.042^{qr}	$1.32\pm0.065^{\alpha\beta}$
Wow	141.9 ± 7.80^{bc}	29.0 ± 0.95^{j}	0.56 ± 0.040^{uv}	$0.98\pm0.067^{\delta-\eta}$
Fiesta	133.4 ± 6.86^{bc}	27.6 ± 1.00^{jk}	0.64 ± 0.040^{su}	$1.14\pm0.072^{\beta-\varepsilon}$
Dark Wow	140.7 ± 7.60^{bc}	28.7 ± 0.85^{j}	0.60 ± 0.041^{tuv}	$0.99\pm0.069^{\gamma\eta}$
Hot Shot	127.9 ± 4.57^{bcd}	25.4 ± 0.9^{kl}	0.66 ± 0.034^{stu}	$1.00\pm0.052^{\delta\varepsilon\zeta}$
Myrna	136.7 ± 3.90^{b}	25.2 ± 0.80^{kl}	0.62 ± 0.034^{stu}	$1.00\pm0.055^{\delta-\eta}$
Red Naomi	125.7 ± 3.78^{cde}	23.2 ± 0.76^{lm}	0.59 ± 0.039^{uv}	$0.96\pm0.062^{\varepsilon\zeta\eta}$
Dolomiti	114.7 ± 4.08^{efg}	21.2 ± 0.60^{no}	0.66 ± 0.032^{stu}	$1.07\pm0.050^{\gamma\delta\varepsilon}$
Heaven	$116.0\pm5.06^{d-g}$	20.2 ± 0.76^{nop}	0.71 ± 0.049^{rst}	$1.11\pm0.076^{\gamma\delta\varepsilon}$
Miss Piggy	104.8 ± 5.81^{gh}	18.2 ± 0.60^{p}	0.74 ± 0.056^{rs}	$1.13\pm0.079^{\beta-\varepsilon}$
Pany Lane	$123.6\pm5.29^{b-f}$	22.2 ± 0.68^{mn}	0.53 ± 0.031^{v}	$0.86\pm0.051^{\eta}$
Grand Prix	112.2 ± 4.30^{fgh}	20.7 ± 0.68^{no}	0.51 ± 0.035^{v}	$0.81\pm0.057^{\eta}$
Brazil	101.1 ± 4.89^{h}	20.2 ± 0.70^{o}	0.37 ± 0.024^{w}	$0.64\pm0.040^{\theta}$

Note. The same letters indicate indicators that do not have statistically significant differences (p > 0.05) according to Student's *t*-test.

2. Pair correlation coefficients ($r_{п}\pm S_r$) of infestation by the common spider mite *Tetranychus urticae* Koch. 18 varieties of roses (*Rosa* sp.) of the hybrid tea group with some parameters of the bushe structure, linear regression equations and the sum of squared deviations of the actual colonization from that expected by the regression equations (greenhouse tests, OOO Agroleader, Leningrad Province, 2011-2018)

Parameter	$r_{п}\pm S_r$	Probability of difference $r_{п}$ from zero	Regression equation (y = a + bx or y = a + bxz)	Sum of squared deviations
Stems in crown (x)	–0.36±0.233	$0.8 < P < 0.9$	y = 1.53 – 0.100x	3.60
Stems in a bush (x)	–0.30±0.238	$0.5 < P < 0.8$	y = 1.50 – 0.061x	3.74
Stem length (x)	0.27±0.241	$0.5 < P < 0.8$	y = –0.97+0.031x	3.81
Number of segments of a compound leaf (x)	0.49±0.218	$0.95 < P < 0.99$	y = –3.09+0.779x	3.07
Number of leaves:				
on the entire stem (x)	–0.03±0.250	$P < 0.2$	y = 1.25 – 0.024x	3.88
per 10 cm stem (x)	–0.19±0.246	$0.5 < P < 0.8$	y = 1.97 – 0.695x	4.05
in the crown of the bush (x)	–0.42±0.227	$0.9 < P < 0.95$	y = 1.73 – 0.014x	3.14
all over the bush (x)	–0.35±0.234	$0.8 < P < 0.9$	y = 1.70 – 0.008x	3.59
Square:				
leaf segments (x)	–0.52±0.214	$0.95 < P < 0.99$	y = 2.44 – 0.060x	2.94
entire sheet (x)	–0.44±0.225	$0.9 < P < 0.95$	y = 2.55 – 0.013x	3.23
bush crowns (x)	–0.70±0.179	$P > 0.998$	y = 2.54 – 2.326x	2.12
whole bush (x)	–0.65±0.189	$P > 0.995$	y = 2.67 – 1.604x	2.31
bush crowns (x) and leaf segments (z)	–0.95±0.081	$P > 0.999999$	y = 2.92 – 0.120xz	0.406
whole bush (x) and leaf segment (z)	–0.89±0.116	$P > 0.99999$	y = 2.92 – 0.077xz	0.790

The largest number of leaves on the entire stem was in the Fiesta variety (12.5±0.32), per 10 cm of the stem in the Deep Water variety (1.74±0.025), in the bush crown in Avalanche (84.8±7 .55), on the entire bush in Peach Avalanch (125±7.4). One variety, the Jumilia had the fewest leaves for all four indicators (7.8±0.27; 1.22±0.036; 35.5±2.16 and 53±3.5, respectively). On the contrary, the Jumilia variety showed the largest area of the lobule and the entire leaf (Table 1). The smallest leaf segment area was in the Miss Piggy variety, and the Brazil variety had the smallest leaf area. The largest leaf area of the crown and of the entire bush was found in the Avalanche variety, and the smallest in Brazil. The remaining varieties occupied an intermediate position in a number of indicators. They were statistically significantly different or not different from each other.

A more definitive pattern of the relationship between the structural elements of rose bushes and their infestation by spider mites was provided by the results of correlation and regression analyzes (Table 2). It was not possible to identify a reliable connection between 8 of the 12 studied morphometric features of the structure of rose bushes and their colonization by *T. urticae*, since the probability of the correlation coefficient differing from zero was less than 0.95, and for the number of leaves on the entire stem it approached zero. Moreover, the sum of squared deviations of the expected colonization according to the calculated regression equations for 18 varieties was significantly greater than 3.

There was a connection (with a probability of a correlation coefficient different from zero > 0.95, but < 0.99) of the *T. urticae* population of rose varieties with the area of a leaf lobule (average negative) and the number of lobes of a compound leaf (average positive). The negative relationship between the infestation of roses by spider mites and the leaf surface area of the crown and the entire bush turned out to be higher, with a probability of > 0.99 but < 0.999, and the sum of squared deviations was more than 2. However, the predictive accuracy of the expected spider mite infestation of a variety when using such simple models is low. The average error in the degree of infestation will range from 0.27 points when using the total area of the leaf surface of the bush as a predictor, to 0.33 points when using the area of the leaf lobule. In this regard, we tried to find a model that takes into account both the factors that determine the climate in the bush zone (the area of the leaf surface of the crown and the entire bush) and the factor that influences the microclimate in the laminar layer of the leaf (the area of the leaf lobule), by multiplying them. The correlation coefficients of such indicators with the population of the studied rose varieties by *T. urticae* sharply increased during the release of phytoseiulus, and the sum of squared deviations decreased (see Table 2). Two-factor analysis of variance did not show the interaction of the area of a leaf lobule and the area of the leaf surface of the crown or the entire bush in their influence on the infestation of rose varieties by spider mites in greenhouses, which indicates the possibility of their use in the model as independent predictors.

Using the average number of segments of a complex rose leaf as a second argument turned out to be ineffective. The correlation coefficients of the products of the average number of leaf segments on the area of the leaf surface of the crown or the entire bush with spider mite infestation were only 0.52±0.214 (0.99 > P > 0.95) and 0.46±0.223 (0.95 > P > 0.90), and their predictive error is 0.34±0.055 and 0.33±0.063 points. In addition, a significant interaction was revealed between the average number of segments and the area of the leaf surface of the crown and the entire bush in their influence on the infestation of rose varieties by spider mites, which makes it difficult to use these indicators in a linear regression model.

3. Pair correlation coefficients ($r_{\text{п}} \pm S_r$) of infestation by the common spider mite *Tetranychus urticae* Koch. in 14 varieties of roses (*Rosa* sp.) of the hybrid tea group with some bush structure parameters, linear regression equations and the sum of squared deviations of the actual colonization from that expected by the regression equations (greenhouse tests, OOO Agroleader, Leningrad Province, 2011-2018)

Parameter	$r_{\text{п}14} \pm S_r$	Probability of difference $r_{\text{п}}$ from zero	Regression equation (y = a + bx or y = a + bxz)	Mean deviation	
				14 сортов	4 сорта
Leaf segments (x)	–0.58±0.235	0.98 > P > 0.95	y = 2.70 – 0.069x	0.28±0.074	0.43±0.131
Total sheet (x)	–0.47±0.254	0.95 > P > 0.90	y = 2.73 – 0.014x	0.31±0.076	0.43±0.132
Bush Crowns (x)	–0.74±0.193	0.998 > P > 0.995	y = 2.74 – 2.649x	0.14±0.040	0.23±0.069
Whole bush (x)	–0.68±0.211	0.995 > P > 0.990	y = 2.77 – 1.705x	0.30±0.067	0.21±0.090
Bush crowns (x) and leaf segments (z)	–0.94±0.096	> 0.999999	y = 2.88 – 0.118xz	0.12±0.029	0.12±0.037
Whole bush (x) and leaf segments (z)	–0.89±0.134	> 0.99999	y = 2.85 – 0.071xz	0.14±0.043	0.21±0.059

Note. 14 varieties served as the basis for calculating correlation coefficients and regression equations, 4 varieties were selected for verification using a table of random numbers..

To verify the proposed model for predicting the infestation of rose varieties by spider mites under releasing phytoseiulus, four varieties were selected from a table of random numbers, the Deep Water, Avalanche, Dark Wow and Miss Piggy. The remaining 14 varieties were used to calculate correlation coefficients and regression equations, based on which the expected population of the four excluded varieties was predicted (Table 3). The average deviations of their expected occupancy rates were practically no different from those for the 14 varieties included in the calculations.

An equation based on the leaf areas of the bush crown multiplied by the leaf lobule areas showed the best predictive properties. Moreover, the average error was only 0.12 points. It should be noted that the identification of these elements of the bush structure as the best predictors of the colonization of rose varieties by *T. urticae* influenced by the predatory mite *Phytoseiulus* is not accidental. Both factors determine the climate, which influences the development of both phytophages and acarifages, i.e., humidity and temperature in the bush zone depend on the total area of the leaf surface, and humidity in the laminar layer of the leaf up to 3-5 mm thick depends on the area of the leaf lobule [34, 35]. Humidity is of particular importance for the effective use of phytoseiulus. It affects its survival, especially at the embryonic and larval stages of development, and the reproductive behavior of females [36-38].

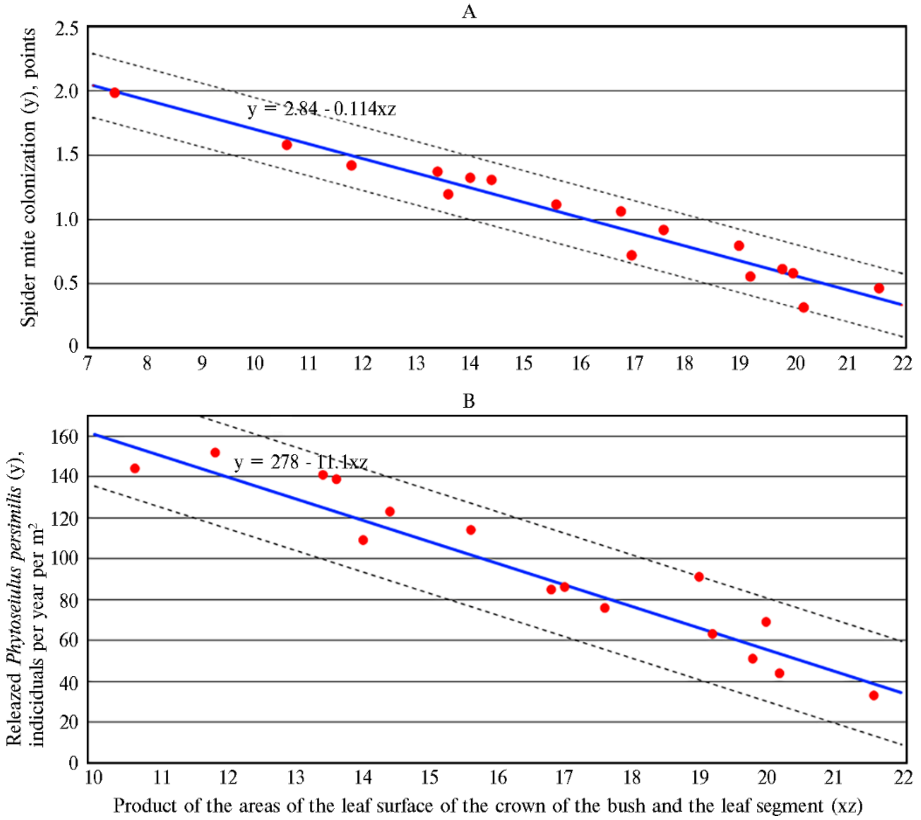

Fig. 2. Dependence of the colonization of roses (*Rosa* sp.) of the hybrid tea group by the common spider mite *Tetranychus urticae* Koch. (A) **and the required number of the predatory mite *Phytoseiulus persimilis* A.-H.** (B) **from the bush crown leaf surface area × a leaf segment area in a certain rose variety:** red dots — actual colonuzation, blue line — expected colonuzation, dotted lines — the boundary of the regression zone ((greenhouse tests, OOO Agroleader, Leningrad Province, 2011-2018).

Further improvement of the model was carried out by clarifying the coefficients in the equations intended to predict colonization of rose varieties in the first year of phytoseiulus application and with its stable use, since they differed significantly [4], and to reduce the forecast error by excluding the Aqua variety, the actual colonization of which was outside the 95% regression confidence zone. For the first year of the phytoseiulus use, the equation is $y_c = 2.57 - 0.073xz$ with the error of 0.102 ± 0.0154 points, and with stable use $y_c = 2.89 - 0.127xz$, the error of 0.081 ± 0.0156 points (Fig. 2, A). In the recommended equitions, y_c is the average infestation of a rose variety by common spider mites, points; x is the average area of a leaf segment, cm^2; z is the average area of the leaf surface of the bush crown, m^2. These equations can be used when selecting new varieties for commercial cultivation in greenhouses, taking into account the protection against the common spider mite. The data obtained made it possible to draw up predictive equations for calculating the number of phytoseiulus required during its use both in the first years and over a fairly long period of time. This is important for planning the mass breeding or purchasing of predatory mites.

After comparing several versions of the equations, to improve the accuracy of prediction, we excluded the varieties Brazil and Aqua, which were the most contrasting in terms of the required volume of acarifage, which fell outside the 95% confidence zone of the regression [39]. To predict the required volumes of phytoseiulus releases on most varieties of roses in the first year, the recommended equation is $y_p = 345 - 11.3xz$, the error of which is 22.0 ± 5.52 individuals per m^2 per year, and with stable use $y_p = 278 - 11{,}1xz$, the error of 9.8 ± 1.36 individuals per m^2 per year (see Fig. 2, B). In these equations, y_p is the number of phytoseiulus required for releases to protect a particular rose variety from spider mites throughout the year, individuals/m^2; x is the average area of a leaf segment for the variety, cm^2; z is the average leaf surface area of the bush crown in the variety, m^2.

Of the 18 rose varieties studied, protection against spider mites by using phytoseiulus turned out to be most effective in the Aqua variety. In the first year, only 9 releases of the predator were required with a total number of 48 individuals/m^2. In subsequent years, the number of required releases decreased to 4-5, and with 11-19 individuals/m^2 (years 2-4), and then to 6-8 individuals/m^2 per year [4]. For 7 years, the Aqua variety has never required the use of acaricides. On the Brazil variety, on the contrary, protection with phytoseiulus turned out to be extremely ineffective. Acarifage releases had to be carried out 2 times a month. The total number of released predatory mites per 1 m^2 in the first year was 418 individuals, in the second 390 individuals. In this case, 7 and 6 double treatments with acaricides were additionally carried out, respectively.

Subsequently, the farm had to abandon the cultivation of the Brazil variety. The transition to using only acaricides to control *T. urticae* on this variety required 13-15 double treatments per year, which, given the presence of only two drugs approved in the Russian Federation for use on roses in greenhouses [39], extremely limited the possibility of their alternation and led to the rapid emergence of a stable population of the phytophage. Currently, this list has been expanded to five drugs [40], but mainly due to chemical acaricides, the constant use of which in greenhouses is undesirable. Improving biological control of spider mites using the predatory mite *Ph. persimilis* remains extremely relevant. Our research allows us to select rose varieties more suitable for biological protection, as well as plan the use of predatory mites. The fitted models, based on the use of leaf lobule area and bush crown leaf area as predictors, are easy to use and seem to have satisfactory accuracy. Thus, when predicting the infestation of a variety by spider mites and the required number of phytoseiulus with its constant use, the coefficients of determination r^2 are 95.6 and 90.9%, respectively.

Identification of morphological, biochemical and other factors [26-28] influencing the reproduction of *T. urticae* and *Ph. persimilis* in the triotroph system (plant variety, phytophage, entomophage) is of particular scientific interest. There has been no significant work on roses in this area of research. There are observations by Australian scientists made on roses that were grown in open ground, where it was noted that in densely growing varieties, the abundance of contacting leaves contributed to the rapid movement of *Ph. persimilis* along the plant. Long-term interactions between the common spider mite and the predator resulted in satisfactory control of the pest compared to varieties where the crown was not in contact [41, 42].

In Iran, laboratory studies were carried out on 10 varieties of roses to assess the main vital parameters of the development of the common spider mite. Some varieties differed significantly in their effects on survival, developmental duration of immature ticks, and fertility of adult ticks, as well as on the rate of population growth, reproductive capacity, and average generation time [27]. The relationship with morphological or biochemical characteristics of the varieties was not assessed.

In Mexico, some of the 13 cultivars showed significant differences in their ability to favor *T. urticae* development, as well as a negative correlation with essential oil content and a positive correlation with terpene content, nitrogen content, and leaf thickness [26]. There, in Mexico, 1 week after the pest uniformly colonized two varieties of roses, contrasting in conditions for the development of *T. urticae*, it was noted that the density of damage caused by *T. urticae* and the chlorophyll content in rose leaves did not differ. After *Ph. persimilis* release, the density of *T. urticae* changed on both varieties. Differences between varieties in the percentage of damage and *Ph. persimilis* density was not recorded. One of the varieties had the lowest chlorophyll content, but *Ph. persimilis* was more effective [28].

Our studies revealed a significant negative relationship between the development of the common spider mite in the presence of phytoseiulus, that is, in the triotroph system, and changes in the area of a compound leaf lobule and the area of the leaf surface of the bush crown and the entire bush in different varieties. This relationship is reflected in the required predator application on varieties with different parameters of these structure elements.

Thus, our surveys on 18 rose varieties grown in greenhouses for cutting under the use of the predatory mite *Phytoseiulus persimilis* A.-H. for biocontrol of the common spider mite *Tetranychus urticae* Koch. for 8 years, showed significant diversity in the colonization by the phytophage. The two most contrasting varieties in terms of average long-term colonization, Brazil and Aqua, differed by an average of 17.8 times. Other varieries could be divided into several (six to eight) groups, of which the most contrasting differed 5-fold. Rose varieties differed significantly in the following elements of the bush structure: the number of stems in the crown and in the entire bush, the number of segments of a compound leaf, the number of leaves per entire stem and per 10 cm of the stem, the number leaves in the crown and per the entire bush, the length of the productive stem, the area of the segment and the entire leaf, the leaf area per bush and its crown. Of the 12 assessed indicators of bush structure, a significant relationship with the rose variety infestation by spider mites controlled by phytoseiulus was noted only for the number of lobes in a compound leaf ($r = 0.49 \pm 0.218$; $0.95 < P < 0.99$), for leaf segment area ($r = -0.52 \pm 0.214$; $0.95 < P < 0.99$), for the crown leaf area ($r = -0.70 \pm 0.179$; $P > 0.998$) and for the leaf area per bush ($r = -0.65 \pm 0.189$; $P > 0.995$). A very close relationship was found between the infestation of rose varieties by the pest and the product of the leaf lobe area by the area of the leaves per bush ($r = -0.89 \pm 0.134$; $P > 0.99999$) or by the crown leaf area ($r = 0.94 \pm 0.096$; $P > 0.999999$). Straightforward regression equations were selected to predict the average infestation of the variety by the spider mite *T. urticae* in the first year of the use of phytoseiulus $y_c = 2.57 - 0.073xz$ (the error of 0.102±0.0154 points), for stable use of phytoseiulus $y_c = 2.89 - 0.127xz$ (the error of 0.081±0.0156 points). The equiations for forecasting the required annual number of the predator and frequency of its application are $y_p = 345 - 11.3xz$ (the error of 22.0±5.52 individuals per 1 m^2 per year) and with stable use $y_p = 278 - 11.1xz$ (the error of 9.8±1.36 individuals per 1 m^2 per year). The y_c is the average colonization of the variety with spider mites, individuals/m^2, y_p is the number of phytoseiulus required to protect the variety from spider mites throughout the year, individuals/m^2, x is the average leaf segment area, cm^2, z is the average crown leaf area, m^2. These equations are recommended for planning biological protection of rose plantings from common spider mites using *Ph. persimilis.*

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