



## Susceptibility levels and grouping of peach cultivars in relation to peach rust under field conditions

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**ABSTRACT.** The objective of this study was to assess susceptibility and classify peach cultivars in relation to rust (*Tranzschelia discolor*) under field conditions. The study was conducted in an orchard during the 2007/08 and 2008/09 growing seasons and included the cultivars: Aurora 1, Chimarrita, Chiripá, Coral, Eldorado, Granada, Leonense, Maciel, Marli, Premier and Vanguarda. Several disease-related variables were evaluated, over a 10 day interval from September to February, based on estimates of disease incidence, severity and defoliation. The logistic model adequate fit to rust severity progress data ( $R^2 > 0.90$ ) in the two years. Principal component analysis (PCA) using all data, irrespective of the year, identified area under the disease progress curve, initial inoculum and disease progress rate as the best variables to differentiate reactions to rust. When PCA analysis was conducted separately for each year, different disease-related variables were selected as a principal component, and cultivars were classified in three groups of susceptibility. There was inconsistency in the grouping of some cultivars, which was likely due to varying environmental conditions between the years. However, 'Coral' was consistently grouped in the low susceptibility group and 'Chimarrita' and 'Granada' in the high susceptibility group.

**Keywords:** *Tranzschelia discolor*, horizontal resistance, *Prunus persica*.

## Níveis de suscetibilidade e agrupamento de cultivares de pessegueiro em relação à ferrugem sob condições de campo

**RESUMO.** Objetivou-se avaliar a suscetibilidade e classificar as cultivares de pessegueiro em relação à ferrugem (*Tranzschelia discolor*) em condições de campo. O estudo foi conduzido em pomar nas safras 2007/08 e 2008/09, com as cultivares: Aurora 1, Chimarrita, Chiripá, Coral, Eldorado, Granada, Leonense, Maciel, Marli, Premier e Vanguarda. Diversas variáveis relacionadas com a doença foram avaliadas, em um intervalo de 10 dias de setembro até fevereiro, baseado em estimativas de incidência, severidade e desfolha da doença. O modelo logístico foi adequado aos dados do progresso da severidade ( $R^2 > 0,90$ ), nos dois anos. Para a análise de componentes principais (ACP), utilizou-se todos os dados, independentemente do ano, identificou-se a área sob a curva de progresso da doença, inóculo inicial e taxa de progresso da doença como as melhores variáveis para diferenciar as reações à ferrugem. A ACP foi realizada separadamente para cada ano, variáveis diferentes foram relacionadas a doença e selecionadas como componente principal, e as cultivares foram classificadas em três grupos de suscetibilidade. Houve inconsistência no agrupamento de algumas cultivares, provavelmente influenciada pela variação das condições ambientais, entre os anos. No entanto, 'Coral' foi consistentemente agrupada no grupo menos suscetível e 'Chimarrita' e 'Granada' no grupo mais suscetível.

**Palavras-chave:** *Tranzschelia discolor*, resistência horizontal, *Prunus persica*.

### Introduction

Peach (*Prunus persica* (L.) Batsch), a member of the Rosaceae family, is native to Asia but is extensively cultivated in different regions worldwide. China is the largest producer with 10.2 million tons, representing 50% of the world's production (FAO, 2011). In Brazil, due to the wide range of peach genotypes available for commercial production (FACHINELLO; MARODIN, 2004),

the crop is grown from the central (latitude 20°S) to southern (31°S) regions of the country. Total national production is approximately 200.000 tons on an area of 19.038 ha (IBGE, 2011).

In the subtropical growing regions, such as those of the state of Paraná in the South of Brazil, the frequency of peach rust epidemics caused by the fungus *Tranzschelia discolor* (Tranz & Litv) has increased over the last decade and represents an economic concern (CITADIN et al., 2005, 2010; ALVES et al., 2008;

RODRIGUES et al., 2008). Although in temperate climates peach rust fungi are often present as several spore states (uredospores, teliospores, basidiospores and aeciospores), uredospores are the main type of inoculum found in Brazil and commonly overwinters in cankers and branches and produce the primary inoculum for epidemics in the following crop season. Damage by peach rust can often occur as a result of early leaf defoliation, which can cause early flowering and budding (SOTO-ESTRADA et al., 2003), and reduced yields (SOTO-ESTRADA et al., 2005; ALVES et al., 2008). Fungicide applications can suppress the disease (SOTO-ESTRADA et al., 2003), and should be used under integrated pest management principles in order to avoid fungicide resistance, fruit contamination with pesticides and increasing production costs. Aiming to reduce fungicide dependence and application, current research is targeting cultivar resistance (CITADIN et al., 2010).

Previous research efforts in Brazil have identified a range of susceptibility in commercial cultivars to peach rust. For instance, Assmann et al. (2010) evaluated 29 peach genotypes and observed differences in susceptibility including incidence, severity and defoliation, suggesting a horizontal, non-race-specific type of genetic resistance. Horizontal resistance is considered a worthy strategy when breeding for perennial crops (DEWDNEY et al., 2003) because it restricts the adaptation of the pathogen population to a broader basis of resistance (multiple genes) (PARLEVLIE, 1979). However, the paradox between the usefulness of horizontal resistance and its limited use by breeding programs may be due to the difficulty of assessing and quantifying the horizontal resistance when compared with monogenic resistance (ANDRIVON et al., 2006).

Multivariate analysis of several responses in combination allows simplification and interpretation of the processes in complex phenomena (LEGENDRE; LEGENDRE, 1998), such as plant disease (MADDEN et al., 2007). In the case of disease data from unmanaged systems, multivariate analysis can be useful to analyze and classify a set of genotypes based on disease-related variables related to host resistance.

Reports on peach rust development in the field are scarce. In California, United States, the analysis of peach rust epidemics over several years have shown that the first symptoms of the disease were observed either early or late in the season, depending on the environmental conditions in spring and summer, and that this had a direct influence on the temporal patterns of the progression of the disease (SOTO-ESTRADA; ADASKAVEG, 2004). To our knowledge, there are no literature data on the temporal progression of peach rust in commercial

cultivars under subtropical climate conditions. The objectives of this study were a) to monitor and analyze rust development in eleven peach cultivars during two consecutive growing seasons and b) to compare and classify the cultivars with regard to the levels of susceptibility to the disease, based on the phenotypical responses.

## Material and methods

### Study area and experimental design

The study was conducted in a 5-year-old orchard located in the metropolitan region of Curitiba, State of Paraná, Brazil (25° 24' 42" S, 49°14' 53" W and altitude of 945 m) during the 2007/08 and 2008/09 growing seasons. This orchard was introduced alongside and two years after the planting of 'Chimarrita', a cultivar that has been recognized as susceptible to peach rust and that has served as the source of the primary inoculum. The climate in the region is subtropical, with cool summers and no dry season (Cfb) according to Köppen.

The peach cultivars studied were: Aurora 1, Chimarrita, Chiripá, Coral, Eldorado, Granada, Leonense, Maciel, Marli, Premier and Vanguarda. The training system used was Y, and the spacing was 1 m between plants and 2.5 m between rows. Each tree was an experimental unit. On each side of the tree, three branches that emerged in the given year from the lower third, middle and top position were marked, and thus, six branches (replications) were evaluated for each cultivar.

### Temporal disease assessments and analysis

For each cultivar, average disease incidence (proportion of diseased leaves related to the total number of leaves on the branch for each of six branches), mean severity (average percentage of the symptomatic area for all leaves) and defoliation (percentage of fallen leaves) were visually assessed in a 10-day interval between September (late bloom to initial fruit growth) and April (natural defoliation). Rust severity assessments were made using, as reference for visual estimation of the injured area, a diagrammatic scale for rust peach tree, with five levels of severity: 1 (0%); 2 (0.8%); 3 (2.4%); 4 (4.5%) and 5 (13.7%) (RODRIGUES et al., 2008).

Disease severity data were analyzed using nonlinear regression procedures of the Statistica 8.0 (STATSOFT, 2008). The logistic model was fitted to the rust progress data, and its biologically-significant parameters: initial inoculum ( $y_0$ ), maximum severity ( $y_{max}$ ) and disease progress rate ( $r$ ) were estimated (MADDEN et al., 2007).

### Univariate and multivariate analysis

Rust reactions among the cultivars were compared based on nine disease-related variables: the three parameters given by the logistic model: initial inoculum ( $y_0$ ), maximum severity ( $y_{max}$ ) and disease progress rate ( $r$ ); time in days to the first leaf symptoms (TFS); time in days from the first assessment until a maximum severity was reached (TMS); maximum severity in a single leaf of the branch (MSL); maximum average severity for all leaves in a branch (MSB); area under the disease (mean severity) progress curve (AUDPC) estimated by the trapezoidal integration method (MADDEN et al., 2007); and defoliation calculated based on the proportion of leaves present during the last evaluation in relation to the maximum foliage of the branch (DEFOL).

Univariate analysis was used to compare epidemics within each year. The three logistic model parameters were compared among the cultivars with a t-test (MADDEN et al., 2007), and the means of the other disease-related variables were subjected to analysis of variance and separated using the Scott-Knott test at 5% probability. The Sisvar program was utilized for the statistical analysis.

In multivariate analysis, principal components analysis (PCA) was used in two different ways. The 22 cases (11 cultivars x two years) were analyzed, first combined and later individually within a single year to group the 11 cultivars into levels of susceptibility. Both analyses took into account the nine disease variables. The 'Gower' index was calculated and used to evaluate the similarity among the sampling units (LEGENDRE; LEGENDRE, 1998). Cluster analysis was based on Ward's criterion with a bootstrap procedure of 1,000 permutations for group sharpness (PILLAR, 1999). The number of principal components (axes) was defined based on the eigenvalues ( $\geq 1$ ) and the accumulated variance ( $\geq 70\%$ ). All multivariate analyses were performed using the multivariate analyses were performed using the MULTIV program (PILLAR, 2004).

## Results and discussion

### Disease description

Peach rust developed in all trees/cultivars and growing seasons. The onset of rust occurred earlier in the second season when compared to the first. Initial rust symptoms were noticed an average of 98 and 38 days from the first assessment for the first and second season, respectively. In the 2007/08 season, cultivars differed in the timing of disease onset. Disease onset was first noticed in December (~80 days from first assessment) on 'Maciel' and 'Aurora 1' and on 'Chiripá' and 'Coral' approximately one month later. In the

following season, the first symptoms were noticed again on 'Aurora 1' much earlier than in the previous season (13 days), and symptoms in 'Vanguardia', 'Marli' and 'Premier' followed (26-29 days) (Table 1).

Rust incidence reached 100% in all 22 cases (data not shown). The maximum severity on a single leaf (MSL) ranged from 9% ('Marli') to 17% ('Chimarrita') for the first year and from 12.8% ('Marli') to 24.8% ('Chimarrita') for the second year. For mean branch severity (MSB), the lowest values, for both years, were observed on 'Aurora 1' (4.8%), 'Coral' (5.0%) and 'Marli' (5.4%), and the highest were on 'Chimarrita' (12.7%) and 'Granada' (13.3%) (Table 1). The time to reach the mean maximum severity (TMS) ranged from 165 days ('Leonense') to 180 days ('Coral') in the first growing season and from 129 days ('Chimarrita' and 'Granada') to 152 days ('Eldorado') in the second season (Table 1).

**Table 1.** Means<sup>1</sup> of disease-related variables<sup>2</sup> assessed in naturally developing peach rust (*Tranzschelia discolor*) on eleven peach trees/cultivars during two consecutive growing seasons (2007/08 and 2008/09) in Curitiba, Paraná State, Brazil.

| Cultivar               | TFS<br>(days) | TMS<br>(days)     | MSL<br>(%) | MSB<br>(%) | DEFOL<br>(%) | AUDPC   |
|------------------------|---------------|-------------------|------------|------------|--------------|---------|
| 2007/08 growing season |               |                   |            |            |              |         |
| Aurora 1               | 80 c          | 166 <sup>ns</sup> | 9.7 a      | 4.8 a      | 58 a         | 123.3 b |
| Chimarrita             | 97 b          | 170               | 17.1 b     | 11.9 d     | 87 b         | 228.1 c |
| Chiripá                | 117 a         | 170               | 15.0 b     | 9.3 c      | 57 a         | 153.4 b |
| Coral                  | 119 a         | 180               | 12.0 a     | 7.8 c      | 44 a         | 46.1 a  |
| Eldorado               | 100 b         | 168               | 12.0 a     | 7.5 b      | 60 a         | 149.1 b |
| Granada                | 92 b          | 170               | 17.0 b     | 13.6 d     | 84 b         | 301.7 c |
| Leonense               | 100 b         | 165               | 14.0 b     | 7.4 b      | 71 b         | 179.5 b |
| Maciel                 | 78 c          | 168               | 12.1 a     | 10.1 c     | 83 b         | 276.9 c |
| Marli                  | 108 a         | 167               | 9.0 a      | 5.7 a      | 66 a         | 110.6 b |
| Premier                | 88 c          | 165               | 11.4 a     | 7.7 b      | 76 b         | 181.0 b |
| Vanguardia             | 97 b          | 165               | 14.0 b     | 9.4 c      | 67 a         | 248.1 c |
| CV <sup>3</sup> (%)    | 25.4          | 4.3               | 33.7       | 34.0       | 27.2         | 36.3    |
| 2008/09 growing season |               |                   |            |            |              |         |
| Aurora 1               | 13 d          | 144 a             | 13.3 a     | 7.8 b      | 88 b         | 446.6 c |
| Chimarrita             | 39 c          | 129 b             | 24.8 b     | 12.7 c     | 93 b         | 622.0 c |
| Chiripá                | 73 a          | 145 a             | 23.7 b     | 13.6 c     | 91 b         | 364.4 b |
| Coral                  | 54 b          | 148 a             | 13.5 a     | 5.0 a      | 70 a         | 138.3 a |
| Eldorado               | 46 b          | 152 a             | 18.0 a     | 9.0 b      | 61 a         | 212.4 a |
| Granada                | 34 c          | 129 b             | 23.8 b     | 13.3 c     | 94 b         | 502.0 c |
| Leonense               | 49 b          | 152 a             | 15.9 a     | 10.5 c     | 87 b         | 304.8 b |
| Maciel                 | 31 c          | 133 b             | 21.3 b     | 12.0 c     | 80 b         | 539.1c  |
| Marli                  | 29 c          | 142 a             | 12.8 a     | 5.4 a      | 87 b         | 184.9 a |
| Premier                | 28 c          | 150 a             | 16.6 a     | 11.0 c     | 72 a         | 306.1 b |
| Vanguardia             | 26 c          | 144 a             | 18.1 a     | 8.6 b      | 86 b         | 395.7 c |
| CV (%)                 | 31.6          | 8.32              | 28.4       | 33.8       | 18.56        | 7.2     |

<sup>1</sup>Means of six replicates. Means followed by same letter in a column do not differ significantly by the Scott-Knott test at 5% significance level. <sup>2</sup>Time in days to the first leaf symptoms (TFS); time in days from the first assessment until reaching the maximum severity (TMS); maximum severity estimated in a single leaf of the branch (MSL); maximum average severity value for all leaves on a branch (MSB); area under the disease (mean severity) progress curve (AUDPC); and defoliation (DEFOL) assessed on 07/03/2008 and 02/14/2009 and estimated based on the proportion of leaves present in the last evaluation in relation to the maximum foliage of the branch. <sup>3</sup>Experimental coefficient of variation.

Defoliation assessment was last made on 7 March 2008 and 14 February 2009, respectively, for the two growing seasons. Defoliation varied from 44% (Coral) to 87% (Chimarrita) in the first season, and from 61% ('Eldorado') to 94% ('Granada') in the second season. In general, 'Chimarrita' and 'Granada' showed the

highest levels of defoliation (> 84%), while ‘Coral’ and ‘Eldorado’ had the lowest defoliation percentage (70 and 60%, respectively).

There was a significant correlation ( $p < 0.05$ ) between DEFOL and MSB ( $r = 0.64$  in 2007/08 and  $r = 0.34$  in 2008/09). In addition to earlier onset, the epidemics were more severe in the second season than in the first season in general, as demonstrated by the higher AUDPC values, which ranged from 138 (‘Coral’) to 622 (‘Chimarrita’) across the cultivars (Table 1).

### Modeling of the temporal disease progress

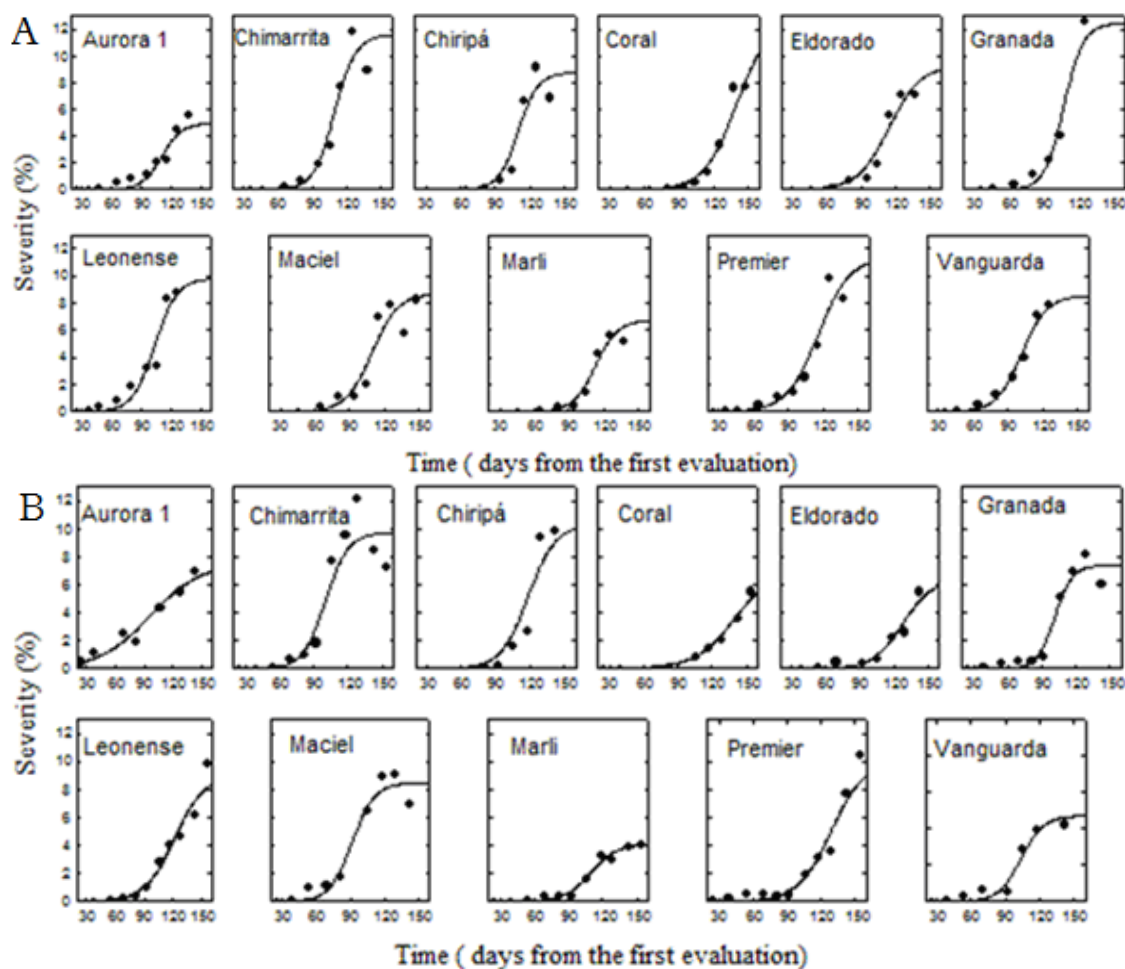
The logistic model had a good fit to mean severity data, with coefficients of determination higher than 0.90 (Table 2, Figure 1). When comparing the model parameters among the cultivars, no significant difference was observed for the initial inoculum ( $y_0$ ), whereas the disease progress rate ( $r$ ) varied across the cultivars. The highest  $r$  values were determined for the epidemics that developed on ‘Chimarrita’ (0.109) and

‘Granada’ (0.119). The maximum severity ( $y_{max}$ ) estimated was 11.62% (‘Chimarrita’) in the first year and 10.34% (‘Chiripá’) in the second year (Table 2).

**Table 2.** Mean values for the parameters  $\mu_1$  and coefficient of determination ( $R^2$ ) from a fitted logistic model fitted to peach rust (*Tranzschelia discolor*) severity progress curves for eleven peach cultivars monitored during two consecutive growing seasons in Curitiba-Paraná state, Brazil.

| Cultivar   | 2007/08 growing season |                          |             |         | 2008/09 growing season |             |     |       |
|------------|------------------------|--------------------------|-------------|---------|------------------------|-------------|-----|-------|
|            | $y_{max}$              | $y_0$                    | $r$         | $R^2$   | $y_{max}$              | $y_0$       | $r$ | $R^2$ |
| Aurora 1   | 4.99 a                 | 0.163 e <sup>-4</sup> ns | 0.099 ab 95 | 7.55 b  | 0.025 ns               | 0.037 a 98  |     |       |
| Chimarrita | 11.62 b                | 0.0611 e <sup>-4</sup>   | 0.109 b 97  | 9.75 b  | 0.402 e <sup>-4</sup>  | 0.101 b 94  |     |       |
| Chiripá    | 8.78 ab                | 0.0208 e <sup>-4</sup>   | 0.032 a 94  | 10.34 c | 0.524 e <sup>-4</sup>  | 0.083 ab 91 |     |       |
| Coral      | 9.57 b                 | 0.438 e <sup>-4</sup>    | 0.044 a 98  | 7.27 b  | 3.45 e <sup>-4</sup>   | 0.056 a 99  |     |       |
| Eldorado   | 7.89 ab                | 0.026 e <sup>-4</sup>    | 0.053 ab 98 | 6.45 b  | 0.584 e <sup>-4</sup>  | 0.076 ab 97 |     |       |
| Granada    | 12.48 b                | 0.0245 e <sup>-4</sup>   | 0.119 b 98  | 7.42 b  | 0.0177 e <sup>-4</sup> | 0.087 ab 97 |     |       |
| Leonense   | 9.83 b                 | 1.02 e <sup>-4</sup>     | 0.089 ab 97 | 9.02 b  | 3.87 e <sup>-4</sup>   | 0.064 ab 97 |     |       |
| Maciel     | 8.70 ab                | 0.604 e <sup>-4</sup>    | 0.088 ab 94 | 8.51 b  | 0.948 e <sup>-4</sup>  | 0.101 b 97  |     |       |
| Marli      | 6.77 ab                | 0.101 e <sup>-4</sup>    | 0.101 ab 97 | 4.12 a  | 0.700 e <sup>-4</sup>  | 0.087 ab 98 |     |       |
| Premier    | 11.38 b                | 0.213 e <sup>-4</sup>    | 0.073 ab 97 | 10.12 c | 0.158 e <sup>-4</sup>  | 0.067 ab 97 |     |       |
| Vanguarda  | 8.55 ab                | 0.845 e <sup>-4</sup>    | 0.091 ab 99 | 7.10 b  | 0.280 e <sup>-4</sup>  | 0.034 a 98  |     |       |

From a logistic model  $y = y_{max}/(1 + ((1/y_0) - 1) * \exp(-rt))$ , where  $y$  = rust severity,  $t$  = time in days after the beginning of the evaluation,  $y_{max}$  = asymptote maximum,  $y_0$  = initial inoculum and  $r$  = disease progression rate in which values followed by the same letter, in a column, do not differ according to a t-test.



**Figure 1.** Disease severity (%) progress curves of peach rust on eleven cultivars (trees) during the 2007/08 (A) and 2008/09 (B) growing seasons in an orchard in Curitiba, Paraná state, Brazil. The first symptoms were observed in December and September, for their respective seasons. Dots represent the means of six evaluations (six branches), and the solid lines represent estimates from a logistic model fitted to the data.

### PCA analysis and clustering of cultivars

When PCA was used to analyze the set of 22 cases (cultivar x year) cases three principal components (PC<sub>1</sub>, PC<sub>2</sub> and PC<sub>3</sub>) were selected that accounted for 76.9% of the total variance, and all had eigenvalues >1 (Table 3). AUDPC, y<sub>0</sub> and r were the variables that best described the diseases and contributed to 24.16%, 22.97% and 33.76%, respectively, of the total variance in each of these components (data not shown). These three variables showed the highest correlation with the axes (Table 4).

**Table 3.** Principal component analysis of the twenty two epidemics of leaf rust (*Tranzschelia discolor*) monitored during two consecutive growing seasons (2007/08 and 2008/09), in eleven peach cultivars, in Curitiba, Paraná State, Brazil.

| Variable  | PC <sub>1</sub> <sup>*</sup> | PC <sub>2</sub> | PC <sub>3</sub> |
|---|------------------------------|-----------------|-----------------|
| Eigenvalues   | 3,504                        | 2,182           | 1,241           |
| % Variance  | 38,93                        | 24,25           | 13,79           |
| TFS Time in days to the first leaf symptoms             | 0,208                        | 0,459           | 0,435           |
| TMS Time in days to reach maximum severity              | 0,114                        | 0,389           | 0,526           |
| MSL Maximum severity for a single leaf of the branch    | 0,467                        | 0,077           | 0,253           |
| MSB Maximum average severity for all leaves on a branch | 0,457                        | 0,255           | 0,190           |
| DEFOL Defoliation                                       | 0,447                        | 0,128           | 0,193           |
| AUDPC Area under the severity progress curve            | <b>0,492</b>                 | 0,154           | 0,063           |
| Y <sub>max</sub> Maximum incidence                      | 0,202                        | 0,409           | 0,232           |
| y <sub>0</sub> Initial inoculum                         | 0,055                        | <b>0,479</b>    | 0,033           |
| R Epidemic progression rate                             | 0,176                        | 0,359           | <b>0,581</b>    |

\*PC= principal components; †eigenvalues and variance associated with the components; ‡eigenvectors of the variable resistance of 11 cultivars of peach trees to *T. discolor* in the 2007/08 and 2008/09 seasons. The variables in bold correspond to 24.16%, 22.97% and 33.76% of the variance descriptors in each of the original components, PC<sub>1</sub> to PC<sub>3</sub>, respectively

**Table 4.** Principal component analysis in the evaluation of the resistance of eleven peach tree cultivars to rust (*Tranzschelia discolor*) over two seasons (2007/08 and 2008/09) in Curitiba-Paraná State, Brazil.

| Variables   | 2007/08 season      |                 | 2008/09 season  |                 |
|---|---------------------|-----------------|-----------------|-----------------|
|   | PC <sub>1</sub>     | PC <sub>2</sub> | PC <sub>1</sub> | PC <sub>2</sub> |
| Eigenvalues   | 3,879               | 2,394           | 4,474           | 2,197           |
| % Variance  | 44,10               | 26,60           | 49,71           | 24,42           |
| TFS Time in days to the first leaf symptoms             | -0,247 <sup>†</sup> | 0,448           | 0,092           | 0,511           |
| TMS Time in days to reach maximum severity              | -0,181              | <b>0,515</b>    | -0,349          | 0,286           |
| MSL Maximum severity for a single leaf of the branch    | 0,381               | 0,374           | 0,435           | 0,080           |
| MSB Maximum average severity for all leaves on a branch | 0,407               | 0,331           | <b>0,426</b>    | 0,093           |
| DEFOL Defoliation                                       | 0,427               | -0,084          | 0,316           | -0,244          |
| AUDPC Area under the severity progress curve            | <b>0,482</b>        | -0,085          | 0,386           | -0,288          |
| Y <sub>max</sub> Maximum incidence                      | 0,182               | 0,463           | 0,336           | -0,186          |
| y <sub>0</sub> Initial inoculum                         | 0,243               | -0,076          | 0,333           | 0,431           |
| R Epidemic progression rate                             | -0,297              | 0,227           | -0,163          | <b>-0,528</b>   |

\*Principal component; †Eigenvalues and variance associated with the components; ‡Eigenvectors of the variables of resistance of 11 cultivars of peach trees to *T. discolor*.

PCA analysis of the data from the 2007/08 season showed that two components, PC<sub>1</sub> and PC<sub>2</sub>, accounted for 71% of the total variance, with an eigenvalue greater than 1 (Table 4). AUDPC and TMS were significantly correlated with the axes (p <0.05, data not shown) and were the

variables that showed the highest coefficients (0.94 and 0.80, respectively), contributing to 23.25% and 26.57% of the total variance in each of these main components.

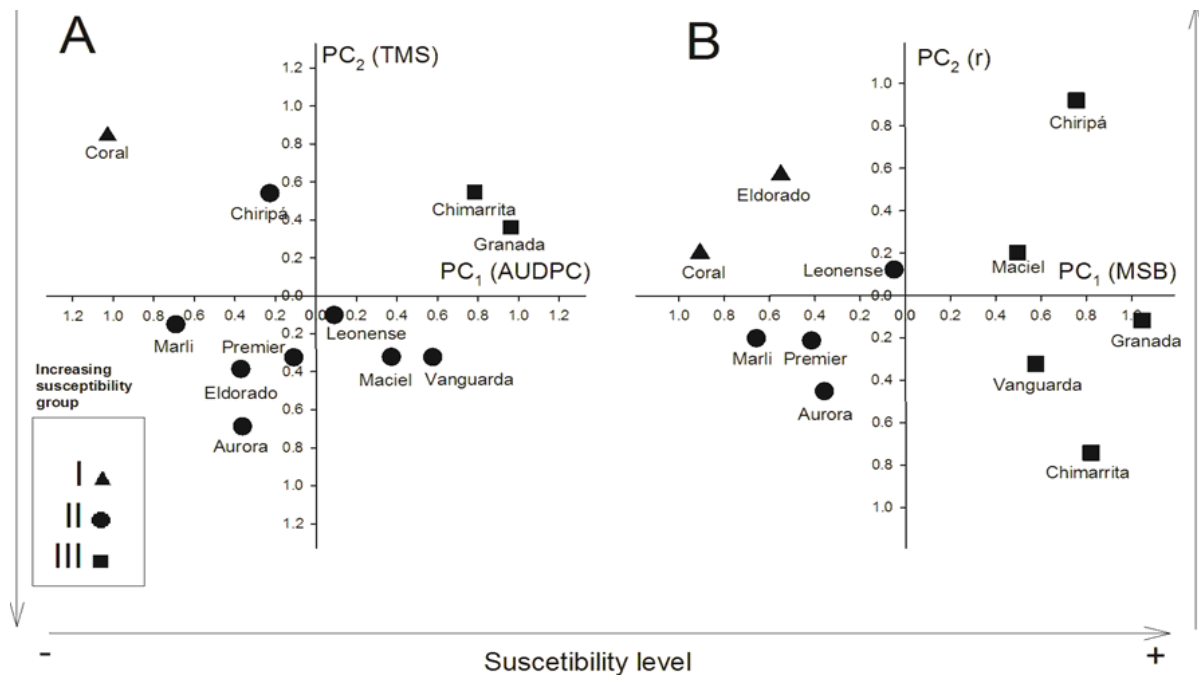
For the data from the 2008/09 season, PC<sub>1</sub> and PC<sub>2</sub> again accounted for 74% of the total variation (Table 4), and the variables MSB and r had the highest coefficients in PC<sub>1</sub> and PC<sub>2</sub>, respectively, explaining 29% and 28% of the total variance in each of these components (Table 4). These components were significantly correlated with the axes (p <0.05), being equal to 0.92 between PC<sub>1</sub> and MSB and -0.78 between PC<sub>2</sub> and r (data not shown). The correlation between variables and axes, as well as the sharpness of the clusters, were used to define the clusters of the cultivars for each year (Figure 2).

### Discussion

In this study, the logistic model had a good fit to the temporal data of rust severity in eleven peach cultivars, or the typical polycyclic nature of this rust disease. In a previous epidemiological study conducted in a temperate climate, no single model could adequately fit most datasets of rust incidence (not severity) progress from California, United States (SOTO-ESTRADA; ADASKAVEG, 2004). The authors hypothesized that the various patterns of the progress curves were likely influenced by seasonal variations in the onset of the disease and observed that the logistic model best described epidemics in which onset was later in the growing season.

According to Bergamin Filho and Amorim (1996), overwintering and the early build-up of inocula for rust epidemics would be enhanced under subtropical compared to temperate climate conditions. The early availability and uniformity of primary inoculum levels for the epidemics assessed in this study are evident based on the lack of difference in the estimated values of the initial inoculum (y<sub>0</sub>) parameter among the cultivars. This suggests that strategies for managing peach rust in the studied region should aim to reduce the epidemic progress rate, either through the use of fungicide sprays or by growing cultivars that show slow rust progress (JEGER, 2004).

The clear differences in disease onset timing and, consequently, the time to reach maximum severity, when comparing the two years in our study, is probably due to a more favorable environmental condition during the 2008/09 growing season, which led to earlier onset and enhanced rust development. The Chimarrita and Granada cultivars had rates approximately two times higher than those observed in 'Coral', which could be related to the quantitative or partial resistance conferred by minor genes, as suggested in previous studies in the region.



**Figure 2.** Grouping of the cultivars of peach trees according to susceptibility to leaf rust (*Tranzschelia discolor*) in the 2007/08 (A) and 2008/09 (B) growing seasons in an orchard in Curitiba, PR, Brazil. Susceptibility increases with the increasing order of roman numerals, according to which the arrows are defined by correlations between the variables area under disease progress curve (AUDPC) ( $r = 0,94$ ), maximum severity on a branch (MSB) ( $r = 0,92$ ) with principal component 1 (PC<sub>1</sub>) and time to reach maximum severity (TMS) ( $r = 0,80$ ), and epidemic progress rate ( $r = -0,78$ ) with the principal component 2 (PC<sub>2</sub>) in their seasons.

For example, Assmann et al. (2010) analyzed 29 peach genotypes grown in the southwestern region of the state of Paraná, Brazil, and suggested that the variable levels of susceptibility, which were determined based on single-time assessments of incidence, severity and defoliation, were due to the horizontal resistance in some cultivars. Similarly, Citadin et al. (2010) evaluated 36 cultivars of peaches in the same geographic region and also found no immune reaction, and they associated the different reactions among the cultivars with variations in the weather conditions from one year to another.

In our study, the highest rust severity levels were observed in 'Chimarrita' (24.8%) and 'Granada' (23.8%). Citadin et al. (2010), when evaluating the maximum severity of these same cultivars in southwestern Paraná, also observed significantly higher values for the Chimarrita cultivar (45%). As for defoliation, 'Chimarrita' reached a maximum of 93% in the present study, whereas 'Chimarrita' showed 58.8% defoliation in southwestern Paraná (CITADIN et al., 2010). Such differences may be due, among other factors, to varying the seasonal inoculum levels and environmental conditions as well as the nutritional status of the tress.

Early defoliation can affect plant growth and, consequently, reduce peach yields in Brazil (ALVES; MAY DE MIO, 2008). Defoliation was

significantly correlated with disease severity in both years. Similar findings were reported by Assmann et al. (2010) ( $r = 0.79$ ,  $p < 0.01$ ) for a distinct set of cultivars. 'Chimarrita' and 'Granada' showed defoliation levels  $>80\%$ , while 'Coral' and 'Eldorado' maintained leaves longer, with higher resistance levels. These results are in agreement with those obtained by Assmann et al. (2010), who observed significantly higher plant foliage in resistant cultivars when compared to more susceptible cultivars.

The multivariate analysis we used allowed the identification of AUDPC as the best variable to synthesize the set of 22 cases, and this may be due its nature of integrating aspects related to both the initial inoculum and disease progress. AUDPC is typically used in studies aimed at measuring the components of the quantitative resistance of plants to pathogens (JEGER; VILJANEN-ROLLINSON, 2001) and has been previously used to compare peach rust epidemics in Brazil (CITADIN et al., 2010). Moreover, AUDPC was significantly correlated to other variables, such as time to the first rust symptom, severity variables and defoliation.

Cluster analysis of epidemics within a growing season allowed us to distinguish three distinct groups of cultivars (I to III) in order of increasing

rust susceptibility. The Coral cultivar was consistently positioned in the least susceptible group, regardless of the year and variables used as the principal components, which suggests the quantitative nature of rust resistance in peach trees (ASSMANN et al., 2010). However, a lack of consistency in the classification of cultivars was observed in our dataset, which may have been influenced by varying environmental conditions that affect the expression of horizontal resistance. The displacement of cultivars from group II in the 2007/08 season to group III in the 2008/09 season, for example, may be due to highly favorable weather conditions for epidemics that developed in the second season (Table 1 and Table 2). The confounding environmental effect when determining disease resistance should not be disregarded when evaluating quantitative disease resistance in plant breeding programs (IRFAQ et al., 2009), which can be attenuated by maintaining and evaluating germplasm in distinct locations and historical series of the detailed epidemic data (CHERIF et al., 2010).

## Conclusion

The peach rust epidemic development in southern Brazil is strongly influenced by both weather and genetic resistance of the cultivars, which suggests that disease control can be enhanced by using less susceptible genotypes.

Coral cultivar was consistently grouped in the low susceptibility group and 'Chimarrita' and 'Granada' in the high susceptibility group.

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*Received on May 16, 2012.*

*Accepted on September 20, 2012.*

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