Susceptibility to Rust (*Puccinia* Sp.) in Cultivars of Italian and Perennial Ryegrass Grown in Two Locations of Italy

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**Abstract**

A large set of foreign varieties of Italian ryegrass (*Lolium multiflorum*) and perennial ryegrass (*L. perenne*) were evaluated for their response to natural rust infection in two Italian locations (Lodi in the north; Perugia in the centre of the country) at three-year intervals in 2001, 2004 and 2007, to acquire information on novel germplasm for Italy and verify any spatial and temporal variation in the varietal response to the disease. Crown rust (caused by *Puccinia coronata*) on Italian ryegrass and stem rust (caused by *P. graminis*) on perennial ryegrass were consistently recorded in appreciable amount (average susceptibility score > 2.0 on a 1-9 scale). Vice-versa, crown rust on perennial and stem rust on Italian ryegrass seldom affected appreciably the crop. Strong interactions of variety response (to the prevailing pathogen) with locations and years of evaluation were observed in both ryegrasses. Subsequently, the repeatability of results between locations, or between years within locations, as measured by rank correlations of variety scores, was sometimes only moderate or low. However, despite such interactions, a few promising varieties were identified in each species with consistently low susceptibility across evaluation environments, which deserve further investigation for a possible direct utilisation, or as donors of useful genes for breeding purposes.

**Key-words**: *Lolium multiflorum*, *Lolium perenne*, *Puccinia coronata*, *Puccinia graminis*, rust, ryegrass.

**Introduction**

Italian ryegrass (*Lolium multiflorum* Lam.) and perennial ryegrass (*L. perenne* L.) are two of the most important pasture and forage grass species throughout the temperate zones of the world (Jung et al., 1996). In Italy, Italian ryegrass was extensively used in the past as a component of sown mixed grasslands, while nowadays it is a basic element of the very intensive forage-livestock system widespread in the northern plain of the country (Tomasoni et al., 2003). Perennial ryegrass, which shows a marked preference for cool and moist environments, is also largely sown in mixed swards, where its rapid germination and early seedling establishment provide early herbage production. In addition to its interesting features as a forage crop, perennial ryegrass is a very important cool-season turfgrass species worldwide (Beard, 1973).

Rust (caused by *Puccinia* sp.) is the most threatening foliar disease in ryegrasses (Jung et al., 1996), widespread throughout Europe (Potter et al., 1990) and elsewhere (Aldaoud et al., 2004). When infection is advanced, the plant surface becomes reddish/brown because of the powdery urediniospore masses. Plants may even die for the lesions and the excessive water loss. Negative economic effects of rust infections include: (i) severe losses in dry-matter yield; (ii) a reduction of water-soluble carbohydrates and, hence, of forage digestibility; and (iii) a diminished competitive ability of the plant (Potter, 1987), causing, in turn, a depletion of the stand density.

Although the chemical control of pathogens is effective, fungicide treatments may be expensive and ever less accepted by the public opinion. The availability of resistant/tolerant culti-
vars represents, therefore, the best option to control the disease. Rust resistance has generally been treated as a polygenic system, and phenotypic recurrent selection is the most adopted selection method (Kimbeng, 1999). Breeding programmes implemented in ryegrasses make use of the existing genetic variation in the response to rust in order to select the healthiest germplasm in naturally-infected field nurseries or in controlled environments under a composite inoculum (Hayward, 1977; Hides and Wilkins, 1978; Rose-Fricke et al., 1986; Clarke et al., 1997; Kimbeng, 1999). Either approach has the disadvantage, however, that physiological races of the pathogen not included in the breeding process may overcome later on the resistance of selected germplasm. Different races with variable virulence on Italian or perennial ryegrass genotypes have been reported within Europe (Potter et al., 1990; Schubiger et al., 2007a) and Australia (Aldaoud et al., 2004).

This study aimed at assessing in two different environments of Italy the response to natural rust infection in a wide range of European varieties of the two *Lolium* species. The research was carried out in the framework of a European network to monitor the susceptibility to rust of ryegrass varieties, which is promoted by the Fodder Crops and Amenity Grasses Section of Eucarpia (European Association for Plant Breeding Research) and includes over 30 sites in more than ten countries (Boller et al., 2003a; Schubiger et al., 2007b). The Italian locations of Lodi and Perugia were comprised in the network, being its two southernmost sites. The geographic distance between the two locations might imply the presence of local races of the pathogens and, hence, different levels of susceptibility in the tested varieties. The assessment was carried out thrice, at three-year intervals, to verify any temporal and/or spatial variation in the variety responses to the disease. The duration of any resistance to pathogens, which may be limited by the appearance of new virulent races, and the stability of response are indeed overriding criteria in breeding programmes.

**Materials and methods**

In 2001, 2004 and 2007 the evaluation was carried out at the same time in Lodi (45°19’ N, 9°30’ E) and Perugia (43°03’ N, 12°23’ E). The former is a typical site of the northern Italian plain, characterised by sub-continental climate, with a mean annual rainfall of 802 mm and a mean temperature of 12.2 °C. The latter location, in inner central Italy, features a transition climate between the Mediterranean and the sub-continental climate, with a mean annual rainfall of 794 mm and a mean temperature of 13.5 °C.

The experimental layout was the same in the two locations and in the three years of evaluation, with the establishment of two contiguous trials, each one according to a randomised complete block design with four replications. In each block, each variety was sown in spring at a rate of 1 g seed/m in a row-plot, 3 m long and 0.5 m apart from contiguous rows. One trial included 15 varieties of Italian ryegrass and three of hybrid ryegrass (*Lolium × boucheanum* Kunth). These latter were described as more similar to Italian ryegrass than perennial ryegrass and were, therefore, included in this trial, comprising eight diploid and ten tetraploid varieties. The other trial encompassed 33 varieties of perennial ryegrass, of which 19 were diploid and 14 tetraploid. The majority of perennial ryegrass varieties (20 out of 33), and nearly the half of Italian and hybrid ryegrass varieties (eight out of 18) were released less than ten years before the first run of the evaluation (the complete list of varieties in each trial is reported in the following Tabb. 3 and 4). As each participant in the European network was allowed to nominate two cultivars for each trial planted, and even though not all participants used their allowance completely (none of the varieties were released in Italy), the geographic origin of the tested varieties was very diversified.

The trials in Lodi received a total of 90 mm (three applications), 60 mm (two applications) and 70 mm (two applications) of irrigation in 2001, 2004 and 2007, respectively. In Perugia the trials received a total of 60 mm per year, given in two applications, viz half at sowing to enhance germination and plant establishment, and the rest after the first cut of the season. Total rainfall in the March-October evaluation period of each year was 485 mm, 517 mm and 402 mm in Lodi, and 387 mm, 536 mm and 309 mm in Perugia; respectively. In the same period of each year, the mean daily temperature was 17.6
In both locations, each *Lolium* species was mostly and consistently affected by one rust species, irrespective of the year. In particular, crown rust was always observed on Italian ryegrass, and stem rust on perennial ryegrass (Tab. 1). The alternative rust species on a given ryegrass, even when present, hardly caused severe symptoms. In most cases, the overall variety mean score for the secondary pathogen did not exceed 2.0, and thus used in the data analysis.

### Results

In both locations, each *Lolium* species was mostly and consistently affected by one rust species, irrespective of the year. In particular, crown rust was always observed on Italian ryegrass, and stem rust on perennial ryegrass (Tab. 1). The alternative rust species on a given ryegrass, even when present, hardly caused severe symptoms. In most cases, the overall variety mean score for the secondary pathogen did not exceed 2.0.
exceed 2.0, and those records were not considered in the analysis. The only exception was an appreciable crown rust attack on perennial ryegrass recorded in Lodi both in 2004 and 2007 (Tab. 1).

Table 2 summarises the results of the combined ANOVA for crown rust on Italian ryegrass, and for stem rust on perennial ryegrass. In both species, all the main factors and their interactions showed significant variation (at $P < 0.001$ in all but one case). Lodi and Perugia had different mean scores, higher in the former location for Italian ryegrass, and in the latter one for perennial ryegrass.

The scores of individual Italian ryegrass varieties in each location and year of evaluation are reported in Tab. 3. The overall mean score in the two locations varied considerably according to the year of evaluation, accounting for the 'location × year' interaction. The interaction effects involving the varieties were explained by the greatly variable response of certain varieties in different locations and/or years. For instance, Pirol, Meryl and Barprisma showed higher scores in Lodi than in Perugia in 2001, but higher scores in Perugia than in Lodi in 2007.

Despite the occurrence of remarkable inter-

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Table 2. Significance level of different sources of variation in the analysis of variance of rust susceptibility in ryegrass varieties evaluated for three years in two Italian locations.

| Source of variation | Italian ryegrass | Perennial ryegrass |
|---------------------|------------------|-------------------|
| Variety (V)         | ***              | ***               |
| Location (L)        | *                | ***               |
| Year (Y)            | ***              | ***               |
| V × L               | ***              | ***               |
| L × Y               | ***              | ***               |
| V × L × Y           | ***              | ***               |

1 Also including 3 hybrid ryegrass varieties. Rust species: *Puccinia coronata*.
2 *Puccinia graminis*.
* *, ***, significant at $P < 0.05$ and $P < 0.001$, respectively.

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Table 3. Rust susceptibility scores (1: min; 9: max) of 15 Italian ryegrass and three hybrid ryegrass varieties evaluated for three years in two Italian locations (rust species: *Puccinia coronata*). Tetraploid varieties (4x) are indicated in parentheses and are compared to diploids by linear contrast.

| Variety | Lodi | Perugia | Lodi | Perugia | Lodi | Perugia |
|---------|------|---------|------|---------|------|---------|
| Gordo   | 7.31a| 4.32a   | 8.75a| 8.00a   | 5.71a| 5.25a   |
| Gumpensteiner | 6.93a| 4.22a   | 8.12a| 7.62a   | 6.42a| 4.75a   |
| Lema    | 7.31a| 3.82a   | 6.75a| 7.62a   | 5.08a| 4.75a   |
| Ligrande| 7.25a| 4.50a   | 6.62a| 6.87a   | 6.33a| 4.75a   |
| Lotta (4x) | 5.44a| 4.82a   | 6.75a| 7.25a   | 5.75a| 4.75a   |
| Danerco (4x) | 5.84a| 3.90a   | 6.00a| 5.87a   | 5.83a| 5.25a   |
| Pirol   | 6.50a| 3.65a   | 3.87a| 6.37a   | 2.83b| 4.25a   |
| Ellire (4x) | 5.27a| 3.20a   | 5.87a| 5.12a   | 5.29a| 3.75a   |
| Meryl   | 5.94a| 2.67b   | 4.25a| 5.25a   | 2.75b| 4.00a   |
| Fastyl  | 5.00a| 3.32a   | 4.00a| 4.87a   | 2.17b| 3.50a   |
| Barprisma| 5.25a| 2.42b   | 3.25a| 3.87b   | 1.67b| 3.75a   |
| Aberexel (4x) | 3.37b| 3.17a   | 3.62a| 3.87b   | 4.00b| 3.75a   |
| Torny (4x) | 4.05b| 2.57b   | 3.12b| 3.87b   | 3.08b| 2.75b   |
| Bolero (4x) | 3.56b| 2.70b   | 3.75b| 3.50b   | 2.54b| 3.25a   |
| Domino (4x) | 3.31b| 2.60b   | 1.87b| 4.25b   | 3.58b| 3.50a   |
| Zorro (4x) | 4.00b| 1.92b   | 2.12b| 3.62b   | 3.33b| 3.50a   |
| Caballo (4x) | 3.19b| 2.90b   | 1.50b| 3.87b   | 3.08b| 3.00b   |
| Tarandus (4x) | 3.69b| 1.90b   | 1.87b| 3.37b   | 1.25b| 2.50b   |
| Mean    | 5.18a| 3.26a   | 4.56a| 5.28a   | 3.93a| 3.94a   |
| LSD (5%)| 0.98a| 1.07a   | 1.42b| 1.44a   | 1.77a| 0.77a   |
| Diploids | 6.44***| 3.62***| 5.70***| 6.31***| 4.12 ns | 4.37*** |
| Tetraploids | 4.17 | 2.97 | 3.65 | 4.46 | 3.77 | 3.60 |

1 *Lolium × boucheanum* (hybrid ryegrass).
2 In each column, values followed by letters 'a' and 'b' do not differ from the top-ranking and bottom-ranking value, respectively, according to LSD. In italics, variety names whose values were consistently in either extreme group in all environments.
3 ns, *, ***, significant at $P < 0.05,$ $P < 0.01$ and $P < 0.001,$ respectively, according to linear contrast.
actions, some varieties showed a consistent behaviour across evaluation environments (combinations of locations and years). Gordo was top-ranking for susceptibility, and Tarandus was bottom-ranking, in four environments out of six (Tab. 3). Statistically, Gumpensteiner was also always included among the highest-susceptible varieties (Tab. 3), and Caballo was another variety of possible interest for its disease tolerance, being in the group of the least-susceptible varieties in five environments out of six (Tab. 3). To a large extent, the inconsistency of variety responses across evaluation environments in perennial ryegrass varieties appeared to be greater than in Italian ryegrass varieties (Tab. 4). As a matter of fact, several perennial ryegrass varieties showed marked inconsistency, such as Arabella, Kells, Litempo, Helmer, Sponsor, Barnhem or Foxtrot, just to mention some of them (Tab. 4). In particular, the individual

| Variety | 2001 | 2004 | 2007 |
|---------|------|------|------|
| Lipresso | 6.37 a | 5.00 | 7.50 a | 6.87 a | 5.55 a | 3.25 a |
| Aurora | 6.62 a | 4.85 | 4.00 | 6.75 a | 4.00 | 3.50 a |
| Corbet | 6.69 a | 5.77 a | 3.87 | 5.75 | 3.37 | 3.25 a |
| Fennema | 5.81 a | 5.50 a | 3.62 | 5.87 a | 2.50 | 3.00 a |
| Arabella | 6.37 a | 5.42 a | 3.37 | 5.50 | 4.37 a | 3.75 a |
| Vincent | 5.00 | 5.32 a | 4.37 | 5.37 | 2.87 | 3.50 a |
| Heraut | 4.62 | 5.42 a | 5.00 | 5.00 | 2.12 b | 3.50 a |
| Gladio | 4.94 | 4.35 | 5.62 | 4.87 | 3.25 | 2.75 |
| Weigra | 6.19 a | 5.42 a | 2.12 b | 5.25 | 4.75 a | 3.50 a |
| Kells | 5.94 a | 5.27 a | 2.87 | 4.87 | 3.06 | 3.50 a |
| Guru | 4.75 | 4.07 | 3.50 | 6.25 a | 2.75 | 3.25 a |
| Litempo (4x) | 3.61 | 3.85 | 6.25 a | 4.62 | 3.00 | 2.75 |
| Roy (4x) | 3.44 | 3.67 | 6.00 | 4.87 | 1.62 b | 2.00 a |
| Helmer (4x) | 3.19 | 4.30 | 6.00 | 4.37 | 2.00 b | 3.25 a |
| Sirocco (4x) | 4.75 | 4.07 | 4.25 | 4.75 | 2.75 | 2.75 |
| Condesa (4x) | 4.05 | 3.57 | 5.00 | 5.12 | 1.62 b | 2.75 |
| Option | 4.00 | 5.82 a | 2.62 | 5.00 | 3.50 | 4.00 a |
| Sponsor | 4.94 | 5.40 a | 1.87 b | 4.75 | 2.94 | 3.50 a |
| Lacerta (4x) | 3.81 | 3.47 b | 5.12 | 4.50 | 3.25 | 2.50 |
| Barnhem | 4.75 | 4.27 | 1.87 | 5.25 | 4.00 | 3.25 a |
| Terry (4x) | 3.06 b | 3.32 b | 4.75 | 5.00 | 2.37 b | 2.25 b |
| Aristo | 4.00 | 4.57 | 2.75 | 4.50 | 2.50 | 2.50 |
| Awerdard | 3.75 | 3.67 | 3.50 | 4.62 | 1.75 b | 2.50 |
| Kentaur (4x) | 3.02 | 3.75 | 3.87 | 4.75 | 2.06 b | 2.50 |
| Foxtrot | 4.37 | 4.75 | 1.25 b | 4.62 | 2.37 b | 3.25 a |
| Tivoli (4x) | 3.50 | 3.52 | 3.37 | 4.50 | 1.75 b | 1.75 b |
| Orval | 3.25 | 4.15 | 3.37 | 3.87 b | 1.62 b | 2.25 b |
| Carrera | 4.25 | 3.47 b | 1.25 b | 4.25 | 2.50 | 2.50 |
| Aubisque (4x) | 2.56 b | 4.17 | 1.62 b | 4.00 b | 1.62 b | 2.50 |
| Pastoral (4x) | 2.37 b | 3.07 b | 2.00 b | 3.50 b | 1.62 b | 1.75 b |
| Elgon (4x) | 3.00 b | 3.07 b | 1.12 b | 3.75 b | 1.75 b | 1.75 b |
| Bocage (4x) | 2.75 b | 3.82 | 1.37 b | 3.00 b | 1.62 b | 2.50 |
| Gwendal (4x) | 2.11 b | 2.75 b | 1.12 b | 3.50 b | 1.12 b | 1.25 b |
| Mean | 4.30 | 4.33 | 3.52 | 4.83 | 2.66 | 2.81 |
| LSD (5%) | 1.01 | 0.74 | 1.42 | 1.01 | 1.33 | 1.15 |
| Diploids | 5.08 *** | 4.87 *** | 3.38 ns | 5.22 *** | 3.14 *** | 3.18 *** |
| Tetraploids | 3.23 | 3.60 | 3.70 | 4.30 | 2.01 | 2.30 |

1 In each column, values followed by letters 'a' and 'b' do not differ from the top-ranking and bottom-ranking value, respectively, according to LSD. In italics, variety names whose values were consistently in either extreme group in all environments.

2 ns, *, **, ***: mean values of diploid and tetraploid varieties not different and different at \( P < 0.05, P < 0.01 \) and \( P < 0.001 \), respectively, according to linear contrast.

Table 4. Rust susceptibility scores (1: min; 9: max) of 33 perennial ryegrass varieties evaluated for three years in two Italian locations (rust species: \textit{Puccinia graminis}). Tetraploid varieties (4x) are indicated in parentheses and are compared to diploids by linear contrast.
disease scores in Lodi and Perugia in 2004 seemed to be mostly inconsistent in the presence of a difference between overall location mean scores which was the largest of the three years (Tab. 4).

Nonetheless, also in perennial ryegrass some varieties were noticeable for their consistent behaviour. In particular, Pastoral, Elgon and Gwendal always appeared among the least-susceptible varieties, with Gwendal being the bottom-ranking variety in five out of six experimental conditions (Tab. 4). Because of the strong variety × year and/or variety × location interaction, no variety was consistently included among the most-susceptible ones in statistical terms. However, Lirezzo was among the highest-scoring varieties in five cases out of six, and in three cases it was the top-ranking variety, highlighting its susceptibility to stem rust (Tab. 4).

A clear and fairly consistent trend was present in both ryegrass species in most evaluation environments, with diploid varieties displaying higher susceptibility than tetraploid varieties (Tabb. 3 and 4). The same trend was also confirmed when only the 15 true L. multiflorum varieties were considered (data not reported).

The repeatability of disease assessment in different years and different locations was assessed by computing Spearman rank correlations. As for Italian ryegrass, the correlation in Lodi was fairly high between 2001 and 2004 results, but only low to moderate (although significant at $P < 0.05$) between 2001 and 2007, and between 2004 and 2007. In Perugia, all three between-year correlations were similar, with $r > 0.80$, and highly significant (Tab. 5).

Between-year correlations in perennial ryegrass were generally lower than those in Italian ryegrass, with the exception of that between 2001 and 2007, which exceeded 0.80 in both locations. The two other correlations did not reach the significance level at $P < 0.05$ in Lodi, but were significant ($r > 0.70$) in Perugia (Tab. 5).

The variety rank correlations between the two locations were significant ($P < 0.01$) in both ryegrass species (Tab. 6). However, except in 2004 for Italian ryegrass, the magnitude of the correlation coefficients was never particularly large, especially for perennial ryegrass (Tab. 6).

When $P. coronata$ was also recorded in an appreciable manner on perennial ryegrass varieties, the mean variety scores reported in Table 7 were obtained. The crown rust attack in 2007 was much milder and less able to discriminate among varieties than in 2004. Although referring to only those two evaluation environments, some varieties with consistent response to crown rust were observed. In particular, Sirocco, Helmer, Litempo and Gladio were susceptible to this disease, whereas Vincent, Weigra, Aristo and Gwendal did not show any symptom of crown rust, and other varieties were only mildly affected in 2004 (Tab. 7). Interestingly, none of the varieties most affected by crown rust appeared among the most-susceptible to stem rust (see Tab. 4). Weigra, which was symptomless to crown rust, was remarkably attacked by stem rust. Pending a confirmation under ad hoc crown rust infection trials, Pastoral, Elgon,

**Table 5. Spearman rank correlation coefficients among mean rust susceptibility scores of ryegrass varieties in three years of evaluation in two Italian locations.**

|                | Italian ryegrass | Perennial ryegrass |
|----------------|-----------------|--------------------|
|                | 2004            | 2007               | 2004            | 2007               |
| **Lodi**       |                 |                    |                 |                    |
| 2001           | 0.87***         | 0.49*              | 0.24 ns         | 0.81***            |
| 2004           | -               | 0.67**             | -               | 0.23 ns            |
| **Perugia**    |                 |                    |                 |                    |
| 2001           | 0.86***         | 0.81***            | 0.62***         | 0.86***            |
| 2004           | -               | 0.88***            | -               | 0.69***            |

1 Rust species: *Puccinia coronata*; N = 18 (including 3 hybrid ryegrass varieties).
2 Rust species: *Puccinia graminis*; N = 33.
ns, *, **, ***: not significant and significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

**Table 6. Spearman rank correlation coefficients between mean rust susceptibility scores of ryegrass varieties in two Italian locations in each year of evaluation.**

|                | Italian ryegrass | Perennial ryegrass |
|----------------|-----------------|--------------------|
|                | 2001            | 2004               | 2007               | 2001            | 2004               | 2007               |
| **Lodi vs Perugia** | 0.67**         | 0.88***            | 0.72***            | 0.74***         | 0.45*              | 0.73***            |

1 Rust species: *Puccinia coronata*; N = 18 (including 3 hybrid ryegrass varieties).
2 Rust species: *Puccinia graminis*; N = 33.
***, ***: significant at $P < 0.01$ and $P < 0.001$, respectively.
Bocage and Gwendal seemed to possess a composite resistance towards both stem rust and crown rust (Tabb. 4 and 8). The rank correlation coefficient between the mean score for the two pathogens was positive and significant in 2004 ($r = 0.70, P < 0.001$) but was not different from zero in 2007 ($r = -0.21, P > 0.22$), where the results for crown rust were at the limit for consideration (mean score = 2.12) and probably less reliable than those in 2004.

In 2004 no significant difference was found in mean susceptibility to crown rust in diploid and tetraploid perennial ryegrass varieties. In 2007 a significantly higher mean score was observed in tetraploid than in diploid varieties, although both values were rather low on the infection scale (2.93 vs. 1.52, $P < 0.05$, respectively).

### Discussion

Boller et al. (2003a) and Schubiger et al. (2007b) summarised the European network’s results for the first (2001) and second (2004) year of evaluation, respectively. The present findings agree with the observations at the continental level (across 30 sites) reporting crown rust as the sole rust species seriously affecting Italian ryegrass, and stem rust being present on perennial ryegrass almost exclusively in eastern and southern Europe. Stem rust is primarily a warm-weather disease (Leonard and Szabo, 2005). The predominance of crown rust also on perennial ryegrass in central and northern Europe and in Australia, where this forage species is widespread, makes this pathogen to be perceived as the most important fungal pathogen on ryegrasses (Potter et al., 1990; Roderick and Thomas, 1997; Aldaoud et al., 2004) and arises vast interest on the crop resistance to this disease (e.g. Wilkins, 1978a; 1978b; Roderick et al., 2000; Muylle et al., 2005; Schejbel et al., 2007; Studer et al., 2007; Sim et al., 2007).

Considering the distribution of the two pathogen species in Europe, specific breeding programmes for the enhancement of stem rust resistance in areas where this species occurs would be advisable. Nowadays, most perennial ryegrass selection is carried out in regions especially prone to crown rust, and the risk may exist of varieties selected under this pathogen’s pressure to be misadapted where stem rust predominates. The present results seem to reassure that some perennial ryegrass varieties are provided with a possible resistance/tolerance to both rust species. A thorough confirmation of their response to crown rust (by *P. coronata* f. sp. *lolii*) in Italian environments would be needed, given the occasional occurrence of this species during the evaluation. However, at least Gwendal, Bocage and Pastoral have shown a generalised tolerance to crown rust across Europe (Schubiger et al., 2007b). Apart from a few varieties, in the current investigation there seemed to be a weak correspondence of variety

### Table 7. Susceptibility scores (1: min; 9: max) to *Puccinia coronata* of 33 perennial ryegrass varieties in Lodi.

Tetraploid varieties (4x) are indicated in parentheses; all other varieties are diploid.

| Variety  | 2004 | 2007 |
|----------|------|------|
| Lipresso  | 6.00 | 2.00 |
| Aurora   | 6.00 | 2.00 |
| Corbet   | 5.00 | 2.00 |
| Fennema  | 6.25 | 3.00 |
| Arabella | 5.00 | 1.00 |
| Vincent  | 1.00 | 1.00 |
| Heraut   | 5.75 | 1.00 |
| Gladio   | 7.50 | 4.50 |
| Weigra   | 1.00 | 1.00 |
| Kells    | 4.25 | 1.00 |
| Guru     | 4.25 | 1.00 |
| Litempo (4x) | 7.25 | 5.75 |
| Roy (4x) | 6.50 | 3.00 |
| Helmer (4x) | 8.00 | 6.00 |
| Sirroco (4x) | 8.75 | 6.50 |
| Condesa (4x) | 8.25 | 3.75 |
| Option   | 4.75 | 1.00 |
| Sponsor  | 2.50 | 1.00 |
| Lacerta (4x) | 7.50 | 1.00 |
| Barnhem  | 3.50 | 1.25 |
| Terry (4x) | 5.25 | 1.00 |
| Aristo   | 1.00 | 1.00 |
| Aberdart | 7.50 | 1.00 |
| Kentaur (4x) | 4.50 | 3.50 |
| Foxtrot  | 4.50 | 1.25 |
| Tivoli (4x) | 6.75 | 3.25 |
| Orval    | 6.00 | 5.00 |
| Carrera  | 1.25 | 1.00 |
| Aubisque (4x) | 4.25 | 1.75 |
| Pastoral (4x) | 1.75 | 1.75 |
| Elgon (4x) | 2.00 | 1.75 |
| Bocage (4x) | 2.25 | 1.00 |
| Gwendal (4x) | 1.00 | 1.00 |
| Mean     | 4.70 | 2.12 |
| LSD (5%) | 1.92 | 2.20 |

In each column, values followed by letters ‘a’ and ‘b’ do not differ from the top-ranking and bottom-ranking value, respectively, according to LSD. In italics, varieties whose values were consistently in either extreme group in both years.
response to the two rust species, in analogy with

the European network’s results (Boller et al.,

2003a).

Resistance to crown rust in perennial rye-

grass may be under major gene [reported by

Potter et al. (1990)] or polygene control (Hay-

ward, 1977). More recently, the use of molecu-

lar marker systems has revealed different quan-

titative trait loci (QTLs) for resistance (Muylle

et al., 2005; Schejbel et al., 2007). A few genes

with major effects (Hides and Wilkins, 1978) and

QTLs of resistance (Studer et al., 2007) have al-

so been reported for crown rust in Italian rye-

grass, where a maternal effect on resistance has

additionally been observed (Adams et al., 2000).

Much more scanty seems to be the knowledge

on the genetic control of stem rust resistance in

perennial ryegrass. Rose-Fricker et al. (1986)

suggested that this resistance was predomin-

antly quantitatively inherited with minor and pos-

sibly some major genes. Should the occurrence

of varieties with resistance to both rust species

be further supported, a possible efficacy of cer-

tain major gene(s) and/or QTL(s) towards both

pathogens could be postulated.

The potential race-specificity of the identi-

fied resistance determinants is largely unknown.

Studer et al. (2007) found differences in posi-

tion and magnitude of QTLs among individual

evaluation locations, suggesting a differential

quantitative response to local pathogen races.

The ability of crown rust isolates to overcome

major genes conferring resistance to a range of

other isolates has been reported in Europe (Pot-

ter et al., 1990) and Australia (Aldaoud et al.,

2004). In addition to race specialisation, environ-

mental effects might also influence rust resistance

(Roderick et al., 2000). Given the array of possi-

ble combinations between genetic variation of the

pathogen and different environmental conditions,

it was no surprise to find the current strong in-

teraction effects on the varietal response to the
disease, and the sometimes only moderate or low

repeatability of response between years and/or lo-
cations. However, whether this was due to a pre-
dominant effect of races, environmental differ-
ences (for instance, the difference in moisture or

temperatures between Lodi and Perugia), or both,
cannot be ascertained.

Although in the presence of G × E interac-
tions, it was worth noting that some varieties of

both ryegrass species had a fairly consistent re-

sponse of “susceptibility” or “tolerance” across

environments. Interestingly, the varieties with

the lowest mean scores, such as Tarandus in Ital-

ian ryegrass, and Gwendal, Pastoral, Bocage and

Elgon in perennial ryegrass, were also among

the least-affected by the same pathogens at the

continental level (Boller et al., 2003a; Schubiger

et al., 2007b), thus suggesting a stability even

across more diversified sites than Lodi and Pe-

rugia. The relative stability of ranking observed

for these varieties might imply the presence of a

polygenic resistance to rust.

The trend of a greater rust tolerance in
tetraploid than diploid varieties here observed is

in line with a general opinion of a better resis-
tance to leaf diseases in tetraploid cultivars of ry-
grasses compared to diploid germplasm (Boller

et al., 2003b). However, the current results suggest

that more evidence is needed regarding the resis-
tance to crown rust in perennial ryegrass.

Greater dosage of resistance genes determined by
the chromosome doubling, or a deliberate exclu-
sion of markedly disease-susceptible diploid plants
from the polyploidisation process, are both reasons
for the possible advantage of tetraploids over the
diploids in disease tolerance. The theo-
retical approach proposed by Oswald and Nuis-
mer (2007) suggests that, in the presence of a
gene-for-gene or an inverse matching alleles mod-
el of genetic mechanism of pathogen resistance,
tetraploids are expected to be more resistant than
their diploid progenitors.

This study brought forward the great varia-
tion in rust susceptibility in Italy of a large set
of varieties, which had never been evaluated be-
fore in this country. The varietal response ap-
peared to be possibly influenced by external fac-
tors (environmental conditions and/or physio-
logical races of pathogens), and the repeatabil-
ity of results subsequently affected. The vari-
eties with consistently low susceptibility might
have a potential for direct introduction into cul-
tivation (provided other agronomic features are
at least satisfactory and appropriate for the lo-
cal conditions) and/or as possible donors of use-
ful genes for breeding purposes.

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