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Effects of agro-pedo-meteorological conditions on dynamics of temperate rice blast epidemics and associated yield and milling losses

S. Bregaglio[a,1,*], P. Titone[b], L. Hossard[c], G. Mongiano[b], G. Savoini[d], F.M. Piatti[d], L. Paleari[e], A. Masseroli[d], L. Tamborini[b]

[a] CREA – Council for Agricultural Research and Economics, Research Centre for Agriculture and Environment, via di Corticella 133, I-40128 Bologna, Italy
[b] CREA – Council for Agricultural Research and Economics, Research Centre for Plant Protection and Certification, Strada Statale 11 per Torino km 2.5, I-13100 Vercelli, Italy
[c] INRA, UMR951 Innovation, F-34060 Montpellier, France
[d] Students of the bachelor course in Agricultural and Food Science, Università degli Studi di Milano, Via Celoria 2, I-20133 Milan, Italy
[e] Università degli Studi di Milano, Department of Economics, Management and Quantitative Methods, Cassandra lab, via Celoria 2, I-20133 Milan, Italy

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ABSTRACT

Rice blast disease is a threat for European rice growers, who apply chemical treatments each year to limit its impact on rice yield and milling quality. Good agronomic practices such as varietal choice and reduced nitrogen fertilization can also be effective in limiting the impact of the disease, which largely varies across sites and growing seasons. Here we present a three-year experiment (2013–2015), in which blast disease severity was dynamically sampled on four varieties grown with two nitrogen doses (standard and double farmer fertilization) in three sites located in Northern Italy (i.e., the largest European rice district). No chemical treatments were applied on these experimental plots, which were compared to blast-treated controls. Field yield and yield after milling (t ha^{-1}) were measured to assess the impact of rice blast. Disease progress curves of leaf and panicle blast were analyzed via F-test for site, nitrogen dose, rice variety, and year. The areas under disease progress curves were correlated with yield losses via linear regression. Finally, a 4-way analysis of variance was performed using field yield losses and head rice yield as dependent variables.

Results: Blast epidemics were significantly affected by all the factors considered, with rice variety and year as the most important sources of variability. Areas under disease progress curves were significantly correlated with losses in field yield and even more in yield after milling, with panicle blast proving to be the most impactful symptomatology. Year and variety ranked first and second among the factors explaining yield losses, both in field and after milling. These results confirm the effectiveness of varietal choice to reduce blast impact, indicating that fungicide applications should be conditional to the conduciveness of weather conditions.

1. Introduction

Rice blast disease (causal agent *Magnaporthe oryzae* B.C. Couch) is present in 85 rice-growing countries (Kato, 2001), and represents a global threat to food security and farmers' income (IRRI, 2006). It is responsible of yield losses up to 50–100% (Ou, 1985; Liu et al., 2016), with annual losses representing food for 60 million people (Pennisi, 2010). Recent estimates report that the blast fungus is responsible for up to 30% of losses in global rice production (Skamnioti and Gurr, 2009; Nalley et al., 2017), and the annual cost of chemical control can reach over $70 ha^{-1} (Nalley et al., 2016), leading to the largest fungicides expenses among all fungal plant diseases (Illana et al., 2013).

The pathogen can colonize all the aerial plant organs at all growth stages (Wang et al., 2014), and leads to distinct symptoms when it attacks the leaves and the panicles (Kobayashi et al., 2001). On the leaves, it causes necrotic elliptical-shaped lesions, which vary in number and size according to environmental conditions and cultivar resistance (Piotti et al., 2005). The effect of leaf blast (LB) on yield losses is indirect, and it is mainly due to the reduction of photosynthetic rate and the increase in leaf respiration, both affecting CO_2 assimilation of the single leaves (Bastiaans, 1991; Bastiaans et al., 1994). Leaf blast impact on leaf tissue was estimated to extend roughly three times beyond the area covered by the visible lesion (Bastiaans, 1993a).

Panicle blast (PB) is considered to be the most serious

* Corresponding author.
E-mail address: simoneugomaria.bregaglio@crea.gov.it (S. Bregaglio).
[1] The research of this paper was partially carried out while the author was at Università degli Studi di Milano, DiSAA, via Celoria 2, I-20133 Milan, Italy.

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symptomatology of the disease (Goto, 1965; Zhu et al., 2005). Its symptoms appear when the fungus develops on the neck node at early grain filling stage, determining necrosis that leads to a premature death of the entire panicle (Gianessi and Williams, 2011). It causes direct yield losses (Shim et al., 2005) due to a reduction in grain weight and in the number of ripe spikelets and fully mature grains (Teng et al., 1990). The lesions in the upper leaves are the main inoculum source for the asexual fungal spores causing PB (Kobayashi et al., 2016; Ghatak et al., 2013). In case of late outbreaks during rice maturity phase, the fungus can also colonize panicle branches, spikes, and spikelets, reducing the remobilization of carbohydrates to the rice grains, which is often subject to breakages (Agarwal et al., 1989) and therefore present lower milling quality (Webster and Gunnel, 1992). PB impacts are known to be larger in temperate environments than in the tropics (Ou, 1985; Bonman et al., 1991), even if the number of monocycles during a growing season is roughly half in the former (Teng, 1994).

Italian rice agriculture is a typical example of a temperate environment where blast largely affects the variability of the national rice production (Bregaglio et al., 2016). Italy is the top rice growing country in European Union, contributing to 55% of the total production (Casati, 2013), with a harvested area of 234,134 ha in 2016 (Ente Nazionale Risi, 2016a) and a total production of 1,386,100 t (FAOSTAT, 2016). Rice cultivation is performed in paddy fields under continuous flooding during most part of the crop cycle (Hill et al., 1991), with two to four water drainages to allow rooting during crop establishment, top-dressing fertilizations at tillering and/or panicle initiation, herbicide spraying and harvesting (Fusi et al., 2014).

Italian rice growers can control blast epidemics combining agronomic practices and chemical sprays. The former includes low doses of nitrogen (Piotti et al., 2005) and adopting partially resistant varieties (Faivre-Rampant et al., 2011). However, resistant or partially resistant varieties are not currently widespread, as rice in Italy is mainly produced for traditional "risotto" dishes, leading farmers to grow blast susceptible varieties which are more suitable for the preparation of these dishes and have high quality value (Titone et al., 2015). The impact of blast disease on rice yields does vary among years, being strictly dependent upon the agro-pedo-meteorological conditions during the growing season, with conducive weather represented by durable presence of leaf wetness and optimal temperature in the range 19–24 °C (Nunes Maciel, 2011; Kim et al., 2015). Nonetheless, rice growers typically apply chemical control two times during the growing season, at early-boot stage and right after heading to limit the occurrence of PB (Padovani et al., 2006), based on the specific rice variety, nitrogen management, and the pedo-environmental conditions that can largely modulate the impact of blast disease.

The main objective of this study is to quantify the effects of agro-pedo-meteorological conditions on temperate rice blast epidemics, and on the associated yield losses. We divided our analyses in three parts. Our first objective is to characterize the dynamics of LB and PB in three sites located in Northern Italy, using field data collected in a three-year experiment testing alternative nitrogen applications and rice cultivars. The second objective is to quantify the contribution of LB and PB blast severity in explaining field (FYL, %) and milling (MYL, %) yield losses. The final objective is the assessment of the impact of the different agro-pedo-meteorological factors on the variability of FYL and MYL.

2. Materials and methods

2.1. Description of the field experiments

2.1.1. Study area and experimental sites

The experimental trials were carried out in the 2013, 2014 and 2015 cropping seasons in three Italian sites located in the provinces of Pavia (Confienza), Vercelli (Collobiano) and Novara (Garbagna Novarese) (Fig. 1). The total rice area covered by these provinces accounts for 81% of the total Italian rice area (82% of national production) and 47% of the EU rice cropped area (39% of EU production) (Ente Nazionale Risi, 2016a).

The pedo-meteorological conditions of the experimental sites are presented in Table 1. Weather data were retrieved by the weather stations of the Regional Agency for Environmental Protection (ARPA, Assessorato Agricoltura – Settore Fitosanitario). The average temperature during the rice growing season (May-September) was similar in the three years and ranged between 20.16–22.55 °C, however precipitation amounts varied, with 206.4 mm in Garbagna Novarese in 2013 as the driest cropping season and 424.2 mm in Confienza as the wettest one in 2013. Confienza and Garbagna Novarese have a silt loam soil, the former with a lower percentage of soil organic matter (1.8% compared to 2.16%) and a higher cation exchange capacity (14.7 cmol kg^{-1} clay, compared to 10.4 cmol kg^{-1} clay). The soil texture in Collobiano is loam, with a high percentage of soil organic matter (2.76%) and a medium cation exchange capacity (11.2 cmol kg^{-1} clay).

2.1.2. Field experiment design and management

In each site, four Italian rice varieties (i.e., Gladio, Balilla, Deneb and Vialone nano) were grown with two nitrogen levels (8 combinations). Nitrogen levels corresponded to the fertilizer dose applied by the farmer (N1), and to a double dose (N2). Each combination was tested in a plot of 8 m × 6 m, all plots were located in a unique field in each site.

No fungicide treatments were applied in the three cropping seasons. In the same fields control plots were grown, for each variety, with N1 with the application of chemical control against blast disease (1 or 2 applications of tricyclazole at 75% a.i. w/w, wettable powder, of 0.5 l ha^{-1} commercial formulation Beam®) to determine attainable yield (van Ittersum and Rabbinge, 1997). Experimental trials were carried out under flooded conditions, with rice seeds soaked in water for 48 h and then broadcast sown. Weeds were controlled with pre-sowing (Oxadiazon, Ronstar FL, 0.75 l ha^{-1}) and post-emergence (Penoxulam, Viper, 2 l ha^{-1}) treatments. Sowing operations in 2013–2015 were performed in the first week of May, and two top-dressing fertilizations were performed during the cropping seasons around tillering and at panicle initiation, with nitrogen doses similar to those typically applied in the farms hosting the experimental trials (Table 2). The set-up of the field trials was performed by the Research Centre for Plant Protection and Certification of the Council for Agricultural Research and Economics.

2.1.3. Characteristics of the rice varieties

The main features of the four Italian rice varieties tested in this study are presented in Table 3. Gladio is the most resistant variety to blast disease among tested ones (3rd most cultivated variety in *Long B* merceological class), with low and medium susceptibility to LB and PB, respectively. Balilla (6th most cultivated variety in *Round* merceological class) is highly susceptible to PB and presents a medium resistance to LB. Deneb (*Medium* merceological class, not widespread) and Vialone Nano (1st most cultivated variety among *Medium* group) are highly susceptible varieties to both symptomatologies of blast disease. Gladio and Deneb present a short life cycle (135 days and 140 days from emergence to physiological maturity, respectively), whereas Balilla and Vialone Nano have a longer duration (155 and 160 days, respectively). The average height of the four varieties ranges from 72 cm for Gladio to 110 cm for Vialone Nano, with Deneb and Balilla presenting intermediate values (80–90 cm).

2.1.4. Field samplings of disease severity and yield determination

LB was weekly assessed in each growing season from July 1st to September 30th on the four top leaves (Surin et al., 1991; Prabhu and Filippi, 1993) on 20 randomly selected plants. Two or three operators carried out sampling of disease severity (DS, the percentage of diseased leaf area) using the standard scoring system proposed by the International Rice Research Institute (IRRI, 1996; Vasudevan et al., 2015). This ordinal scale presents ten classes assigned to leaves with a

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