Impact of Downy Mildew on the Yield of Quinoa

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Downy mildew (*Peronospora farinosa* (Fr.) Fr) is the most important disease of quinoa (*Chenopodium quinoa* Willd.) in the Andes. To quantify the impact of the disease on grain yield under natural conditions, a field experiment with eight quinoa cultivars with and without application of fungicides, was carried out in Huancayo, Junín, Peru (3200 m), where the crop is grown traditionally. Area under the disease progress curve (AUDPC) values were calculated, based on evaluations of disease severity (percentage leaf area affected). The cultivar Utusaya, originating from the Bolivian salt desert (200 mm annual rainfall), was strongly affected by downy mildew, which caused complete defoliation, premature maturation, and a yield loss of 99%. Even in the most resistant cultivar, yield was reduced 33%, indicating the destructiveness of this disease.

Quinoa has been cultivated in the Andean highlands for several thousand years. It is one of the most important crops in the region and has great potential because it is highly nutritious and resistant to various adverse abiotic factors such as drought, frost, and saline soils (Galwey, 1989; Jacobsen et al*.,* 1998; Jensen et al., 2000).

Downy mildew is endemic in Bolivia, Chile, Colombia, Ecuador, and Peru, where it is the most important disease of quinoa (Alandia et al., 1979; Aragón and Gutiérrez, 1992). Downy mildew has also been detected in Canada (Tewari and Boyetchko, 1990) and Europe (Hockenhull and Jacobsen, KVL, Copenhagen, Denmark, 1998, pers. comm.).

Downy mildew reduces the photosynthetic area of the plant due to the development of chlorotic and necrotic spots on the leaves and causes leaf loss. The few reports on downy mildew of quinoa deal with pathogen detection, symptom description, host specificity identification, and screening for resistance in the field (Alandia et al., 1979; Aragón and Gutiérrez, 1992; Bonifacio and Saravia, 1999; Ochoa et al., 1999; Otazú et al., 1976). Despite its importance and wide dissemination, very little is known about the effect of downy mildew on quinoa grain yield.

This work is part of the Quinoa Project CIP-Danida, whose research on downy mildew of quinoa began in 1999. Research included in the project is characterization of the pathogen using molecular and phenotypic markers, development of disease evaluation methods, and assessment of the impact of downy mildew on grain yield and quality. The objective of the study reported here was to determine the yield loss under natural, high disease conditions caused by downy mildew in eight quinoa cultivars with different agroecological adaptations.

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Materials and Methods

The trial was carried out in the experimental field of CIP, Huancayo, Junín, Peru, (3200 m) during the 1999/2000 growing season under conditions of natural downy mildew infection.

Soil and climate

The soil is characterized as clay to clay loam with a pH of 7.6–7.9. The diurnal temperature ranged from 4–9° C min and 15–26° C max, and relative humidity between 20 and 95%. Total precipitation during the growing period was 400 mm. Two additional irrigations were made.

Soil disease control

To prevent the attack of soilborne diseases caused by *Rhizoctonia* and *Fusarium*, the seeds were treated with PCNB and benomyl at sowing, and the plants treated later in the season as needed.

Cultivars

Eight quinoa cultivars with different geographical origins were included in the study: Utusaya (salt desert); LP-4B, La Molina 89 (coast); Blanca de Juli, Kancolla, and Jujuy (highlands); and Amarilla de Maranganí and Ingapirca (valley). Utusaya and LP-4B are the earliest maturing cultivars; La Molina 89, Amarilla de Maranganí, and Ingapirca the latest.

Control of downy mildew

Two weeks after sowing, treated plots were sprayed with a commercial dose of metalaxyl (systemic fungicide). Three weeks later mancozeb (contact fungicide) applications were begun. The mancozeb treatment consisted of three applications spaced one week apart. This cycle was repeated throughout the growth period to keep infection at a minimum. The last application was given at the end of the rainy season, one month before the beginning of harvest.

Experimental design

The experiment was a split-plot design with four replicates. The principal plots were those that received the fungicide treatments and the subplots were the different cultivars.

Each plot consisted of six rows 3.5 m long, with a distance between rows of 60 cm. Two rows of maize were planted between each principal plot to limit fungicide drift between treated and untreated plots. A path of 1 m was established between subplots.

Evaluations of downy mildew

Ten plants of the four center rows of each plot were selected at random for the evaluations. The first evaluation was performed 69 days after sowing (DAS) and once a month thereafter, three times in total. Disease severity was evaluated on three leaves/plant selected at random. A leaf was taken from the lower, middle, and upper part of each plant sampled, and rated according to the scale developed by Danielsen and Ames (2000). The average of the three leaves represents the disease severity value of the plant. Based on these measurements, AUDPC (area under the disease progress curve) was calculated according to the equation of Campbell and Madden (1990):

$$\text{AUDPC} = \sum_{i}^{n-1} (y_i + y_{i+1})/2 \text{ X } (t_{i+1} - t_i)$$

where n is the number of evaluations, y is disease severity, and t is the number of days after sowing when the evaluation is done; $(t, y) = (0, 0)$ is included as the first evaluation. The advantage of using AUDPC values, rather than single severity measurements, is that AUDPC reflects disease progress throughout the whole growing season. Single severity readings do not capture changes caused by environmental fluctuations.

Harvest

Seed yield was estimated from harvest of the four center rows. The number of plants in each plot was counted. Harvest was done when the plants were mature, starting 131 DAS with Utusaya and LP-4B, and ending 165 DAS with La Molina 89, Amarilla de Maranganí, and Ingapirca.

Statistical analysis

The effect of cultivar and fungicide on yield and AUDPC, and the effect of fungicide treatment on the number of plants per plot were analyzed by ANOVA. The correlation between yield and AUDPC was analyzed with correlation analysis (SAS® System version 6.12, SAS Institute Inc., Cary, NC).

Results

The plants were harvested between 131 and 165 DAS. In general, the plots without fungicide application matured between 9 and 13 days earlier than the plots with fungicide application. The number of plants/plot was reduced significantly ($P = 0.0174$) due to the effect of downy mildew. For this reason, a covariance analysis was not made to correct the yield according to the number of plants/plot.

The severity of downy mildew measured as AUDPC was significantly higher in the untreated than in the treated plots (Table 1, Figures 1 and 2). According to AUDPC values, Utusaya was the most susceptible cultivar and La Molina 89, Amarilla de Maranganí, and Ingapirca the most resistant (Figures 1 and 2). In all cultivars the level of downy mildew was kept at a minimum in the fungicide treated plots with no significant difference in AUDPC between cultivars.

Downy mildew caused a significant yield reduction in all cultivars (Table 1). Yield loss ranged between 33% (Amarilla de Maranganí) and 99% (Utusaya). The correlation analysis showed a strongly significant negative correlation between AUDPC and yield ($r = -0.73$, $P = 0.0001$).

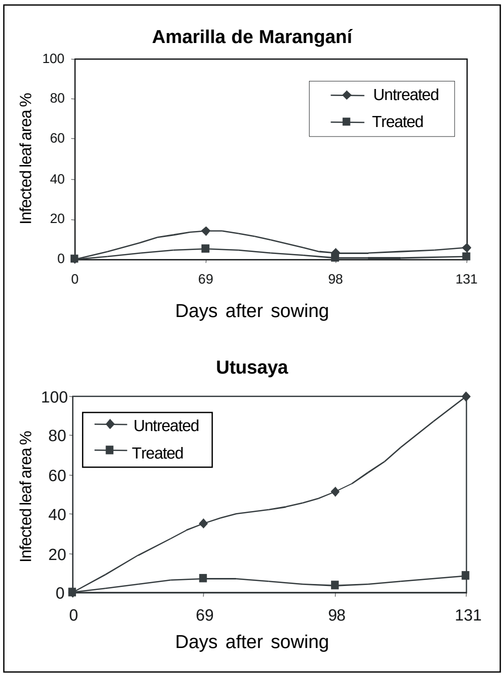

Figure 1. Disease progress curves in two quinoa cultivars with two levels of downy mildew (with and without fungicide). The difference in AUDPC for the entire growth season between treated and untreated is significant in both cultivars, P = 0.0432 and 0.0001 for Amarilla de Maranganí and Utusaya, respectively.

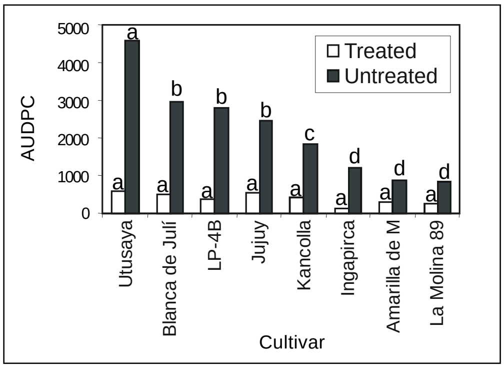

Figure 2. AUDPC values in quinoa cultivars with two levels of downy mildew (with and without fungicide). Columns marked with different letters are significantly different ($P < 0.05$). Columns for treated and untreated are compared separately.

Discussion and Conclusions

This confirms the observations of Bonifacio and Saravia (1999) who pointed out that

Table 1. Seed yield and AUDPC values in eight quinoa cultivars with two levels of downy mildew (with and without fungicide treatment).

Cultivar	Yield (kg/ha)[1]			AUDPC[2]		
	Treated[3]	Untreated	Yield loss (%)	Treated[3]	Untreated	Difference
Salt desert cultivar						
Utusaya	2106	23	99 ***	579	4636	4057 ***
Coastal cultivars						
LP-4B	4092	1021	75 ***	384	2790	2406 ***
La Molina 89	7686	3263	58 ***	256	852	596 *
Highland cultivars						
Blanca de Juli	5891	1465	75 ***	510	2976	2466 ***
Kancolla	4748	3083	35 *	408	1829	1421 ***
Jujuy	5424	1846	66 ***	544	2478	1934 ***
High altitude valley cultivars						
Amarilla de M.	7559	5073	33 ***	303	882	579 *
Ingapirca	6570	3562	46 ***	144	1207	1063 ***

Level of significance: * P = 0.05, *** P = 0.001 (ANOVA)

1 The harvested area of each plot was 8.4 m^2. The yield was converted into kg/ha by multiplying g/parcel with a factor 1.19.

2 Area under the disease progress curve.

3 The plots were sprayed with metalaxyl (systemic) and mancozeb (contact) to control downy mildew.

late cultivars in general are more resistant to downy mildew than early cultivars. That was true for the most resistant cultivars in this study: Ingapirca, La Molina 89, and Amarilla de Maranganí. Despite low AUDPC values, these three cultivars registered yield reductions ranging from 33 to 58%. This indicates that even a mild attack of downy mildew can cause a substantial reduction in seed yield. These findings may mean that the AUDPC fails to sufficiently describe the disease.

The severity measurement only considers the foliage left on the plant and not the leaves that have been shed as an effect of the disease. Furthermore, severity is a relative parameter that does not take into account total size of the plant or foliage density. However, a strongly significant negative correlation between AUDPC and yield was found, which means that under these conditions AUDPC explains most of the yield variation. Another promising method, the measurement of canopy reflectance, is presently being developed at CIP to detect late blight in potato and downy mildew in quinoa.

Because of their high susceptibility to downy mildew, cultivars originating from the Bolivian salt deserts (e.g., Utusaya) are restricted to areas with low precipitation where downy mildew is not a problem. Cultivars originating from the coast, valleys, or highlands can give satisfactory yields in the presence of downy mildew. But the 33-58% yield reductions experienced by representative cultivars from those areas used in this study demonstrate the severe effect downy mildew has on quinoa yield.

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