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Enhancing grain yield and quality of winter barley through agronomic strategies to prolong canopy greenness

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ABSTRACT

An agronomic improvement in grain yield and quality in winter wheat could be obtained through the application of strategies, such as application of foliar fungicides or fertilizers, that protect health of the last leaves and delay the senescence process during ripening. Only a few studies have reported the effect of these practices on barley, although these treatments could represent a new opportunity to specialize in feed and food barley markets and raise farmer profitability.

The aim of this study was to compare the effect of different late-season strategies, N and S foliar fertilizers and fungicides applied at barley anthesis, on crop canopy greenness during the ripening stages and to establish the relationship between these strategies and barley yield and quality. Four field experiments have been conducted in NW Italy during 3 growing seasons, according to a full factorial design with four treatments, three barley cultivars and four replications. The following parameters were recorded: canopy greenness, grain yield, test weight (TW), thousand kernel weight (TKW), grain protein content (GPC), foliar disease incidence and severity and deoxynivalenol (DON) contamination. The collected data clearly underline the importance of prolonging canopy greenness of barley in order to increase grain yield and to improve quality. Of all the compared treatments, the application of a fungicide with an azole mixture at anthesis has shown to play the most important role in delaying the senescence process, and has resulted in a higher gran yield (+25%), TW (+1.3 kg hl^{-1}) and TKW (+2.8 g).

The effect of the fungicide treatment on barley grain yield was significant for all the compared cultivars and in almost all the environmental conditions, but led to a greater advantage in the cooler environments with prolonged ripening. The fungicide also led to a clear, significant control of foliar disease and a reduction in DON contamination.

The use of N and S foliar fertilizers was able to prolong canopy greenness and enhance barley yield and quality but only in environments characterized by a prolonged grain filling period.

1. Introduction

Barley (*Hordeum vulgare* L.) is the fourth most important crop in the world, after wheat, maize and rice; in Italy the crop is equally distributed throughout the territory with 6.8 million t produced each year (Ansovini, 2009). Although this crop is characterized by a lower production cost than other cereals, and it can also be adapted to marginal environments, the barley surface has gradually been decreasing in the recent years. This reduction could be related to low trade prices, low incomes, poorly characterized supply chains and a lack of specific field programs.

In Italy, winter hexastichous barley, which is normally used for animal feed is the most commonly grown type. However, the use of barley for food production, as pearled kernels, and for beverage in the malting industry, is increasing, and is generally based on distichous varieties. The use of barley in the food chain can be considered a new economic opportunity, but barley kernels with a high kernel size and test weight (TW) are required (Błażewicz et al., 2007) together with a low occurrence of contaminants (Lancova et al., 2008). Therefore, an improvement of the crop techniques in order to increase grain yield, grain protein content (GPC) and sanitation of this crop, could be a new opportunity to specialize feed and food barley and raise farmer profitability.

An improvement in yield and in the technological and sanitary quality in winter wheat could be obtained through the application of strategies that protect the health of the last leaves and delay the

Abbreviations: AUCGC, area under canopy greenness curve; DON, deoxynivalenol; FHB, fusarium head blight; GDDs, growing degree days; GS, growth stage; GPC, grain protein content; STNB, spot-type net blotch; TW, test weight; TKW, thousand kernel weight.

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senescence process during ripening (Blandino and Reyneri, 2009). The duration of the photosynthetically active leaf area, for which the role of the last leaves is crucial, positively affects grain yield (Gooding et al., 2000; Zhang et al., 2010), the kernel size and its quality (Entz et al., 1990). The chlorophyll concentration of the plant is related to several factors, but is primarily influenced by the N status in the leaves, and the N fertilization rate clearly affects canopy greenness.

The practice of adding a foliar N fertilizer at anthesis to a mineral fertilization program could increase the duration of the wheat green leaf area, maintain canopy longevity during grain filling and enhance grain yield (Gooding et al., 2007). N applied as a foliar at anthesis has also shown to increase GPC in several experiments conducted with common and durum winter wheat (Gooding and Davies, 1992; Bly and Woodard, 2003).

A late-season S application, could also contribute by increasing canopy greenness and grain yield, as a positive interaction between N and S in wheat has been shown, which could reflect in a higher GPC (Pedersen et al., 1998; Luo et al., 2000).

As far as biotic stress is concerned, the occurrence of fungal foliar diseases could clearly negatively influence greenness canopy duration. A reduction in foliar disease development leads to yield benefits, related to a longer period of green leaf area and higher absorption of photosynthetically active radiation by healthy green tissues (Waggoner and Berger, 1987). The disease spot-type net blotch (STNB) of barley caused by *Drechslera teres* f. *maculata* (Sacc.) has become one of the most important worldwide foliar diseases of this crop (Jayasena et al., 2002). Spores are produced on infected plants and are spread by wind or rain, and cooler temperatures and higher moisture levels favor infection (Tekauz, 1986). STNB causes a net-type lesion, which is characterized by dark brown blotches with a net-like pattern and the presence of chlorosis (Richter et al., 1998).

Fungicides could be used to control this disease, although they are generally rarely applied on barley by farmers. Among the various fungicides that are available, azole applications at anthesis have shown to have a significant effect on the decline of the green leaf area in wheat (Kettlewell et al., 1982) and on the increase in grain yield and kernel weight (Egli, 1998). However, some azoles have shown beneficial effects that are not only attributable to disease control, but also related to a physiological action on plants (Riesen and Close, 1987). The use of fungicides at anthesis also plays a key role in obtaining wheat grains with a low deoxynivalenol (DON) contamination, especially in environments in which there is a high frequency of Fusarium head blight (FHB) (Blandino et al., 2012). This disease can be produced by several species of *Fusarium* but *F. graminearum* (Schwabe) is the principal barley infecting species. The maximum permissible levels of DON contamination in barley have been established as 1250 $\mu g\,kg^{-1}$ for food (EC, 2006b) and at 8000 $\mu g\,kg^{-1}$ for feeds (EC, 2006a).

Since winter barley is characterized by a higher precocity and a shorter ripening time in temperate areas, compared to winter wheat, the aim of this study was to verify whether the application of agricultural strategies that are able to prolong crop greenness could also lead to advantages for this cereal. Another aim of this study was to compare the effect of different late-season strategies, N and S foliar fertilizers and fungicide applications at barley anthesis, on crop canopy greenness during the ripening stages and to establish the relationship between these strategies and barley yield and quality.

2. Materials and methods

The study has been carried out in North West Italy (Piedmont region), during 3 growing seasons (2010–2011, 2011–2012, 2012–2013) at Cigliano, (VC, 45°14′N, 8°00′E; at an altitude of 194 m, in a shallow and sandy soil-Typic Hapludalfs) and during one growing season (2012–2013) at Cuneo (44°23′N, 7°32′E; at an altitude of 480 m; in a deep and fertile sandy soil—Typic Eutrochrepts).

Different foliar treatments were applied at mid anthesis [growth stage (GS) 65] (Zadoks et al., 1974) in order to reduce the canopy senescence process and prolong the grain filling period:

- A nitrogen (N) foliar fertilizer (T3);
- A sulfur (S) and nitrogen (N) foliar fertilizer (T4);
- A fungicide mixture, with physiological activity (T5).

The treatments were compared with an untreated control at the same N fertilizer rate (T2). Moreover, another untreated control, which received half of the N fertilizer rate of the other treatments (T1), was introduced as a spy-control, in order to obtain a term of comparison for the foliar application effect on greenness and for the productive and qualitative parameters in the different environmental conditions. The following active ingredients or products were used:

- Foliar N fertilizer: YaraVita ™ Last® N (Yara S.p.A., Milano, Italy), 312 g N l^{-1} (25%), applied at 5 kg N ha^{-1} (15 l of product formulation ha^{-1});
- Foliar N and S fertilizer: Sulfamon® (Cifo S.p.A., S. Giorgio di Piano, BO, Italy), 100 g N l^{-1} (8%) and 1275 g S l^{-1} (22%), applied at 0.4 kg N ha^{-1} and 5 kg S ha^{-1} (4 l of product formulation ha^{-1});
- fungicide: prothioconazole + tebuconazole (Prosaro®, Bayer CropScience S.r.l., Milan, Italy, formulation: emulsifiable concentrate) both applied at 0.125 kg active ingredient (AI) ha^{-1}.

The complete treatment schedule is summarized in Table 1. The application of fungicides or a foliar fertilizer to winter barley is not a common crop technique in Italy. The treatments were compared in each trial containing 3 winter barley varieties: cv. Ketos (Limagrain Italia Spa, Busseto, PR, Italy), a hexastichous, late maturity variety, intended mainly for feeds, cv. Cometa (Apsovsementi, Voghera, PV, Italy), a distichous medium maturity variety, intended mainly for feeds, and cv. Sfera (Centro di ricerca per la genomica e la postgenomica animale e vegetale, Fiorenzuola d'Arda, PC, Italy), a distichous early maturity variety intended mainly for malting and food. The main crop and agronomic information relating to the experimental fields is reported in Table 2, while the main soil properties are reported in Table 3.

Table 1
Treatments compared in the four experimental trials conducted in the 2010–2013 period in North West Italy.

Treatment	N fertilization[a] (kg N ha^{-1})		Foliar application
	Tillering	Stem elongation	Flowering
	GS[b] 25	GS 33	GS 62
T1	25[c]	40	–
T2	50	80	–
T3	50	80	N fertilizer[c]
T4	50	80	N + S fertilizer[d]
T5	50	80	Fungicide[e]

[a] Using granular ammonium nitrate (27%) fertilizer.
[b] Growth stage (Zadoks et al., 1974).
[c] The applied foliar N fertilizer was YaraVita TM Last® N (Yara S.p.A., Milano, Italy), composition: 312 g N l^{-1} (25%); application rate: 11 l ha^{-1}.
[d] The applied foliar N and S fertilizer was Sulfamon® (Cifo S.p.A., S. Giorgio di Piano, BO, Italy), composition 100 g N l^{-1} (8%) and −1275 g S l^{-1} (22%); application rate: 4 l ha^{-1}.
[e] The applied fungicide was a mixture of prothiconazole and tebuconazole (Prosaro®, Bayer Crop Science S.r.l., Milan, Italy, formulation: emulsifiable concentrate), both applied at 0.125 kg of active ingredient (Al) ha^{-1}.