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Do single, double or triple fungicide sprays differentially affect the grain quality in winter wheat?

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ABSTRACT

Foliar fungicides in wheat are typically used to safeguard against economic losses from diseases. In this study, we assessed the effects of three fungicide spray regimes [single, double, and triple treatments] on four different grain quality parameters [thousand grain weight (TGW), test weight (TW), grain protein content (GPC), and Zeleny sedimentation volume (ZSV)] during the 2006–2009 period at two sites in Luxembourg. The fungicides used were generally a mix of chlorothalonil and triazoles. At Burmerange, (cultivar Cubus), the values of TGW, TW, GPC and ZSV ranged from 38 to 62 g, 67 to 83 kg hl^{-1}, 12.0% to 14.7% dry matter (DM), and 27 to 54 ml, respectively. Whereas, at Everlange (cultivar Achat), the ranges of TGW, TW, GPC and ZSV were 42 to 65 g, 65 to 81 kg hl^{-1}, 11.0% to 15.0% DM, and 21 to 66 ml, respectively. In more than 75% cases, the results indicate that fungicides did not significantly affect TW or ZSV at either sites ($P > 0.05$). However, there was a significant and positive fungicide effect on GPC in 2006 and 2009 at Burmerange, and only in 2006 at Everlange ($P < 0.05$). On the contrary, TGW was significantly affected at Burmerange in all years, except 2008 when a positive increase was observed compared to control plots; and in 2006 and 2007 at Everlange. Interestingly, when there was an effect of fungicides on a quality parameter, there was no difference among different fungicide treatments. Thus under conditions prevailing in Luxembourg, a single fungicide treatment applied with judicious timing generally resulted in statistically similar grain quality parameters when compared with a double or triple fungicide treatment.

1. Introduction

Wheat is one of the top three staple foods in the world (next to rice and maize), with a total production estimated as 700 million metric tons in 2013 (FAO, 2014). In Luxembourg, winter wheat (*Triticum aestivum* L.) is the major cereal crop, accounting for 21% of the arable land planted in 2013 (Ministère de l'Agriculture, 2014). Generally, the profit of winter wheat cropping relies upon sustained high grain yields and production over many years, while maintaining high quality grain. Common wheat quality parameters include protein content and quality, specific weight, grain hardness, thousand grains weight, Hagberg falling number, moisture content, sedimentation volume and foreign contaminants. Wheat is typically milled into flour which is used to make a wide range of foods (e.g., bread, semolina, cereal bars, confectionery, etc.). In Luxembourg, about half of the wheat production is dedicated to bread making (36 001 metric tons) and the other half to animal feed (34 726 metric tons) (2014 data; Ministère de l'Agriculture, 2014). Therefore, the quality of the grain has a major influence on the market value of a particular harvest; so farmers seek and employ economically sustainable means to ensure the best production, with sometimes insufficient attention paid to environmentally friendly agronomic practices.

Apart from unpredictable adverse environmental conditions (e.g., frost events during critical phenological stages, strong winds, hail and perseverative rainy periods during maturation and harvest, etc.), fungal diseases are the major issues that can negatively impact potential gain, either in grain yield or resulting financial return, in winter wheat crops in Luxembourg (El Jarroudi et al., 2012b). Yield losses caused by fungal diseases are affected by disease severity, the incidence and timing of occurrence, and the duration of the epidemic (Teng, 1983; Gaunt, 1995; Oerke, 2006; El Jarroudi

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Table 1
Agronomic input information for winter wheat experiments conducted at two sites in Luxembourg during the 2006–2009 cropping seasons.

Site	Year	Cultivar	Sowing date	Harvest date	Mineral N fertilization (kg ha^{-1})
Burmerange	2006	Cubus	30 September 2005	19 July 2006	192
	2007	Cubus	11 October 2006	26 July 2007	192
	2008	Cubus	6 October 2007	5 August 2008	228
	2009	Cubus	6 October 2008	29 July 2009	228
Everlange	2006	Achat	10 October 2005	7 August 2006	225
	2007	Achat	10 October 2006	26 July 2007	195
	2008	Achat	8 October 2007	5 August 2008	195
	2009	Achat	13 October 2008	6 August 2009	195

et al., 2012b). The main fungal diseases of increasing concern in Luxembourg include Septoria leaf blotch (SLB, caused by *Zymoseptoria tritici* (Desm.) Quaedvlieg & Crous), leaf rust (WLR, caused by *Puccinia triticina* Roberge ex Desmaz.), powdery mildew (WPM, caused by *Blumeria graminis* DC. f. sp. *tritici* em. Marchal), and *Fusarium* head blight (FHB, primarily caused by *Fusarium graminearum*) Schwabe (El Jarroudi et al., 2012b). Beyond reducing yield, *Fusarium* species reduce the quality by release of toxic secondary metabolites in the grain and by modifying the amino acid profile of winter wheat (Beyer and Aumann, 2008). To ensure beneficial outcomes in their farming practice, Luxemburgish famers typically use stress and disease resistant cultivars, in conjunction with suitable management practices (for example, crop rotation). Nonetheless, preventive fungicide applications are needed to protect winter wheat crops from fungal disease, particularly on the three upper leaves that contribute the most to the final yield; generally two to three foliar fungicide treatments are applied during the cropping season. With the potential environmental damage caused by over-and/or misuse of agrochemicals in protecting winter wheat against fungal diseases, warning bulletins based on a decision support system (DSS; PROCULTURE and add-ons; El Jarroudi et al., 2009, 2014, 2015), and available from various websites (for example, http://www.centralpaysanne.lu, http://www.agrimeteo.lu, http://www.lwk.lu/mediathek), have been issued weekly throughout the growing season in Luxembourg for the last decade, in order to provide farmers with information regarding disease risk, the need to spray fungicides, the optimum timing, and thus control fungal diseases in a profitable and more environmentally friendly way (El Jarroudi et al., 2013, 2015).

Several studies have dealt with the effects of foliar fungicides on the quality of wheat grain (Gooding et al., 2000; Kelley, 2001; Dimmock and Gooding, 2002a; Wang et al., 2004; Blandino et al., 2009; Blandino and Reyneri, 2009; Fernandez et al., 2014; Rodrigo et al., 2015). In these studies, although one to three fungicide applications were compared, at most two fungal diseases (i.e., FHB and SLB) were targeted. The experiment aims were primarily to ascertain fungicide efficacy, while the timing of an optimum single fungicide treatment received only partial or no attention. In further experiments, El Jarroudi et al. (2015) reported that a double or triple fungicide treatment (using mixes of strobilurins and triazoles) did not necessarily increase the financial return compared to a single fungicide treatment due to only mild diseases severities developing on the three upper leaves during grain development. Additionally, in years with no severe fungal disease, the double and/or triple fungicide treatment could be avoided entirely when following the recommendations of the decision support system (El Jarroudi et al., 2015). In order to gain more insights to minimizing and optimizing fungicide applications, we asked the question: does a double or triple fungicide treatment significantly improve the quality of winter wheat grain compared with a single, judiciously applied fungicide spray (i.e., determined through a decision support system) as the single fungicide application is aimed to maximize disease control while minimizing potential harmful impacts on the environment thus, providing the grower with sustainable financial returns? The objective of this research was to establish whether there were differences in four wheat grain quality parameters [i.e., thousand grain weight (TGW), test weight (TW), grain protein content (GPC), and Zeleny sedimentation volume (ZSV)] from winter wheat fields treated with either one, two or three fungicide sprays.

2. Material and methods

2.1. Experimental fields

Field experiments were conducted at two sites [i.e., Burmerange (49°29′N, 6°19′E, 248 m above mean sea level (amsl)) and Everlange (49°46′N, 5°57′E, 309 m amsl)] during 2006–2009. The experiments were designed in a randomized block with four replicates (one replicate plot = 12 m^2); each replicate block consisting of fungicide treated and non-treated (control) plots. New plots were selected each year in the same locations to maintain a crop rotation system. Agronomic inputs and crop husbandry were typical for a Luxembourgish farm (Table 1). Nitrogen fertilization, a practice known to have influence on grain quality parameters (Ruske et al., 2004), was split as follows: all plots received 40–70 kg N ha^{-1}, in the form of ammonium nitrate, at growth stage (GS) 25 (main shoot and 5 tillers; Zadoks et al., 1974), followed by 60–70 kg N ha^{-1} at GS32 (second node detectable), and a final application of 65–95 kg N ha^{-1} at GS59 (emergence of inflorescence completed). During the 4-year period, three fungicide treatments were compared at each site: a single application (1T) based on a decision support system (El Jarroudi et al., 2015), a double (2T) and a triple (3T) spray application, alongside control plots (0T). The fungicides used, along with the growth stage at which they were applied are reported (Table 2).

Various fungal diseases (i.e., SLB, WLR, WPM, FHB, and stripe rust) were monitored weekly from GS 29–30 to GS 85. Estimates of fungal disease severity were made on the same 10 plants in control plots throughout the growing season, and bi-weekly on 10 randomly selected plants in each of the treated plots. FHB severity was monitored three weeks post-anthesis for year 2007 and 2008 by counting the number of symptomatic spikelets per head on a total of 100–200 plants (Giraud et al., 2010).

The meteorological data (minimum, maximum and mean air temperatures, precipitation, and relative humidity) were automatically retrieved from a web-based database system (www.agrimeteo.lu), processed using an automatic data processing chain for quality checking and gap filling, and provided at an hourly resolution (Junk et al., 2008). From the start of the disease monitoring period, a forecast of weather conditions covering the following seven days was used for predicting the time point for the single fungicide application (for details see El Jarroudi et al., 2015 and References therein).

2.2. Grain quality parameters

The period of winter wheat harvest in Luxembourg spans mid-July to the beginning of August (Zadoks' growth stage 92 and all leaves senesced, Table 1). Grain yields were obtained by harvest-