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Grain weight response to foliar diseases control in wheat (*Triticum aestivum L.*)

Román A. Serrago[a,*], Ramiro Carretero[a], Marie Odile Bancal[b], Daniel J. Miralles[a]

[a] Departamento de Producción Vegetal, Cátedra de Cerealicultura, Universidad de Buenos Aires, IFEVA and CONICET, Av. San Martin 4453, C1417DSE, Buenos Aires, Argentina
[b] Environnement et Grandes Cultures, INRA, F-78850 Thiverval Grignon, France

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ABSTRACT

Foliar diseases are the main biotic restriction reducing yield in wheat crops affecting both, grain number and/or grain weight, depending on developmental stage at which infection occurs (pre- or post-anthesis, respectively). Grain weight reductions due to foliar diseases were widely reported in the literature mostly associated with decreases on radiation interception during the grain filling period. However, different evidences in wheat showed variations on grain weight responses when fungicide was applied during the grain filling period, probably associated with the timing of fungicide application or with the amount of available resources per grain set when fungicides are applied. The present study was designed to determine the causes of grain weight reduction due to foliar diseases complex (including leaf rust, *Septoria* leaf blotch and tan spot) in wheat crops growing under contrasting agronomic and environmental conditions (i.e. different years, locations, cultivars and N supply). The experiments were carried out during 4 years under field conditions in different locations of Argentine and France. Five different commercial wheat cultivars were sown on early and late sowing dates; and two contrasting N availability and two fungicide treatments (protected and unprotected) were applied. Grain number was not affected by foliar diseases as their appeared after anthesis. Grain weight was strongly, poorly or not affected by foliar diseases and was not associated individually with both, the sink size and the source size. However, when the grain weight response due to fungicide application was plotted against the healthy area absorption per grain (HAA_G), a significant negative association ($r^2 = 0.81$; $p < 0.0001$) was found for the Argentine experiments. When the HAA_G was corrected by the grain weight potential (HAA_{GW}) all experiments conduced in Argentine and in France fit well to a common negative linear regression ($r^2 = 0.74$, $p < 0.0001$) for the relationship between grain weight variation and HAA_{GW} demonstrating that grain weight potential is an important feature to consider in diseases control programs. Foliar diseases forced the crop to use the accumulated reserved increasing the utilization rate of the water soluble carbohydrates (WSC_{UR}), depleting as a consequence the water soluble content at physiological maturity (WSC_{PM}) in all experiments. The association between WSC_{UR} and the healthy area absorption per grain corrected by grain weight of healthy crops (HAA_{GW}) suggest that foliar diseases in wheat cause source limitation, forcing to the crop to use the WSC reserve which could be insufficient to fill the grains previously formed.

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1. Introduction

Considering a simple model, grain yield can be described as the product of grain number and grain weight. However, in wheat, as in many other grain species, these yield components are generated during particular developmental stages. Grain number is mainly determined during the period immediately previous to anthesis (Fischer, 1985) when the spike and stem are competing for assimilates and the number of fertile tillers (Slafer and Rawson, 1994) and florets per spikelets are being established (Kirby, 1988). Grain weight is defined during the period from anthesis to physiological maturity (PM) or even early (i.e. from booting to anthesis) as suggested by Calderini et al. (1999), as carpel size could be associated with the potential size of grains. The grain filling period can be divided in two different phases; (i) *lag* phase (LP) and (ii) active grain growth phase (AGGP) up to physiological maturity (i.e. the time when the grains reach the maximum dry weight). During the LP, endosperm cell division takes place defining the final number of endosperm cells per grain and thereby the potential grain weight (Brocklehurst, 1977; Sofield et al., 1977; Nicolas et al., 1985; Schnyder and Baum, 1992). The AGGP is characterized by a rapid grain biomass accumulation beginning in the LP and finishing in PM. Finally, from the end of the AGGP to harvest maturity, grain weight remains stable and the water content decrease until harvest time.

Foliar diseases are the main biotic restriction reducing yield in wheat crops affecting both, grain number and/or grain weight,

* Corresponding author. Tel.: +54 11 45248053; fax: +54 11 45248053.
E-mail address: serrago@agro.uba.ar (R.A. Serrago).

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Table 1
Summary of the different experiments presented in the present study. SD: sowing date, NT: nitrogen treatment, NF: nitrogen from fertilizer (kg ha^{-1}). N_0 and N_1 represent the low and high nitrogen application rates.

Years	Locations	Genotype	SD	NT	NF	Experimental code
2002	Arrecifes (A)	Baguette 10 (B10)	15 June	N_1	N_{120}	A2002
2004	Buenos Aires (BA)	K. Pegaso (KP)	29 June	N_0	N_0	BA2004
				N_1	N_{150}	
	Grignon (GR)	Soissons (SO)	20 October	N_0	N_{160}	G2004SO
				N_1	N_{240}	
		Isengard (IS)	20 October	N_0	N_{160}	G2004IS
				N_1	N_{240}	
2005	Buenos Aires (BA)	K. Pegaso (KP)	3 August	N_0	N_0	BA2005
				N_1	N_{290}	
	Pergamino (P)	Baguette 10 (B10)	24 June	N_0	N_0	P2005E
				N_1	N_{115}	
		K Don Enrique (KDE)	26 July	N_0	N_0	P2005L
				N_1	N_{115}	
2007	Buenos Aires (BA)	K. Pegaso (KP)	24 July	N_0	N_0	BA2007
				N_1	N_{250}	

depending on developmental stage at which infection occurs (Madden and Nutter, 1995). Grain weight reductions due diseases infection were widely reported in the literature, mostly associated with decreases on leaf area duration reducing radiation interception during the grain filling period (Gooding et al., 2000; Dimmock and Gooding, 2002; Ruske et al., 2003; Robert et al., 2004). However, different evidences in wheat showed variations on grain weight responses when fungicide was applied during the grain filling period (Cornish et al., 1990; Gooding et al., 1994; Pepler et al., 2006). These variations could be associated with (i) the moment of fungicide application according to the grain biomass accumulation (Dimmock and Gooding, 2002) and/or (ii) the amount of available resources per grain set when fungicides are applied. Regarding the last point, different results were found in the literature. Kramer et al. (1980) hypothesized that non-tolerant cultivars (i.e. higher variations in grain weight due to foliar diseases) showed a relatively low source–sink ratio and, thereby, any loss in photosynthetic capacity cannot be compensated by reserves translocation determining grain weight reductions. However, Zilberstein et al. (1985) could not found an association between tolerant (i.e. null or lower variations in grain weight due to foliar diseases) and non-tolerant cultivars and the sink size.

During the grain filling period, the assimilate availability to fill the grain is provided by different sources as current photosynthesis by the healthy area absorption (HAA), and the water soluble carbohydrates (WSC) stored in stems that could be translocated to the grains (Ehdaie et al., 2008; Bingham et al., 2009). The availability of the WSC stored in the stems, depends on the growing conditions explored by the crop before anthesis, and the WSC mobilization to growing grains is mainly affected by: (i) sink size, (ii) environmental conditions and (iii) cultivars (Blum, 1998; Ehdaie et al., 2008). In those situations where foliar diseases decrease HAA during grain filling period, the importance of WSC stored in stems become particularly important, depending on the sink size previously established, to fill the formed grains (Gallagher et al., 1975; Zilberstein et al., 1985; Cornish et al., 1990; Gaunt and Wright, 1992). Probably, the differences found on grain weight reductions due to foliar diseases could be better explained by a simple model that incorporates the source–sink ratio in terms of HAA available per grain (HAA_G) and the amount and mobilization capacity of WSC stored in stems previous to anthesis.

The aim of this paper was to determine the effects of foliar diseases appearing during the grain filling period of wheat, growing under a wide range of environmental field conditions, on final grain weight. The HAA and WSC on stems were measured during the grain filling period to determine its relative contribution to grain filling on diseased wheat crops.

2. Materials and methods

2.1. Treatments and experimental design

Field experiments were carried out during 4 years (2002, 2004, 2005 and 2007) in 4 locations (three in the rolling pampas of Argentine and one in the northern of France). The particular combination of cultivars, sowing date and N fertilizer for each location and year are presented in Table 1. For details on experimental site and growing conditions see Serrago et al. (2009), as only a brief summary of inoculation method and the experimental design are given here.

In the experiments conduced at Buenos Aires (2004, 2005 and 2007), the diseases infection was promoted by artificial inoculation. Thus, the plots assigned to the unprotected treatment (UP) were sprayed with spores of *Puccinia triticina* (leaf rust) at different times during the crop cycle; at the onset of stem elongation (Z3.1) in 2004, at the onset of stem elongation and at middle of stem elongation (Z3.1 and Z3.7, respectively) in 2005, and at flag leaf emergence (Z3.9) during 2007 experiments. The inoculation was carried out by pulverization over the plots of spores and water suspension with surfactant (Tween 20®). After inoculation, plots (including healthy plots) were kept moisten by: (i) spraying using automatic sprinklers with water at several times a day during the following three days immediately after the inoculum application (2004) and (ii) by covering the plots with plastic tents during the following three nights (2005 and 2007) after inoculation. In the experiments carried out at Pergamino, Arrecifes and Grignon diseases were not artificially promoted as usually the infection appears naturally (normally leaf rust) from flag leaf emergence to physiological maturity as occurred in the present experiments. With the exception of experiments carried out at Grignon (France) and at Buenos Aires (Argentine) in 2007, which were sown under conventional tillage system, the rest of the experiments were sown under zero tillage. In all the experiments the healthy plots (protected plots-P-) were sprayed with fungicide (750 cm^3 ha^{-1} of Tebuconazole) every 15 days from inoculation to the end of grain filling to prevent the foliar diseases infection.

The experiments at Grignon (France) and Pergamino, (Argentine), were arranged in a split plot design with three replicates per treatment. The arrangement of the treatments of the experiments carried out in Buenos Aires corresponded to a split plot design with three blocks (replicates). N treatments (N_0, low N application and N_1, high N application, see Table 1) corresponded to the main plots, and fungicide treatments (protected and unprotected treatment, P and UP, respectively) to the sub-plots. In A2002, the treatments consisted in fungicide application only (P and UP) using a completely randomized design with three replicates per treatment.

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