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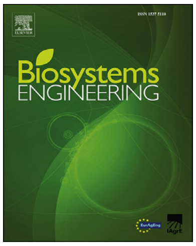

Research Paper

Hyperspectral measurements of yellow rust and fusarium head blight in cereal crops: Part 1: Laboratory study

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This paper assesses the potential use of a hyperspectral camera for measurement of yellow rust and fusarium head blight in wheat and barley canopy under laboratory conditions. Scanning of crop canopy in trays occurred between anthesis growth stage 60, and hard dough growth stage 87. Visual assessment was made at four levels, namely, at the head, at the flag leaves, at 2nd and 3rd leaves, and at the lower canopy. Partial least squares regression (PLSR) analyses were implemented separately on data captured at four growing stages to establish separate calibration models to predict the percentage coverage of yellow rust and fusarium head blight infection. Results showed that the standard deviation between 500 and 650 nm and the squared difference between 650 and 700 nm wavelengths were found to be significantly different between healthy and infected canopy particularly for yellow rust in both crops, whereas the effect of water-stress was generally found to be unimportant. The PLSR yellow rust models were of good prediction capability for 6 out of 8 growing stages, a very good prediction at early milk stage in wheat and a moderate prediction at the late milk development stage in barley. For fusarium, predictions were very good for seven growing stages and of good performance for anthesis growing stage in wheat, with best performing for the milk development stages. However, the root mean square error of predictions for yellow rust were almost half of those for fusarium, suggesting higher prediction accuracies for yellow rust measurement under laboratory conditions.

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1. Introduction

With the world's population estimated to reach 9 billion by 2050, sustainable approaches to increase crop yield are a necessity (Hole et al., 2005; Godfray et al., 2010). Current farming practices are unsustainable, relying on external inputs and high-yield varieties susceptible to disease (Hole et al., 2005). Site specific management of inputs would reduce the amount required (Wittry & Mallarino, 2004; Maleki, Mouazen, Ramon, & De Baerdemaeker, 2007). Among these resources, fungicide application may well be reduced by targeted site specific spraying (FRAC, 2010). However, accurate measurement of fungal diseases is a main requirement for sustainable application of fungicides, and expected to contribute to the reduction and prevention of the spread of crop disease and the losses of quantity and quality incurred from them.

Fungal disease control is a large task for a successful production of cereals worldwide. Both yellow rust and fusarium are fungal diseases, which infect small cereal crops, and are responsible for causing severe yield losses (de Vallavieille-Pope, Huber, Leconte, & Goyeau, 1995; Bravo, Moshou, West, McCartney, & Ramon, 2003). Yellow rust caused by *Puccinia striiformis* is a foliar disease, which can reduce crop yields by up to 40%. Alternatively known as stripe rust, the pathogen produces yellow uredo spores on the leaves. Infection starts with chlorosis occurring parallel to leaf veins, in a narrow 2 mm wide stripe, which develops later into multiple yellow coloured rust pustules (de Vallavieille-Pope et al., 1995). Disease presence can vary considerably between plants. In severe epidemics the yield can be reduced by up to 7 tonne ha^{-1} (Bravo et al., 2003). Fusarium head blight is one of the most important pre-harvest diseases worldwide, reducing yield quantity and quality. The most aggressive and prevalent fusarium strain is *Fusarium graminearum*, which is a highly pathogenic strain producing mycotoxins, which can become a significant threat to both humans and animals. Fusarium head blight symptoms in wheat and barley appear in the head and peduncle tissues, causing discolouration and early senescence. Disease presence can vary considerably between plants (Brennan, Egan, Cooke, & Doohan, 2005; Desjardin, 2006; Leslie & Summerell, 2006; Rotter, Prelusky, & Pestka, 1996), hence, it is required to adopt site specific treatments of fungal diseases.

Advanced methods for disease detection in crops are vital for improving the efficacy of treatment, reducing infection and minimising the losses to yield and quality. Traditionally, disease detection is carried out manually, which is costly, time consuming and requires relevant expertise (Schmale & Bergstrom, 2003; Bock, Poole, Parker, & Gottwald, 2010). Alternative methods of detection are needed to enable mapping the spatial distribution of yellow rust and fusarium head blight. Among those methods, optical sensing methods are recommended candidates since they are non-destructive and allow for fast and repeated data acquisition throughout the growing season without inhibiting crop growth. It was recognised by West et al. (2003) that although optical technologies are available for development into suitable disease detection systems, many challenges are still needed to be overcome, and this is still arguably the case. Spectroscopy and imaging techniques have been used in disease and stress monitoring (Hahn, 2009). One of the optical methods reportedly used to measure disease in crops is hyperspectral imaging in the visible (vis) and/or the near infrared (NIR) spectral ranges. The reflectance at vis wavelength range is relevant to leaf pigmentation whilst the NIR wavelength range provides information on the physiological condition of the plant. The wavelength function for light intensity in hyperspectral imaging adds to the brightness information of the spectral image, providing a rapid image-contrast (Huang et al., 2007). Within the vis spectrum, the radiation reflectance from an environmentally stressed plant will increase. This is due to an increase in the incidence reflection within the leaf of a stressed plant (Cibula & Carter, 1992). Bélanger, Roger, Cartolaro, Viau, and Bellon-Maurel (2008) showed that disease could be quantified on detached leaves, and reported that the ratio of blue (near 440 nm) over green (near 520 nm) intensities between the healthy and diseased tissue was significantly different shortly after inoculation. Using a vis-NIR imaging, Bravo et al. (2003) detected early symptoms of yellow rust on winter wheat, with a quadratic discriminant model analysis, reporting a correct discrimination accuracy of 92–98%. To our knowledge none of the above studies incorporated the effect of water stress, in the prediction model of yellow rust and fusarium head blight intensity in cereal crops. Some studies have focused on bringing the technology to the field. However, the first step towards field application is to test the accuracy of the methods under laboratory conditions (allowing more control and observation of the crop), where disease and water stress are accounted for simultaneously.

The aim of this paper is to assess the potential implementation and performance of a hyperspectral imager for recognition of yellow rust and fusarium head blight diseases in winter wheat and winter barley under laboratory conditions, with the intention to establish calibration models and a spectral library for potential use under mobile on-line measurement conditions. Both diseases and water stress were introduced and accounted for.

2. Materials and methods

2.1. *Wheat and barley cultivation and inoculation*

Treated seeds of winter wheat *Triticum sativum* (Solstice variety) and winter barley *Hordeum vulgare* L. (Carat Variety) were grown outdoors in 600 × 400 mm trays (depth of 120 mm), with 100 seeds evenly sown and spaced in 5 parallel lines. After seeding the trays were predominantly rain fed, to reduce input of excess salts from treated tap water. Three treatments were adopted, where each treatment was triplicated in three separate trays. A total of 18 trays of wheat, and 18 trays of barley were grown for each of the following three treatments:

1) Treatment 1 – Healthy: consisting of six trays of each that were kept healthy by applying a broad spectrum fungicide (Rubric and Epoxiconazole, at a rate of 1 l ha^{-1}).
2) Treatment 2 – Naturally (non-inoculated) yellow rust infected: consisting of six trays that were not treated with fungicide, as these were to represent the more heavily