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Early Detection of Fungal Diseases in Winter Wheat by Multi-Optical Sensors

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Abstract

Biotic factors such as pests and pathogens cause a substantial damage to wheat crops which leads to reduction in yield in a range from 10% to 50%. Application of fungicides and pesticides on one hand protects the crop but it also increases the crop production cost. Pathogens affect photosynthesis, respiration, translocation of water and nutrients of the crop and mostly the visual symptoms are detected too late to protect the crop. The objective of this study was to detect the plant fungal diseases by non-invasive sensor technologies and to determine the early outbreak of the disease. The experiment was conducted in the greenhouse where the two wheat cultivars namely; Monopol and Kalahari were infected with three fungal diseases viz. *Fusarium culmorum*, *Septoria tritici* and *Blumeria graminis f.sp. tritic*. Throughout the experiment four spectral sensors were used namely, Isaria, Handyspec, Multiplex and Infrared thermal camera. The results showed that as early as 2 days after inoculation (DAI), an increase in the average canopy temperature and maximum temperature difference within the canopy (MTD) was observed. Similarly, the REIP calculated from Handyspec showed significant difference between the infested and the control plants before the visual symptoms appeared. Multiplex measured chlorophyll content which is related to the photosynthesis process allowed to detect the early symptoms in contrast to the Isaria which, does not show a significant difference between control and infected plants.

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Keywords: Thermal camera, Isaria, Handyspec, Multiplex, Fungal infection, winter wheat

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1. Introduction

Biotic factors such as pests and pathogens cause substantial damage to wheat crops leading to yield losses ranging from 10% to 50% dependent on different diseases and regions [1]. The most serious fungal diseases which results in yield loss of wheat includes Septoria blotch (*Septoria tritici*), Powdery mildew (*Blumeria gramnis*), and Fusarium head blight (*Fusarium spp*.)[2]. Controlling of these diseases requires large quantities of fungicides which increase production cost. Pathogens affect the photosynthesis, respiration, translocation of water and nutrients and reproduction of the plants and the symptoms are visible on the plant after a certain time. The fungal disease identification in the field is mostly done by visual evaluation according to farmers' experience based on weather conditions from weather reports. In this way, the fungicides might be misapplied even when there is no disease yet on the plants. Therefore, effective methods for fungal disease detection at early stage of disease development are required to avoid the overuse of fungicides and maintain the yield. The objective of this study is the early detection of fungal diseases by sensing technologies which are suitable for monitoring plants health condition.

2. Materials and Methods

The experiment was conducted under greenhouse conditions. Two wheat varieties namely Monopol (sensitive) and Kalahari (resistant) were planted on 30th March. The wheat was infected with three fungal diseases viz. *Fusarium culmorum*, *Septoria tritici* and *Blumeria graminis f.sp. tritici*. The wheat plants were inoculated 18 days after sowing (DAS) at tillering stage. The experiment layout is presented in Fig. 1.

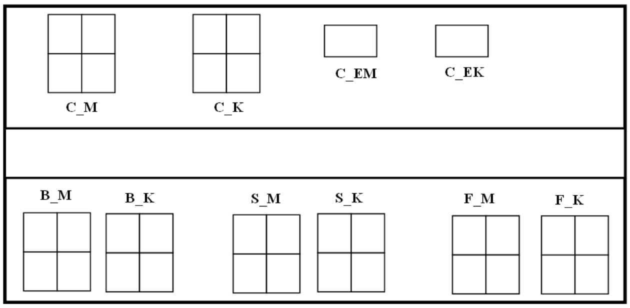

Fig. 1. Experimental setup of the treatment options in the greenhouse

C_E: Control without fungicide
C: Control with fungicide
F: Fusarium treatment
S: Septoria treatment
B: Blumeria treatment
M: Monopol variety
K: Kalahari variety

The following spectral sensors were applied in the experiment: Isaria, Handyspec, Multiplex and Thermal camera (Fig. 2 and Table 1). Multiplex as a real-time and non-destructive fluorescence spectroscopic sensor was used to measure the chlorophyll and polyphenol contents which can help to evaluate the vegetation and physiological state of plants. RF_UV and FRF_UV measured by Multiplex stand for red fluorescence under UV excitation and far red fluorescence under UV excitation respectively. Red fluorescence is only emitted by chlorophyll *a* which is an indicator for photosynthetic efficiency. BRR_FRF from Multiplex is blue to red emission ratio, it indicates water stress [3] and [4] or the stress from pathogens [5]. FLAV is the logarithm of FRF_R (far red fluorescence under red excitation) and FRF_UV. According to Cerovic (2002) FLAV relates to flavonol content of the leaf. NBI_G and NBI_R are Nitrogen Balance Index and are linked to edipermal phenolics and chlorophyll [6]. They were calculated as following:

$$NBI\_G=FRF\_UV/RF\_G \qquad (1)$$

$$NBI\_R = FRF\_UV / RF\_R \tag{2}$$

Isaria and Handyspec measure the reflection wavelength in the range of 660nm to 780nm and 400nm to 1000nm, respectively. Parameters such as Red Edge Inflection Point (REIP) and Normalized Difference Vegetation Index (NDVI) were measured to determine the plant chlorophyll and nitrogen content.

The Red Edge Inflection Point (REIP) was calculated by

$$REIP = 700nm + 40nm \times \frac{\left(\frac{R_{670} + R_{780}}{2}\right) - R_{700}}{R_{740} - R_{700}} \tag{3}$$

The Normalized Difference Vegetation Index (NDVI) was defined by Carlson and Ripley [7] as following:

$$NDVI = \frac{(near\ IR - Red)}{(near\ IR + Red)} \tag{4}$$

Lastly,Infrared thermal camera was used to monitor the impact of the fungal diseases on the crop physiological parameters such as transpiration.

SPSS version 16.0 for Windows was used to perform Analysis of Variance (ANOVA) to evaluate the effect of the various disease treatments.

Table 1. Descriptions for the Sensors applied in this study.

Sensors	Type	Spectral range	Parameters
Multiplex	Fluorometer	UV, red, green and blue	RF_UV, FRF_UV, BRR_FRF, FLAV, NBI_G, NBI_R
ISARIA	Spectrometer	660nm - 780nm	REIP
Handyspec	Spectrometer	400nm - 1000nm	REIP,NDVI
Thermal camera	VarioCam	(8... 13) µm	Canopy temperature, MTD

(a) (b) (c) (d)

Fig. 2. (a) ISARIA; (b) Handyspec; (c) Multiplex; (d) Thermal camera;

3. Results

The experiment was finished on 38 DAI (Days after Inoculation). Symptoms from *Septoria* and *Fusarium* did not appear until the end of the experiment on both wheat varieties i.e., Monopol and Kalahari. However, the symptoms of *Blumeria* appeared on the inoculated Monopol plants on 15 DAI. 2 DAI showed a rise in canopy temperature of about 1°C and it could be detected by using thermal camera. Before the symptoms were visible, the highest difference observed between the average temperature of the control and the *Blumeria*-inoculated plants was 1.8°C on 9 DAI, 6 days before the symptoms of the disease became visible on the leaves (Fig. 3 (a)). After a certain time, the average canopy temperature decreases although the disease was continuously developing. Fig. 3 (b) shows obvious differences in MTD between the *Blumeria* inoculated plants and the control of Monopol variety. Increasing levels of fungal colonization could reflect in increasing level of canopy temperature in term of MTD even after the syptom appeared on the plants.

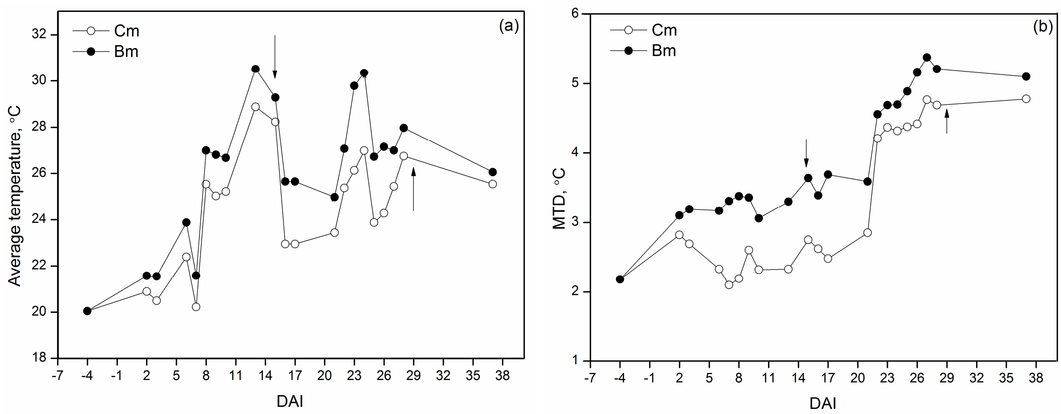

Fig. 3. (a) Effects of *Blumeria* on the average canopy temperature of inoculated plants (Bm) and control group (Cm) of Monopol;

(b) Effects of *Blumeria* on the maximum temperature difference MTD of inoculated plants (Bm) compared with the control group (Cm) of Monopol

Arrows in the graphs pointed out the time point when fungal symptoms showed on the plants.

Table 2. ANOVA tests for different parameters from each sensor between the control and the Blumeria infested plants in Monopol

Sensors	Parameters	Until symptom shows on the infested plant
Multiplex	RF_UV	***
Multiplex	FRF_UV	***
Multiplex	BRR_FRF	**
Multiplex	FLAV	NS
Multiplex	NBI_G	NS
Multiplex	NBI_R	***
ISARIA	REIP	NS
Handyspec	REIP	**
Handyspec	NDVI	NS
Thermal camera	AVE	NS
Thermal camera	MTD	***

*** Significant at 0.01 level
** Signigicant at 0.05 level
* Significant at 0.1 level
NS Not Significant

Furthermore, a statistical analysis has been done among different parameters which are measured from different sensors. The result is listed in Table 2. It is proven that before the symptom occur on the *Blumeria* infested plant of Monopol the differences in NBI_G, NBI_R, BRR_FRF and REIP observed from Multiplex, Handyspec and Thermal camera are significant. It indicates that fungal inoculation influences mainly the photosynthesis and transpiration of the leaves before the symptoms occur on the plant.

4. Conclusion

In this study it was proven that the thermal camera could be a good solution for fungal disease detection before the symptom appears on the plants. Furthermore, other sensors such as Multiplex and Handyspec, which measured chlorophyll fluorescence, could be good tools for fungal disease detection. A combination of two different sensors will be recommended for fungal disease detection to exclude other abiotic and biotic stresses on the plants.

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