Using Hyperspectral Images and the Fusarium Index for Estimating Deoxynivalenol Concentration in Wheat Kernels

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ABSTRACT

The Fusarium Index (FI) is a measurement based on hyperspectral infrared images that was recently proposed as a means for detecting Fusarium Head Blight (FHB) in wheat kernels. Early studies have indicated that FI has some correlation with deoxynivalenol (DON) levels, which is a mycotoxin that can cause serious health problems. This paper presents a deeper study on the use of FI for estimating the DON concentration in wheat kernels, having as basis the original Fusarium Index algorithm and a comprehensive and carefully labeled image dataset. The results indicated that FI provides relatively good estimates when the DON concentration is high, but it needs some improvement to be able to adequately deal with low and medium levels of DON.

KEYWORDS: Deoxynivalenol, Fusarium Head Blight, Hyperspectral Images, Infrared Band.

RESUMO

O Índice de Fusarium (IF) é uma medida baseada em imagens hiperespectrais na banda do infravermelho recentemente proposta como uma maneira de detectar a doença giberela em grãos de trigo. Estudos iniciais indicaram haver um certo grau de correlação com os níveis de deoxinivalenol, a qual é uma micotoxina capaz de causar sérios problemas de saúde. Este artigo apresenta um estudo mais aprofundado do uso do IF para estimar a concentração de DON em grãos de trigo, tendo como base o algoritmo original do Índice Fusarium e um conjunto de imagens abrangente e cuidadosamente rotulado. Os resultados indicam que o IF fornece estimativas relativamente boas quando a concentração de DON é alta, porém aperfeiçoamentos serão necessários para estimar adequadamente níveis baixos e médios de DON.

PALAVRAS-CHAVE: Deoxinivalenol, Giberela, Imagens Hiperespectrais, Banda do Infravermelho.

INTRODUCTION

Wheat is an important part of the diet of many people around the world. Thus, any factor that may affect the quality of wheat-derived food products is treated very seriously. One problem that is particularly important in that regard is the Fusarium Head Blight (FHB) disease, which not only reduces the productivity, but it also has associated a very noxious mycotoxin, called deoxynivalenol (DON). This mycotoxin can disrupt normal cell function by inhibiting protein synthesis (SCHMALE; BERGSTROM, 2003), causing significant health problems.

Normally, DON concentrations are determined manually by first selecting a number of wheat kernels, which are then ground and submitted to some standardized method, such as liquid chromatography–mass spectrometry (LC-MS), to measure those levels - a more complete list of methods for measuring DON concentrations can be found in Schaafsma et al. (2004). Those processes are usually expensive and time consuming, which makes the computer-aided estimation of DON concentrations a highly coveted goal. Although some methods to detect FHB automatically have been proposed in the literature, such as Polder et al. (2005), Wegulo and Dowell (2008), Menesatti et al. (2009), Delwiche, Kim and Dong (2011), Shahin and Symons (2011), there has been little work on the computer-aided estimation of DON concentrations. This is partly due the fact that most automatic methods would have to rely on visible characteristics of the kernels in order to estimate the concentrations, and as reported in Paul, Lipps and Madden (2005), the correlation between visual features and DON concentrations is not very high (between 50% and 70%). Because of those difficulties, alternative approaches have sometimes been adopted, like the use of optical sorting for reducing the overall levels of DON in a batch (DELWICHE; PEARSON; BRABEC, 2005).

Despite the difficulties and inherent limitations of using images for DON concentration estimation, Barbedo, Tibola and Fernandes (2015) proposed a method for FHB detection that briefly addressed this point. This method, which uses hyperspectral images captured in the 528−1785 nm wavelength range for detecting FHB in individual wheat kernels, outputs a value (Fusarium Index - FI), which was shown to have some correlation with DON levels. This paper aims at delving deeper into the subject of DON level estimation by using a more comprehensive and carefully labeled image dataset. It is shown that FI provides relatively good estimates when DON levels are high, but needs improvement when low or medium levels of DON are present.

MATERIAL AND METHODS

Image Dataset

The database used in this work is composed by 50 hyperspectral images (1630 kernels in total), each one having 256 spectral bands in the red and infrared regions of the spectrum. Each image contains a mixture of 25 to 50 kernels of different wheat varieties, including FHB susceptible, moderately susceptible to FHB and moderately resistant to FHB genotypes. All images contain diseased kernels with different degrees of severity.

Deoxynivalenol (DON) concentrations were determined for the kernels of all images in the database. The DON concentrations were measured by ELISA (AgraQuant® Deoxynivalenol). The range of measurement was 250-5000 ppb, and the detection limit was 200 ppb.

Details about image capture, treatment and storage can be found in Barbedo, Tibola and Fernandes (2015). Figure 1 shows, as an example, the grayscale representation of the reflectance captured for the 647-nm band.

Fusarium Index Algorithm

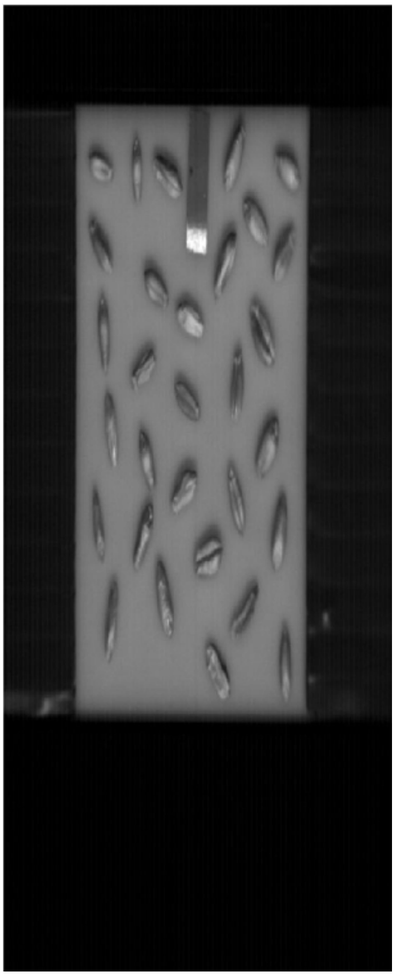
As commented related before, the Fusarium Index algorithm used here was proposed in Barbedo, Tibola and Fernandes (2015), where it was thoroughly described. For that reason, it will be only briefly described here.

Figure 2 shows the basic diagram of the algorithm. Each step of the algorithm will be briefly described in the following.

- Hyperspectral image: from all 256 bands present in each hyperspectral image, the algorithm considers only the bands with the following wavelengths: 647 nm, 672 nm, 1361 nm, 1411 nm, 1509 nm, and 1657 nm. The reasons for these choices will be presented later in this section.

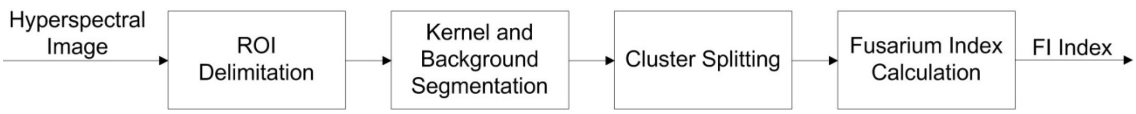
- Delimitation of the region of interest (ROI): this delimitation is performed using the 647-nm band, which provides the best contrast between the ROI (area where the kernels are placed) and the regions to be discarded. After some preprocessing, the grayscale representation of the 647-nm band is thresholded, and spurious elements are removed by means of some morphological operations, such as opening and hole filling.

Figure 1 – Example of grayscale representation of band 25 (647 nm).



Source: Barbedo, Tibola and Fernandes, 2015

Figure 2 – Basic diagram of the Fusarium Index algorithm structure.



Source: Barbedo, Tibola and Fernandes, 2015

- Kernel and background segmentation: this segmentation is performed using four bands: 672 nm, 1361 nm, 1509 nm, and 1657 nm. They are combined using some mathematical expressions (see Barbedo, Tibola and Fernandes, 2015), and then a threshold is applied, and spurious objects that eventually remain are removed by means of a set of size and shape rules.

- Cluster splitting: sometimes touching kernels may appear merged after the kernel segmentation, which means they will be treated as a single entity by the algorithm. This is normally done by applying morphological operations such as erosion, dilation and opening.

However, this may distort the shape of the kernels. Because of that, a more sophisticated approach was adopted, in which the concepts of convexity and concavity are used as basis for a set of rules that, in the end, separate touching kernels with minimal loss of the original conditions. Currently, the algorithm is capable of reliably split clusters of up to three kernels.

- Fusarium Index calculation: the 1411-nm band was used in the calculation of the so-called Fusarium Index (FI), which is given by the proportion of pixels in a kernel with values larger than 0.58 (considering that the pixel values may vary from zero to one). The larger the FI value, the more likely is the presence of FHB. The algorithm was calibrated in such a way an FI value of 0.5 would be the best threshold that separates sound and diseased kernels. The objective of this work was to determine how the FI value relates to DON concentrations.

Test Setup

Three different measurements were used in the tests: actual DON concentrations obtained by laboratorial analysis, visual assessments performed by experienced technicians, and the Fusarium Index. To determine how close those different measurements relate, they were compared in pairs considering the correlation between the corresponding values. They were also compared visually, where results were summarized graphically, together with a curve representing the linear relationship between the measurements, as shown in the next section.

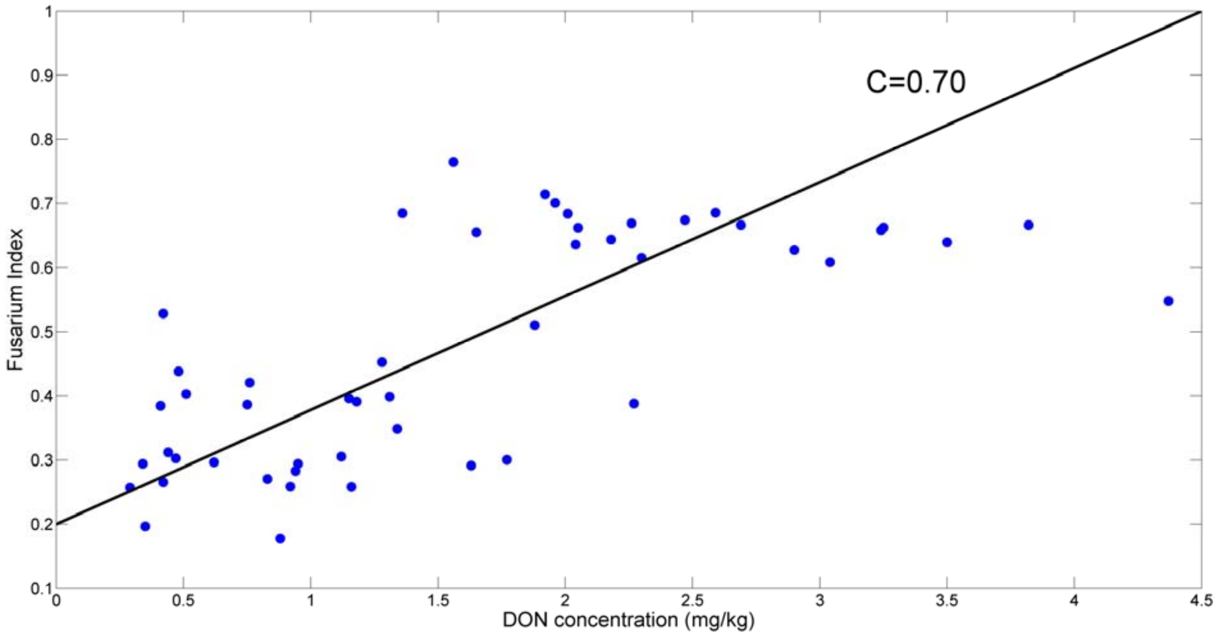
RESULTS AND DISCUSSION

Figure 3 presents the relationship between actual DON concentrations and the Fusarium Index, where the circles indicate the correspondence of Fusarium Index values and DON concentrations for each of the images considered, the line represents the first order (linear) approximation of the relationship between those values, and C is the overall correlation between the measurements.

The correlation between DON concentrations and FI is 0.70, which indicates a significant relationship between those values. This is confirmed by the fact that, although there are some outliers, especially for high DON concentrations, the graphic shows a concentration of points around the linear approximation. Part of the discrepancies found in Figure 3 can be explained by the fact that, as pointed out by Paul, Lipps and Madden (2005), the relationship between FHB severity and DON concentrations is not very strong (see Introduction). This is reflected in Figure 4, which shows the relationship between DON concentrations and the scores obtained by visual assessment of the kernels. As it can be seen, the correlation in this case is only slightly better than that between DON concentrations and

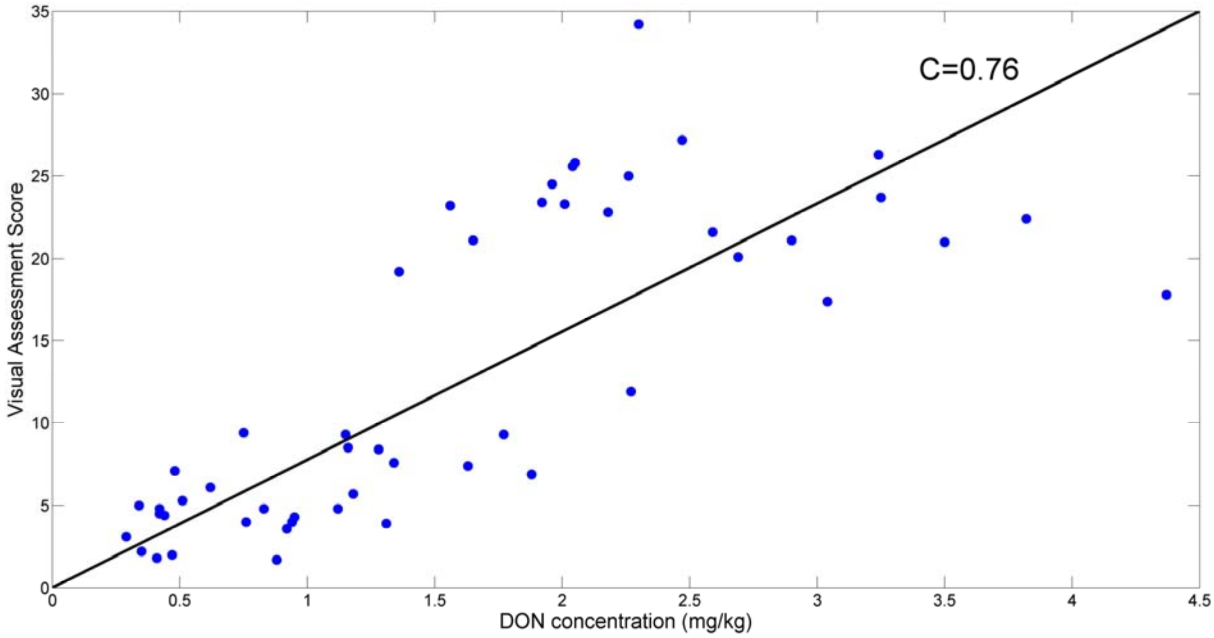
FI, which is a strong indication that the Fusarium Index is successfully exploring most of the visual cues provided by the images.

Figure 3 – Comparison between DON concentrations and the Fusarium Index.



Source: paper authors.

Figure 4 – Comparison between DON concentrations and the visual assessment of the samples.



Source: paper authors.

Figures 3 and 4 indicate that there is still a little room for improving DON concentration estimations using digital image processing. However, it is important to highlight that high levels of accuracy is not always necessary. In fact, a system that can indicate with reasonable certainty that a given batch of kernels is likely to present DON levels above those considered acceptable can prevent many of the problems related to FHB and DON. This is particularly important to define in advance the segregation strategy and the final destination of wheat lots, based on their initial levels of contamination by mycotoxins. The results shown in Figure 3 indicated that the Fusarium Index is a strong candidate to be the core of such a system, mainly if improvements expected to be introduced in the near future result in more accurate estimates.

CONCLUSIONS

This paper presented a study devoted to investigate the performance of the so-called Fusarium Index (FI) in estimating deoxynivalenol (DON) concentrations in wheat kernels affected by the Fusarium Head Blight (FHB). Using a 50-sample image database, it was shown that the DON concentration estimates provided by the FI are almost as reliable as those based on visual assessment scores provided by experienced technicians. This fact, together with its simplicity and low computational power demands, makes this algorithm an interesting candidate to be the core of an alert system capable of detecting excessive levels of DON in wheat lots. The results also indicated that there is still some room for improvement. Future research will concentrate in the further exploration of the morphological differences between healthy and diseased kernels, which, together with the procedures already in place, may improve the estimations.

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