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Detecting and grading severity of bacterial spot caused by *Xanthomonas* spp. in tomato (*Solanum lycopersicon*) fields using visible spectrum images

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ABSTRACT

We introduce a novel method to detect and classify the severity of bacterial spot (*Xanthomonas* spp.) in tomato (*Solanum lycopersicon*) fields. Visual spectrum images were used as inputs and they were taken at 85 days of the plantation. Two hybrids, Hypeel 108 and U2006, were planted and then inoculated separately with *X. perforans* and *X. gardneri*, respectively at 37 and 57 days. Ten (10) different plantation areas were then evaluated taking 18 image samples of each in sub-areas, which were analyzed by 7 experts to grade them and be used as comparison. Productivity was also measured in the areas in order to correlate those to the different severities of the disease in the experiment. Visual spectrum images were preprocessed to area size adjustment and brightness correction and then transformed to a CIELab color space for more stable chroma analysis. A clustering process was applied in the *a* channel in order to group regions related to healthy leaves, unhealthy ones, bare soil and other artifacts. Post-filtering was applied to channels *L* and *b* to evaluate regions with over and underexposition of light and reddish fruits being detected. All of the processed regions were then measured and compared using a novel Severity Index *SI*, which automatically grades, from 1.0 to 5.0, the presence and the severity of the disease. Sixteen classes of severity *SC* are also proposed, as equal intervals of *SI* index. Images were taken in a variety of conditions and results showed besides strong correlation with experts analysis, better explanation and smaller error when analyzing the productivity affected by the disease measurements. Results indicate potential for using this methodology for detecting and grading the severity of bacterial spot in tomato fields, with advantages such as capability of repeatable results with low variance, speed and direct field-based applicability.

1. Introduction

Tomatoes (*Solanum lycopersicon*) were firstly reported as wild cherry-sized berries in the South American Andes in the 1500s when they began to be harvested and transplanted to other areas around the world. Nowadays tomatoes are amongst the leading horticultural crops worldwide considering value and amount (FAO, 2013). There are almost 8000 known tomato varieties and some are bred with solid contents more appropriate for the processing industry, often called processing tomatoes (Quezado-Duval et al., 2004). One of the major diseases of processing tomato crops is bacterial spot caused by *Xanthomonas* spp. (Quezado-Duval et al., 2004; Jones et al., 2004). The disease starts by affecting the leaves and fruits of the tomato plants and continues resulting in complete defoliation and sun scalded fruits. Different species of xanthomonads causing bacterial spot disease have been isolated in all the major tomato growing countries (Potnis et al., 2015). The yields can be reduced drastically and early detection and treatment is very important.

The pathogen of bacterial spot commonly produce lesions on all parts of the tomato plant showing above the ground, i.e. leaves, stems, flowers and fruits. Initially the symptoms may appear in the leaves as small yellow haloes which grow becoming darker in the center. As the disease evolves leaves and parts look as they

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were slightly burned, foliage turns yellowish and dies, with severe defoliation exposing fruits and stems.

Assessing the presence and the stage of the disease in tomato fields is usually done by field and plant scouting, which is time-consuming and expensive, besides it can be prone to errors due to fatigue and lack of personnel. An efficient ability to detect and evaluate the bacterial spot in tomato fields using visual spectrum images would be much valuable in these conditions.

We introduce in this study a method to detect and classify bacterial spot disease automatically in processing tomato fields. A handheld comercial camera is used to acquire color images of regular areas of the fields. Images are pre-processed and transformed to CIELab color space where a clustering procedure is applied to channel *a* grouping regions of interest related to healthy, unhealthy and other areas in the image. Post-filtering checks *L* and *b* channels to ensure areas were not mistakenly grouped. An index is proposed computing a combined measure of healthy, unhealthy and damaged areas which is directly relevant to the presence and severity of the disease in the fields. To test the method we gathered 180 images in an experimental field, where we had 2 hybrid plants in 10 different areas being inoculated with compounds of *Xanthomonas* spp. and treated differently providing a large variety of disease severities. The productivity of those areas were also measured when crop was harvested. Parallel to the image acquisition process 7 expert agronomists evaluated visually the areas providing an independent grade measure with their analysis. The scale ranges from 1.0 to 5.0, meaning undetectable presence of the disease when 1.0, and total defoliation or maximum severity when 5.0.

2. Related work

Agriculture can benefit highly with non-destructive automated plant disease detection systems. Early detection of symptoms, ease of use, and specificity of diseases are desirable features for candidate methods (Lopez et al., 2003). Unfortunately, none of the existing techniques nowadays fulfill all these desirable qualities. There is a need for cheaper, handheld systems that could be used in field conditions and for evaluating the stage of the diseases in crops.

Molecular techniques are direct plant disease detection methods that work by extracting samples of the plants and marking specific reactions to confirm alterations when compared to healthy plants. Genetic material profiling and antibodies injections are examples of such techniques. Besides molecular techniques being lab-based they are usually expensive and require more specialized laboring in the procedures. Gutierrez-Aguirre et al. (2009) designed a pcr-based technique to identify *pepino mosaic virus* in tomato plants. They were successfull in detecting all the known genotypes of PepMV. In Araújo et al. (2012), it was tested a multiplex PCR protocol for the purpose of concurrent species identification, and they were able to identify four species of *Xanthomonas* strains. Although molecular methods are precise and efforts are being taken to provide kits for common plant diseases they are not fast and have limited capacity for automation in the fields (Sankaran et al., 2010).

Spectroscopic and imaging techniques are indirect methods that could be applied in laboratory or in field-based conditions. Generally these techniques are plant and disease specifics, since some symptoms may appear in specific wave bands and not others, depending on the disease and the plant. They can also be mixed and not very distinguishable from others regarding the band. The cost is very much related to whether many hyperspectral wave bands are used or not. Some wave bands require more expensive equipments to acquire data. If visual spectrum bands (400–750 nm) are used the cost of acquisition is one of the lowest nowadays, since handheld consumer cameras could be used.

Xu et al. (2007) studied spectral wavelengths sensitivity to correlate with levels of damage caused to tomato plants infected with leaf miner. In laboratory conditions they have found strong correlation for the reflectance values of leaves damage caused by the leaf miner and the measurements at wavelengths of 1450 and 1900 nm.

Jones et al. (2010) studied spectral-based prediction models in laboratory conditions for diagnosing bacterial spot in tomato plants. The spectral diffuse reflectance of leaf samples was studied from 200 to 2500 nm using a spectrophotometer. Disease levels were more strongly correlated with wavelengths between 500 and 700 nm, and near infrared between 750 and 900 nm. Spectral signatures have been used also as a way to identify significant wavelengths upon which fruit maturation and plant health can be classified. In Yang et al. (2012), authors present a study for precisely classifying blueberry maturity based on measurements at six wavelengths (500, 525, 550, 575, 680, 750) nm.

Camargo and Smith (2009) presented a study for identifying plant disease visual symptoms using color images in visible spectrum. They describe a system where color images of the leaves of the plants are captured and processed with enhancement, segmentation and labeling algorithms making the visual symptoms marked for comparison. A dataset of banana, plantain, alfalfa, cotton and soya leaf images with symptoms was tested with results of misclassification varying from 2.2% to 35.5% in 20 images.

Bashish et al. (2010) reported an image processing system to detect and classify damaged areas of leaves caused by 5 different diseases: early scorch, cottony mold, ashen mold, late scorch and tiny whiteness. Texture features of the regions are extracted and classified with a backpropagation Artificial Neural Network. Number of images tested and conditions of acquisition were not reported.

A survey of methods using digital image processing techniques to detect and quantify plant diseases is presented in Barbedo (2013).

A method to work in field-based conditions, using visual spectrum images for detecting and classifying severity of bacterial spot disease in processing tomato crops is presented in this study. The remainder of this paper is organized as follows. Materials and methods are described in the next section. Results on experimental data and analysis are then explained. Finally a section of conclusions ends it with the main findings.

3. Materials and methods

3.1. Materials

Image data were acquired in an experimental area owned by Unilever Bestfoods, located in Goiânia, state of Goiás, Brazil (16°35′12″S, 49°21′14″O, 730 m of altitude). The tomato fields consisted of two hybrids, Hypeel 108 and U2006, with between rows spacing of 1.3 m and intra-plant spacing of 0.25 m. Plants were inoculated with compound EH 2005-54 of *X. perforans* at 37 days, and with compound EH 2006-17 of *X. gardneri* at 57 days, both with concentration of 10^8 ufc/mL. For this experiment, ten major areas (parcels) of the plantation received different treatments in the expectation to induce different degrees of severity of the disease. Each major area had six subdivisions, with hybrids equally divided in areas. Three samples (images) were taken at each of those subdivisions making a total of $10 \times 6 \times 3 = 180$ samples. These one hundred and eighty (180) pictures were taken using a digital camera Sony Cybershot DSC-S700, with a shooting position of 1.8 m above the canopy, randomly spotting the area of the experiment. *In situ*, seven experts visually analyzed the same area (framed with a wooden board in the field) and graded for the presence and severity of the disease.