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Non-destructive detection of blackspot in potatoes by Vis-NIR and SWIR hyperspectral imaging

Ainara López-Maestresalas [a], Janos C. Keresztes [b], Mohammad Goodarzi [b], Silvia Arazuri [a], Carmen Jarén [a], Wouter Saeys [b, *]

[a] *Department of Agricultural Projects and Engineering, Universidad Pública de Navarra, Campus de Arrosadia, 31006, Navarra, Spain*
[b] *KU Leuven Department of Biosystems, MeBioS, Kasteelpark Arenberg 30, 3001, Leuven, Belgium*

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ABSTRACT

Blackspot is a subsurface potato damage resulting from impacts during harvesting. This type of bruising represents substantial economic losses every year. As the tubers do not show external symptoms, bruise detection in potatoes is not straightforward. Therefore, a nondestructive and accurate method capable of identifying bruised tubers is needed. Hyperspectral imaging (HSI) has been shown to be able to detect other subsurface defects such as bruises in apples. This method is nondestructive, fast and can be fully automated. Therefore, its potential for non-destructive detection of blackspot in potatoes has been investigated in this study. Two HSI setups were used, one ranging from 400 to 1000 nm, named Visible-Near Infrared (Vis-NIR) and another covering the 1000–2500 nm range, called Short Wave Infrared (SWIR). 188 samples belonging to 3 different varieties were divided in two groups. Bruises were manually induced and samples were analyzed 1, 5, 9 and 24 h after bruising. PCA, SIMCA and PLS-DA were used to build classifiers. The PLS-DA model performed better than SIMCA, achieving an overall correct classification rate above 94% for both hyperspectral setups. Furthermore, more accurate results were obtained with the SWIR setup at the tuber level (98.56 vs. 95.46% CC), allowing the identification of early bruises within 5 h after bruising. Moreover, the pixel based PLS- DA model achieved better results in the SWIR setup in terms of correctly classified samples (93.71 vs. 90.82% CC) suggesting that it is possible to detect blackspot areas in each potato tuber with high accuracy.

1. Introduction

According to the FAO (Food and Agriculture Organization of the United Nations), worldwide potato production was above 360 million tons in 2013 (FAO, 2014). So, potato is a major food crop for which it is essential to ensure food quality along the potato supply chain (López, Arazuri, García, Mangado, & Jarén, 2013).

Blackspot bruise in potato (*Solanum tuberosum* L.) is an internal damage mainly produced from impacts either between the tubers and hard surfaces or between each other during mechanical harvesting and subsequent handling (Boeriu, Yuksel, Van der Vuurst de Vries, Stolle-Smits, & Van Dijk, 1998; Fluck & Ahmed, 1973; Mathew & Hyde, 1997). This type of bruise appears at the sub-surface and most frequently at the stem end of the tubers due to the fact that the radius of curvature is smaller there (Sawyer & Collin, 1960). The resulting blue-black discoloration of the damaged tissue is a consequence of oxidation of tyrosine by polyphenol oxidase (Dean, Jackowiak, Nagle, Pavek, & Corsini, 1993; Fluck & Ahmed, 1973). The damaged tissue tends to absorb more oil during frying (Baritelle, Hyde, Thornton, & Bajema, 2000), resulting in after-cooking darkening, one of the most undesirable effects reported by consumers (Wang-Pruski & Nowak, 2004).

The economic losses in the fruit and vegetable industry related to bruising are considerable (Van Zeebroeck et al., 2003). According to Peters (1996), in the American potato industry, bruising represents substantial economic losses every year and 70% of total damage is caused by harvesting. Mathew and Hyde (1997), reported an estimated \$20 to \$60 million losses due to potato tuber bruising in the Washington State, the second major potato producer in the US, in a particularly bad year.

An important factor contributing to the financial loss is the fact that the affected tubers do not show external damage and are, therefore, processed as healthy ones, resulting in a waste and loss of

* Corresponding author.
E-mail address: Wouter.saeys@biw.kuleuven.be (W. Saeys).

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confidence among consumers (Evans & Muir, 1999). However, the detection of those affected tubers, would allow those potatoes to be assigned to other uses like fourth range products, where tubers are processed and commercialized generally peeled and cut avoiding the use of damage areas.

In the past, damage in potatoes was assessed using catechol dye. Catechol reacts with exposed starch and discolours the surface areas with external damage (O'Leary & Iritani, 1969). This method was not suitable for blackspot determination since this type of damage occurs at the subsurface of the tubers without exposing starch. For this, tetrazolium, a chemical capable of identifying blackspot bruising, was used. However, both products were later known to be toxic to animals while tetrazolium was also toxic to humans (Kleinschmidt & Thornton, 1991) and therefore, they are no longer used.

Different protocols have been used in order to test tuber damage at either harvest or packaging. Since some types of bruises can take long to become visible (two to four days), the use of a hot box is a recommended option as it speeds up bruising development allowing damages to be visible within six to 12 h (Thornton & Bohl, 1998).

In a report published by Jack, Dessureault, and Prasad (2013) damage of potatoes in a real washing and packaging line was identified. To this end, they collected 42 samples of potatoes from 4 to 3 different points along the washing and packaging line, respectively, and placed them in a hot box for a minimum of 12 h with the temperature set to 35 °C. After that period, tubers were washed gently to remove dirt and visually assessed after peeling. They found that 10 ± 8% of the tubers presented some kind of damage at the washing line, while a notably higher proportion of the samples (52% ± 30%) were damaged in the packaging line. These numbers highlight the need for a non-destructive technique to detect this internal damage before tubers reach the market, in order to reduce the current losses and regain customers' trust.

Hyperspectral imaging, a technique combining the principles of spectroscopy and imaging, has been applied to subsurface defect detection in fruit and vegetables, such as apples (ElMasry, Wang, Vigneault, Qiao, & ElSayed, 2008; Lu, 2003; Xing & De Baerdemaeker, 2005; Xing, Saeys, & De Baerdemaeker, 2007), pears (Zhao, Ouyang, Chen, & Wang, 2010) and mushrooms (Gowen et al., 2008). In the case of potatoes the usefulness of hyperspectral imaging has been reported for the discrimination between potato tubers and clods (Hägg, Häkkinen, Kumpulainen, Ahvenainen, & Hurme, 1998; Vanderslice, Higgs, Hayes, & Block, 1990), the detection of hollow heart (Dacal-Nieto, Formella, Carrión, Vazquez-Fernandez, & Fernández-Delgado, 2011b) and the detection of common scab (Dacal-Nieto, Formella, Carrión, Vazquez-Fernandez, & Fernández-Delgado, 2011a). Thybo, Jespersen, Lærke, and Stødkilde-Jørgensen (2004) were able to identify internal bruises in potato slices of cultivar Saturna by applying magnetic resonance imaging. Rady and Guyer (2015) recently reviewed the state of the art in non-destructive quality evaluation of potatoes from the first application in the sixties up to now. However, no reports were found on the non-destructive detection of blackspot damage in intact potatoes.

Considering the promising results reported for hyperspectral imaging techniques in identifying subsurface defects in different fruit and vegetables and other potato defects, the objective of this study was to evaluate the potential of hyperspectral imaging for blackspot detection in potatoes. Two wavelength regions of the electromagnetic spectrum were considered: Visible-Near Infrared (Vis-NIR, 400–1000 nm) and Short Wave Infrared (SWIR, 1000–2500 nm).

2. Material and methods

2.1. Sample preparation

A total of 188 potato tubers of three different cultivars (Hermes, Bintje and Magnum) harvested in 2013 were analyzed in this study. Samples from cv. Hermes (109 tubers) were provided by The Basque Institute for Agricultural Research and Development (NEIKER-Tecnalia), Spain and were sent to KU Leuven Department of Biosystems, MeBioS, Leuven, Belgium, for the measurements. Samples from cv. Bintje and Magnum, consisting of respectively 44 and 35 tubers, were supplied by a local farmer in Leuven, Belgium. The tubers were randomly divided in two groups of equal size. The potatoes of the first group ($n_b = 94$) were subjected to impact in order to induce internal bruising, while the others ($n_h = 94$) served as the control group. Prior to analysis samples were kept in a refrigerator at 4 °C. Then, samples were washed and weighted.

In order to induce the bruises, the tubers were dropped 300 mm inside a cylinder above an impactor facing the stem end (Fig. 1). They were left to fall free and hit a hemispherical head of 25 mm in diameter attached to a circular flat plate. The calculated impact energy varied between 303 mJ and 994 mJ depending on the mass of the potatoes. After impact, tubers were kept in a hot climate

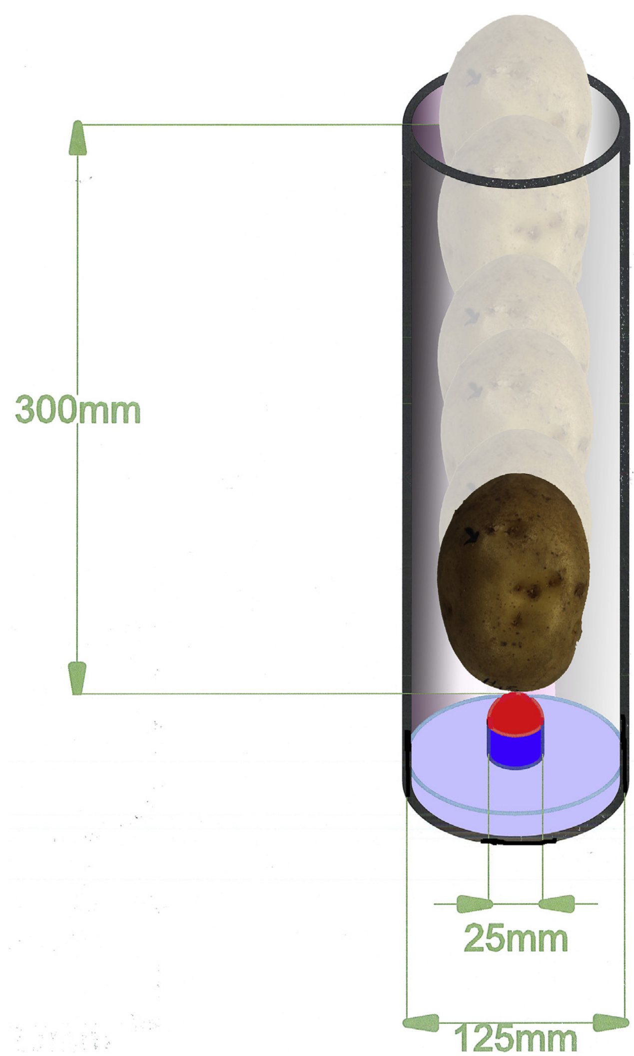

Fig. 1. Schematic diagram of the system used to induce bruises.