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Mass loss determination of wheat kernels infested by granary weevil from X-ray images

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ABSTRACT

Mass losses in wheat kernels infested by the granary weevil were determined using soft X-ray imaging. The mass loss strongly depended on the life stage of the pest insect. Hence, determination of the correlation between developmental stage and mass loss may help to decide management strategies and can also be used to determine time and place of infestation. The mass losses were calculated from X-ray images, taken from 20 to 66 days after infestation, using the grey scale. To compare calculated mass loss (CML) with the actual mass loss, wheat kernels were weighed. Interdependence of the mean values of the CML and weighed mass (WM) on infestation time was determined and fitted by linear and polynomial curves. During these studies kernels from the infested sample were assigned to six categories based on the CML and morphological features obtained from the X-ray images. The categories were as follows: sound, small larva, medium larva, large larva, pupae and emerged. Comparison of kernels assigned to categories based on mass with kernels classified by area of grey scale revealed that mass was more reliable in assigning grain to particular classes. The mass index decreased the number of wrongly classified kernels. The polynomial curve for mass loss can be used to give an indication of the time and place of infestation.

1. Introduction

The granary weevil (*Sitophilus granarius* L.) is one of the most harmful pests of stored grain and other products stored in temperate climates. The degree of damage is directly related to the infestation rate which is determined by factors such as the number of eggs laid, and the survival and fecundity of offspring (Nawrot et al., 2010). Traded grain is prone to weevil infestation due to warm conditions, little physical movement and long storage times. Two kinds of infestation are distinguished: external and internal. The external infestation is connected with feeding of adult insects and is easy to detect whereas the internal (hidden) infestation of developmental stages inside the wheat kernel is much more difficult to detect. The infestation causes grain losses by consumption and contamination of the grain with excrement and fragments of pests. It causes nutritional losses and degrades the quality of flour (Sanchez-Marinez et al., 1997, Pearson et al., 2003).

A fast and real-time detection method for internal infestation is needed and though a number of methods have been developed, currently none of them are being used in the monitoring of grain either in storage or transportation on a wide scale. The main reason is the high price of the instrumentation needed. Some of the methods are time-consuming, need to destroy kernels during the test, or do not detect hidden infestation. Among methods used in research laboratories we may find: flotation and cracking (Brader et al., 2002; Haff and Slaughter, 2004), acoustic detection (Neethirajan et al., 2007; Gutierez et al., 2010; Pearson et al., 2007), immunoassay methods such as ELISA (Brader et al., 2002; Neethirajan et al., 2007; Piasecka-Kwiatkowska et al., 2005; Krizkova-Kudlikova and Hubert, 2008; Atui et al., 2007), thermal imaging (Gowen et al., 2010; Manickavasagan et al., 2008), a single kernel characterization system (SKCS) (Pearson et al., 2003) and electrical conductance (Neethirajan et al., 2007; Brabec et al., 2010; Pearson and Brabec, 2007). Most of these methods, however, are unable to detect low-level internal infestation and do not show potential for automated inspection. Nowadays, mainly near-infrared hyperspectral imaging and soft X-ray roentgenography are carried out to detect hidden infestation in the food industry.

Near-infrared spectroscopy (NIRS) is well established as a nondestructive tool for multi-constituent quality analysis of food materials. It uses the spectral differences between healthy and

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damaged products which are connected with different chemical composition of these products (Singh et al., 2009). Nowadays, the NIRS method is usually connected with the hyperspectral imaging (HSI) system. HSI is an emerging platform technology that integrates conventional imaging and spectroscopy to attain both spatial and spectral information from an object (Gowen et al., 2007). Insect-damaged kernels were studied by Singh et al. (2009, 2010) using near-infrared hyperspectral imaging (NIR-HSI) system. It was observed that insect-damaged wheat kernels had less starch compared to healthy ones, due to consumption of starch by insects during their development. However, NIR spectra do not reveal insect stages hidden inside kernels.

Hidden insects can be located by applying soft X-ray imaging of grain. The X-ray technique can be used for detection of any kind of insect pest in a variety of agricultural products (grain, fruits, vegetables). Haff and Pearson (2007) developed an automatic recognition algorithm to detect wheat kernels infested with granary weevil, *S. granarius* (L.) and olives infested with the olive fly, *Bactrocera oleae* (Gmelin), using X-ray imaging. For this research 64 features were extracted from each image, and the discriminant analysis routine was used to test every possible combination of three features. The algorithm yielded results comparable to those obtained by human subjects evaluating digitized X-ray film images. However, this algorithm did not properly classify images containing early larval stages. Wheat kernels, artificially infested by red flour beetle, were X-rayed by Karunakaran et al. (2004a). An algorithm was developed to extract features based on histogram groups, textural features, and histogram and shape moments from the X-ray images of wheat kernels. In this study, identification of sound and infested kernels was assumed by means of the DISCRIM procedure of the statistical classifiers and Back Propagation Neural Network (BPNN) analysis, but detection of early stage infestations was poor. Keagy and Schatzki (1993) developed an algorithm for machine recognition of granary or maize weevil damage in wheat kernels. The algorithm used convolution masks to look for intersections at eight orientations. The intersections were defined as additional edges and lines which were seen at angles to the crease on binary images of infested kernels. In sound kernels, the central crease was represented by a line on the binary image. Using this algorithm, it was possible to identify infestation by larger stages only. Fornal et al. (2007) applied a three-stage algorithm to detect eggs and internal stages of granary weevil in wheat grain from the soft X-ray images. It used segmentation of image objects and a Local Equalization filter for the extraction of image detail. They also proposed equations for calculation of the approximate date of infestation.

The aim of the current study was to determine the relationship between a calculated mass loss (CML) from X-ray imaging, weighed mass (WM) and the time of infestation, and to verify the algorithm so developed. As calculated mass loss is related to weevil larval feeding in wheat, the algorithm was based on a grey scale calibration marker (made from plexiglass) obtained from X-ray images, which represented kernel mass loss due to larval feeding. It was used as a basis for adjustment of the on-line real-time separation method.

2. Materials and methods

2.1. Wheat samples and sample preparation

The study was carried out on the Bogatka variety of winter wheat (*Triticum aestivum* L.) which belongs to a bread category, and it is often mixed with higher class flour. The mass of one thousand kernels is 40.3 g (Descriptive List of Varieties, 2010). The Bogatka variety was obtained from the Research Centre for Cultivar Testing in Słupia Wielka near Poznań (Poland). The SKCS analysis showed that the values of mass, diameter, moisture content and hardness index of a control sample were 37.3 (9.3) mg, 2.84 (0.39) mm, 11.1 (0.4)% and 59.0 (16.3), respectively. The standard deviation of measured values is placed in brackets.

The infestation experiments took place at the Institute of Plant Protection – National Research Institute in Poznań (Poland). Grain was conditioned for seven days in an incubator at 75 ± 5% r.h. and 26.5 ± 0.5 °C. After this conditioning, 20 pairs of adult granary weevils [*S. granarius* (L.)], which had emerged from kernels during the previous 24 h, were introduced to a 400-kernel sample (Niewiada et al., 2005). After two weeks the weevils were separated from the grain. After sifting, infested wheat kernels were separated initially by using roentgenography to identify the presence of weevil larvae. Next 30 infested kernels were fixed on thin papers with an adhesive cover (see Fig. 1). The kernels were placed in transverse rows with the grooves and germs oriented downwards. The studied sample number was 750 kernels (36.6 g) but only in 377 kernels (17.7 g) was weevil development observed. The samples were X-rayed three times a week and simultaneously the infested kernels were weighed. The X-raying was started on the 20th day after infestation and finished on the 66th day after infestation. The experiment thus lasted seven weeks and images

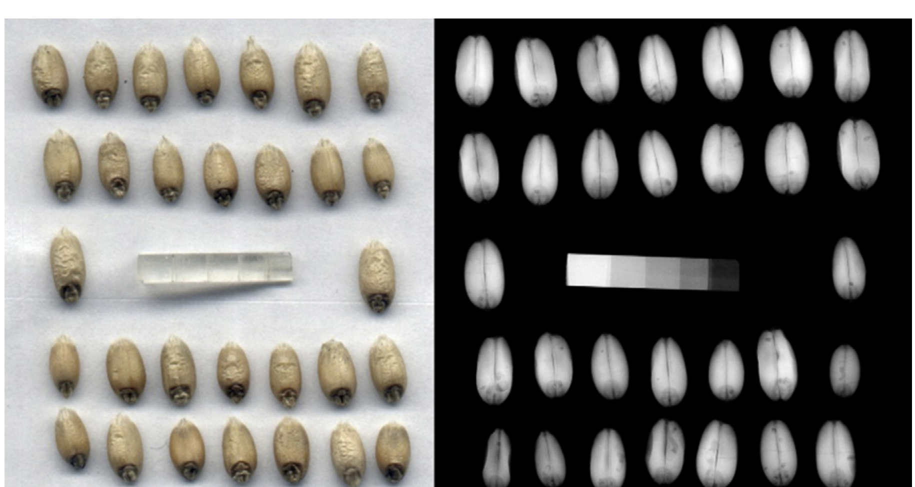

Fig. 1. Image of the X-rayed sample and the calibration marker.