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Detection of potatoes damages by thermal imaging

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Abstract: *Detection of potatoes damages by thermal imaging.* The aim of the study was to develop a method of detecting non-visible mechanical damages of potatoes by means of thermovision. The study was conducted on two varieties of potatoes: Charlene and Terka. The tests were carried out with a VIGOcam v50 camera operating in the spectral range of 8–14 μm. Damaged potatoes after 24 h were cooled at temperature 5°C for 1 h and then at 25°C their images were taken with a thermal camera every 1 min in 50 min. The imaging of the potato tubers of the Charlene variety allowed for unambiguous identification. Too little difference in temperature between the undamaged surface of potato variety Terka and damaged surface did not allow for a precise identification of the damaged area.

Key words: thermography, potato damage, thermal imaging camera

INTRODUCTION

The progress that can be made in the mechanization of the harvesting, transportation, post harvesting and storage processes is leading to obtaining good quality vegetables, but some operations continue to cause mechanical damages. An example is potato tubers damage. Damaged vegetables lose their quality and are disqualified as consumer and processing raw materials. A side effect of mechanized potato harvest is the occurrence of mechanical damage to tubers. Research conducted in Poland and abroad has shown that a relatively large proportion of the crop is damaged at the stage of harvesting and further processing (the damage index can reach as much as 30% and more) [Marks 2009].

Mechanical damage of potato is caused by collision and pressure with foreign bodies such as lumps of earth or stones and equipment during work processes such as harvesting, transport, storage and separation. The mechanical damage of potato tubers is mainly in two forms [Marks 1986]:

- external damage (visible to the naked eye); these include tuber rupture, abrasion of the skin, extensive and spot crushing of the parenchyma and all kinds of cut damages;
- internal damage (under the skin of the tuber); these occur in the form of defects of the parenchyma without destroying the surface layer; they appear mainly as darkening, crushing or cracking pulp and the creating hollow chambers inside the tubers.

Darkening spots after the impact are visible outside and inside the tuber in the form of black, blue or gray spots. They are formed as a result of melanin formation. These symptoms usually do not exceed an area with a diameter of 5–10 mm and 2 mm of depth. High shear stresses cause cell wall cracking and deformation [Marks 2009]. Many scientists have classified the damages, but each of these classifications is slightly different. The exact classification of damages was done by Hughes [1980], which was refined by Noble [1985]. It was intended to demonstrate how physical factors affect potato defects. In the following years, researchers have described another type of damage – that is white spot and internal cracks. Bajema et al. [1998] found that white spot is a small area of damage with a slight discoloration or discoloration, whereas internal cracks occurs when the tubers fall from considerable height, which may result in discoloration of the tissue. Tissue damage is the most common symptom of internal damage of potato tubers. Changes in the color of damaged area cause pigmentation of yellow, red, brown, blue and black. Undamaged tissue of cream colored is in contrast to the stains resulting from internal damages. Sypuła [2013] studied the mechanism of deformation of cells in potato tubers after impact as a result of free fall. He concluded that as a result of potato drop from height higher than 0.4 m, the share of potato damage in the form of abrasion and darkening of the tubers was reduced, but cracks and crushes of the parenchyma began to dominate, which are more dangerous for the potato. Damage-induced changes and internal stress responses are strictly based on the physical and biochemical properties of potatoes [Hara-Skrzypiec 2013].

The increased interest of food manufacturers in the quality of the offered plant products stimulates research into the development of innovative non-invasive methods for detecting damage of agricultural products. Thermal imaging is an excellent tool for assessing damage and quality control of food products, since the change in certain properties of a biological object can be related to changes in temperature. Using the radiation from the infrared range, you can contact-free, in real time to obtain the temperature distribution on the surface of the objects under test. Infrared radiation is electromagnetic radiation emitted by all the bodies with a temperature above absolute zero. It is caused by vibrations of atoms, ions and particles. The wavelength of the infrared radiation is from 0.78 μm to 1 mm. Infrared radiation is not only emitted by the body, but also absorbed, reflected and transmitted. Atmospheric air partially absorbs infrared radiation. The least absorbed is radiation with wavelengths in the ranges of 3–5 and 8–14 μm. These ranges are called atmospheric windows and in these ranges work thermal imaging cameras. The basic law on which imaging is based is Stefan's and Boltzmann's law, which assumes that the total energy of the radiation emitted by the perfect black body (PBB) from the surface unit is directly proportional to the fourth power of the black body's temperature [Ludwicki and Ludwicki 2015]. Perfect black body which not occur in nature, is characterized by the fact that it absorbs the radiation completely and the emissivity of such a body is 1 [Więcek and De Mey 2011, Więcek et al. 2017]. However, a body that does not completely absorb radiation incident on them (called a gray body) has an emissivity of less than one, then:

$$E = \varepsilon \cdot \sigma_0 \cdot T^4$$

where:
E – radiation density [$W \cdot m^{-2}$];
ε – emissivity;
σ_0 – the Stefan's and Boltzmann's constant [$W \cdot m^{-2} \cdot K^{-4}$];
T – body temperature [K].

In thermal imaging cameras, infrared radiation is focused by an optical system and projected onto a matrix made of thousands of infrared sensors. In these sensors, due radiation, electrical changes occur that are detected by the electrical system and processed on a monitor image in the form of a thermogram. The sensitivity of the cameras is very high and is about 0.1 K. Thermal imaging methods use active and passive thermography. Passive thermography is used to observe the radiation emitted by the body without using additional external impulses. Its application is possible if the temperature differences on the surface of the object are significant. Active thermography is used when additional external (usually thermal) impulses are required to detect the heterogeneity of thermal properties within the examined object and the imaging temperature differences on the examined object [Świderski 2009]. Active thermography is divided according to the stimulation method for many types including [Oliferuk 2008]:

- pulsed thermography – it consists in testing the object during its cooling, after preheating it; it is the simplest and most popular method of active thermography;
- lock-in (modulated) thermography – it uses the theory of thermal waves; in this method, the object under study in the time sequence is heated by a sinusoidally variable wave; during imaging, a map of amplitudes and phase shifts is obtained, which makes it possible to detect defects in the surface layer of an object;
- pulse phase thermography, which is a combination of the above-mentioned methods of active thermography.

Thermography has proven to be an effective way to detect damage to walnut shells. For this purpose active thermography was used. In studies of damage shell nuts a thermal impulse was applied to the examined object. It turned out that after 3 min heating sessions of objects, a significantly higher temperature difference was observed in the images of nuts with open shell than in nuts without damage [Wang et al. 2006]. Van Linden et al. [2003] investigated the possibility of using thermovision systems in detecting tomato damage. It was found that on thermograms temperature differences were observed at the area of damage after 15-second heating with microwaves. Baranowski [2008] used active thermography to identify damages in apples of different cultivars. He developed a method of early identification of apples bruises using phase-pulse thermography (PPT).

MATERIAL AND METHODS

Test material consisted of 15 potato tubers varieties Charlene i Terka harvested by machine and washed. Damage the potatoes was obtained by dropping them from a height of 2 m on a hard surface. Imaging defective tubers was carried out after about 24 h with a VIGOcam v50 camera working in the 8–14 μm spectral range. To obtain thermal contrasts on photograms, the potato tubers were cooled at 5°C for about 1 h. Subsequently, the tubers were heated at ambient temperature of 25°C and a sequence of images was recorded every 1 min in 50 min measurement sessions. The camera was set at a distance of 0.5 m from the test object, while the emissivity value was 0.98. For each selected image were selected two fields including the damage surface and the undamaged surface. In these areas it has been determined: the number of pixels in a given area, the minimum and maximum temperature and average temperature.

RESULTS AND DISCUSSION

Damage detection of potato variety Charlene

In the experiment immediately after the potato damage, there were no significant changes in the temperature of the potato surfaces in damaged and undamaged areas. Differences between the temperatures compared surfaces were observed after 24 h and after an additional cooling pulse. The detection rates of damage were average temperatures of damaged and undamaged areas and their differences, i.e. thermal contrasts. Figure 1 shows an example of a thermogram from a sequence of images of a damaged potato tuber of the Charlene variety and a photograph of a potato section showing the area of potato damage.

The course average temperatures of the area without damage and damage of the potato variety Charlene during imaging is shown on Figure 2.

An assessment was made whether the surface temperatures of the areas without damage differed significantly from those with damage. Due to the fact that the temperature distribution is not normal for hypothesis testing the non-parametric Mann–Whitney U test was used. The statistical hypothesis H_0 was that the average temperatures for the areas studied were the same, in comparison to the alternative hypothesis H_1 that the average temperatures were different. Calculations were made using Statistica 13.1. This test shows that at the significance level $\alpha = 0.05$, we can reject the null hypothesis that the mean temperatures of the potato surface damaged and undamaged are equal, therefore, temperature differences

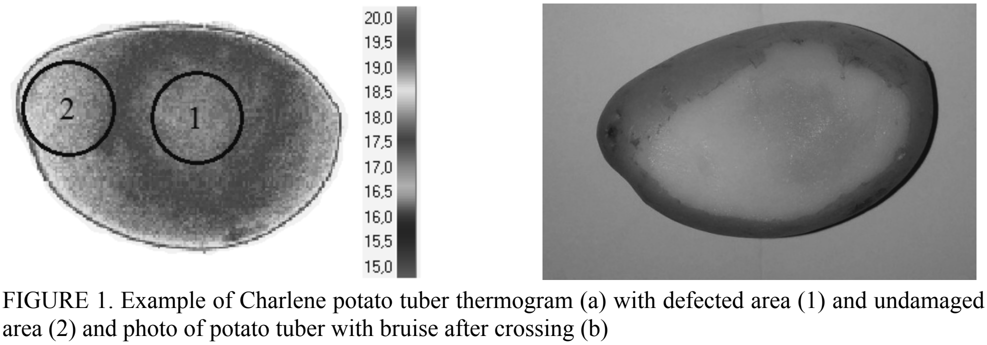

FIGURE 1. Example of Charlene potato tuber thermogram (a) with defected area (1) and undamaged area (2) and photo of potato tuber with bruise after crossing (b)

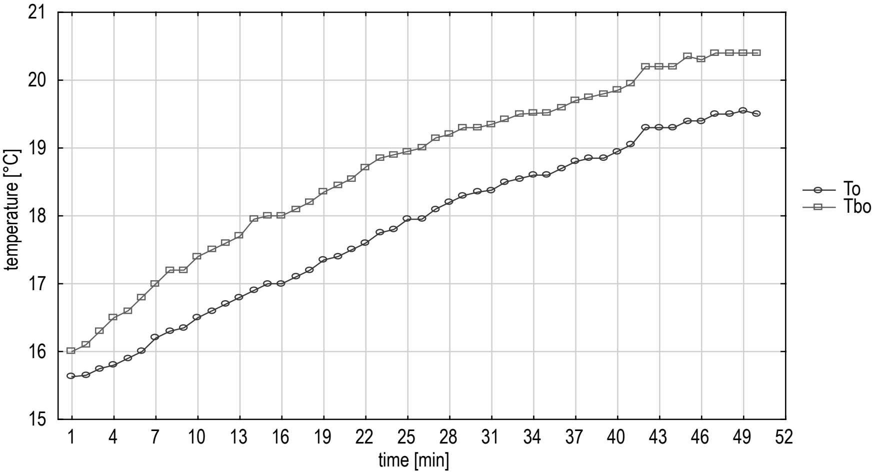

FIGURE 2. Course of average temperature value during imaging in the area without damage (Tbo) and with damage (To) for potato Charlene variety

are significant. Figure 3 shows the median values and the scattering of measured temperature values for the considered areas of potatoes variety Charlene.

It was found that, for the Charlene variety, the average surface temperature of damaged areas was in each case lower than the average temperature of the undamaged area. In the process of heating the cooled potatoes at ambient temperature the highest temperature difference (1.12°C) was observed at 22 min of heating (Fig. 4).

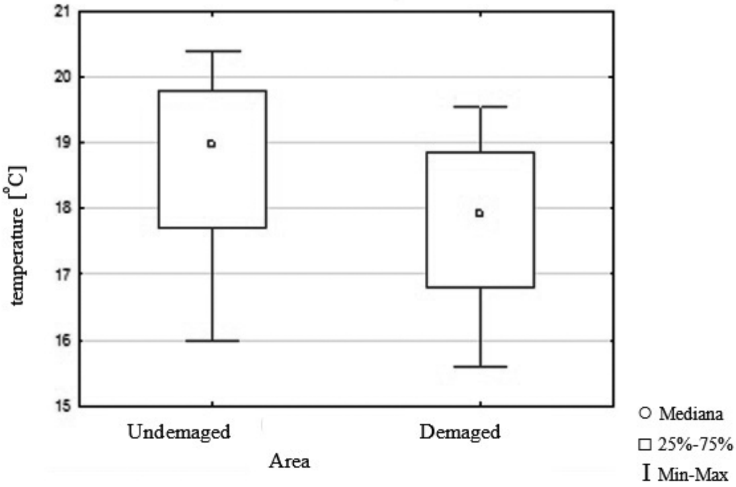

FIGURE 3. Graphical representation of medians of surface temperature of the areas without damage and damaged and the scattering of measured temperatures for the considered areas of potato variety Charlene

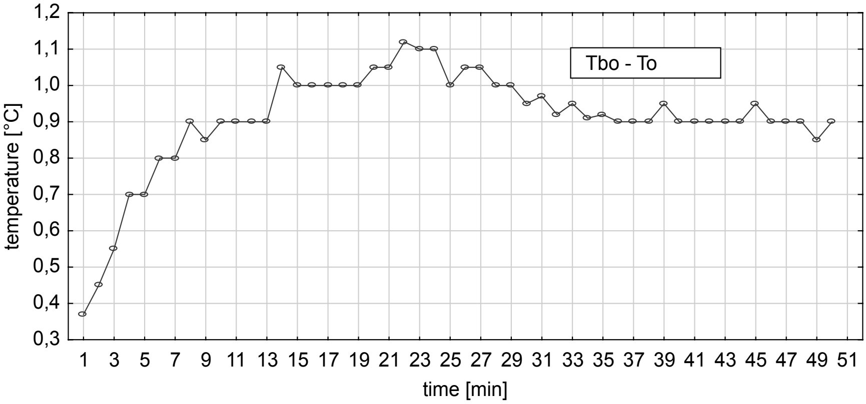

FIGURE 4. Graph showing the differences in mean surface temperatures of the undamaged area (Tbo) and damaged area (To) Charlene potato during imaging

Damage detection of potato varieties Terka

Figure 5 shows the course of the average surface temperatures of the areas without damage and with the damage of potato variety Terka registered using thermal images.

As at previous potato variety, the Mann–Whitney U test was used to evaluate the significance of the average surface temperature difference between Terka potato area without damage and damaged area. For the Terka variety potatoes at significance level α = 0.05 it can be assumed that the average temperature difference is statistically insignificant. Figure 6 on the chart box and whisker plot shows the medians and the range of the temperatures for the tested areas of

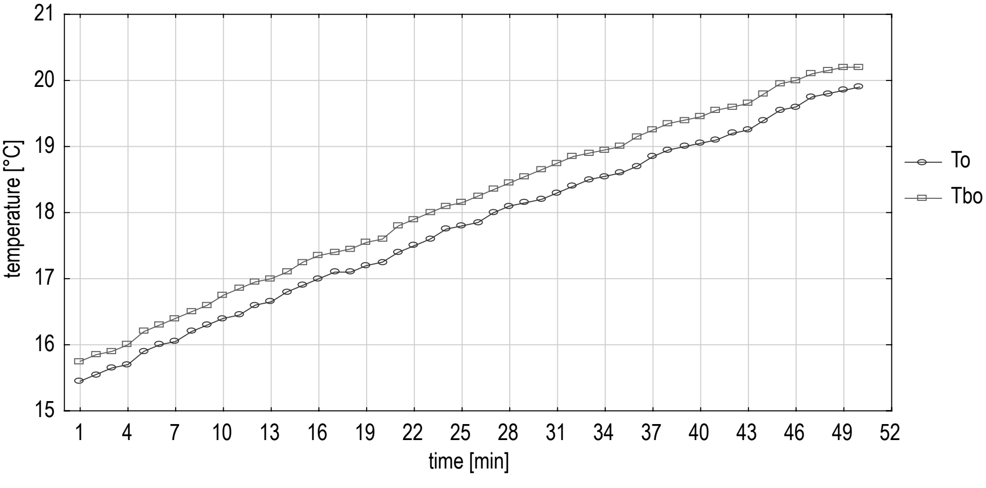

FIGURE 5. Course of average temperature value in the area without damage (Tbo) and with damage (To) for potatoes Terka variety during imaging

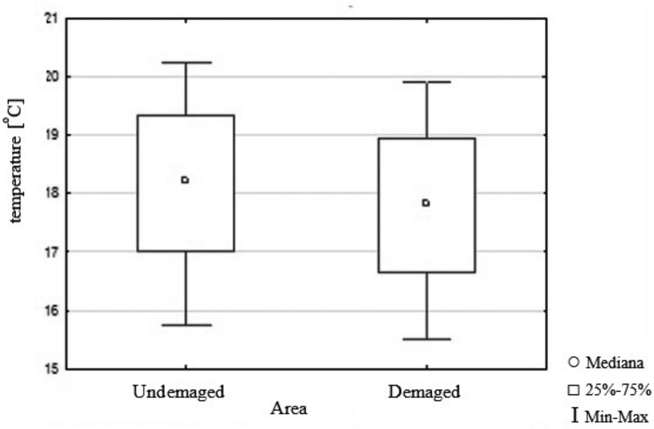

FIGURE 6. Graphical representation of medians of surface temperature of the areas without damage and damaged and the scattering of measured temperatures for the considered areas of potato variety Terka

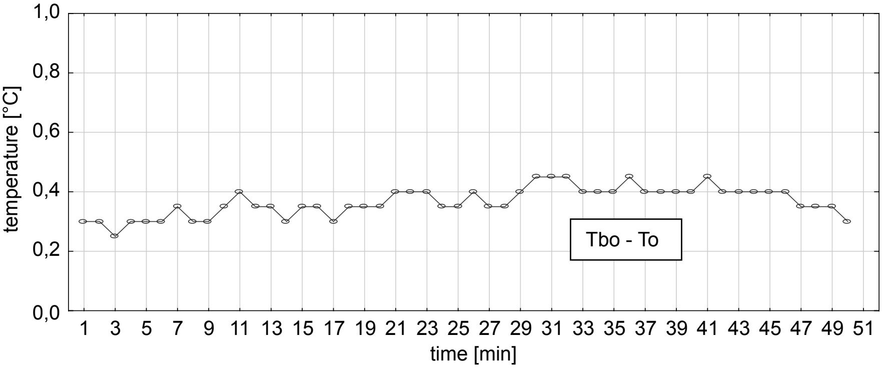

FIGURE 7. Graph showing the differences in mean surface temperatures of the undamaged area (Tbo) and damaged area (To) Terka potato during imaging

the potato variety Terka without damage and with damage. Figure 7 shows the difference in surface temperature of the areas of the potato varieties Terka without damage and with damage obtained from the sequence of thermal images.

During heating at ambient temperature, the highest temperature difference of 0.43°C was recorded between 42 and 43 min of heating potato Terka. The observed difference is relatively small compared to the value obtained for a variety of potato Charlene.

CONCUSIONS

1. The thermal imaging of the potato tuber of the Charlene variety under described conditions has allowed unambiguous identification of the damage surface of the potato.
2. In the heating process at a temperature of 25°C chilled potato variety Charlene the maximum registered surface temperature difference between healthy and damaged tissues was 1.12°C.

3. Too small temperature difference between the damaged and undamaged surface the Terka variety potato tubers did not allow accurate identification of the damaged area.

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Streszczenie: *Wykrywanie uszkodzeń ziemniaków za pomocą termowizji*. Celem badań było opracowanie metody wykrywania niewidocznych okiem nieuzbrojonym uszkodzeń mechanicznych ziemniaków za pomocą termowizji. Badania przeprowadzono na dwóch odmianach ziemniaków Charlene i Terka. Badania przeprowadzono z użyciem kamery VIGOcam v50 pracującej w zakresie spektralnym 8–14 μm. Uszkodzone w sztuczny sposób ziemniaki po 24 h schładzano w temperaturze 5°C przez 1 h, a następnie w temperaturze 25°C wykonywano zdjęcia ich powierzchni kamerą termowizyjną co 1 min przez 50 min. Obrazowanie termowizyjne umożliwiło jednoznaczną identyfikację powierzchni uszkodzeń bulw ziemniaka odmiany Charlene. Zbyt mała różnica temperatury między powierzchnią nieuszkodzoną ziemniaka a miejscami z uszkodzoną tkanką bulw ziemniaka odmiany Terka nie pozwoliła na dokładną identyfikację obszaru uszkodzenia.

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