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Influence of thermal radiation on leaves and fungal pathogens

In terms of the decreasing number of pesticides and rising energy costs, it is necessary to search for alternatives to control weeds and pests. The irradiation of leaf tissue and fungal pathogens with bundled infrared radiation could be a solution here. It turned out in the test series that young leaf tissue can be damaged already with a short heating by radiation, however, a non-lethal heat does not affect already established pests.

Keywords
Apple, infrared irradiation, fungal abatement

Abstract
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In the context of Precision farming and the reason of Environmental protection, in recent years, new, non-chemical strategies, for targeted weed control were developed. Thermal weed control plays a decisive role because of her effectiveness. This includes the use of lasers as thermal radiation source [1; 2]. Those can be applied accurately to cause evaporation of water in plant tissue due to their high energy density and heat effect.

A simpler method is the heating by infrared radiation. Already in 1969 it was shown that brief heating of plant material on 57 °C leads to lethal tissue damage [3]. Previous heating trails with plants, however, were mostly carried out using a hot water bath, whereby a very fast and above all complete treatment of the plants. The fact that brief heating can have a positive effect on the resistance to pathogens was showed on trails with barley. So led heating to 50 °C for one minute to induced resistance to powdery mildew (*Blumeria graminis* f. sp. Hordei) [4].

In this study it was the attempt to heat plant tissue with as low energy and material possible. In the first test series it was examined, whether a nonlethal irradiation that only has a fatal effect to pest infected tissue, can take an impact on fungal growth.

Material and Methods

For irradiation of the plant tissue two moveable converging lenses and a leaf holder were attached to a lamp housing. To heat the tissue, different halogen bulbs with a high proportion of infrared radiation were used. The temperature pattern of the heated leaf tissue was recorded and evaluated with an infrared camera (Optris® PI). A frame rate of 50 images per second allowed precise statements about the temperature behavior of the test plants (**Figure 1**). Within the experimental setup the leaf temperature could be regulated by displacing the collecting lenses. The power consumption of the light bulb could be adjusted by using a transformer. The radiation power, that has an impact on the leaf, was measured with a laser power meter, the amount of infrared radiation of the total radiation was determined with a spectrometer. Furthermore, the water content of the leaves was determined gravimetrically and a leaf thickness measurement was carried out. In order to differentiate the occurring damage due to the different temperatures, the leafs were measured, photographed and visually rated directly after the treatment at 24, 48 hours and a week later, using a binocular microscope. The irradiation effect was tested on apple seedlings (Breed 'Jonagold') that were inoculated with apple powdery mildew (*Podosphaera leucotricha*) and apple scab (*Venturia inequalis*). The leaves had an average tissue thickness of 0.26mm and a water content of 71 %.

Results

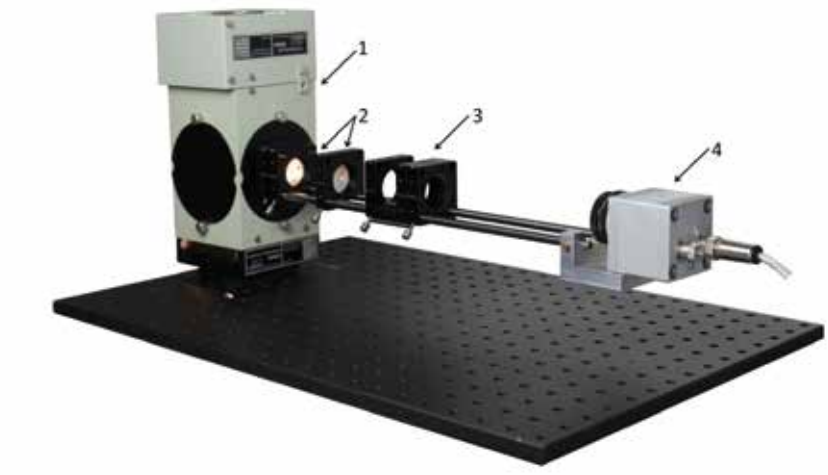
The irradiation experiments showed a linear relationship connection between the power set of the halogen bulb and the leaf temperature. Differences in power/temperature ratio were occurring due to different leaf thickness and water contents. For each power adjustment of the halogen lamp there is a maximum temperature value that depends on the leaf thickness and the size of the irradiated area. If the maximum temperature for the set power is reached, the temperature intake and disposal levy in balance. With some small manual corrections, a predetermined temperature can be held. In this way selected leaf areas can be exposed to fixed temperature for a defined period of time. It was found that a leaf temperature of about 55 °C leads to partial tissue destruction and formation of necrosis. The water content of destroyed cells evaporates due to the heading and causes a local cooling of the destroyed tissue.

The irradiation leads to a characteristic temperature pattern (**Figure 2**). A leaf heating of the same spot, for 10 seconds with

different power shows a correlation between temperature and power of $R^2 = 0.98$. If different leafs of the same plant get heated up to the point of 57 °C before the tissue destruction starts, there still is a correlation between temperature and power of $R^2 = 0.98$. Once the crucial point of tissue destruction is exceeded, the temperature pattern changes (**Figure 2**) due to the water disposal of the damaged cells. After switching off the radiation source the tissue cools down to room temperature very quickly. However, the water-filled veins cool down slower than the surrounding tissue.

Cells that were destroyed by high temperature do not regenerate once they are damaged. The damaged tissue collapses due to the water loss. On the damaged surfaces the shape of the coiled filament of the light bulb gets visible. During the first few hours after a tissue destruction the outer edge of the irradiated leaf areas turns brownish. This coloring migrates slowly from the outer edge inwards towards the center spot. Within 24 hours the damaged areas can easily be identified because they get brighter. Long-term monitoring shows that damaged leaf areas are sharply-limited and do not spread (**Figure 3**).

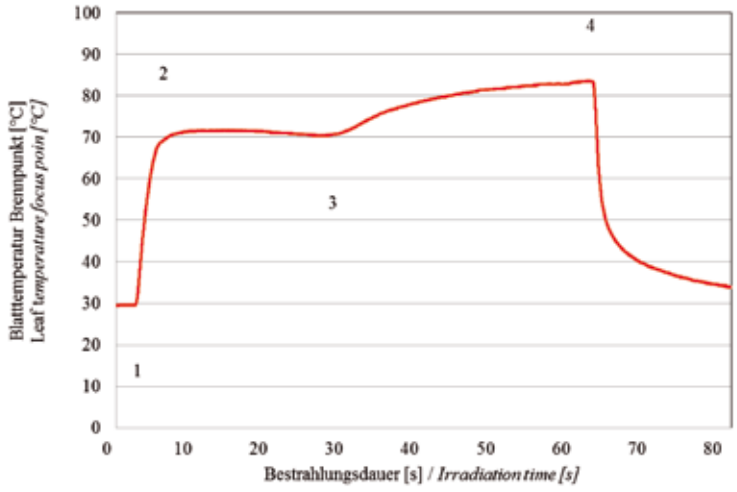
Fig. 1



1 Lampengehäuse/*Lamp housing*
2 Blatthalterung/*Leaf holder*
3 Linsen/*Lenses*
4 Infrarotkamera/*Infrared camera*

Experimental Setup with light housing, collecting lenses, leaf holder and infrared camera

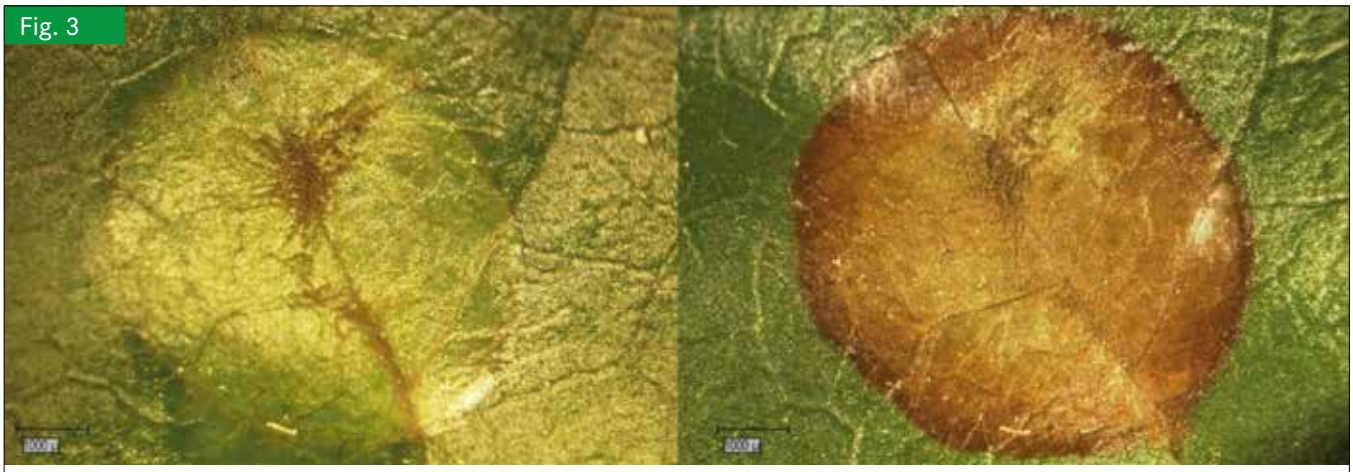
Fig. 2



1 Einschalten der Strahlungsquelle/*Engaging of the radiation source*
2 Verdunstung setzt ein/*Evaporation starts*
3 Zellwasser ist verdunstet/*Cell water is evaporated*
4 Ausschalten der Strahlungsquelle/*Deactivating of the radiation source*

Temperature pattern of the heating of an apple leaf at 40 Watt bulb power

Fig. 3



Young apple leaf with apple scab; heated to a lethal temperature; shot directly after heating (left) and one week later (right)

A non-lethal heating on 50 °C, up to one minute, did not show an effect on both leaves and fungi. The pests were not damaged or clearly influenced in their growth behavior.

A lethal heating of plant tissue up to 80 °C for a time of 30 seconds did not show a result with apple powdery mildew as well. In contrast, some of the treated apples scab areas dyed from their brown to a dark green and some treated leafs showed a partial dying.

Discussion

It could be shown that it is possible to heat plant tissue sufficiently and precise. Within a few seconds a leaf area of 3 mm^2 could be damaged by a radiation power of 0.5 Watts. Thus, with little expenditure of energy it is possible to damage plant tissue lethal. Nevertheless, there was no effect on the used fungus by a non-lethal irradiation of the affected tissue. Neither a change nor a growth depression of the pests could be detected.

Also a lethal irradiation for the leafs did not had an effect on the powdery mildew colonies. However, it can be assumed that the necrotic tissue no longer serves as a nutrient base for the haustoria. A few with apple scab infested test leafs, that were heated above 80 °C, showed a discoloration of their sporulation organs and partial death of leaf areas. Perhaps the multiple stresses by pathogens and cell death through heating leads to a dump of fungus affected leaf areas. In each case the destruction of leaf tissue withdraws the basic food source of the used obligate biotrophic pathogens. However, there is a food source for necrotrophic pathogens created at the same time.

Due to the lack of detectability the experiments were only directed to fungi that were already in fructification stadium. Mycelium, which was not visible on the leaf surface, got not examined, because a whole-area treatment of crops neither were possible nor sought. It should be emphasized that a locally heated spot builds a sharp edged form that does not spread. Therefore it can be assumed that the local treatment of leafs without losing the whole leaf is possible.

Conclusions

A treatment of infected plant tissue, with the proposed method, only makes sense, when the fungus can be detected and treated in an early stage of his development. According to the current state of art this cannot be done. However, the damaging of plant tissue by infrared radiation is simple and can be done with low energy consumption, little construction and investment effort. It thus provides an alternative treatment method to present methods such as large-scale treatments with gas burners. In conjunction with an automatic recognition method of weed in early stages of growth, a targeted treatment may be feasible and useful.

References

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