STRESS FACTORS IDENTIFICATION USING THERMAL CAMERA

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Abstract
The yields of plant production are limited by a number of stress factors affecting the plants during its vegetation. Heat, water stress, herbivorous organisms and other stress factors have a negative effect on the crop yields. This study is focused on describing the impact of stress factors of plants by monitoring the rape drying process by a thermal camera. The results of the measurement showed that the plant of rape resists heat and water stress for quite a long time without obvious damage, but after three hours of the drying process the damage started to occur very quickly. The plant transpiration stopped and gradually dries from the bottom leaves. Data collection of drying processes can help to decrease the loss of the yield during the heatwaves by setting the right time and amount of water for irrigation of the crops.

Key words: *Stress factors; plant production; thermal camera.*

INTRODUCTION
The growth of the world population and there to related increasing food consumption requires higher yields from food producers. Therefore the food producers have to seek new options how to increase the yields of their production. Stress factors are one of the main risks for the plant production and plant producers are looking for new methods how to eliminate the negative impacts of the stress factors. Plants are exposed to a variety of abiotic stresses such as drought, flood, salinity, freezing, cold and hot temperature, various light intensity and many others during their growth and development *(Mohanta et al., 2017).* The living organisms are also interacting with other organisms and the environment. They have positive, negative or neutral impact on the environment. In case of negative influence, the organisms are designated as the biotic stressors. Those could be bacteria, viruses or even humans. Stress factors usually interact in the various combinations together. For instance the high temperature stress is usually accompanied with water stress and high light intensity *(Procházka, 1998)*. When the stress influence crosses the limit of plant stress tolerance, plant organs dysfunction and other disabilities occur *(Bláha, 2003)*. Different crops respond differently to the stress exposure, but high temperatures during days could lead to damage on reproductive processes. Interestingly, certain wild crop species have developed mechanisms to escape the stress damage. This could be examples for breeding field crops that are resilient to heat stress *(Prasad et al., 2017).*
It is highly relevant to detect the stress early, but it is very hard to achieve it. Near infrared imaging could be used to uncover stress related processes in the early stages *(Behmann et al., 2014)*. Detection of plant stress in the early stages is of utmost importance for breeding crops with a higher stress tolerance as well as for improvement of methods of crop management and therefore, it is vital for irreversible damages and yield loss prevention. *(Tester & Langridge, 2010).* One of the method how to prevent yield losses and ensure the water supply of the plants is the utilization of the thermal infrared imaging system. This system maintains high measurement accuracy and could be considered for measuring crop water stress at high spatial and temporal resolution. These are required for managing water irrigation. Thermal sensing is sensitive to crop water requirements and leads to efficient allocation of available water resources for irrigation *(Mangus et al., 2016)*. Thermal image analysis have also potential to estimate leaf area index (LAI). The LAI derived from thermal imaging could be a very accurate indicator of the crop biophysical parameters and moisture stress condition *(Banerjee et al., 2018)*. The main aim of this study was utilization of thermal camera to monitor the process of water stress affecting rape plant since it allowed to recognize the stress in its early stages. Such ability is vital in order to take adequate agronomical measures and thus prevent the plant damages and overall yield losses.

MATERIALS AND METHODS

The simulation of the water stress impact on the rape plant was done in growth stage 2, decimal 19. The simulation took place in laboratory. To provide stable temperature, the laboratory was air-conditioned and the windows were darkened for the elimination of reflected heat. Thermal camera FLIR A655sc was used for the measurement. The camera was hold on a frame construction. The construction was built over a measured plant and the camera was hanged under the right angle down above the plant. FLIR A655sc is a R&D thermal camera for science and research purposes. The camera belongs to the LWIR (Long-Wavelength Infrared) category with a spectral range of 7-14 µm. This camera is equipped with a very good temperature stability, homogenous picture, high measuring accuracy and temperature sensitivity (<30mK). The experiment was set up according to the camera producer instructions to reach the highest measuring accuracy.

The results of the measuring were processed with the Workswell CorePlayer software which was optimized for this particular research. The measuring was running for eight hours, therefore the software had to be modified for long sequences recording.

Before the experiment commenced the emissivity of the measured surface had to be specified. The accurate setting of the emissivity is required for the correct measuring results. If the thermal camera was set up for a higher emissivity than what the actual level in the environment in which the object is, the camera would measure lower temperature than what the actual temperature is. And vice versa, if the camera was set for a lower emissivity than what the actual level in the environment in which the object is, the camera would measure higher temperature. The emissivity is governed by following relation:

$$\varepsilon_T = \frac{H_E}{H_{OE}} \qquad (1)$$

where: H_E is the radiation intensity of the measured surface and H_{OE} is the radiation intensity of the black object. In this case the emissivity was set on $\varepsilon_T = 0{,}7$.

The measuring took 8 hours, while a picture was taken every 5 minutes. Shots with a period of 20 minutes were used for evaluation of the experiment. This article includes selected thermal images showing the impact of water and heat stress on a rape plant.

RESULTS AND DISCUSSION

Upon commencement of the experiment (4:19 p.m.) the rape plant did not suffer by heat nor water stress. The processed thermal image showed that the surface of the leaves was cool, the pores in leaves were open and the photosynthesis proceeded. It was confirmed in Fig. 2 where the majority of the plant surface temperatures ranged between 20-22 °C.

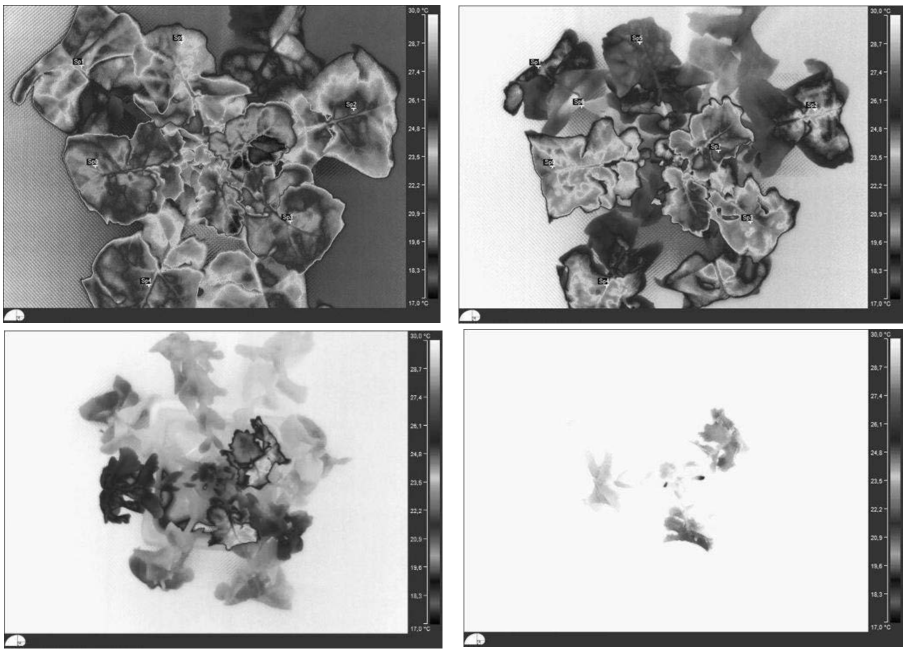
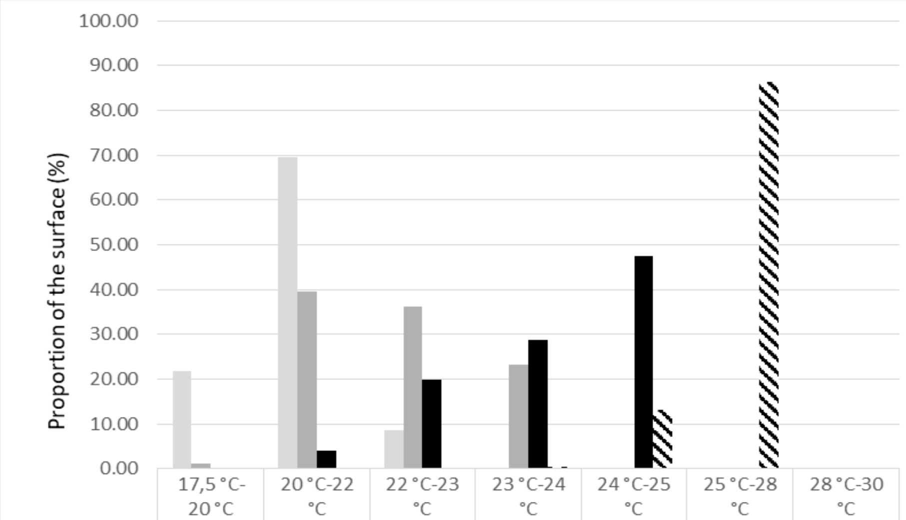


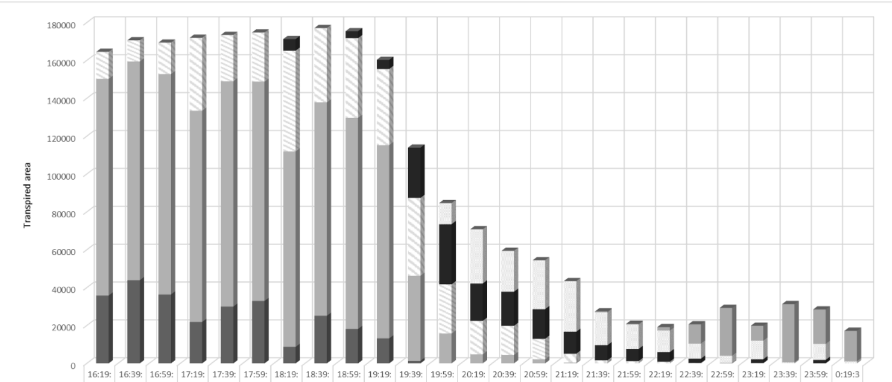
Fig. 1 Plant surface temperature at 4:19 p.m. (top left), 7:39 p.m. (top right), 8:59 p.m. (bottom left) and 10:59 p.m. (bottom right)



	17,5 °C-20 °C	20 °C-22 °C	22 °C-23 °C	23 °C-24 °C	24 °C-25 °C	25 °C-28 °C	28 °C-30 °C
4:19 p.m.	21.76	69.58	8.65	0.00	0.00	0.00	0.00
7:39 p.m.	1.13	39.48	36.09	23.30	0.00	0.00	0.00
8:59 p.m.	0.00	3.91	19.89	28.76	47.44	0.00	0.00
10:59 p.m.	0.00	0.00	0.00	0.50	13.20	86.29	0.00

Fig. 2 Representation of temperatures during the experiment.

The water and heat stress began to significantly affect the plant within 3 hours from the start of the experiment. In comparison with the thermal image at the beginning of the experiment, the temperature of leaves on the ground whorl of the plant was increased. The water potential was reduced and the transpiration was decreased. The plant concentrates its water potential to the upper whorl leaves in order to cool them down. The lack of water became critical for the rape plant after next one and half hour of stress influence (at 8:59 p.m.). Water potential was reduced to the critical limits, which resulted in decrease of the turgor pressure down to 0 and fading of leaves. The pores in leaves were closing, the photosynthesis and transpiration was slowed down until it ceased completely. The only leaves ensuring the transpiration were on the top of the plant. The drying process continued very quickly. At 10:59 p.m. the plant was almost completely dried up. In Fig. 1 is clearly proved that the surface of the plant ability to transpire is significantly reduced in comparison with the beginning of the experiment. The only transpiring and cooled down leaves were on the upper part of the plant. The Fig. 3 depicts the whole measuring process in a timescale. Water stress is considered to be one of the main threats for winter oilseed rape plants within the next few decades *(Pullens et al., 2019).*



	16:19:31	16:39:31	16:59:31	17:19:31	17:39:31	17:59:31	18:19:31	18:39:31	18:59:31	19:19:31	19:39:31	19:59:31	20:19:31
28 °C-30 °C	0	0	0	0	0	0	0	0	0	0	0	0	0
25 °C-28 °C	0	0	0	0	0	0	0	0	0	0	0	0	0
24 °C-25 °C	0	0	0	0	0	0	0	0	0	0	0	11141	28662
23 °C-24° C	0	0	0	0	0	0	6105	0	3651	4836	26542	31773	19702
22 °C-23 °C	14232	11165	16652	38508	24472	25976	53240	39267	42066	40189	41114	26007	17677
20°C-22°C	114448	115539	116384	111573	118992	115822	103195	112680	111555	102083	44969	15715	4768
17,5°C-20°C	35803	43896	36356	21863	29983	32943	8704	25121	18127	13187	1282	0	0

	20:39:31	20:59:31	21:19:31	21:39:31	21:59:31	22:19:31	22:39:31	22:59:31	23:19:31	23:39:31	23:59:31	0:19:31
28 °C-30 °C	0	0	0	0	0	0	0	0	0	0	0	0
25 °C-28 °C	0	0	0	466	336	1892	10240	25282	7847	30744	18247	16082
24 °C-25 °C	21627	25829	26755	17357	12932	11340	7940	3869	9872	541	8396	1065
23 °C-24° C	17994	15659	11606	7983	6404	5077	2219	147	1978	2	1816	20
22 °C-23 °C	15390	10832	4706	1610	1177	860	250	1	174	0	31	0
20°C-22°C	4423	2127	387	18	20	14	0	0	0	0	0	0
17,5°C-20°C	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 3: Transpired area surface during the experiment

Together with other kinds of stresess which have an adverse effect on plants, it is crucial to establish effective strategies in order to maximize the yield. *(Sabagh et al., 2019)* Our measuring not only confirmed results from previous experiments made on different crops *(Mangus et al., 2016)*, *(Banerjee et al., 2018)*, but also proved that the utilization of thermal camera imaging is a highly acccurate method for detecting water stress and utilization thereof could have a positive impact on reduction of yield losses. Aforesaid is also in accordance with a study which found out that utilization of thermal imaging is the most suitable technology for monitoring and assessment of crop water status *(Ezenne et al., 2019)*.

CONCLUSIONS

The measuring of the rape plant proved clearly that the plant is able to resist to the stress impact without an obvious damage for nearly three hours. After this time period first consequences start to appear. The rape plant ceases to cool down leaves in the bottom level. They cease to transpire as well as the photosynthesis stops and leaves wither away. Upon reaching this breakpoint, the damage on the rape plant is irreversible. From 6:59 p.m. to 21:59 when the stress affected the plant, the transpiration area decreased by almost 90%. The withering of the plant proceeds from the lower levels to the top floors of the plant, which are cooled down and provide photosynthesis as the last leaves from the rape plant. The measuring also proved the existence of connection between the heat and water stress. Since the first water stress started to appear, the average leaf temperature increases up to the point where the whole rape plant withers away.

Performance of experiments of water and heat stress could help to set the stress damage breaking points and help to prevent damages and yield losses in the plant production.

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