

Elicited changes in the individual transpiration rates of the *Solanum* genus plants

Eugenia Stepanova^{1*}, *Dmitry Zakharov*¹, *Mark Paskhin*¹, *Dina Kazantseva*¹, *Natalia Semenova*¹, *Vladimir Kosolapov*², *Sergey Gudkov*¹, *Alexey Glinushkin*^{1,3}, *Denis Yanykin*¹, *Elena Dumacheva*², *Vladimir Chernyavskikh*², *Yulia Zueva*², *Svetlana Akimova*¹

¹ Prokhorov General Physics Institute of the Russian Academy of Sciences, 119991 Moscow, Russia

² Federal Williams Research Center of Forage Production & Agroecology, Moscow region, Russia

³ Orenburg State Agrarian University, 460014 Orenburg, Russia

Abstract. In this study tomato plants are affected by infecting stress factor and subjected to photonic pumping. The pathogen can cause symptoms of diseases that are dangerous for plants and are exhibited on the level of organs of plant by changes in metabolism rates. The objective of this study is to trace the modification of transpiration parameters patterns of green tomato leaves under the influence of the stress factor, to provide means to assess damage and to further restore optimal parameters of plant growth and development.

1 Introduction

Agricultural research is of crucial importance for the development of methodological and instrumental base founded on the principles of interdisciplinary interactions of various branches of science. Owing to the scientific research in crop production, the qualitative characteristics of agricultural products are being developed and improved. The study of optimal parameters of growth and development of plants of various groups and families is the framework of the scientific findings of many researchers [1 – 3]. The search for optimum conditions regarding each plant species is an important issue in scientific inquiry.

Chlorophyll fluorescence is a promising mechanism to evaluate and analyze the photosynthesis process, which is functionally related to the transpiration process through fluid exchange, including through stomata channels. The study of the relations between chlorophyll fluorescence and photosynthesis is an object of modern scientific research [4 – 6], the frontier research for considering the influence of various external factors on this process is now expanding.

The accumulation of data arrays on the study of the features of photosynthesis, transpiration and gas exchange processes in the green parts of plants, the physiological aspects of monitoring the state and technological realization of the biological potential of hybrids and varieties of different threads are carried out by Dual-PAM-100 and Portable Gas Exchange Fluorescence System GFS-3000 [7], as well as by LI-COR LI-6800 [8].

These devices are equipped with visible and near-infrared spectrometers for simultaneous measurement of active and passive fluorescence, gas analyzers designed for measurements in various modes of supply and pumping of target substances, and also are provided by

* Corresponding author: jacky-st@yandex.ru

software for calculating parameters based on the data obtained and analyzing the information received.

A change in the process of photosynthesis, including pathological, is a lapse associated, among other things, with the destruction of chlorophyll and some enzymes, introducing weakening in all synthesis processes inside the plant. The lack of chlorophyll is accompanied by a decrease in the content of green pigments, i.e. loss of intensity of coloring of entire leaves or their particular sections. If the change in the chlorophyll amount in the cells is insignificant, the plant only slightly lags behind in growth and brings a reduced yield. With a strong weakening of photosynthesis, deviations from the results achieved in the control groups of plants (in yield or quality) are formed and recorded, often leading to total plant destruction. There are many factors that stimulate a decrease in the content of chlorophyll in cells, one of such factors is various plant diseases.

The object of this study is tomato plants which are cultivated in various countries on Earth. Unfortunately, despite their high economic importance, to date, this genus is affected by many diseases and other stressful factors. While humic and fulvic acids are one of the types of phytoprotectors that reduce the negative effects of various stressful effects on plant organisms [9, 10]. Tomatoes are a popular crop, which is included in the list of strategic agricultural plants of Russia, which confirms the relevance of research aimed at studying the growth, development, flow of the main metabolic processes, to study methods of combating harmful objects that affect the health of tomatoes [11].

The volume of tomato imports in the Russian Federation in 2021 amounted to 462.0 thousand tons, which is 4.4% (21.1 thousand tons) less than in 2020, in general, the dynamics of imports has multidirectional trends (Fig. 1), reflecting the state of both domestic production and the international situation. According to an independent assessment [12] in 2022, the gross harvest of tomatoes in Russia increased by 2.9%: from 3.06 to 3.15 million tons. Production efficiency of course depends on weather conditions, pricing policy in the markets on basic raw materials, equipment and expendable materials (seeds, fertilizers, packaging, agricultural machinery parts), investment component, well-organized logistics and retail chains policies.

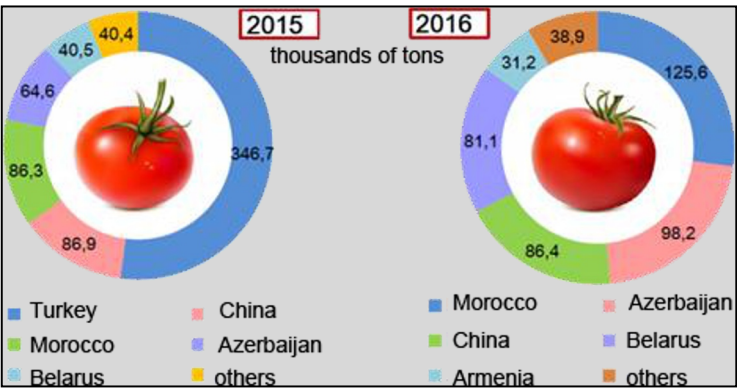


Fig. 1. Structure of tomato imports in Russia during 2015 – 2016 [13, 14].

Tomatoes are affected by pathogens of more than 60 species [15], crop losses due to bacterial and fungal diseases can reach 60%, therefore, measures for the prevention and protection of plants come to the fore [16 – 18]. To enhance the indicators of import substitution, it is necessary to apply research results and promote the introduction of advanced technologies in the process of growing tomatoes, to ensure timely prevention and control of yield limiting factors. One of the research objectives to ensure the stability of growth indicators is the study of the physiology of photosynthesis, transpiration and

transformation processes associated with changes in physiological and phytosanitary status of plants.

To obtain reference indicators of healthy plants and study changes in these indicators in plants under the influence of a stress factor, as well as for further processing and analysis of the results obtained, algorithms for determining plant stress based on precision measurements of transpiration parameters have been developed.

In this study, the stress factor affecting tomato plants is inoculation with *Penicillium* sp. – one of the most common pathogenic organisms. This infection affects various parts of many plant species, causing root rot, stem rot and spotting of fine-grained cereals, cob rot. The pathogen can cause symptoms of diseases, including severe forms, produce toxins that are dangerous for both plants and animals and humans [19–21].

The objective of this study is to identify patterns inherent in the transpiration parameters of green tomato plants under the influence of a stress factor, as well as with humic and fulvic acids application to restore optimal parameters of plant growth and development.

2 Materials and methods

The experiment was planned and implemented at the Biophotonics Center of GPI RAS [22]. The subject of the research are tomato plants and their leaf surface, divided into 3 tiers, where: 1st tier – lower-located leaves, 3d tier – upper-located leaves, 2nd tier – leaves between the first and third tiers. The tomato plants of the Demidov variety are used (see Fig. 2). During the planning of the experimental study, it is decided to use a one-factor experiment, where only the pathogen acted as a variable factor. Tomato plants are inoculated with a culture liquid containing pathogen fractions.

The control of the culture mass of suspension rasters is carried out with the calculation of the stress in the Goryaev chamber. The culture liquid is diluted to the required acting content, according to the standard methodic.

Physiological aspects of monitoring the condition and technological realization of the biological potential of tomatoes (hybrids and varieties) are carried out with Dual-PAM-100 and GFS-3000, LI-6800 devices (calculates the mass flow of gases, i.e. micromole $\text{CO}_2 \text{ s}^{-1}$ and $\text{mmol H}_2\text{O s}^{-1}$, into and out of the measuring chamber, per unit of time). The differences between the concentrations of CO_2 and H_2O in the leaf cell and outside it are due to the assimilation of CO_2 and transpiration processes, the calculation is based on the known area of the leaf surface ($\text{micromole CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ and $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$). During photosynthetic carbon assimilation, the leaf absorbs CO_2 differently from the air entering the cell. The processes of CO_2 assimilation and transpiration are related to each other, since water vapor and carbon dioxide pass through the stomatal openings, however, the efficiency of the processes changes significantly under the influence of external conditions, changing the mutual ratio when additional acting factors appear.

The importance of knowledge about the quantitative and qualitative components of photosynthesis and the distribution along its paths in natural and anthropogenic plant communities, the change in these ratios over time and in various landscapes is a very serious and urgent object for study, because there is a wide variety of green plants with a predominance of different ways of photosynthesis. The main C3 pathway of photosynthesis (the Calvin cycle) consists in the carboxylation of ribulose diphosphate (C5) to form two molecules (C3) of 3-phosphoglyceric acid (3-PHC), part of the 3-PHC molecules is reduced to 3-phosphoglycerine aldehyde (3-PHA), which further participates in the formation of C6 photosynthetic products.

At the same time, the process of photosynthesis of C4 (the Hatch-Slack pathway), unlike C3, got its name from the primary product of the light-independent reaction of CO_2 with phosphoenolpyruvic acid (PELPVC) with the formation of oxalic acid (OXA). In C4 plants,

photosynthesis can also be carried out with almost closed stomata, since carbon dioxide is already stored in the tissues in the form of OXA, closing stomata in the hottest time of the day reduces water loss.

In these studies, the use of the device provided for a change in the concentrations and flows of water and carbon dioxide between the control chamber and the chamber for the study of vegetative parts of plants. The gas exchange parameter (net CO₂ assimilation and stomata conductivity) is studied in a steady state (change of parameters by no more than 1% within 1 minute) at three levels, at a constant temperature. The measurement of the parameters of the change in the spectral response of a vegetating plant to the radiation of a green LED source is adjusted by changes in intensity at a wavelength of 500 nm. The closure of stomata helps the plant to reduce water loss caused by transpiration, as a reaction to a decrease in soil moisture content. Restriction of the opening of stomata is considered to be the main factor in the weakening of photosynthesis under stress.

During the research, the control of maintaining nominal values – 50 micromol, for a stable state, which can be achieved within 10 minutes, is clearly carried out. At nominal values of 500 µmol and 1500 µmol, a stable state is achieved over a longer period of time – within 20 minutes. During the measurements, data containing a large number of parameters were obtained, in this material two variants of the study with a change in one factor are considered:

1. Option 1 (Standard) – Study and analysis of variable values of transpiration on tomato, which in the absence of limiting factors.

2. Option 2 (Load) – Analysis of the effect of photon loading on the change of transpiration parameters on the studied tomato (both in the presence of a limiting factor and in its absence).

Measurements on the devices in both were carried out with a constant supply of CO₂ at a concentration of 400 micromole m⁻² s⁻¹. The index of the flux density of photosynthetic photons of radiation varied according to the variants: (1) – 0 micromole m⁻² s⁻¹, (2) – 1500, 1200, 900, 600, 300, 150, 50, 0 micromole m⁻² s⁻¹. Also, in the course of working with plants, a qualitative analysis of the obtained fruits is carried out by parameters of organoleptic, visual and other technically controlled issues.

3 Research results

During the experiment, we decided to consider some of the parameters: photosynthesis (micromole m⁻² s⁻¹), transpiration (mol m⁻² s⁻¹), stomatal conductivity. (mol m⁻² s⁻¹).

The selected tomatoes were pre-prepared for observation: the studied tiers were placed; the time of day is selected; biometric data is measured, etc. The results of measuring the transpiration parameters of option 1 (Standard) are shown in Fig. 3.

In this paper, the average indicators of the parameters under consideration are given. This form of presentation – in the form of averaged indicators – is chosen to simplify and facilitate the analysis and comparison of results. Also, when calculating the average values, their errors were estimated, indicated on the graph (Figure 3), with a predetermined level of significance.

According to research data, it turns out that the transpiration parameter of an object subject to a limiting factor is equal to: lower tier (1) – 650.0 ± 10.0 micromol m⁻² s⁻¹, middle tier (2) – 300 ± 10.0 micromol m⁻² s⁻¹, upper tier (3) – 60.0 ± 10.0 micromol m⁻² s⁻¹.

When, as in the observed tomato, which is not subjected to limiting effects, the transpiration parameter appears to be lower: upper tier (3) – 610.0 ± 7.0 micromol m⁻² s⁻¹, middle tier (2) – 50.0 ± 5.0 micromol m⁻² s⁻¹, lower tier (1) – 41.0 ± 6 micromol m⁻² s⁻¹.

The analysis of the averaged data obtained shows that the transpiration parameter on the second tier, which is subject to the crisis factor, is lower than the indicator on the same tier, but without a limiting effect.



Fig. 2. Tomatoes (Demidov variety) at the measured vegetation stage.

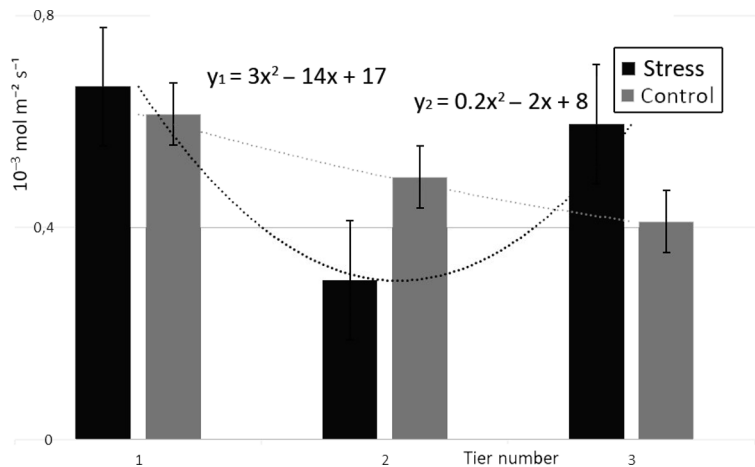


Fig. 3. Variation of averaged tomato transpiration indices, 10⁻³ mol m⁻² s⁻¹.

Comparing the indicators of the lower (1) and upper (3) tiers with and without the crisis component, we can conclude that the differences are not significant. For further analysis and confirmation of the regularity, we will consider the response of the transpiration of the crisis and control tiers to the wave load (Fig. 4).

According to the variation of the predicted factors, it follows that the effect of photon loading on two different tiers of tomato leaves is specific. It is found that the studied leaves, under the influence of a stress factor (photon load), as well as under the influence of a pathogen, reacted in a variety of ways to changes in wave conditions. The leaves exposed to the stress factor actively change and increase their transpiration parameters, within the framework of the experiment, while the leaves free from the stress factor practically do not show a reaction to changes in the intensity of the photon load.

Option 2, with photon pumping, showed the following spread of the obtained values in the control series from 5.0 to 14.0 mmol m⁻² s⁻¹; inoculated series from 7.0 to 15.0 mmol m⁻² s⁻¹. In the illustrations (Fig. 3 and 4) and based on the values of the approximation coefficients (Table 1), the relationship between the two variants that have been measured in full changes in radiation intensity is traced.

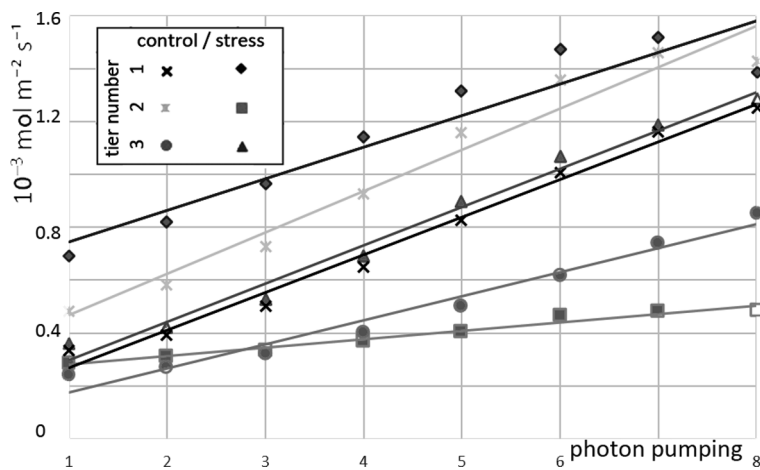


Fig. 4. Sequence of light response of tomatoes of the Demidov variety, milimole m⁻² s⁻¹

Table 1. Averaged values according to the measured data of the transpiration index (10⁻⁴ mol m⁻² s⁻¹).

	Presence of limiting factor	
	+ (pathogen)	–
Variant 1 (control)	5.2	5.1
Variant 2 (photon pumping)	7.8	7.5
Average deviation by variants	0.65	0.63

Statistic processing of the obtained data is based on the fact that the obtained values of the efficiency of transpiration processes were close for all measurements in each of the variants and in each of the photon load intensities. The average deviation of the variants is represented by a visual numerical value of the difference between the two factors under consideration: option 1 (standard) and option 2 (photon pumping). When calculating this parameter using standard formulas, it turned out that the crisis leaves have an overestimated deviation, which reflects the differences between the options.

The average transpiration value of leaves exposed to the stress factor in variant 1 (standard) is 0.52 mmol m⁻² s⁻¹; in variant 2 is 0.78 mmol m⁻² s⁻¹; for control copies of leaves according to variants 0.51 and 0.75 mmol m⁻² s⁻¹, respectively. According to the studied information, it turned out that the difference in the selected variants in crisis and control leaves is significant (6.5 ± 0.2 micromol m⁻² s⁻¹ and 63.0 ± 0.7 micromol m⁻² s⁻¹). These indicators suggest a pattern between the average deviation and the phyto-health of the studied plant.

4 Discussion

The obtained results were discussed at scientific seminars in various communities of scientists representing various schools: the Department of Herbiology (founder – academician of the Russian Academy of Sciences Spiridonov Yu. Ya.), Resistentology (head – academician of the Russian Academy of Sciences Glinushkin A.P.), during which accompanying advice and methodological recommendations were received.

The work is partially carried out within the framework of an economic contract, which imposes some restrictions, and also shows that the scientific idea is interesting and is ready to be supported not only by representatives of the scientific community, but also by direct

participants in the agricultural production process. The scientific and practical prospects of the obtained research data are enormous.

Before the start of the laboratory study, a huge amount of work is carried out on the collection and analysis of many literary sources, in which there is little information about the LI-COR system used, but enough about the mechanism and principle of plant physiological processes (photosynthesis, transpiration, stomatal conduction, etc.). According to the results of which, it turned out that the optimal assimilation of CO₂ by photosynthesis at the leaf level is directly related to the loss of H₂O. The use of energy, from the capture of light photons during carbon assimilation and loss of H₂O, is coordinated through the regulation of stomatal conductivity. The research is mainly aimed at understanding the interdependence of these regulatory mechanisms, which led to interest in the choice of methods of analysis. Based on this, we have chosen two methods of research: 1 — to analyze the reaction of the plant at different concentrations of CO₂; 2 – to consider the effect of fluorescence at different pulses of photon radiation.

The applied measuring systems effectively monitor the parameters of fluorescence and gas exchange. With the help of these tools and further analysis, the influence of various factors on the fluorescence intensity is clarified. The results of the observations explain the obvious connection between the stress caused and the shift in the values of the parameter under study.

It is important to note that changes in stomata and chlorophyll fluorescence will react in different time periods, but in general, this leads to a decrease in photosynthetic ability.

5 Concluding remarks

Portable systems make it possible to successfully measure several parameters in the same area of a green leaf: photosynthesis (micromole m⁻² s⁻¹), transpiration (mol m⁻² s⁻¹), stomatal conductivity (mol m⁻² s⁻¹). With the help of these systems, the influence of the regulated flow of photosynthetic quanta on the studied tomato leaf under different conditions, as well as with different background, is studied. Changes in fluorescence, transpiration, and stomatal conductivity are shown in the illustrations.

The influence of the pathogen culture on the transpiration indices in the leaves of the tomato under study, depending on the tier of leaves exposed to the stress factor, is brought forward. An increase in transpiration intensity is observed in variants 1 and 2 (control, photon pumping). The average level of transpiration in the studied tomato leaves on stressed tiers is different and amounts to variants (further by 10⁻⁴): (1) (control) 5.2 ± 0.1 mol m⁻² s⁻¹, (2) (photon pumping) 7.8 ± 0.2 mol m⁻² s⁻¹. The average level of transpiration of the studied tomato leaves on the control tier according to the variants (further by 10⁻⁴): (1) (control) is 5.1 ± 0.03 mol m⁻² s⁻¹, (2) (photon pumping) 7.5 ± 0.04 mol m⁻² s⁻¹.

In stressed leaves under the influence of photon loading in variant 2, the transpiration efficiency is higher than in variant 1. When using a photon load on the stress layer under study, the overall level of transpiration increases compared to the control leaves.

One of the most important results of applying this approach to measuring the parameters of the physiological activity of tomato plants under the influence of various factors is the development of methodological foundations of an approach to research to identify the most biologically productive systems of reproduction of agricultural products with specified qualitative characteristics.

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