Dualism of technical and technological solutions as an alternative focus area of vegetable production

Viacheslav Nestiak¹, Oleg Ivakin¹, Sergei Usoltsev¹, Vladimir Kosianenko¹, Iurii Guskov²

¹Siberian Federal Scientific Center for Agrobiotechnology of the Russian Academy of Sciences, 630501, Krasnoobsk, Russia
²Novosibirsk State Agrarian University, Dobrolyubova str., 160, 630039, Novosibirsk, Russia

E-mail: nestyak-vs@yandex.ru

Abstract. The study is aimed at reducing the negative impact of open ground on plants during the growth season and during adverse extreme impacts, with the maximum reduction in response time to changes in external conditions. The developed screens do not limit the conditions of natural pollination and access to plants for irrigation, machining and harvesting, extend the vegetation period of plants, and contribute to increased yield. The proposed solutions are based on the dualism principle stating that the cultivated plant is both in open ground and under the protection of screens. The objectives of the study: to reveal the impact of design parameters of protective screens on the temperature regime in the inter-screen space; to determine the possibility of monitoring the plant moisture supply under the screens using the method of calculating the moisture stress index in real time; to assess the effectiveness of protecting the plants with screens from the effects of negative factors caused by open ground.

The reason for the temperature change in the presence of insolation is the effect of interlocking of vertical convective air currents that form in the space between the screens. By changing the opening parameters of the face ends, it is possible to increase the air temperature in the plant zone or to protect them from overheating. The moisture stress index can be used to quickly monitor the water regime of plants. Protective screens contribute to the accumulation of active temperatures, extending the growing season, reducing the risks of negative impact caused by open ground factors, and increasing the productivity compared to open ground conditions.

1. Introduction
Contradictions between agriculture and the biosphere are the main factor determining the development of the latter [1 - 3]. This is clearly manifested in vegetable growing and, most noticeably, when growing heat-loving vegetables in regions with unstable environmental conditions.

The basis for the production of heat-loving vegetables is open and protected ground, the latter operating according to the principle of complete isolation of plants from the environment. Therefore, many of the contradictions between the agriculture and biosphere are dismissed. However, the industry has not been in the best condition since 1990, the fixed assets of old greenhouses are being worn out, and production areas are decreasing despite the local construction of new greenhouse complexes. The opportunities for their rapid growth in the current situation are problematic and limited by the high cost of projects.
As for the open ground, which is completely dependent on the external environment, the heat-loving vegetables in the region are grown mainly in the private sector. Their commercial production in open ground is associated with high risks due to climatic features of the zone, and is practically absent. Vegetables of this group, which are bearing a completely different genetic code, and often of dubious quality, are provided through external supplies.

A possible solution could be a sharp increase in the production of the most valuable vegetables of this group (tomatoes in particular) due to the warmed soil area expansion. During bad weather, plants are temporarily isolated from the adverse effects of open ground, and in fine hours they are again returned to natural conditions. In this case, new contradictions appear, now between plants and means of protection. Means of protection impede certain biological processes (for example, pollination), require considerable labor and time for opening and closing, and limit access to plants when performing plant care work. This is the main limiting factor for commodity production in modern conditions. It is necessary to reduce the contradictions between the habitat of heat-loving vegetable crops, their requirements for growing conditions and the capabilities of technical plant protection products to provide all this.

The research is aimed at minimizing the negative impact of open ground factors on plants throughout the entire growing season, including during adverse extreme impacts, with a maximum reduction in the operational response time to the current change in external conditions. The plant protection function does not limit the conditions of natural pollination and access to plants for irrigation, machining and harvesting. Conditions have been created for extending the vegetation period of plants and increasing their heat supply, contributing to an increase in productivity [4, 5]. Technical solutions provide the possibility of using digital technologies both for automatic control of ventilation parameters, and for deciding whether to irrigate, feed plants and perform other operations. A criterion for the watering need, for example, can be the value of the water stress index, which is determined on the basis of measuring the characteristics of the habitat and plant condition in real time [6 - 8]. Further improvement of technologies with the use of protective screen should be aimed at controlling the production process of plants through direct technological impact on other characteristics of the indoor habitat. The development of technical means and technological processes ensuring the creation and rational combination of controlled environmental factors required to obtain a given crop is the basis for crop programming and an important condition for the development of modern technologies [9].

Obtaining high crop yields is based on completely satisfying the needs of plants for vital environmental factors, such as light, heat, water, air, and mineral nutrition [10, 11]. In this case, the main problem to be solved in specific conditions is to determine the factor that is currently at a minimum. Technological impacts on it allow increasing productivity at the lowest cost of labor and money. The complexity of the problem lies in the fact that the biological processes taking place in plants are continuous, and largely depend on varietal characteristics, the development phase and other biological parameters, the values of which vary with time. This requires monitoring of indicators characterizing the status of plants and their environment in real time.

According to the climatic conditions of the forest-steppe zone of Western Siberia, the heat supply factor comes first for heat-loving vegetable crops in open ground. The moisture availability is in the second place, especially during the survival of seedlings and intensive growth of fruits. In third place is the availability of nutrients.

The proposed technical and technological solutions are based on the dualism principle stating that the cultivated plant is located both in open ground and under special protection. Located in open ground, which eliminates the risk of artificial overheating in hot summer days, the plant is also under constant protection of special screens that reduce the influence of negative environmental factors.

The purpose of the study is to increase the growing efficiency of heat-loving vegetables, such as tomatoes, under the influence of negative factors of open ground.

According to the goal of the research and to the need to meet the plant requirements in the priority environmental factors for the zone, the following research tasks were identified:
1. To determine the influence of the design parameters of the protective screens on the temperature regime in the inter-screen space.
2. To determine the possibility of monitoring the moisture supply of plants by the method of calculating the moisture stress index in real time.
3. To evaluate the effectiveness of plant protection with protective screens from the effects of negative factors of open ground.

2. Materials and methods
A long-term laboratory and field experiment was carried out in the spring-autumn period of 2011-2018 on an open ground area under the experimental greenhouse of the institute with approximately the same lighting conditions, air flow conditions and soil cover composition. Various screen structures were mounted for experiments, the plants were planted there. Control plots, equal in area, were laid in open ground parallel to the screens. Tomato seedlings of the standard type of the “Buyan” variety were used in the experiment in the phase of the appearance of the first flower brush.

In contrast to the known constructions, protective screens contain only racks forming a supporting frame, and the screens themselves (made of cellular polycarbonate), installed opposite to each other with a technological gap between them (Figure 1). The face ends of the screens can be additionally equipped with an end barrier, depending on the conditions.

![Figure 1. Protective screens (without end barrier).](image1)

The thermal regime of screens and their protective functions (from overheating, frost, negative influences) were studied in the experiments conducted between 2011-2015. The screens were equipped with devices (Figure 2) for recording the air temperature in automatic mode, which made it possible to control this parameter under cover as well as in the open ground during the entire growth season.

![Figure 2. Experimental equipment for studying the thermal regime: a – measuring sensor (in the assembly); b – installation of sensors between screens; c – multichannel unit for collecting and storing information.](image2)
Measurements were taken in various zones for the width, height and length of the screens. Small-sized copper thermal resistances were used as temperature sensors, fixed in the assembly with the help of holders made to provide the sensors with minimal thermal inertia from solid foam (Figure 2a). They were installed in the inter-screen space on a special grating (Figure 2b). The signals were registered from the sensors by the TPM 138 detectors. The signals were converted to digital form and transmitted to the MSD 100 data acquisition module (Figure 2c), which recorded them in files on the memory card at a specified frequency. The registrars and the data acquisition module were set up using a computer connected via the AC-4 adapter.

According to the experiments of 2017-2018, the possibility of controlling the production process of tomatoes by bringing limiting factors into line with the needs of plants was additionally considered. At the first stage, the possibility of monitoring the water regime by the value of the water stress index was evaluated in real time.

The air condition outside the screens was determined using the DWS-11z automatic weather station, which includes a radio module with a power supply and a set of following sensors: a temperature and humidity sensor, a rain sensor, a pyranometer, and a wind direction and speed sensor. Indices of the air inside the screen were measured with an aspiration air temperature and humidity sensor RTH-2z complete with a radio module, power supply and a B12-R pyranometer. In order to assess the condition of the soil and plants inside and outside of the screen, the same sets of following sensors with radio modules and battery power were used: a stem diameter change sensor SD-5z, leaf temperature sensor LT-4z, fruit growth sensor FI-Mz and soil sensor SMTE-3z (Figure 3).

![Figure 3. Weather station and equipment for measuring habitat and plant parameters.](image)

Throughout the entire period of research (2011-2018), the effectiveness of protective screen usage was assessed by their response to the negative effects of environmental factors, the possibility of extending the growth season, the quality and quantity of the obtained crop. The same types of works were performed on the plots under protective screens and in the open ground, such as tillage, cultivation of planting holes, the introduction of organic matter and fertilizers, planting of seedlings, treating plants and collecting products. The layout of plants in all variants is single-line. The axial distance between the rows (0.9-1.0 m) was determined by the minimum possible distance for the installation of protective screens. The planting step was taken from the calculation of at least 3 plants per 1 m² of accounting area. Measurements of controlled parameters, which are the timing of the onset of ripening and harvesting, were taken every 7 days for all options. The accounting for immature products was
carried out at the end of the growth season (including the case of impossibility of further development due to environmental conditions).

3. Results and discussion
Throughout the research (Figure 4), it was established that the reason for the temperature increase in the plant area under the protective screens with the insolation is the effect of interlocking the vertical convective air flows generated in the space between the screens. The interaction of these flows during the maximum insolation period ensures the air release from the zones with the highest heating, which helps to limit the maximum air temperature in the plant zone. The main regulating flow in the daytime is the air flow in the service passage.

![Figure 4. Trends in changes of daily air temperatures: a – the ends are open, b – the ends are closed; 1, 2 – sunny, 3.4 – overcast; – air temperature in the plant zone (screens); –– outdoor temperature (control).](image)

Opening the end walls (when installed) reduces the interlocking effect of vertical convection flows. By changing the opening parameters of the end walls, it is possible to increase the air temperature in the plant zone or to protect them from overheating. When the ends were fully open, the indoor temperature was 2°C higher than the outside. The maximum contribution of artificial factors to the formation of temperature in the plant zone was 11% according to the results of 2011-2013, the minimum is 5%.

The basis for monitoring the water regime is the ability to determine the leaf temperature in real time, air temperature and humidity and the subsequent calculation of the remaining parameters using the algorithm for calculating the moisture stress index. The process of registering these and other parameters was carried out automatically. The measurement results were transmitted over the air to a phytomonitor and then to a computer through a USB adapter. The algorithm for calculating moisture stress indices was developed and implemented in Excel. The block diagram of the algorithm is presented in Figure 5.
A fragment of processing the measurement results, which were made in accordance with the algorithm, is presented in the diagram form in Figure 6. From the graph it follows that the value of the moisture stress index is less than the 0.3 critical value. Thus, the plants did not lack water during the measurement period. The standard deviation of the outdoor moisture stress index completely covers...
the variation interval of the moisture stress index inside the shelter. Therefore, the difference between them is within the experimental error. The experiment showed high reliability of the phytomonitor, weather station and a set of sensors, not a single failure was recorded.

![Moisture stress index calculation results.](image)

**Figure 6.** Moisture stress index calculation results.

The disadvantage of this complex is that it uses point sensors of leaf temperature, i.e. in fact, the temperature of the leaf apparatus of all plants in the experiment is estimated by the temperature of one leaf. Therefore, it is advisable to use infrared leaf temperature sensors that measure the surface temperature of all plant leaves that got into the capture zone. It should also be noted that determining the water availability of plants according to the Idso-Jackson method has a significant drawback. It does not take into account solar radiation and the effect of wind, the size and closure of plants, which affect the evaporation of water from the leaf surface.

The efficiency of the screens was especially clearly visible in the laboratory and field experiments in 2011, 2014 and 2015, which significantly differed in weather conditions. The 2011 conditions were generally positive for growing tomatoes in the open. However, the use of protective screens contributed to a higher dynamics and duration of the production process in the fruiting phase under the screens compared to open ground (Figure 7). The sum of average daily active temperatures under the screens in 2011 was almost 50°C higher than in open ground, and the increase in active temperatures went relatively evenly throughout the summer period. As a result, the yield under the screens was more than 2 times higher than in the open field, and an additional yield (more than 70%) was obtained outside the growing time for control in the open field, and the products in a state of technical ripeness amounted to more than 62%.
Figure 7. Dynamics of the production process: — screens; — control.

In 2014, the air temperature was comfortable for plants during almost the entire summer period, as a result, the screens should have performed the function of operational protection and preventing the plants from overheating under them. And this function was successfully provided, the temperature under the protective screens, especially at the maximum temperatures, almost coincided with the temperature of the outside air (Figure 8). However, on the night of September 4-5, a sharp short-term drop in temperature to –2… – 3°C was observed, and protective screens mitigated this negative phenomenon. As a result of freezing, plants in the open ground died, but plants under cover survived and bore fruit for another 2 weeks. The screens also provided an increase in average daily active temperatures, they were 65.6°C higher than in open ground during the growth season, and the yield was one and a half times higher under protective screens than in open ground.

In 2015, 5 days after the seedlings were planted in the ground (June 10), a hail passed, after which the plants that were put in the open ground were injured, and 7.5% of them did not recover and died. The plants under the protective screens were not affected. The growth season under the screens was two weeks longer compared with the open ground. However, the increase in active temperatures under the protective screens in 2015 was only 23.70°C and formed mainly in June. This was most likely caused by the peculiarities of the month, on June 20 there was a flash in the sun, on June 21 there was a summer solstice, on June 22-23 an extremely strong magnetic storm was recorded. Apparently, this affected the production process, which differs from previous years, and also on productivity. The crop yield under protective screens was 1.8 times larger than in the control zone, with 91.5% of the total harvest being commercial products (in a state of technical ripeness), and 28.2% of the crop yield under the screens was obtained beyond the deadlines for growing tomatoes under control in open ground.
Figure 8. Change in daily average air temperature (2014): – air temperature in the plant zone (screens); .................. – outdoor temperature (control).

4. Conclusions
The following conclusions can be made according to the above-mentioned:
1. The reason for the temperature change in the plant area under the protective screens in the presence of insolation is the interlocking effect of vertical convective air flows generated in the space between the screens. By changing the opening parameters of the face ends, it is possible to increase the air temperature in the plant zone or to protect them from overheating. When the face ends are completely open (absent), the temperature under the screens does not exceed the outside temperature by more than 2ºC.
2. The moisture stress index can be used for real-time monitoring of the water regime of plants. In the experiment, the index value was less than the critical value of 0.3; therefore, the plants did not lack water during the measurement period.
3. Protective screens contribute to the accumulation of additional active temperatures (up to 70ºC), extension of the growth season by 2-3 weeks (when the fruiting phase is active), reduction of the risks caused by negative effects of open ground factors (overheating, freezing, hail) and to an increased productivity (by 2-2.5 times compared to open ground).

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