The Effect of Impulse Pressure on the Crop Productivity and Physiological Characteristics of Some Tomato (*Lycopersicon esculentum*) Hybrids

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ABSTRACT

The influence of pre-sowing treatment of tomato *(Lycopersicon esculentum)* seeds by impulse pressure on the seed germination, content of free phytohormones, and crop productivity in plants was studied. The impulse pressure promoted changes in the content of all phytohormones. The crop increase was 12-31% as compared to control plants.

(Additional Keywords: pressure, stress, hothouse, phytohormone, yield)

INTRODUCTION

The application of new technologies is very important for intensifying agricultural production. Therefore, the research in physical factors influencing physiological processes in plants is a very important problem for agricultural biology. Plant growth regulators are effective and convenient for increasing plant productivity. X-rays, γ -radiation, changes of temperature and pressure, etc. have an influence on many physiological processes. The cell membranes usually are known to be the primary target of the influence of physical factors (Barka et al. 2000). The effect of physical factors on plant growth and development is mediated by changes in the phytohormone content. The plant protective response involves the increase in the abscisic acid content (Neumann et al. 1989). This effect was also found under the influence of temperature, water and allelopathic stress in plants (Kosakovskaya and Maidebura 1990). Ethylene is another stress hormone (Meyer et al. 1987). The level of auxins, cytokinins, and gibberellins is normally decreased so that hormones-inhibitors play a leading role in stress reactions (Jackson et al. 1992).

Plants are sensitive to pressure. Osmotic pressure is essential for cell growth and water uptake. The phloem transport of substances is controlled by pressure gradients (Fensom et al 1994). Soil tightening also has an influence on plant growth. We have proposed the method of pre-sowing seed treatment by impulse pressure generated by a blast. The advantages are effectiveness, ecological safety, and an excellent reproducibility of results (Atroschenko et al. 1997).

It has been shown that some physiological processes depend on the impulse pressure and that pressures from three to 35 MPa are optimal. This study seeks to examine the content of major phytohormones in plants, treated by impulse pressure. Plant productivity depends on photosynthesis and growth; therefore it was necessary to include these processes in our study. The aim of this work was to study those physiological processes in plants, which treated by the impulse pressure, promote crop increases.

MATERIALS AND METHODS

The subject of this research was tomato plants *(Lycopersicon esculentum)*. We used tomatoes of different hybrids F_1. These hybrids were planted in State Unitary Enterprise "Teplichnoye", Penza. These are semi-determinant hybrids bread for yield.

The seeds were treated by impulse pressure generated by the detonation of a water resistant explosive in an aqueous medium. The seeds experienced the volumetrical pressing during a 15-20 μ second period. The pressure in the epicenter was calculated by formulae, taking into account the mass of the explosive (spot charge) and the distance between the center of the explosive charge and the surface of treated material (Atroschenko et al. 1997). The experiment allows for the exact calculation (with error about 1.0 to 1.5%) of the pressure of the blast as it passes the material. The density of suspension material was not changed in tests and it formed 0.4 g · cm^{-2} of the base. Both the size of seeds and the energy absorbed by seeds were postulated as equal.

Plants were grown in hothouses in wintry-spring rotation, autumnal rotation, and extended rotation (Table 1) by standard agricultural technology. Seedlings were planted in special compartments with an artificial light source. After final planting, the specimens received natural light. Light intensity, nutrient availability, moisture and temperature were maintained under technological control and growing conditions were kept constant through the different tests. The productivity of treated plants was examined in comparison with the control. There were four biological series (the areas are indicated in Table 3).

Table 1. Dates of Agricultural Measures.

Rotation	Date of Sowing	Date of Pricking Off	Date of Planting	Date of Last Harvesting
Wintry-spring	November 25-30	December 1-5	February 1-5	July 10-15
Autumnal	June 10-15	June 15-20	July 15-20	October 5-15
Extended	November 25-30	December 1-5	February 1-5	September 20-25

We examined the contents of phytohormones, auxin (indole-3-acetic acid, IAA), gibberellin A_3 (gibberellic A_3 3-acetate, A_3), zeatin ([trans-6-(4-hydroxy-3-methylbut-2-enyl)-aminopurine]), and abscisic acid (3-methyl-5-1-oxy-4-oxo-2,6,6-trimethyl-2-cyclogexen-1-il-2-cys,4-transpentadien acid, ABA). The tests were carried out during the phase of flowering and fruit formation in leaves of medium tier. Material was fixed with liquid nitrogen and phytohormones were extracted and purified. The amounts of hormones were analyzed by the high performance liquid chromatography (HPLC).

We calculated arithmetic means, standard errors of means, and Student-t criteria for the content of phytohormones. An ANOVA was used for calculation of plant productivity (Lane 2001).

RESULTS AND DISCUSSION

The work for this study began in 1994. Primarily we found the optimal pressures for the stimulation of growth, development, and plant productivity. We treated the seeds of tomato plants (hybrid F_1 Carlson) with pressures from 3 to 35 MPa. It was found that the germinating power of seeds depends on the treated pressure (Figure 1). Pressures in the range of 17 - 35 MPa promoted the lowering of seed germination of tomato plants considerably (39-75%). The damage of seeds by pressure led to the germination reduction. Our unpublished observations demonstrated that the mortality of seeds occurred during germination but not directly after the impulse pressure treatment, so any physiological reactions promoted by the stress of the treatment developed in seeds. The reaction resulting in seed damage/destruction depends on the magnitude of the pressure used in the pre-sowing process.

Impulse pressures in the 3-29 MPa range had an influence on the plant productivity (Figure 1). We estimated the productivity in four groups of 15 plants per variant in wintry-spring rotation of 1994. The yield of control plants was 11.3 kg· m^{-2}. The raising of tomato plant productivity after pressure treatment of 3 MPa was about 20% (13.5 kg· m^{-2}). The influence of pressures 5-8 MPa promoted the augmentation to 32-34% over the control level of yield (14.9 - 15.1 kg · m^{-2}). The productivity of plants treated with the pressure 11 MPa, increased only to 24% (14.0 kg · m^{-2}), so the effect decreased versus the previous pressures. After the treatment of pressure at 17 MPa, the productivity fell to 87% of the control level (9.8 kg · m^{-2}). It is interesting that the plant productivity topped the control 2.02 times after the treatment of pressure 29 MPa (22.8 kg · m^{-2}).

There are about 10% of genotypic and phenotypic "off-types" in the mass of hybrid plants. These plants demonstrate poor overall performance, significantly reduced yield, low vigor and poor germination. It is likely that these weaker off-types were the target of damage/destruction from the impulse pressure treatment. The increase of plant productivity is likely the result of the mortality of "week" seeds. The treatments of impulse pressures of 17-35 MPa decrease the seed germination at a rate of 24 -58%, so they destroyed not only "off-types", but the more robust seeds as well. There are at least two stress strategies that are observable through this experiment: the damage of "week" seeds and the stimulation of physiological processes in others.

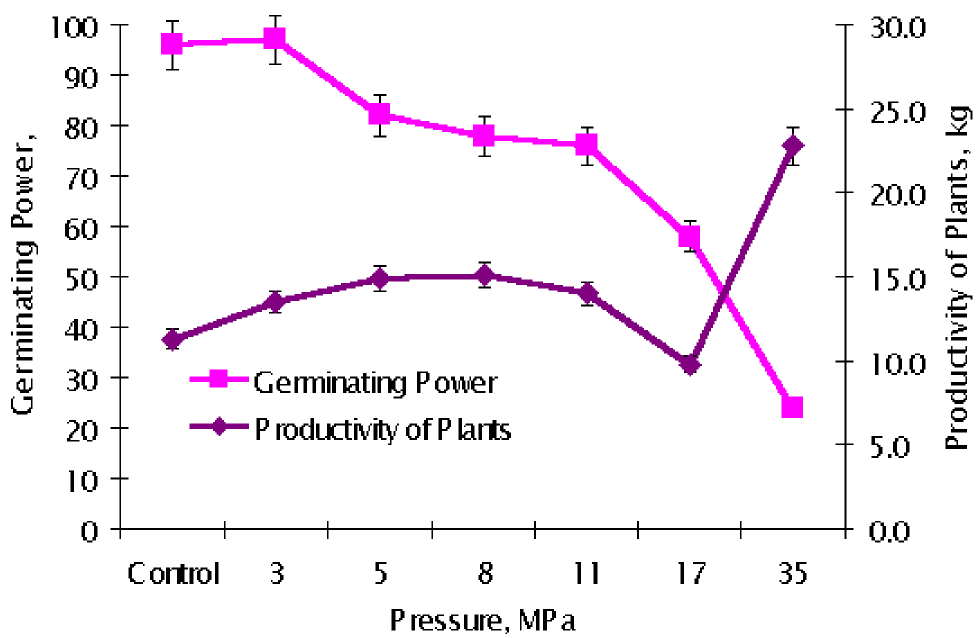

Figure1: Germinating Power of Seeds and Productivity of Tomato Plants

On the grounds of obtained data, we recognize the influence of pressures between 5 and 8 MPa as optimal for tomato plants. These parameters were used for preparation of agricultural productions.

Tomato plants (hybrid F_1 Carlson) were tested in wintry-spring rotation of 1995. The seeds were treated with the pressures of 5 and 29 MPa. There were four plots of 115 m^2 (total area was 460 m^2) for each variant, including the control. Some morphological features were also investigated.

The germination of tomato seeds was 94± 3% in control variant, 89± 5% after the treatment of 5 MPa pressure and 43± 7% after the treatment of 29 MPa pressure.

The length of stem of the tomato plants (Figure 2) treated with pressure at 5 MPa, topped the control level at the age of three months (flowering stage). The height of plants, treated with pressure at 29 MPa, corresponded to control. The growth, as an integrated process, reflects changes of internal processes due to the influence of external factors. This fact gives reason to consider growth as a leading physiological process. Its scope and intensity allows us to judge the realization of the crop program.

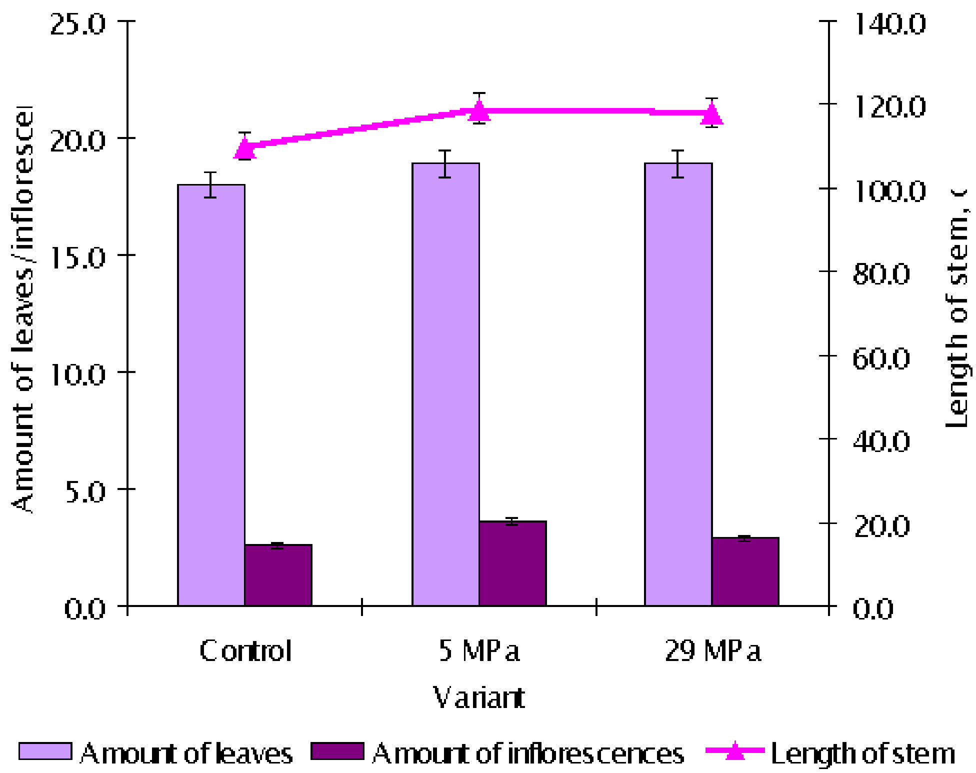

Figure 2: Morphological Features of Tomato Plants

The plants are known to develop intensively and accumulate dry substance in a flowering phase. At the same age, the treated tomato plants had a tendency to increase the number of leaves (Figure 2). The large area of leaves serves as the basis for active assimilation of organic substance. High levels of the photosynthetic process are necessary for the stress adaptation (Yordanov et al. 1996). Vegetative growth is considered as the basis of plant productivity. Differences in growth characteristics influenced by impulse pressure promote the increase of plant productivity.

Morpho-physiological programs are known to influence differences in phytohormone ratios. Therefore it is important to determine the content of phytohormones in the treated tomato plants (Table 2).

Table 2. Content of Phytohormones in Leaves of Plants after the Impulse Pressure Treatment (nmol· g – 1 of fresh weight)

Variant	Content of phytohormones, nM× g - 1 fr wt				Ratio of phytohormones				
	IAA	Zeatin	A_3	ABA	IAA: ABA	A_3: ABA	Zeatin: ABA	IAA: Zeatin	IAA: A_3
Control	0.26± 0.02	0.78± 0.07	0.29± 0.02	0.21± 0.02	1.23	1.38	3.17	0.33	0.89
5 MPa	0.34± 0.03	0.67± 0.06	0.23± 0.02	0.16± 0.01	2.13	1.44	4.10	0.51	1.48
29 MPa	0.41± 0.04	1.16± 0.10	0.38± 0.04	0.35± 0.03	1.17	1.09	3.31	0.35	1.07

It was found that the fluctuations of phytohormones were significant. The pressures 5 and 29 MPa promoted the increase of the IAA level by 30% and 55% in comparison with the control. The concentration of the gibberellin A_3 decreased after the treatment of 5 MPa pressure by 20% and it was enhanced by 33% versus control by 29 MPa of pressure. The level of zeatin was lowered by 14% at 5 MPa of pressure and raised by 50% at 29 MPa of pressure. The contents of ABA changed similarly. The pressure of 5 MPa promoted the decrease of the ABA concentration by 25% and the pressure of 29 MPa raised the ABA level by 67% versus control.

The greatest daily gain of stem length is known to characterize the phase of flowering and fruiting. Therefore the study of the change of growth processes determined by the hormone balance is of special interest. The auxins and gibberellins are the main hormones in this process - stimulators of growth in length, and the inhibitor of growth is ABA (Doerfling 1985).

The increase of the IAA content was observed after the influence of impulse pressure at 5 MPa. Auxins play a large role in the growth of an ovary and fruit. These hormones are regulators of water inflow and nutritious substances. The levels of ABA lowered in comparison with the control, hence, the ratio IAA/ABA was increased. Despite the decrease of zeatin and gibberellin A_3 concentration, the ratio A_3/ABA and zeatin/ABA is slightly raised. So the synthesis and transport of carbohydrates were stimulated by these ratios. The growth of stem amplifies because the stimulators prevail over the inhibitors in the treated plants. The prevalence of stimulators supports the high activity of physiological processes of plants treated with the impulse pressure. The change of the ratio IAA/zeatin with prevalence of IAA promotes the growth of roots. The increase of IAA concentration rather than A_3 stimulates the activity of the cambium and promotes the active development of the xylem.

The contents of IAA, A_3, zeatin, and ABA in plants treated by the pressure at 29 MPa was higher than in the control and in the previous series. High concentrations of IAA, A_3 and zeatin are necessary for the activation of physiological processes. Auxins support the attractive activity of the organ and gibberellins promote the accumulation of spare substances. Cytokinins strengthen these processes, accelerating the movement of substances. Auxins and gibberellins accelerate the growth of ovaries and fruits. The gibberellins are known to stir the photosynthetic phosphorylation to activity, but the content of chlorophylls is simultaneously reduced. These phenomena were observed in plants treated by the pressure 29 MPa. Cytokinins also raise the intensity of photosynthesis, however, they do not promote the decrease of the chlorophyll content. The ABA is a hormone-inhibitor, but its activity depends on the level of other hormones. The ratios of IAA/ABA, A_3/ABA, zeatin/ABA were decreased in comparison with the control. The increase of the stem length (Fig. 2) is caused by the prevalence of A_3 over IAA. Plants are known to be supplied with the optimum quantity of auxins; therefore it is seldom possible to speed up the growth of plants with the introduction of auxin (Doerfling 1985). However, the exogenous gibberellins are capable of strengthening the growth of plants. There are data that the cytokinins participate in the unloading of phloem (Clifford et al. 1986). Hence, the increase of zeatin and ABA concentration promoted the formation of fruits, the accumulation of assimilats, and the increase of plant productivity. The ratio of IAA/zeatin corresponded to the control, hence, the root system developed normally.

The changes of hormone balance described above, affected plant productivity. The number of inflorescences of tomato plants rose by 38.5% and 11.5% after the treatment of impulse pressures of 5 and 29 MPa (Figure 2). The productivity of tomato plants, treated with the pressures of 5 and 29 MPa, increased by 20% and 31%, respectively (Table 3).

Table 3. Productivity of Plants after the Impulse Pressure Treatment

Hybrid F_1	Pressure, MPa	Year	Rotation	Plots	Plot Area	Plants	Yield, kg/plot	F	Yield, kg·m^{-2}	% Crop Increase
Carlson	0	1995	1	4	115	288	730	7.1	6.35	-
Carlson	5	1995	1	4	115	288	876		7.62	20
Carlson	29	1995	1	4	115	288	954		8.30	31
Kostroma	0	1997	1	4	12,500	31,250	112,500	18.8	9.0	-
Kostroma	5	1997	1	4	12,500	31,250	129,375		10.35	15
Kostroma	0	1998	3	4	7,500	18,750	187,500	25.4	25.00	-
Kostroma	4	1998	3	4	7,500	18,750	223,125		29.75	19
Kostroma	0	2000	3	4	25,000	62,500	575,000	20.4	23.00	-
Kostroma	4	2000	3	4	25,000	62,500	661,250		26.45	15
Kostroma	0	2001	3	4	30,000	75,000	900,000	26.3	30.00	-
Kostroma	4	2001	3	4	30,000	75,000	1,044,000		34.80	16
Kostroma	0	2001	2	4	12,500	31,250	62,500	4.8	5.00	-
Kostroma	4	2001	2	4	12,500	31,250	71,875		5.75	16

Note: Rotation codes are as follows: 1) wintry-spring rotation; 2) autumnal rotation; and 3) extended rotation. Plot area measured in square meters. F represents F distribution values (ANOVA).

The results of this research show that the increase of the activity in plant physiological processes provided the augmentation of plant productivity. The application of the impact wave treatment was recognized as the perspective method.

As a result of these findings, the experimental industrial batches of tomato seeds were treated with the impulse pressure of 5 MPa and sowed since 1995. The pressure of 29 MPa was not used for processing of tomato seeds because of the corresponding decrease in germination. It was revealed that the productivity of tomato plants increased to 20% versus control levels, correspondingly (Table 3). The seed germination was lowered 10-15%. The amount of sown seeds was increased by 20-30%.

Table 3 shows the results of tests realized in different years. The plants of hybrid F_1 Kostroma were more productive in wintry-spring rotation than plants of hybrid F_1 Carlson. However, hybrid Carlson realized their potential to a fuller extent, after the treatment. Extended crop rotation allowed the gathering of more productivity when compared to the wintry-spring rotation, because it lasted 70 to 75 days longer. Growth conditions of autumn rotation were worse of all because the continuance of light period decreased, so the productivity of plants waned. Consequently the differences in plant productivity in different rotations were conditioned by genetic and growing conditions. F-ratios allow us to conclude that the mean yield is not homogenous between control and treated groups. The effect of impulse pressure promoted the certain differences within rotations between treated and control plants.

The effectiveness of this method of seed processing was recognized. The economic effect of the scientific and technical measure was assessed, but is not presented in this study, because the parameters will, to a certain extent, different from country to country. In this particular case, however the economic effect was rather significant. The added expenses resulting from seed treatment and from the additional amount of seeds did not exceed 1.5%.

Since 1998 the pressure of 4 MPa was used for the treatment of seeds (Table 3). This level is advantageous since it does not lead to the significant lowering of seed germination.

CONCLUSIONS

At present, the effect of the method of impact wave treatment of seeds is recognized. Our findings show that the productivity of cultivated areas, under plants treated by impulse pressure, is increased. In 1998, the introduction of this method on the whole area of the State Unitary Enterprise "Teplichnoye" was carried out. In 2000 this method was expanded to whole areas of three other agricultural enterprises. Thus, the method is approved, recognized, and recommended for widespread use.

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