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COMPARATIVE EFFECTIVENESS OF SHORT-TERM DAILY TEMPERATURE DROP AND PERIODIC DROUGHT AS METHODS TO REGULATE ELONGATION OF CUCUMBER (*Cucumis sativus* L.) PLANTS

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Abstract

Daily short-term temperature drop (DROP) and "periodic drought" (non-lethal water deficit) are used for plant height control as techniques inhibiting plant growth as an alternative to the use of retardants (chemical growth control). However, it is not known which of these two techniques is more effective and whether their combined effect can be stronger. In this paper taking cucumber as an example we have shown for the first time that a temperature drop technique is more effective than "periodic drought". Temperature drops combined with "periodic drought" retard plant growth and enhance plant tolerance, but depending on the relative air humidity may decrease values of some physiological and morphological parameters. The aim of this work was: (a) a comparative assessment of the effectiveness of DROP treatments and "periodic drought", and (b) the study of the combined effects of these two techniques on plant growth and tolerance to chilling temperature and water stress. Cucumber plants (*Cucumis sativus* L.) were exposed daily to a temperature of 10 °C for 2 hours at the end of the night (DROP treatment) for 6 days. The plants were watered daily or watered after the drying of the substrate (once every 2-3 days) creating "periodic drought" (drought treatment). Control plants were watered daily and not exposed to low-temperature treatments. All experiments were carried out at a low (30 %) or high (80 %) relative air humidity (RH). After the termination of the DROP treatments, plants from each treatment (control, DROP, drought, DROP + drought) were subjected to a cold test in the darkness for 1 day at a temperature of 4 °C. The plant height, length of leaf petioles, the area and number of leaves and plant dry mass were determined. The compactness of the plants was determined as the plant dry weight or leaf area per unit stem length (in mg/cm or cm^2/cm). Plant tolerance to low temperature and water stress was estimated by relative electrolyte leakage from leaf tissues and the intensity of lipid peroxidation, as assessed by the content of malonic dialdehyde. Differences between the treatments means were tested with one-way ANOVA followed the least significance difference (LSD) test with $p < 0.05$ level of significance. The obtained results indicate that DROP-treated plants had more dry mass and leaf area per unit length of the stem compared to those treated by "periodic drought". However, DROP treatments were effective in increasing plant compactness only under high (80 %) RH, while low (30 %) RH leveled out the effects of a temperature drop. "Periodic drought" can produce small, but not truly compact plants due to a more significant decrease in the leaf area and plant biomass compared to plant size. Thus, a temperature drop is a more effective technique compared to "periodic drought" that can be used to control plant growth and obtain compact plants. The combination of DROP treatments with "periodic drought" also increases plant compactness and besides enhances plant tolerance to water stress induced by low temperature. However, for a number of parameters (number of leaves, compactness of plants at low RH), the combination of DROP treatments and "drought" led to a worse result than the application of only the first of these two agro-practices.

Keywords: chilling temperature, water stress, plant growth, tolerance, release of electrolytes, lipid peroxidation

For many years, the use of chemical regulators with a retardant effect was considered the most effective way to control the linear growth of plants [1, 2]. However, over the past 30 years, new legal restrictions on their use have been constantly introduced in the world due to the risk of environmental pollution and the potential danger of chemical residues to human health. This has become a significant incentive to conduct research in order to find new methods and techniques for managing the growth of greenhouse crops [5-8]. In this case, natural factors affecting plant growth, such as temperature, light (intensity and spectral composition), photoperiod, relative air humidity (RH), CO_2 concentration, as well as planting density and container size, were used. The results of manipulation of these factors and their analysis showed that not all methods that effectively reduce the height of plants are applicable in terms of commerce. The most promising method in practical terms was the control of plant growth by changing the temperature and parameters of the moisture regime [2, 4, 9, 10]. So, in the mid-1980s, it was found that with the help of lower daytime temperature, it is possible to reduce the height of plants of many species [3, 5, 7]. However, the practical use of this feature is limited to periods with low air temperature during the year. A little later in greenhouses, a more economical method of daily short-term temperature reduction was applied, called "temperature drop" (in Europe) and "temperature dip" or "cool morning pulse" (in the USA), which inhibited the growth in height of many crops [7, 11, 12]. Usually, in this case, the temperature is reduced at the end of the night, and in the morning, an additional influx of energy is provided using the backlight in order to raise the temperature after the drop.

Similarly to the low-temperature effect, the so-called "periodic drought" (non-lethal water deficit) is also used in crop production to inhibit plant growth as another alternative to retardants [13-16]. It is believed that in this case not only the height of plants is decreased, but also their resistance is increased, so that they better tolerate possible stresses, for example, during transportation, sale or after planting in the ground [17]. Water stress is mainly used in the greenhouse production of seedlings of flower beds [14, 17, 18], in which the height is an important quality indicator, since excessive growth leads to increased transportation costs and greater sensitivity to storage conditions [15, 16].

Therefore, both daily short-term temperature drops (DROP effects) and water stress ("periodic drought") can inhibit the linear growth of plants. However, the literature does not contain data on which of these two agricultural methods is more effective. It is also unclear whether the effect can be enhanced by their combined use, since the mechanisms of action of these factors on plants are not the same.

In this report, for the first time, the authors showed the great effectiveness of the DROP method using the example of cucumber plants. A decrease in temperature, combined with periodic drought, also inhibits linear growth and at the same time increases the resistance of plants to water deficiency, but worsens some physiological and morphological characteristics depending on the relative humidity (RH).

The purpose of the work was to study the separate and combined influence of two natural factors (temperature and humidity) as ways to influence the linear growth and plant resistance in a greenhouse.

Techniques. Cucumber plants (*Cucumis sativus* L., Zozulya F_1 hybrid) were grown in pots (250 ml) with sand in an environmental chamber (Vötsch VB 1014, Vötsch Indusrietechnik GmbH, Germany) under watering with a nutrient solution (in mg/l: 226 N, 55 P, 370 K, 180 Ca, 40 Mg, 45 S, 17 Na, 52 Cl, 2.5 Fe, 0.6 Mn, 0.35 B, 0.3 Zn, 0.15 Cu and 0.05 Mo, pH 6.2-6.4); air temperature 23 °C, photosynthetically active radiation (PAR) 150 μmol/($m^2 \cdot s$), photoperiod

12 h. All experiments were carried out at relatively high (80%) or low (30%) RH. From the 6th day after the soaking of the seeds, when the cotyledonary leaves developed, different watering regimes were applied − daily or after drying of the substrate (sand) (1 time in 2-3 days), thereby creating the conditions of the so-called "periodic drought" ("drought" option). From the 14th day after the soaking of the seeds, when the first true leaf was in the phase of active growth and reached half the final size, some plants with different irrigation regimes were exposed to a temperature of 10 °C for 2 h (plus 30 min to decrease and 30 min to increase temperature) at the end of the night period (DROP variant) for 6 days. The temperature was decreased and increased at a rate of 0.4 °C/min. The control variant was plants receiving daily watering and not exposed to low temperature. In total, two series of experiments under conditions of different RH − high (80%) or low (30%) were conducted, in each of which there were 4 variants with the following conditions: 1st option — constant temperature 23 °C, daily watering (control); 2nd option — DROP exposure, daily watering (DROP); 3rd option — constant temperature 23 °C, "periodic drought" ("drought"); 4th option — DROP exposure, "periodic drought" (DROP + "drought").

Upon completion of DRO exposure, 6 plants from each variant (control, DROP, "drought", DROP + "drought") were exposed to a temperature of 4 °C in the dark chamber with RH of 90-100% within 24 hours ("cold test"), after which they were placed for 24 hours in a chamber with a temperature of 23 °C.

All measurements were carried out 1 day after the completion of DROP exposure or 1 day after the completion of the cold test. The height of the plants, the length of the leaves petioles, the area and number of leaves reaching a length of 10 mm or more, and the dry biomass of the plants were determined. The compactness of plants was calculated as the ratio of the dry mass of the plant to its height (mg/cm) or as the ratio of the area of leaves to the height of the plant (cm^2/cm) [19].

The resistance of leaves to low temperature and water stress was estimated by the relative release of electrolytes (RRE) from leaf tissue, which was determined using an Expert-002 conductivity meter with a probe for microvolumes UEP-P-S (Econix-Expert, Russia), and the intensity of lipid peroxidation, estimated by the content of malondialdehyde (MDA) according to the method of Heath and Packer [20].

Each experiment was repeated twice. The figures show the average values (M) for $n \geq 6$ and their standard errors (±SEM). The difference between the mean values was determined on the basis of the analysis of variance (according to the LSD criterion) using the Statistica software (v. 8.0.550.0, StatSoft Inc., USA) and was considered statistically significant at $p < 0.05$.

Results. The study showed that both DROP exposure and "periodic drought" reduce the height of the plant and the length of leaf petioles at high and low RH (Fig. 1, A, B, Table). In the case of the combination of DROP and "drought", the effect was more intensive, which led to an even greater decrease in the height and length of leaf petioles. It should be noted that the table shows the values of the indicators as a percentage of the control variant, but under the conditions of low RH, the biometric parameters of the control variant plants (plant height, leaf petiole length, leaf area, and dry plant weight) were halved, and the number of leaves was reduced by a third.

The leaf area did not decrease as a result of DROP exposure (with daily watering) at high RH and decreased by 10% at low RH. "Drought" led to a significant ($p < 0.05$) decrease in the leaves area by 23 and 25% under conditions of a correspondingly high and low RH (see Fig. 1, B, Table). In the case of the combined action of DROP and "drought", the effect was intensified (decrease in the leaf area by 41%, $p < 0.05$) only under the conditions of low RH. DROP exposure and "drought" did not affect the rate of leaf development; however, when these factors were combined, the number of leaves decreased by 20 and 27%, respectively ($p < 0.05$) under the conditions of high and low RH (see Table).

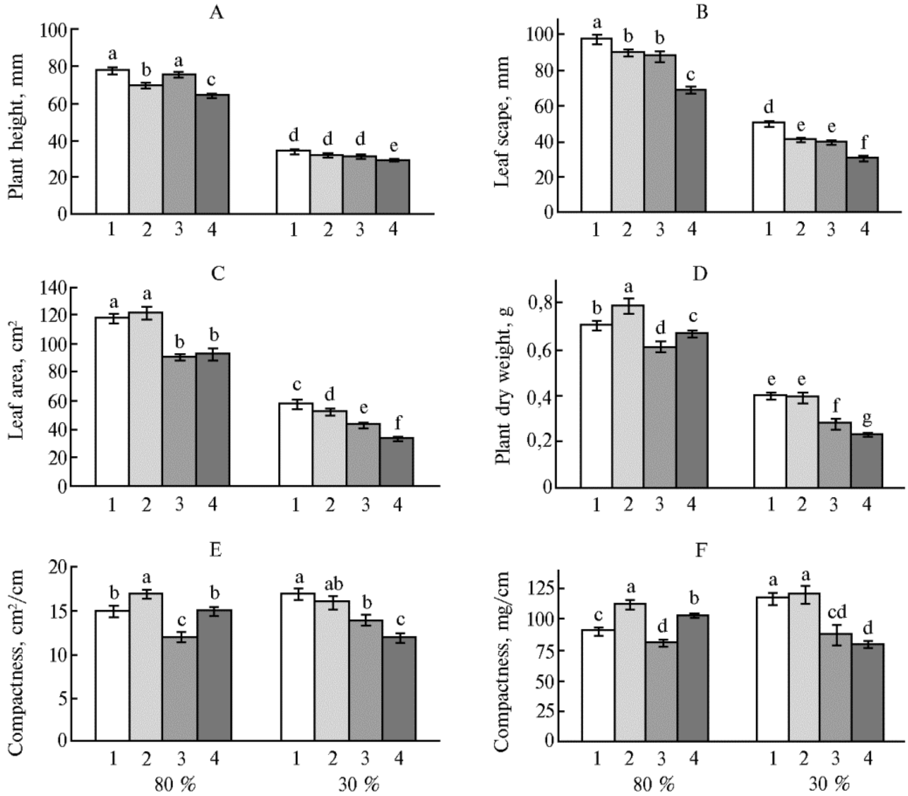

Fig. 1. Plant height (A), **leaf petiole length** (B), **area** (C), **dry weight (D) and compactness** (D, E) of the **control** (1), **subjected to DROP exposure** (2), **"drought"** (3) **and the combined action of DROP and "drought"** (4) **plants of the cucumber (*Cucumis sativus* L., Zozulya hybrid F_1) at a relative humidity of 80% or 30%** (pot trials). Different letters indicate the statistical significance of differences in mean values at $p < 0.05$.

Indicators of growth, development, and resistance of cucumber plants (*Cucumis sativus* L., Zozulya hybrid F_1) under the DROP exposure, "periodic drought" and their combination (% of the control variant) (pot trials)

Показатель	Options of the experiment					
	RH 80%			RH 30 %		
	DROP	"drought"	DROP + "drought"	DROP	"drought"	DROP + "drought"
Plant height	90*	97	83*	95	92*	87*
Petiole length	92*	90*	71*	83*	79*	61*
Leaf area	103	77*	79*	90*	75*	59*
Number of leaves	100	100	80*	103	94	73*
Dry weight of plants	112*	87*	95*	98	69*	59*
Compactness						
acc. to biomass	124*	89*	114*	103	75*	68*
acc. to leaves area	113*	80*	100	94	82*	71*
MDA content	95	48*	34*	100	93	83*
RRE	102	57*	21*	65*	76*	65*

N o t e. Indicators of control plants were taken as 100%. Absolute values of the indices of the control plants are shown in Figs. 1 and 2. The content of malondialdehyde (MDA) and the relative release of electrolytes (RRE) are given for plant leaves after a cold test. RH — relative humidity.
* Differences with control are statistically significant at $p < 0.05$.

The dry weight of plants under the influence of DROP exposure increased by 12% compared to the control variant ($p < 0.05$) at high RH and did not differ from the control variant at low RH (see Fig. 1, D, Table). "Drought" reduced the dry weight of plants under the conditions of high and low RH by 13 and 31%, respectively ($p < 0.05$). In the case of the combined action of DROP and "drought", the dry mass decreased by 5% ($p < 0.05$) at high RH and by 41% ($p < 0.05$) at low RH. Under the influence of DROP exposure and at a high RH, the ratio of dry biomass to plant height increased (by 24%, $p < 0.05$), as well as the ratio of leaf area to plant height (by 13%, $p < 0.05$); at low RH, these indicators did not differ from the control variant (see Fig. 1, D, E, Table). "Drought" in all variants of the experiment led to a decrease in the compactness of plants. The combination of DROP and "drought" caused an increase in the ratio of dry biomass to plant height by 14% ($p < 0.05$) only under the conditions of high RH, and at low RH compactness was even lower than in the case of using these methods separately.

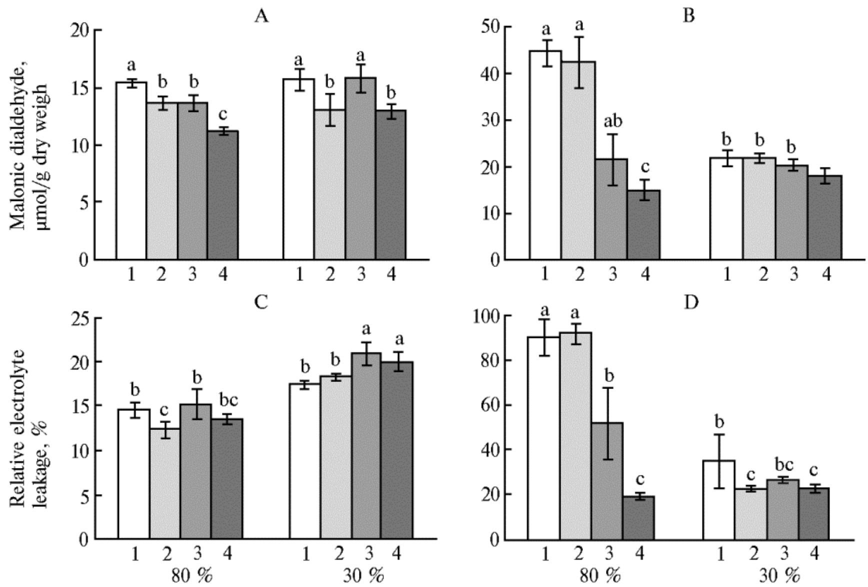

Fig. 2. The content of MDA (A, B) **and the relative release of electrolytes** (RRE) (C, D) **before cold testing** (A, C) **and after it** (B, D) **in the control** (1)**, subjected to DROP exposure** (2)**, "drought"** (3) **and the combined action of DROP and "drought"** (4) **in cucumber plants (*Cucumis sativus* L., Zozulya hybrid F_1)) at a relative humidity of 80% or 30%** (pot trials). Different letters indicate the statistical significance of differences in mean values at $p < 0.05$.

The MDA content, which indicates the intensity of lipid peroxidation, was 11 and 17% lower ($p < 0.05$) in the leaves of plants subjected to DROP exposure, at high and low RH, respectively (Fig. 2, A). "Drought" reduced the content of MDA by 11% ($p < 0.05$) only under the conditions of high PH, without affecting this indicator at low PH. In the case of the combined action of DROP and "drought" and high RH, there was a greater decrease in the content of MDA (by 27%, $p < 0.05$), while at low RH it was 17% ($p < 0.05$), as in the case of a separate DROP exposure. The values of RRE at high RH in plants under the influence of DROP were 15% lower ($p < 0.05$) than the control, but in the variants "drought" and DROP + "drought" these values did not differ significantly from the control (see Fig. 2, B). At low PH, DROP effects did not affect the RRE, but separate "drought" and DROP + "drought" led to an increase in the RRE by 20 and 15%, respectively ($p < 0.05$).

After the cold test (4 °C for 1 day), visually fixed cold injuries (leaf necrosis) in all experimental variants were more pronounced in plants grown under conditions of high RH (Fig. 3). The leaves of the control plants were the most injured, and the plants subjected to the combined action of DROP and "drought" were the least injured (see Fig. 3). The MDA content in the leaves of plants subjected to DROP exposure did not differ from the control plants (see Fig. 2, B, Table), irrespective of the RH. The leaves of plants subjected to the "drought" effect had a significantly lower (52%) MDA content at high RH and comparable to the control at low RH. In the DROP + "drought" variant, the MDA content was 66 and 17% lower than in the control plants, at high and low RH, respectively.

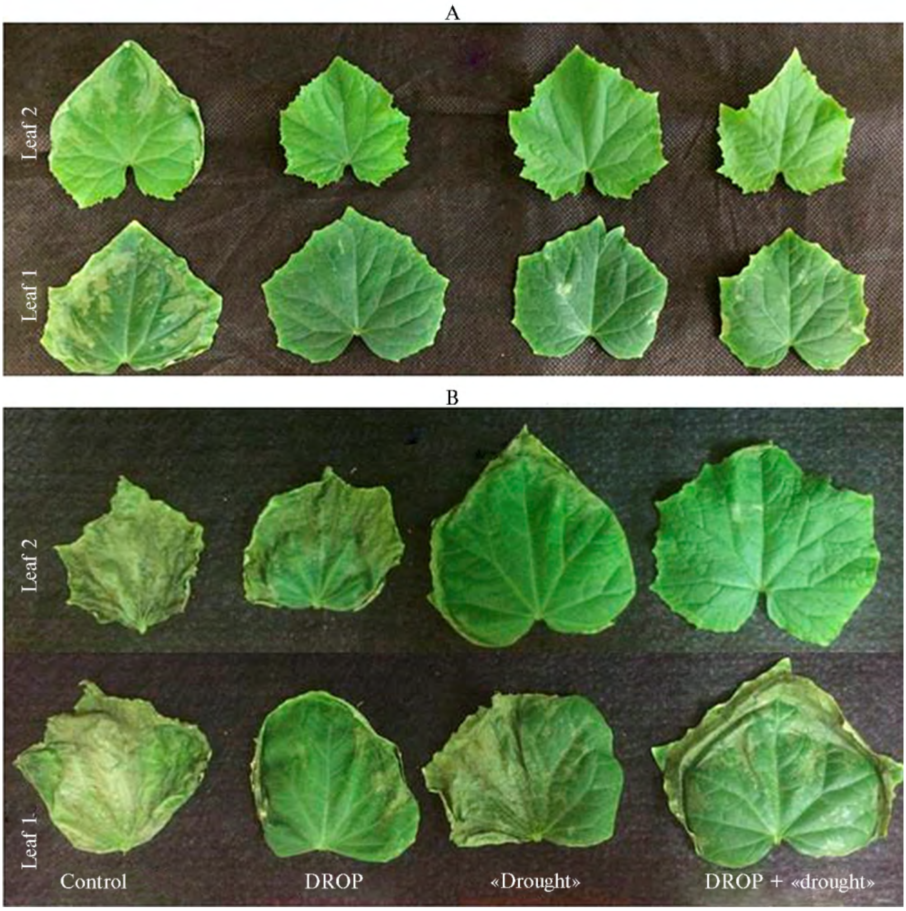

Fig. 3. The first and second true leaves of the control plants (Control) **and plants subjected to DROP exposure** (DROP)**, "periodic drought"** ("drought") **and DROP + "drought" at relative humidity** (RH) **30%** (A) **or 80%** (B) **after a cold test** (4 °C for 1 day) **of cucumber (*Cucumis sativus* L., Zozulya hybrid F_1)** (pot trials).

After the cold test, the RRE was at the control level in plants exposed to DROP at high RH, and 24% less at low RH. In the "drought" and DROP + "drought" variants, the RRE decreased significantly at high RH – by 43 and 79%, respectively, and at low RH – only by 24-35% (see Fig. 2, D, Table).

The results of the study showed that under the conditions of high RH and normal watering, DROP exposure has a pronounced morphogenetic effect, reducing the linear dimensions of plants. At the same time, the dry weight of plants increases slightly, which leads to an increase in the ratio of dry weight to plant height. The ratio of the leaves area to plant height also increases, that is, plants become more compact. A similar effect was previously shown when watering tomato seedlings using cold water (5 °C and 15 °C), which led to an increase in the ratio of dry weight to plant height by 28 and 32% compared with the variant in which watering was carried out using water at a temperature of 27.5-30.5 °C [21]. The compactness of plants, which is defined not only as a decrease in the linear dimensions of plant organs but also as the ratio of the dry mass of the plant to its height [19], increased as a result of a decrease in plant height while maintaining the biomass accumulation rate, as in the authors' experiment.

At low RH, the authors observed a significant inhibition of all growth processes, both linear growth and biomass accumulation; however, the relative decrease in plant height was greater than the decrease in dry weight, which also led to an increase in the ratio of plant biomass to its height under normal watering. Under these conditions, DROP exposure did not give an additional effect. Consequently, it can be concluded that low RH levels the effect of DROP in terms of plant compactness. The low RH in the authors' experiments led to a significant decrease in plant height, which contradicts the opinion of some authors [22, 23] about the weak effect of RH on plant growth in height, but is consistent with the findings that there is a positive correlation between shoot length and RH [24-26]. However, it should be noted that although growth retardation occurs at a low RH, and the ratio of the plant's dry mass to its height increases, this method can hardly be an alternative to retardants due to a significant reduction in the leaves area and plant biomass.

"Periodic drought" also had a pronounced morphogenetic effect on plants, which involves a decrease in the height and length of leaves petioles, but, unlike DROP exposure, "drought" reduced the leaves area and dry weight of plants. As a result, the ratio of the dry mass of the plant to its height and the ratio of the leaves area to plant height decreased. Similar results, when "drought" reduced the linear sizes of plants, but did not increase their compactness, were also observed in other species [19]. Other side effects of using water stress to control plant growth are also noted in the literature: a decrease in the rate of photosynthesis, a decrease in branching, an increase in the dispersion in terms of height of plants, deterioration of decorative properties (for example, due to a change in the angle of inclination of leaves), later and less abundant flowering [16, 27, 28].

The combined effect of DROP and "drought" increased the inhibition of linear growth compared to their separate application, but due to a decrease of the leaves area and dry mass of plants, this led to an increase in the ratio of dry mass of plant to its height by only 14% ($p < 0.05$) and only under conditions of high RH, while the increase in this indicator under the influence of DROP exposure under normal watering was 24% ($p < 0.05$). In addition, in the case of the combined action of DROP and "drought", a delay in the development of leaves was observed.

It should be noted that, according to the authors' data, both DROP exposure and "periodic drought" do not lead to either an increase in the lipid peroxidation rate, estimated according to the MDA content, or to an increase in the permeability of cell membranes, characterized by the RRE index. The results of the cold test showed that plants subjected to the combined action of DROP and "drought" were the most cold-resistant. It is likely that their increased resistance to low temperature is due to greater resistance to water stress caused by the action of low temperature. Many papers have shown that cooling affects thermophilic plants indirectly through water stress by disrupting plant water metabolism [29]. In such cases, the primary cause of cold damages in thermophilic species is the fall of turgor as a result of the violation of the stomatal conductance control and water loss during transpiration with reduction of the ability of the roots to compensate for these losses. After returning to normal conditions, necrotic spots appear on the dried parts of the leaves, which was observed in the authors' experiments, especially in control plants grown under the conditions of high RH. It was also previously reported that drought hardening prevents cold damage in thermophilic plants [30]. The higher resistance of plants to low temperature in the variant of combining DROP exposure and "drought" is apparently due to their better ability to regulate stomatal conductance under stress.

Thus, the obtained data indicate the effectiveness of DROP exposure for the inhibition of linear growth of plants with a simultaneous increase in the ratio of the leaves area and plant biomass to its height under the conditions of high RH, that is, DROP makes plants more compact. Under the conditions of low RH, these effects are leveled. Despite the fact that the watering regime, under which the conditions of "drought" are created, leads to a decrease in the size of plants, it reduces the ratio of the leaves area and plant biomass to its height. Therefore, it can be concluded that DROP exposure as an agricultural method is more effective than "periodic drought" and can be used to control the growth and obtain more compact plants as an alternative to retardants. The combination of DROP exposure with "periodic drought" also provides more compact plants, while increasing their resistance to water stress induced by low temperature. However, for a number of parameters (number of leaves, plant compactness under conditions of low RH), the combination of DROP exposure and "drought" has worse results than in the case of using only the first of these two methods.

REFERENCES

1. Rademacher W. Plant growth regulators: Backgrounds and uses in plant production. *J. Plant Growth Regul.*, 2015, 34: 845-872 (doi: 10.1007/s00344-015-9541-6).
2. Bergstrand K.-J.I. Methods for growth regulation of greenhouse produced ornamental pot- and bedding plants — a current review. *Folia Hort.*, 2017, 29(1): 63-74 (doi: 10.1515/fhort-2017-0007).
3. Heins R.D., Erwin J.E. The history of DIF and the use of a morning temperature dip to control plant height. *Minnesota Commercial Flower Growers Bulletin*, 1991, 40: 1-4.
4. Runcle E. Non-chemical height control techniques. *Greenhouse Product News*, 2014, 8: 58.
5. Moe R. Control of plant morphogenesis and flowering by temperature alterations. *Flowering Newsletter*, 1993, 15: 30-34.
6. Bachman G.R., McMahon M.J. Day and night temperature differential (DIF) or the absence of far-red light alters cell elongation in ‘Celebrity White’ petunia. *Journal of the American Society for Horticultural Science*, 2006, 131: 309-312 (doi: 10.21273/JASHS.131.3.309).
7. Runcle E. Controlling height with temperature drops. *Greenhouse Product News,* 2009, 4: 50.
8. Poorter H., Bühler J., van Dusschoten D., Climent J., Postma J.A. Pot size matters: a meta-analysis of the effects of rooting volume on plant growth. *Functional Plant Biology*, 2012, 39: 839-850 (doi: 10.1071/FP12049).
9. Currey C.J., Lopez R.G. Non-chemical height control. *Greenhouse Grower*, 2010, 11: 24-30.
10. Dean J. Using temperature to control growth. *Greenhouse Management*, 2011, 6: 1.
11. Myster J., Moe R. Effect of diurnal temperature alternations on plant morphology in some greenhouse crops: a mini review. *Scientia Horticulturae*, 1995, 62(4): 205-215 (doi: 10.1016/0304-4238(95)00783-P).
12. Moe R., Heins R.D. Thermo- and photomorphogenesis in plants. In: *Advances in floriculture research. Report no 6/2000.* E. Strømme (ed.). Agricultural University of Norway, Spekter, Oslo, 2000: 52-64.
13. Hendriks L., Ueber E. Alternative methods of regulating the elongation growth of ornamental plants: a current assessment. *Acta Horticulturae*, 1995, 378: 159-167 (doi: 10.17660/ActaHortic.1995.378.20).
14. Latimer J.G., Severson R.F. Effects of mechanical and moisture-stress conditioning on growth and cuticle composition of broccoli transplants. *Journal of the American Society for Horticultural Science*, 1997, 122: 788-791 (doi: 10.21273/JASHS.122.6.788).
15. Liptay A., Sikkema P., Fonteno W. Transplant growth control through water deficit stress — a review. *HortTechnology*, 1998, 8(4): 540-543 (doi: 10.21273/HORTTECH.8.4.540).
16. Carvalho S.M.P., van Noort F., Postma R., Heuvelink E. Possibilities for producing compact floricultural crops. Report 173. Wageningen UR Greenhouse Horticulture, Wageningen, 2008. Available http://library.wur.nl/WebQuery/wurpubs/fulltext/11685. No date.

17. Latimer J.G., Oetting R. Greenhouse conditioning affects landscape performance of bedding plants. *Journal of Environmental Horticulture*, 1998, 16: 138-142.
18. Brown R.D., Eakes J., Behe B.K., Gilliam C.H. Moisture stress: An alternative method of height control to B-nine (daminozide). *Journal of Environmental Horticulture*, 1992, 10: 232-235.
19. van Iersel M.W., Nemali K.S. Drought stress can produce small but not compact marigolds. *HortScience,* 2004, 39(6): 1298-1301 (doi: 10.21273/HORTSCI.39.6.1298).
20. Heath R.L., Packer L. Photoperoxidation in isolated chloroplasts. I. Kinetics and stoichiometry of fatty acid peroxidation. *Arch. Biochem. Biophys.*, 1968, 125(1): 189-198 (doi: 10.1016/0003-9861(68)90654-1).
21. Chen J.J., Sun Y.W., Sheen T.F. Use of cold water for irrigation reduces stem elongation of plug-grown tomato and cabbage seedlings. *HortScience*, 1999, 34(5): 852-854 (doi: 10.21273/HORTSCI.34.5.852).
22. Mortensen L.M. Effects of air humidity on growth, flowering, keeping quality and water relations of four short-day greenhouse species. *HortScience*, 2000, 86: 299-310 (doi: 10.1016/S0304-4238(00)00155-2).
23. Eveleens B.A., Heuvelink E., Van Noort F.R. *Invoed van EC en RV op de groei en kwaliteitvan Kalanchoe.* Wageningen UR Glastuinbouw, Bleiswijk, 2007.
24. Armitage A.M., Kowalski T. Effect of irrigation frequency during greenhouse production on the postproduction quality of *Petunia hybrida* Vilm. *Journal of the American Society for Horticultural Science*, 1983, 108: 118-121.
25. Mortensen L.M. Effect of relative humidity on growth and flowering of some greenhouse plants. *Scientia Horticulturae*, 1986, 29(4): 301-307 (doi: 10.1016/0304-4238(86)90013-0).
26. Gislerød H.R., Nelson P.V. Effect of relative air humidity and irradiance on growth of *Dendranthema grandiflorum* (Ramat.) Kitamura. *Gartenbauwissenschaft*, 1997, 62: 214-218.
27. Hanssen S.W., Petersen K.K. Reduced nutrient and water availability to hibiscus rosa-sinensis Cairo Red as a method to regulate growth and improve post-production quality. *European Journal of Horticultural Science,* 2004, 69: 159-166.
28. Runcle E. Height control for vegetable transplants. *Greenhouse Product News,* 2010, 2: 50.
29. Janowiak F. Effect of water saturated atmosphere on chilling injuries of maize seedlings (*Zea mays* L.). *Acta Physiologiae Plantarum*, 1989, 11(2): 89-96.
30. Starck Z., Choluj D., Gawronska H. The effect of drought hardening and chilling on ABA content in xylem sap and ABA — delivery rate from root of tomato plant. *Acta Physiologiae Plantarum*, 2004, 20(1): 41-48 (doi: 10.1007/s11738-998-0041-1).