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EFFECT OF RETARDANT FOLICUR ON MORPHOGENESIS, PHOTOSYNTHETIC APPARATUS AND PRODUCTIVITY OF TOMATOES

Abstract. The results of the study show the effect of triazole derivative retardant on morphogenesis, redistribution of organs weight, features of nonstructural carbohydrates assimilation in the stems, roots and leaves of tomato plants hybrid Solerosso during the fruitification stage. It was established that application of Folicur by spraying method during the budding phase led to slowing the longitudinal growth and intensification of tomato breeding, resulting in a weight increase of the whole plant. Application of Folicur realized by redistribution of organs weight: the leaf weight increased with a simultaneous decrease of the stem and root weights compared with control, resulting in the formation of a more powerful donor sphere of plant. Drug treatment led to increase the leaf surface area and an important cenotic index for the production process - leaf index. The formation of a more powerful leaf apparatus led to increase the content of sugars and starch in vegetative organs of experimental plants, followed by the active reutilization of these substances for the fruit formation. It was established that the formation of a more powerful photosynthetic apparatus under Folicur treatment led to increase the yield of tomatoes.

Key words: antigibberellin compounds, area of leaf surface, leaf mesostructure, net photosynthetic productivity, yield.

INTRODUCTION

Application of drugs based on the native phytohormones, their analogues and modified action creates the possibility of exogenous influence on the yield and crop production quality [6, 11, 13]. The development of donor-acceptor ("source-sink") systems of plant opens the prospects of artificially redistributing of assimilates flows from vegetative growth processes to the fruits formation and growth needs, and therefore, it is a potential factor in increasing the agricultural crops productivity [3, 20]. Synthetic growth regulators application can artificially change the morphogenesis, activity of growth and photosynthetic processes, regulate plant loading with fruits and seeds [1, 10, 12, 16]. Among modern regulators of plant growth and development, not only stimulators occupy an important place, but inhibitors of growth processes - retardants. They block the synthesis of gibberellins in the plant or prevent the formation of hormone-receptor complex, which alleviates the effect of already synthesized phytohormones [15].

One of the most common groups of synthetic plant growth regulators is retardants – antigibberellin compound that either inhibit the gibberellin synthesis or block formation of the hormone-receptor complex, that preventing the growth-stimulating effect of phytohormone [9]. Therefore, the effect of retardants on plants is not limited to inhibition of linear growth, but is often manifested in changes in the intensity of physiological processes, improved plant productivity, improved yield quality, resistance of plant organism to stress factors, etc. [4, 18]. For the agricultural plants regulation of growth and development of production, retardants - representatives of quaternary ammonium compounds are widely used [8]. However, the analysis of literature data presents only a few amount of retardant effects of new generation - the triazole derivative compounds on morphogenesis and physiological and biochemical processes of vegetable cultures [16].

In this case, the issue of this study was to find out the effect of antigibberellin triazole derivated compound Folicur on the features of morphogenesis, formation of leaf apparatus, accumulation and redistribution of nonstructural carbohydrates in plants and productivity of tomatoes.

METHODS

The active compound of commercial drug Folicur is tebuconazole ($C_{16}H_{22}ClN_3O$)-(RS)-1 α -chlorophenyl-4,4-dimethyl-3-(1H-1,2,4-triazol-1-yl-methyl) pentan-3-yl. The manufacturer is Bayer Crop Science AG (Germany).

A field-based micro-trial setup was established at a specialized farm FG "Solskyi" in Vinnitsa region from 2015 to 2017 on the high-yield ultra precocious deterministic hybrid of Dutch selection tomatoes Solerosso. The experiment followed a randomized block design (10 m²) with five replication. The treatment was applied via foliar spraying OP-2 with aqueous solution of 0,025 % Folicur (per active compound) once at the time of initiation of budding to complete wetting of leaves. Control plants were treated with water.

Phytometric measurements (plant height, leaf area, weight of dry matter of organs and full plants, area of leaf surface) were determined on 20 plants at the green ripeness stage at the fruitification phase. At the same phase, the leaf index (LI) was defined as the area of all leaves per unit soil surface.

The weight of dry matter of plants organs was determined by the liquid nitrogen fixation, dismembered, kept in a drying-oven for one hour at 105 ° C, than for 4 hours at 85 ° C and dried in air to an air-dry state.

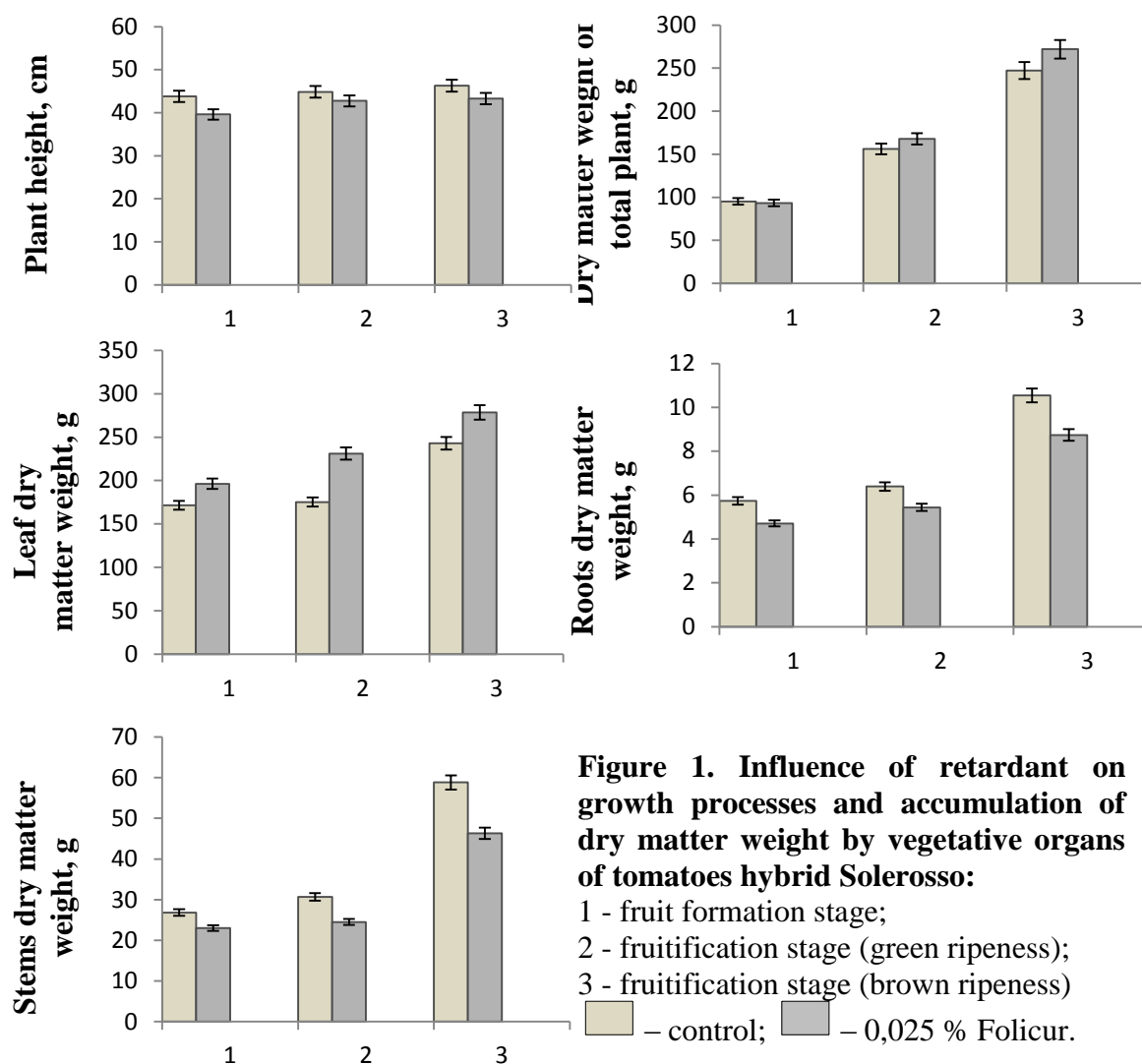
Mesostructural organization of leaves during the field-based micro-trial setup was studied at the end of the vegetative season at a fixed material of the middle-layer leaves of the shoots, which completely ended their growth. For preservation was used a mixture of equal parts of ethanol, glycerol and water (1:1:1) with addition of 1 % formalin. Measurement of cells sizes was performed by using a microscope "Mikmed-1" and ocular micrometer MOB-1-15x. Determination of individual cells size of chlorenchyma was carried out after the maceration of leaf tissues with a 5% solution of acetic acid in 2 mol/l hydrochloric acid. Stomatal index is defined as the ratio of number of stomata form to the total number of epidermal cells on the same leaf area. At the beginning of fruitification phase (three weeks after treatment), in the stages of green and brown tomatoes ripeness, it was determined the total of sugars and starch in vegetative organs by the using iodometric method, the total nitrogen content – by Kjeldahl, chlorophylls – by spectrophotometric method on the spectrophotometer SF-16. It was determined the content of sugar and organic acids in fruits [2]. Net photosynthetic productivity is determined as the growth of dry matter per day for unit leaf surface. Sampling for analysis was carried out in the middle of day with five analytical replication of the research. The statistical processing of results was performed using the computer program "Statistica-6". The reliability of obtained results between control and experiment variant was assessed with the use of Student's t-test. Tables and figures show mean values for the three years of research (2015-2017) and their standard errors.

RESULTS AND DISCUSSION

Synthetic growth regulators application can artificially change the morphogenesis, activity of growth and photosynthetic processes, regulate plant loading with fruits and seeds [4, 7]. The results of the study indicate that application of retardants Folicur caused a typical inhibition effect on the linear growth of tomato plants. The height of Folicur treated plants decreased compared with control during the whole period of vegetation, but

in experimental plants the dry weight matter increased with the changes in relative proportion of dry matter weight between organs of the total plant compared with control.

Leaf apparatus that performs the processes of photosynthesis plays the main role in the formation of crop production. It was found that Folicur application reduced the dry matter weight of roots and stems, but the leaf dry matter weight was significantly increased at all vegetation stages of plant development (Figure 1).



The number of leaves per plant, their total area, structural features and life expectancy are the important indicators of production process. The obtained results testify to the significant influence of Folicur treatment on the formation of leaf apparatus of tomatoes (Figure 2).

The results of the study suggest that at the fruit formation and fruitification (green ripeness) stages under retardant application formed a large number of leaves, which was caused by the strengthened branches of the stem. Deceleration of growth processes was accompanied by changes in the formation of surface assimilation. The area of surface assimilation is one of the cardinal components in the formation of provision level of plastic material for plant growth and respiratory processes. The dimensions of surface assimilation during the growing season largely determine the nature of production process and crop yield [19]. The obtained results indicate that an increase in the number of leaves under the retardant treatment was accompanied by a significant increase in the area of leaf surface.

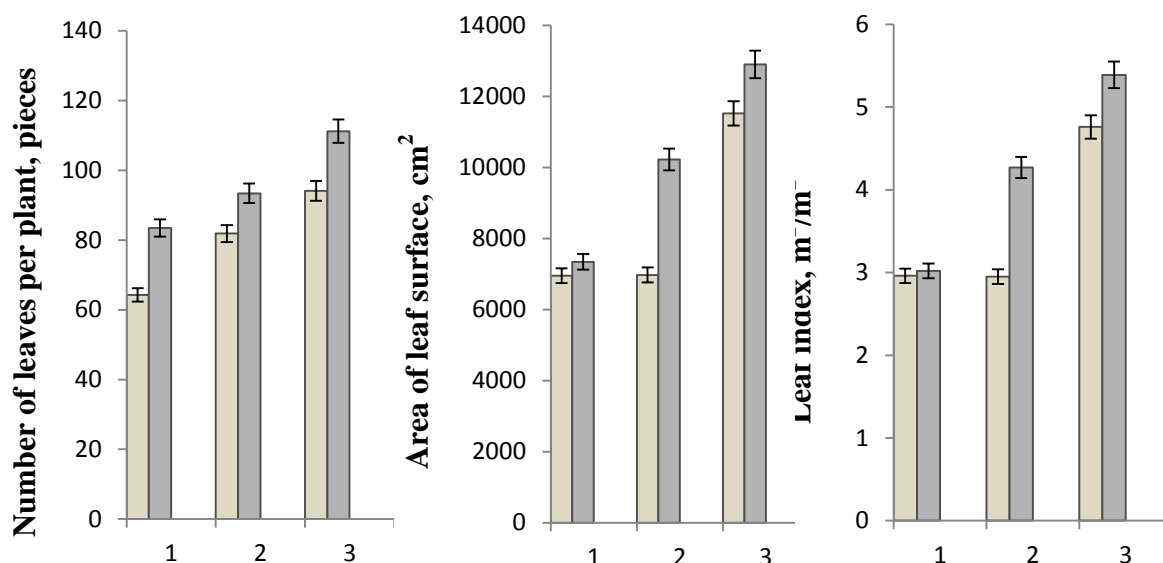


Figure 2. Formation of leaf apparatus of tomatoes hybrid Solerosso under Folicur treatment:

1 - fruit formation stage; 2 - fruitification stage (green ripeness); 3 - fruitification stage (brown ripeness)

□ – control; ■ – 0,025 % Folicur.

Leaf index is an important cenotic index for the total crop yield, which is defined as the green leaf area per unit ground surface area. The analysis has shown that drug application increased the leaf index compared with control at the fruitification period.

Consequently, the interaction of Folicur enhanced the leaf surface as a single plant and agrocenosis as a whole. This contributes to the formation of a powerful assimilation apparatus and more active accumulation of dry matter weight, which is an important prerequisite for increasing the crop yield.

Analysis of leaf mesostructure testified that changes in the thickness of leaf blade of Folicur treated plants are due to the growth of photosynthetic tissue - chlorenchyme (Table 1). It was found that retardant increased the linear dimensions of spongy parenchyma and cell volume of palisade parenchyma – the main assimilation tissue of leaf. Analogical dimensions of leaf thickness as a result of the chlorenchyma growth are noted on another cultures treated by triazole derivative compounds [14, 19].

Table 1. Influence of the retardant Folicur on the leaf mesostructural organization of tomatoes hybrid Solerosso

Measurements	Control	Folicur
Thickness of leave, μm	247,69 \pm 7,43	*272,35 \pm 7,28
Thickness of chlorenchyma, μm	211,27 \pm 6,74	*227,77 \pm 7,18
Volume of palisade parenchyma, μm^3	46299,25 \pm 1435,28	*58613,09 \pm 1817,01
Length of spongy cells, μm	20,77 \pm 0,44	*23,17 \pm 0,75
Width of spongy cells, μm	15,49 \pm 0,48	14,71 \pm 0,45
Thickness of upper epidermis, μm	20,39 \pm 0,59	*24,61 \pm 0,75
Thickness of lower epidermis, μm	16,02 \pm 0,46	*19,98 \pm 0,67
Number of stomatas on 1 mm ² of the abaxial leaf surface, pieces	27,23 \pm 0,68	*37,05 \pm 1,19
Area of a stomata, mcm ²	397,01 \pm 10,91	*365,23 \pm 9,68
Stomatal index	0,35 \pm 0,01	*0,39 \pm 0,01

Note.* - difference is significant at $p < 0,05$.

Significant changes occurred in the epidermal tissue of leave. The analysis of the results shows that Folicur application resulted in an increase the thickness of upper and lower epidermis of leave compared with control. It is grounded that inhibitors and growth stimulators have an influence on the number of stomatas per unit of abaxial leaf surface. The influence of Chlormequat chloride and triazole derivatives Folicur and Paclobutrazole on poppy oil plants cv. Berkut [14] and potatoes cv. Nevsky [19] increased the area and number of stomatas, while the epidermal cells area of potatoes did not change.

The results of the research suggest that the number of stomatas per unit leaf area of experimental plants increased with reducing of area of one stomata. The calculation of stomatal index, which characterizes the ratio of number of stomata form to the total number of epidermal cells on the same leaf area, indicates that Folicur increased this measerement compared with control. It can be concluded that such anatomical component of the photosynthetic apparatus functioning can positively influenced on the intensity of transpirational processes.

Thus, the interaction of retardant Folicur resulted in an increase the number of leaves and leaf surface area due to the enhancement of stem branching. There was an optimization of leaf mesostructure of tomato plant under retardant treatment. Consequently, the application of retardant Folicur led to forme a more powerful donor sphere of the plant compared with control, which is an important prerequisite for increasing the crop yield.

The results of the study indicate that during the period of fruit formation there is a gradual increase of important indicator – leaf area density value (Table 2). It was found that leaf of Folicur treated tomatoes were characterized by the highest value of this indicator. This correlates with the results of mesostructural characteristics of treated plants, where, at the end of vegetation, the thickness of leave under triazole derivatives drug was the largest. Analysis of literary data suggests that the effect of retardants is determined by the dose of drug, its specificity and weather conditions [8, 19]. A number of researchers observed an increase in the chlorophyll content under the influence of Paclobutrazole and Dextrel on the leaves of potato plants [19], under the action of Folicur on the leaves of poppy oil [9].

Table 2. Anato- and physiological parameters of leaf apparatus of Folicur treated tomato plants hybrid Solerosso

Vegetation period	Measurement	Control	Folicur
Fruit formation stage	Leaf area density value, mg/cm ²	1,79±0,06	*2,12±0,05
	Total chlorophyll content, % per leaf fresh matter weight	0,72±0,022	0,74±0,021
	Net photosynthetic productivity, g/(m ² ·day)	6,41±0,16	*10,83±0,43
Fruitification stage (green ripeness)	Leaf area density value, mg/cm ²	2,88±0,09	*2,93±0,07
	Total chlorophyll content, % per leaf fresh matter weight	0,71±0,011	*0,76±0,021
	Net photosynthetic productivity, g/(m ² ·day)	7,32±0,17	8,29±0,31
Fruitification stage (brown ripeness)	Leaf area density value, mg/cm ²	3,57±0,08	*4,54±0,13
	Total chlorophyll content, % per leaf fresh matter weight	0,54±0,011	*0,71±0,021
	Net photosynthetic productivity, g/(m ² ·day)	6,54±0,19	*9,36±0,21

Note.* - difference is significant at p<0,05.

The data show that Folicur treatment not lead to significant changes in the chlorophyll content at the fruitification stage. At the same time, at the stage of green and brown ripeness of fruit, the chlorophyll content of leaves was higher compared to control.

The index of net photosynthetic productivity is characterized by photosynthetic productivity of unit leaf surface. The analysis of the data shows that this indicator was higher under Folicur application. In our opinion, a significant increase in the net photosynthetic productivity together with an increase in area leaf surface under retardant action created the prerequisites to enhance a gross photosynthetic crop production and accumulation of a greater number of photoassimilates in the plant.

It is grounded that some of assimilates may be temporarily deposited in the stock organs with subsequent reutilization on the carpogenesis processes. At the same time, the depositing possibilities of plants vegetative organs after phytohormones and synthetic growth regulators application are not adequately explored. It was found only certain scholarship, in which are considered the issues of dependence of photosynthetic processes and the carbohydrates content in plants under the action of retardants [17, 20].

In our opinion, it is expedient to determine the dynamics and correlation of nonstructural carbohydrates content in plant organs at the different fruit formation stages in order to assess the depositary capacity of vegetative organs of experimental variants. Analysis of depositing possibilities of vegetative organs of the plants during fruitification phase showed the importance of temporarily accumulation of nonstructural carbohydrates in them with subsequent reutilization for carpogenesis needs. The obtained results indicate that in the vegetative organs of tomato plants – roots, stems and leaves, the amount content of nonstructural carbohydrates (sugars + starch) was higher compared to control. Obviously, this indicates some of their redundancy, which is not fully spent on the fruits formation, but is temporarily accumulated to reserve. The highest content of carbohydrates in all stages of the fruitification stages was noted in stems of tomato plants, that indicates the powerful depositing capabilities of this vegetative organ. At the same time, the total content of sugar and starch in roots, stems and leaves of Folicur-treated plants was the highest throughout the fruit formation phase. Analysis of obtained results indicated that the content of carbohydrates decreased in the leaves, roots and stems of tomatoes gradually throughout the fruit formation stage (from the stages of green to brown tomato ripeness), the most intense effect was marked by interaction of Folicur. In our opinion, this is an indication that at this period plant is over-load with assimilated sugars and uses them not only for the growth and formation of fruits, but also for the creation of carbohydrates reserve, which is deposited in vegetative organs with followed their utilization at the the stages of green to brown fruit ripeness.

Anatomo-morphological and physiological changes that occurred in tomato plants under the action of Folicur led to a significant enhanced the crop production by increasing an average weight of one fruit (Table 3).

Table 3. Product quality and productivity of tomatoes hybrid Solerosso plants under Folicur treatment

Measurements	Control	Folicur
Yield, t/ha	68,16±1,71	*87,78±1,69
Weight of fruits from one bush, kg	1,61±0,03	*2,08±0,04
Number of fruits on a bush, pieces	35,41±1,07	36,41±1,29
Weight of one fruit, g	41,54±1,05	*51,15±1,21
Content of ascorbic acid, mg/100 g	26,38±0,82	*22,95±0,58

Titrated acidity, g /100 g	0,58±0,02	*0,81±0,02
Reducing sugar, % per fresh matter	0,95±0,02	*1,27±0,03
Sucrose, % per fresh matter	0,68±0,01	0,69±0,02
Total sugars, % per fresh matter	1,65±0,03	*1,94±0,05

Note.* - difference is significant at $p < 0,05$.

The results indicate that the application of drug significantly increased the titrated acidity of fruits with increased in the content of sugars and decreased in the content of ascorbic acid under triazole derivative compound treatment compared to control (Table 3). However, fluctuations of the tomatoes quality under the influence of Folicur are within the typical values for a given crop, which not lead to significant changes in the product quality.

Consequently, the application of retardant Folicur leads to more intensive accumulation of nonstructural carbohydrates (sugars and starch) in vegetative organs of tomato plants, followed by the active reutilization of these substances for the fruit formation and growth needs, which leads to the enhancement of crop yield.

CONCLUSION

Application of Folicur on tomato plants at the budding phase is formed a more powerful photosynthetic apparatus due to increase in the number of leaves, their weight and assimilation surface area of the plant and the cenosis in general which is an important prerequisite for increasing the crop production.

The interection of Folicur resulted on the mesostructural optimization of leave: the thickness of chlorenchyma, linear dimensions and assimilatory cells size of palisade and spongy parenchyma are increased, enhanced the leaf area density value, chlorophyll content which lead to an increase the net photosynthetic productivity. Significant enhancement in the net photosynthetic productivity with the increase in the leaf surface area, under the retardant treatment, creates the prerequisites for increasing the gross photosynthetic productivity of plant. Accumulation of a greater number of photoassimilates in plant provides depositing an excess of assimilates in vegetative organs with followed their utilization on fruit growth.

Retardant treatment provides a reliable enhancement in the crop yield of tomato due to an increase in the average weight of one fruit. Fluctuations of the tomatoes quality under the influence of Folicur are within the typical values for a given crop, which not lead to significant changes in the product quality.

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АНОТАЦІЯ

ДІЯ РЕТАРДАНТУ ФОЛІКУРУ НА МОРФОГЕНЕЗ, ФОТОСИНТЕТИЧНИЙ АПАРАТ ТА ПРОДУКТИВНІСТЬ ТОМАТІВ

Регуляція донорно-акцепторних відносин рослин відкриває перспективи штучного перерозподілу асимілятів в бік господарсько цінних органів і підвищення урожайності сільськогосподарських культур. Застосування синтетичних регуляторів росту різної хімічної будови дозволяє штучно змінювати напруження між процесами росту і плодоношення з одного боку (акцепторна сфера) і активністю фотосинтетичного апарату рослини (донорна сфера). Зокрема, обмеження лінійного росту рослин за допомогою ретардантів може призвести до накопичення надлишку фотоасимілятів і перерозподілу їх з процесів вегетативного росту на процеси формування плодів.

Отримані результати свідчать про важливе значення морфологічної та мезоструктурної складових у формуванні і функціонуванні донорно - акцепторної системи томатів під впливом ретарданту триазолового ряду фолікуру. За дії препарату відбувалися суттєві анатомо - морфологічні зміни у формуванні листкового апарату: зростала кількість листків, площа листкової поверхні та маса листків та важливий ценотичний показник продуктивності рослин - листковий індекс. Відбувалися зміни у співвідношенні мас сухої речовини вегетативних органів: у оброблених препаратом рослин маса листків збільшувалася, а маса стебла і коренів зменшувалася, що свідчить про формування більш потужної донорної сфери рослин томатів. Суттєві зміни відбувалися також у мезоструктурній організації листків: зростала товщина листка і основна фотосинтетична тканина - хлоренхіма, лінійні розміри та об'єм клітин стовпчастої та губчастої асиміляційної тканини. За дії препарату протягом всієї фази формування плодів відмічався більш високий показник поверхневої щільності листка. Це добре корелює з результатами мезоструктурних характеристик оброблених триазолпохідним препаратом рослин, де на кінець вегетації товщина листка була найбільшою. При цьому слід відмітити, що під впливом фолікуру відбувалося зростання вмісту хлорофілів в тканинах листка у порівнянні з контролем. Наслідком оптимізації мезоструктури та накопичення хлорофілів було зростання показника чистої продуктивності фотосинтезу у варіанті із застосуванням ретарданту. Цей показник характеризує фотосинтетичну активність одиниці поверхні листка і з урахуванням зростання сумарної площі листкової поверхні свідчить про підвищення валової фотосинтетичної продуктивності культури та накопичення більшої кількості фотоасимілятів у рослині.

Внаслідок більш потужної роботи фотосинтетичного апарату протягом всієї фази плодоношення вміст неструктурних вуглеводів (крохмаль + цукри) у вегетативних органах оброблених фолікуром рослин був більш високим, ніж у контролі. Очевидно, у цей період рослина надлишково забезпечена продуктами

фотосинтезу і тимчасово депонує їх з наступним використанням при переході від зеленої до бурої стадії стиглості плоду.

Найбільшим вмістом неструктурних вуглеводів відрізнялося стебло, що свідчить про потужні депонувальні можливості цього вегетативного органу.

Анатомо-морфологічні та фізіологічні зміни, які відбулися в рослинах томатів за дії фолікуру призвели до достовірного підвищення урожайності культури внаслідок збільшення середньої маси одного плоду. За дії препарату відбувалися наступні якісні зміни в плодах томатів: достовірно збільшувалася загальна кислотність, при цьому підвищувався вміст цукрів та зменшувався вміст аскорбінової кислоти у порівнянні з контролем. Разом з тим, коливання вмісту якісних показників томатів під впливом препарату фолікуру знаходяться в межах типових для даної культури значень, що не призводило до суттєвих змін у якості продукції.

Отже, за дії ретарданту фолікуру формувалася більш потужна донорна сфера, підвищувалася фотосинтетична активність листкового апарату, надлишок продуктів фотосинтезу накопичувався не лише в листках, але і в інших вегетативних органах – стеблі і корені, з наступним використанням резервних вуглеводів на процеси карпогенезу (формування плодів), що призводило до зростання урожайності.

Ключові слова: антигіберелінові препарати, площа листкової поверхні, мезоструктура листків, чиста продуктивність фотосинтезу, урожайність.