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PHYSIOLOGICAL PARTICULARITIES OF MAIZE PLANTS AND THE EFFECT OF SOME ANTIOXIDANTS UNDER CONDITIONS OF MODERATE DROUGHT

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ABSTRACT. Complex investigation on the effect of Thiourea, Galmet and Thiogalmet compositions on water status, intensity of photosynthesis, water use efficiency, growth and yield of 'P458' maize plants under conditions of natural humidity in field trials was performed. The beneficial effect of seed and foliage pre-treatment with Thiourea, Galmet and, in particular, the new chemical composition Thiogalmet on plants' biological processes conditioning a better realisation of the physiological processes associated with plant growth and productivity was established. A significantly greater positive impact of Thiogalmet on the optimisation of hydration degree, water retention capacity, stomatal conductance for CO_2/H_2O, assimilation, water use efficiency, plant growth and productivity was recorded. There was an additive action of Thiourea and Galmet in the composition of the Tiogalmet preparation. Thiogalmet increased the yield per unit area and improved the commercial quality of the grain. Treating plants with Thiourea, Galmet and Thiogalmet ensured a 27.20, 52.08 and 68.20% yield increase, respectively, compared to the plants in the control variant. Therefore, a major effect was registered in the plants treated with the new composition. The obtained information demonstrates the possibility of mitigating the adverse effects of drought on the physiological response and production by applying antioxidants.

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Keywords: growth; photosynthesis; physiologically active substances; plants; productivity; resistance; transpiration.

INTRODUCTION

It has become an axiom that the abiotic stress associated with climate change is the main cause of crop losses. Adverse weather conditions, such as temperature, precipitation and radiation, caused by climate change can have an enormous negative impact on plants, exposing agriculture to unprecedented risk. Recent climate change predictions suggest that the stability of the most important crops is severely affected by both high temperatures and hypothermic stress (IPCC, 2022). Drought, accompanied by excessive temperatures and solar radiation, induces tissue dehydration and uncontrolled formation of reactive oxygen species (ROS), especially superoxide radicals and singlet oxygen, which cause destruction of the cell structure and photooxidative death of plants. ROS generated during drought induce chlorophyll degradation and peroxidic oxidation of phospholipids and cause oxidative destruction of cellular structures. Hydrogen peroxide in chloroplasts causes the stomata to close, stop photosynthesis and reduce plant productivity (Asada, 2006; Wang *et al.*, 2012). In many European countries, drought, accompanied by excessive temperatures and solar radiation, induces an uncontrolled formation of ROS, especially superoxide radicals and singlet oxygen, which cause the photooxidative death of maize plants in many fields (*Figure 1*). There is a need to prevent and manage the specific risks and vulnerabilities that can be caused by abiotic stressors, including water deficiency, strong radiation and superoptimal temperatures (FAO, 2023). Exogenous application of physiologically active compounds (PhASs), including compounds with antioxidant properties, can reduce oxidative stress by increasing the activity of antioxidant enzymes, leaf water content and rate of photosynthesis under moderate drought conditions (Ștefîrță *et al.,* 2021).

Figure 1 – Photooxidative death of maize plants (https://glavagronom.ru)

Providing plants with moisture and necessary nutrients, especially potassium and magnesium, can reduce the effects of factors involved in regulating plant water status and the negative effects of complex hydrothermal and photooxidative stress. In this sense, the possibility of increasing plant tolerance using a new chemical composition called **Thiogalmet,** with well-expressed antioxidant properties (Ștefîrță *et al.,* 2022), presents interest. The new composition, conventionally called **Thiogalmet**, contains 66.7% of thiourea (CH_4N_2S) and 33.3% of **Galmet**, a preparation consisting of a mixture of gallates ($C_7H_5O_5^-$) of potassium, ammonium, magnesium, potassium molybdate and ammonium paramolybdate, taken in the respective mass ratio of 1:1:1:0.1:0.1.

Based on what was reported, the following *hypothesis* was suggested:

Thiogalmet, through its chemical composition and antioxidant properties, can have the effect of reducing the impact of unfavourable hydrothermal conditions of the external environment by regulating plants' ability to maintain water homeostasis and optimising photosynthesis, growth and productivity under conditions of moderate drought.

The general objective of this work consisted of evaluating the effect of the complex preparation **Thiogalmet** on the growth, development and productivity of *Zea mays* (L.) plants under natural humidity conditions with the recurrence of drought.

MATERIALS AND METHODS

Zea mays L. plants of cultivar 'P 458' were used as the objects of study. Maize, in terms of its value as a cereal crop, ranks third after wheat and rice and plays a significant role in solving food security problems at the global level (Chaves *et al.*, 2003). *Zea mays* L. plants are considered to have wide adaptability to different climatic and soil conditions. According to its requirements for the soil water regime, corn is a plant with a determinate growth type and belongs to isohydric mesophytes (Larcher, 1978; Tardieu and Davies, 1993), which under conditions of insufficient moisture have the property of regulating their water status, thus ensuring the maintenance of metabolic processes at a relatively adequate level. However, the decrease in humidity to the threshold level or below the critical values causes disturbances because of dehydration and the inhibition of photosynthesis in leaves. These disturbances can cause not only a reduction in productivity but even plant death.

The experiments were carried out on the experimental fields of the Institute of Genetics, Physiology and Plant Protection of the USM in 2021 and 2022, using the block method with three repetitions of variants located randomly.

The scheme of the experiment included the following variants:

Ist variant - plants grown from seeds treated with water, control;

IInd variant - seeds treated before sowing and plants treated during vegetative growth with a 0.005% aqueous solution of **Thiourea**;

IIIrd variant - seeds treated before sowing and plants treated during vegetative growth with a 0.005% aqueous solution of **Galmet**;

IVth variant - seeds treated before sowing and plants treated during vegetative growth with an aqueous solution of **Thiogalmet** of the same concentration. During vegetative growth, three consecutive treatments were performed: the first treatment was performed three weeks after germination, at the "5th leaf" phase; the second treatment - at the "7th leaf" phase; and the third treatment - at the "9th leaf" phase.

Indices characterising photosynthesis intensity (A), transpiration intensity (E), stomatal conductance (Gs), water use efficiency (WUE), plant height and productivity were determined. The water status parameters were determined using classical methods (Kushnirenko, 1970; Vasseu and Sharkey, 1989).

Photosynthetic intensity, stomatal conductance, and transpiration intensity were determined using an LCpro-SD portable gas analyser (ADC biotech-scientific Limited, UK) according to the scheme of experiments under photosynthetically active radiation (PhAR) from 1000 µmol flux density photons $m^{-2}s^{-1}$; leaf temperature, air humidity and CO_2 concentration were determined based on their environmental values. The measurements were carried out between 8 and 11 AM. The experimental results were recorded using paper registers, stamped and validated by the administration of the institute. The results were statistically analysed using the "Statistica 7" software package for PC. According to the National Bureau of Statistics of the Republic of Moldova, the vegetation period in the reference year in the area where the experiments were carried out (Chisinau weather station) was characterised by a thermal regime and uneven precipitation (*Figure 2* and *Figure 3*).

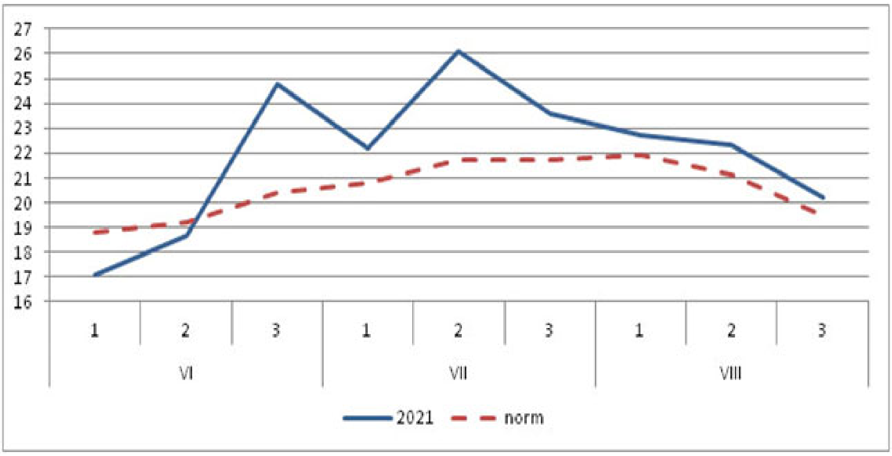

Figure 2 – Average air temperatures (°C), Chisinau weather station

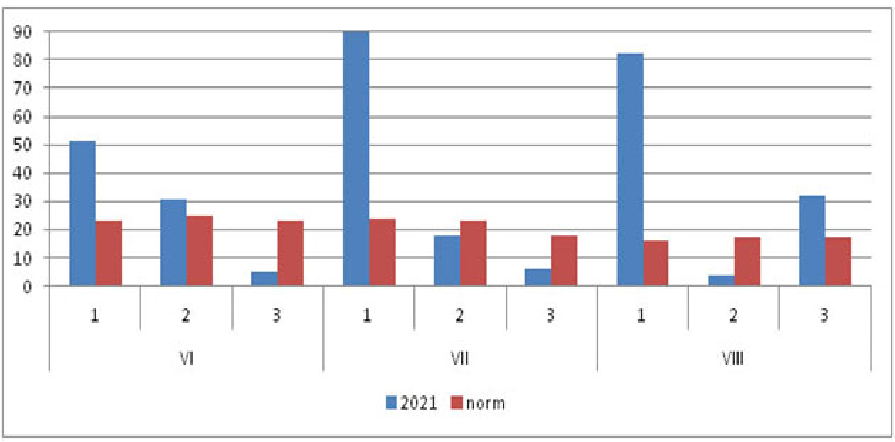

Figure 3 – The average amount of precipitation (mm) per decade in the summer months, Chisinau weather station

The average air temperature during the spring season was +7.9...+9.9 ºC, being 0.5–0.9°C lower than the norm (*Figure 2*). Average daily air temperatures on June 1–2 were +10 … +12°C, being 5–8°C lower than the norm. The summer was warmer than usual. The average air temperature for this season in the area was +20.4 ... +22.4°C, being 1.0–2.2°C higher than the norm. Hot weather was reported in July. The average monthly air temperatures exceeded the norm by 2.0–3.5°C, which was reported on average once every 5–15 years. The maximum temperature reached 38°C.

However, even under average seasonal weather conditions with a temperature increase of 1°C, the production losses for the main field crops were 6–7% (Lesk *et al.*, 2016). The high thermal regime and significant precipitation deficit (*Figure 3*) during this time led to atmospheric and edaphic drought, with repercussions on crop growth and development. The agrometeorological conditions during most of the vegetation period and in 2022 were generally unfavourable for the formation of the harvest of the main agricultural crops due to the high thermal regime and lack of precipitation.

A significant precipitation deficit and high thermal regime were reported in the May–July period, which contributed to the development of atmospheric and pedological drought. They created unfavourable conditions for the growth and formation of fruit in agricultural crops. The hydrothermal coefficient (which characterises the level of wetting of the territory), on average, on the territory of the republic, in the period May–July 2022 was 0.3–0.4, which corresponds to a very strong drought.

RESULTS

The results of the current study (*Table 1*) demonstrated significant differences in the water status of *Zea mays* L. plants, depending on pre-treatment with PhASs.

The water status in the leaves of corn plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** was significantly higher compared to the degree of hydration in control plants and varied in the range of 74.9–76.2 g/100 g f. w., unlike the water content in the leaves of control plants, which recorded a value of 69.5 g/100 g f. w. The degree of increase in leaf turgor, ensured by **Thiourea**, **Galmet** and **Thiogalmet**, was 6.87, 7.60 and 10.40%, respectively, compared to the values of leaf turgescence in the control plants (*Table 1*).

Lower temperatures compared to the multi-year norm during spring (*Figure 2*) significantly restrained seed germination, seedling emergence and growth. The more significant seedling growth and transition into the “5th leaf“ phase was recorded only in the 2–3 decades of June, when favourable thermal conditions were established. The plants of the variants that underwent seed and foliage pre-treatment reacted differently to temperature conditions and precipitation deficit established in the 3rd decade of June (*Table 2*). The use of **Thiourea**, **Galmet** and **Thiogalmet** stimulated the intensity of photosynthesis by 52.2, 70.7 and 121.4%, respectively, and transpiration by 17.5, 24.4 and 34.0%, respectively. These changes affected the effectiveness of water use by plants during the synthesis of organic substances and biomass formation (*Table 2*).

Soil moisture improvement due to the precipitation in the 1st decade of July (*Figure 3*) conditioned a veridical optimisation of the vital processes in plants in the "7th–9th leaf" phase (*Table 2* and *Table 3*). Stomatal conductance for water and carbon dioxide and transpiration and photosynthetic rate increased in the plants treated with **Thiourea**, **Galmet** and **Thiogalmet** by 50.5, 57.0 and 98% (*Table 3*), respectively.

Exogenous administration of **Thiogalmet** ensured a higher CO_2 assimilation intensity by 120.6% compared to the control plants and by 38.5 and 19.2% higher compared to the photosynthetic intensity of the plants pre-treated with **Thiourea** and **Galmet**. The same differences were also recorded for the values of the transpiration process. The use of water in the process of synthesising organic substances was more effective in the pre-treated plants, especially in the plants that were exogenously administered **Thiogalmet** composition (*Table 3*). In the pre-treated plants, significantly higher values of the coefficient of water use efficiency were detected in the production process (45–82% compared to the control plants). Under the conditions of the hydrothermal regime installed at the "tasselling" phase (one of the plant's critical periods with significant consequences for productivity), the insufficiency of precipitation and high temperatures (*Figure 2* and *Figure 3*) conditioned stomatal closure and a significant decrease in CO_2 assimilation by the leaves (*Table 3* and *Table 4*; *Figure 4*). Lack of soil moisture at the "tasselling" phase caused a decrease of 40.90% in stomatal conductance, of 9.95 in transpiration intensity and of 48.93% in carbon assimilation in control plants. In maize plants, PhAS used for seed and foliage pre-treatment caused changes in the assimilation processes of the same characteristic but was quantitatively less significant (*Table 4*, *Figure 4*).

During this period, stomatal conductance in control plants was reduced 1.7-fold and 1.8–2.0-fold in plants pre-treated with PhAS compared to the stomatal status of plants at the "9th leaf" phase. Water consumption during transpiration was reduced 1.1-fold in control plants and 1.2-fold in plants pre-treated with PhAS. Photosynthesis intensity in plants pre-treated with **Thiourea** remained at a higher level and constituted a 32.7% increase in the values in control plants, while carbon assimilation in plants pre-treated with **Galmet** and **Thiogalmet** was higher by 44.1 and 54.2%, respectively.

The data obtained in the current work (*Table 4*; *Figure 4*) demonstrated that exogenous administration of PhAS for seed and foliage pre-treatment conditions reduced the impact caused by fluctuations in soil moisture levels and air temperature on the functional state of plants.

Stomatal conductance for CO_2 and H_2O throughout the experiments was higher in plants treated with PhAS, indicating a higher photosynthetic and transpiration intensity (*Figure 4* and *Figure 5*).

Table 1 – Water status in the leaves of maize plants pre-treated with PhASs

Variant	WC*, g/100 g, f.w.		SD, % of complete saturation		WRC, lost water, % of initial WC		WRC, retained water, % of initial WC	
	M ± m	Δ, %M	M ± m	Δ, %M	M ± m	Δ, %M	M ± m	Δ, %M
Control	69.45 ± 0.87		14.96 ± 0.21		16.57 ± 0.19		57.81 ± 0.50	
Thiourea	74.37 ± 1.24	7.08	9.12 ± 0.12	−39.03	15.91 ± 0.16	−3.98	62.27 ± 0.76	7.71
Galmet	74.96 ± 0.98	7.93	8.50 ± 0.15	−43.18	14.26 ± 0.21	−13.94	64.35 ± 1.07	11.31
Thiogalmet	76.16 ± 1.15	9.66	6.12 ± 0.11	−59.09	13.29 ± 0.17	−19.79	66.16 ± 0.85	14.44

*WC - water content; f.w.- fresh weight; SD - saturation deficit; WRC - water retention capacity

Table 2 – PhAS influence on the intensity of CO_2 assimilation, transpiration, stomatal conductance and water use efficiency in 'P458' maize plants. The "5th leaf" phase

Variant	gs, $mol \cdot m^{-2} \cdot sec^{-1}$		A, $\mu mol \cdot m^{-2} \cdot sec^{-1}$		E, $mmol \cdot m^{-2} \cdot sec^{-1}$		WUE	
	M ± m	Δ, %M	M ± m	Δ, %M	M ± m	Δ, %M	$\mu molCO_2/mmol\ H_2O$	Δ, %M
Control	0.075 ± 0.002		8.83 ± 0.21		25.83 ± 0.28		0.342	
Thiourea	0.146 ± 0.004	94.66	13.44 ± 0.26	52.20	30.36 ± 0.43	17.54	0.443	29.53
Galmet	0.145 ± 0.004	93.33	15.07 ± 0.22	70.66	32.14 ± 0.49	24.44	0.469	37.13
Thiogalmet	0.187 ± 0.005	149.33	19.55 ± 0.26	121.40	34.63 ± 0.31	34.07	0.564	65.07

gs - stomatal conductance; A – Photosynthetic rate; E – Transpiration rate; WUE - water use efficiency

Table 3 – Intensity of photosynthesis, transpiration and water use efficiency in 'P458' maize plants at the "7th–9th leaf" phase

Variant	gs, $mol \cdot m^{-2} \cdot sec^{-1}$		A, $\mu mol \cdot m^{-2} \cdot sec^{-1}$		E, $mmol \cdot m^{-2} \cdot sec^{-1}$		WUE	
	M ± m	Δ, %M	M ± m	Δ, %M	M ± m	Δ, %M	$\mu molCO_2/mmol\ H_2O$	Δ, %M
Control	0.093±0.002		**9.64±0.12**		29.03±0.25		0.332	
Thiourea	0.140±0.004	50.53	**15.36±0.26**	**59.33**	31.81±0.43	9.57	0.483	45.48
Galmet	0.146±0.004	56.98	**17.85±0.19**	85.17	33.56±0.49	15.60	0.532	60.24
Thiogalmet	0.184±0.005	97.85	**21.27±0.31**	120.64	35.18±0.31	21.18	0.604	81.93

gs - stomatal conductance; A – Photosynthetic rate; E – Transpiration rate; WUE - water use efficiency

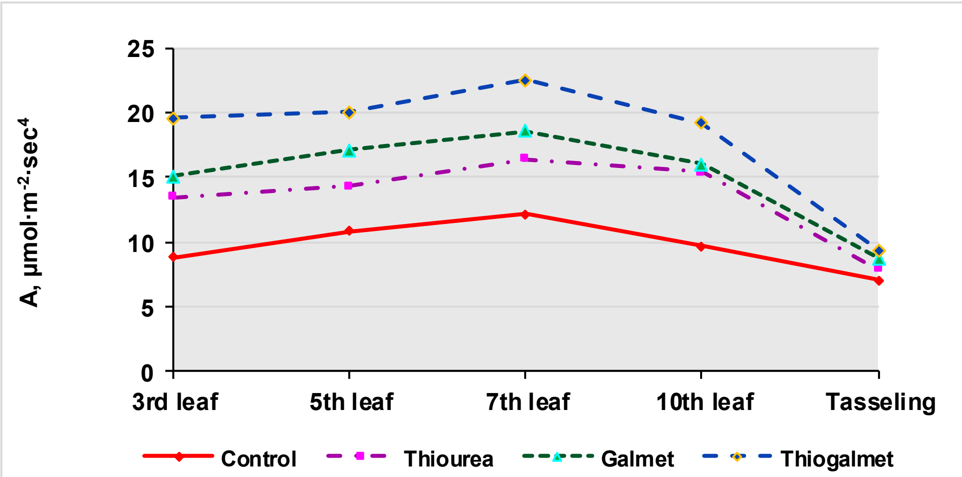

Figure 4 – Dynamic of photosynthetic intensity in maize 'P458' plants pre-treated with **Thiogalmet** under natural moisture levels

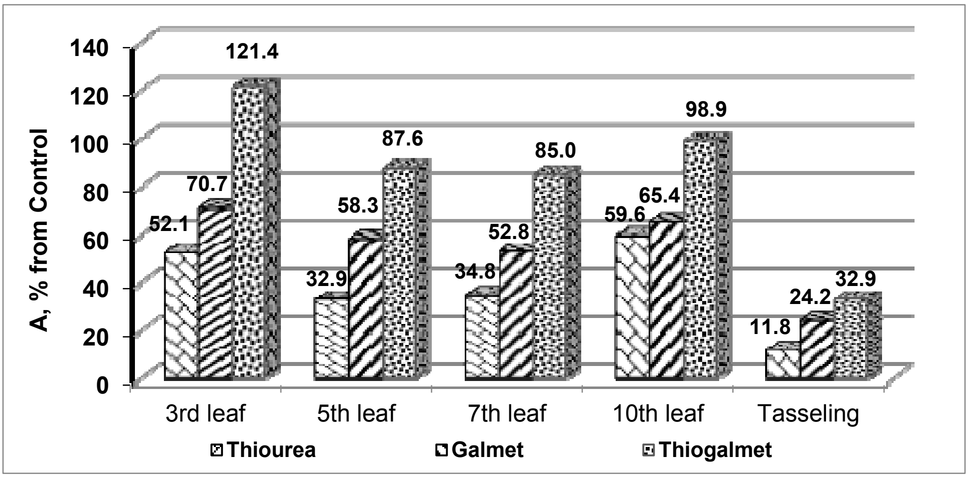

Figure 5 – Modification of carbon dioxide assimilation in the leaves of 'P458' plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** during the seed stage and vegetative growth

Plant pre-treatment with **Galmet** ensured a 71–65% increase in the rate of photosynthesis, with **Thiourea** showing a 52–59% increase and exogenous administration of **Thiogalmet** causing a 100–121% intensification of assimilation processes compared to control plants.

During tasselling, the intensity of assimilation decreased in all groups, the process being conditioned by the aggravation of the hydrothermal regime characterised by insufficient soil moisture and high air temperatures. Nevertheless, at this stage of ontogenesis, the intensity of the assimilation process in plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** exceeded that of control plants by about 12, 24 and 33%, respectively.

Since photosynthesis is the main metabolic process that ensures the formation of plant biomass, it is natural to assume that the impact of PhAS on optimising CO_2 assimilation processes has a beneficial effect on plant growth. According to the obtained data, the inhibition of CO_2/H_2O gas exchange in the processes of photosynthesis and transpiration (*Table 2*, *Table 3*, *Table 4*) caused significant changes in plant growth (*Figure 6*). Significant optimisation of height parameters of plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** was recorded at 7.9, 10.2 and 14%, respectively. The height of plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** exceeded the height of control plants by 18, 23 and 32 cm, respectively.

Therefore, the intensification of carbon dioxide assimilation and more efficient water use conditioned by the administration of PhASs ensured significant changes in plant growth, with an impact on productivity and yield (*Table 5*). The productivity of the plants treated with **Thiogalmet, Thiourea** and **Galmet** exceeded that of the control group by 68.13 32.20 and 10.56%, respectively. The **Thiogalmet** preparation conditioned an increase in the harvest per surface unit and improved the commercial qualities of the grains. Plant treatment with **Thiourea**, **Galmet** and **Thiogalmet** ensured a 27.20, 52.08 and 68.20% yield increase, respectively. Therefore, a major effect of the new preparation was registered in the plants.

Thiogalmet, administered to *Zea mays* L. plants by treating the seeds before sowing and the foliar apparatus during vegetative growth, has a beneficial influence on the biological performance of the plants, conditioning even under natural humidity and better realising the processes of growth and formation of productivity, including the valuable agricultural part.

The new composition **Thiogalmet** amplified the beneficial effect on the biological performance of plants by improving the water status in plant tissues, photosynthesis and water use efficiency, as well as plant growth and productivity.

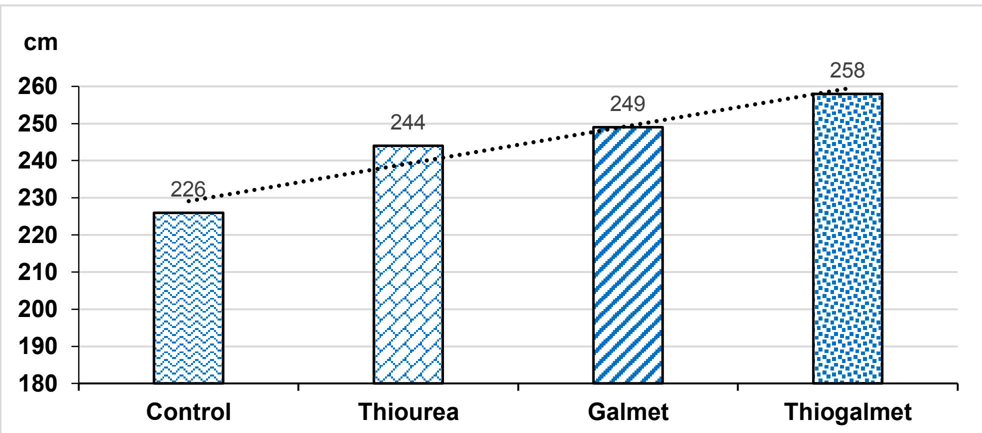

Figure 6 – Effect of seed and foliage pre-treatment with **Thiourea**, **Galmet** and **Thiogalmet** on height (cm) of 'P458' maize plants

DISCUSSION

Under drought conditions, plants react instantly by changing their water status, which affects all vital processes. The cause of water loss under stressful environmental conditions is the increase in membrane permeability (Davidescu and Davidescu, 1979; Levitt, 1986) as a result of the opening of ion channels and the exit of K^+ from the cells. The role of potassium in vital processes is well known and indisputable._K^+ is the cation with the most significant regulatory function in plants. It participates in the regulation of photosynthetic activity, the effective assimilation of solar energy, and the reactions of the synthesis and transfer of plastic substances. Being sufficiently supplied with potassium, plants can withstand short-term drought and thermic stress more easily. However, the impact of drought can be mitigated by the use of bioactive substances (BAS), particularly phytohormones. Certain data reflect the property of gallic acid and its compounds to regulate the AIA content in vivo (Gudvin and Merser, 1983), and gallic acid glycosides in hormonal concentrations have the property of regulating the turgor of cells and the activity of the stomatal apparatus, due to which fact they were estimated to be a new group of phytohormones - turgorins (Ovchinnikov, 1987; Schildknecht, 1984). To optimise the water status under drought conditions, the use of Thiogalmet, which contains potassium, ammonium, magnesium, potassium molybdate and ammonium paramolybdate - factors involved in regulating plant water status, as well as thiourea and galat-anion with antioxidant function, is justified.

The obtained results demonstrated that the pre-treatment of plants with **Thiourea**, **Galmet** and **Thiogalmet** optimises water status in leaves by preserving water homeostasis at a higher level compared to control plants (*Table 1*). The degree of modification of the water content under the influence of the pre-treatment of the plants with these PhASs is authentic according to the first and second levels of probability (*Table 6*). In the statistical analysis of the differences in the effect of Thiogalmet compared to the effect of Galmet, but also of Thiogalmet compared to that of Thiourea on the water content in the leaves, no significant differences were recorded, although there was a tendency for an increased influence of Thiogalmet.

The study demonstrated that both **Thiourea** and **Galmet** optimised the degree of tissue hydration, increased turgor and decreased saturation deficit in leaves (*Table 1*), increased the water use efficiency in plants and significantly intensified the assimilation of carbon dioxide (*Table 2*, *Table 3*, *Table 4*). A major effect (*Table 1*) was recorded in plants pre-treated with **Thiogalmet**, but the effect was an additive action and not a synergistic one, as might be expected, considering the individual action of the components of Trifeden.

This was also confirmed by the t-criterion value (*Table 5*). According to the experimental data (*Table 1*), after pre-treatment with **Thiogalmet,** the value of saturation deficit in maize leaves was 2.5 times lower than the respective value in control plants and 32.9 and 28.0% lower compared to the plants pre-treated with **Thiourea** and **Galmet** preparation, respectively.

Table 4 – Intensity of photosynthesis, transpiration and water use efficiency in corn plants at the tasselling phase

Variant	gs, mol·m^{-2}·sec^{-1}		A, µmol·m^{-2}·sec^{-1}		E, mmol·m^{-2}·sec^{-1}		WUE	
	M ± m	Δ, %M	M ± m	Δ, %M	M ± m	Δ, %M	µmolCO_2/mmolH_2O	Δ, %M
Control	0.055±0.001		5.26±0.15		26.14±0.22		0.201	
Thiourea	0.071±0.002	29.09	6.99±0.19	32.70	27.04±0.39	3.44	0.258	28.60
Galmet	0.080±0.001	45.45	7.58±0.22	44.10	27.90±0.24	6.73	0.282	40.29
Thiogalmet	0.087±0.002	58.18	8.11±0.11	54.18	28.45±0.33	8.83	0.285	41.92

gs - stomatal conductance; A – Photosynthetic rate; E – Transpiration rate; WUE - water use efficiency

Table 5 – Impact of PhAS on productivity and yield parameters in 'P458' maize plants

Variant	The average weight of 1 cob, g	The grain mass, g cob^{-1}	1000 grain weight, g	Productivity, g plant^{-1}	Yield, * q·ha^{-1}
	M ± m	M ± m	M ± m	M ± m	M ± m
Control	121.22±1.20	104.20±1.82	230.77±3.41	109.41±2.72	65.65±0.83
Thiourea	156.29±2.51	131.31±0.90	242.44±3.10	139.19±3.15	83.51±1.31
Galmet	172.65±1.72	145.96±2.62	253.96±2.82	166.39±1.56	99.84±2.44
Thiogalmet	178.59±3.41	153.57±1.31	263.71±1.95	183.96±2.26	110.37±1.63

*- calculated at 14% grain moisture, resulting from 60,000 plants per ha

Table 6 – Authenticity of differences (Student's t-test) in the degree of modification of the physiological processes of corn plants conditioned by the exogenous use of antioxidants*

Parameters / Variants	Control Thiourea	Control Galmet	Control Thiogalmet	Thiogalmet Thiourea	Thiogalmet Galmet
WC	3.30	3.20	4.69	1.06	0.79
WRC	4.33	5.73	8.52	3.89	1.33
A - "5th leaf" phase	13.80	20.52	23.07	16.61	13.15
A - "7th–9th leaf" phase	8.84	36.54	34.98	14.61	8.29
A - "Tasselling" phase	7.14	8.71	15.32	5.10	2.15
E - "5th leaf" phase	8.82	11.18	21.06	8.05	4.29
E - "7th–9th leaf" phase	5.58	8.23	6.15	6.35	3.11
E - "Tasselling" phase	2.01	5.40	5.82	2.76	1.35
Creșterea în înălțime	5.65	6.09	8.22	3.45	1.52
Productivity	7.16	18.20	21.06	11.53	6.39

* The standard value of the t-criterion at the 5, 1, and 0.1% probability level and at γ 10 is (2.23 – 3.17 – 4.59)

The value of the saturation deficit to a certain extent depends on the ability of the protoplasmic biopolymers to retain water, as well as on the relative activity of water in cells, which increases the water retention capacity. Changing the water retention capacity is one of the key moments in the plant's response to the action of an external factor. Comparative statistical analysis of the water loss rate in leaves under experimental wilting demonstrates the existence of significant differences in the average value of the water retention capacity in *Zea mays* L. cv. 'P458' plants (*Table 5*). The water loss rate in plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** was 3.98, 13.94 and 19.79%, respectively, lower than that in control plants. The water retention capacity in treated plants was 7.7, 11.3 and 14.4% higher than in untreated plants (*Table 1*).

The differences were genuine according to the second level of probability (Table 5). Reduction in the hydration degree and turgor diminution in plants conditioned by the lack of moisture is associated with dysregulation of the assimilation processes, reduction of the accumulation of organic substances and growth arrest. Exogenous administration of PhASs ensured the preservation of the assimilation intensity of CO_2 from the atmosphere and water consumption during transpiration at a higher level compared to the control plants (*Table 2*, *Table 3*, *Table 4*; *Figure 2*).

The highest values of photosynthetic rate and transpiration were recorded in plants pre-treated with **Thiogalmet**. The differences in the effect on photosynthesis in plants pre-treated with the respective compounds compared to the photosynthesis process in control plants were statistically authentic and significant (*Table 5*). Under the conditions of the hydrothermal regime, which was installed at the tasselling phase, a critical period of plant development, the lack of precipitation and high temperatures conditioned stomatal closure and a significant reduction in carbon dioxide assimilation in leaves (*Table 3* and *Table 4*; *Figure 4*). Data in *Table 2* demonstrate that stomatal conductance in leaves of the plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** is preserved at a higher level compared to the conductance index in control plants, demonstrating that CO_2/H_2O gas exchange in pre-treated plants takes place more intensively.

Consequently, maximum values of photosynthetic intensity and transpiration were recorded in plants pre-treated with **Thiogalmet.** Stomatal closure reduces water loss through transpiration but inevitably also leads to a decrease in the photosynthetic rate as a result of reducing the access of carbon dioxide to chloroplasts (Asada, 2006; Tardieu *et al.*, 1993, 1998; Şişcanu and Piscorscaia, 2001). Inhibition of photosynthesis is a common plant reaction to insufficient moisture and during the initial stages of stress factor's action, it is conditioned by stomatal closure.

Only under its intensification is it connected to dehydration and biochemical changes in cells. Pre-treatment of maize seeds prior to sowing and foliage during growth with PhAS caused changes in the assimilation processes of the same character but was quantitatively less significant (*Table 4*, *Table 5*; *Figure 3*).

Plant growth processes are an objective indicator of the plant's reaction to environmental stress and have a primary role in signalling and the plant's reaction to soil water deficit (Walter *et al.*, 2013). Maintaining growth under insufficient moisture is an adaptation reaction associated with an organism's drought resistance. Dehydration of the organs conditions stomatal closure, alterations in photosynthesis, and growth inhibition (Gray and Brady, 2016; Hamann *et al.*, 2021).

An increasing number of studies have demonstrated the positive effect of using growth regulators in eradicating the negative impact of water stress caused by drought (Abid *et al.*, 2017; Aimar *et al.*, 2011; Leufen *et al.*, 2016; Virlouvet and Fromm, 2015; Yakhin *et al.*, 2017).

A decrease in shoot growth and formation of small leaves reduces water evaporation by the plant, which ensures its survival under short-term drought conditions but has a negative impact on photosynthesis and productivity. One of the most prominent plant adaptations to moisture deficiency is maintaining adequate growth (Gray and Brady, 2016; Hamann *et al.*, 2021; Sharp and Davies, 1989). An impressive number of studies have provided evidence for the effective role of PhASs in modulating physiological mechanisms and improving plant growth and productivity (Wahid *et al.*, 2017).

Intensification of carbon dioxide assimilation and optimisation of water use efficiency conditioned by administration of PhASs ensured significant changes in plant growth (*Figure 6*). The height of plants pre-treated with **Thiourea**, **Galmet** and **Thiogalmet** exceeded the height of control plants by 18, 23 and 32 cm, respectively. The differences were statistically authentic (*Table 5*). The productivity of plants treated with **Thiogalmet, Thiourea** and **Galmet** was 68.13, 32.20 and 10.56% higher compared to the control group. The statistical analysis of the data demonstrated the major effect of **Thiogalmet** on the elements of plant productivity and yield. The preparation increased the harvest per surface unit and improved the commercial quality of the grains. Treating plants with **Thiourea**, **Galmet** and **Thiogalmet** ensured a 27.20, 52.08 and 68.20% increase in yield, respectively. Therefore, a major effect was registered in the plants treated with the new composition.

The ability of plants pre-treated with Thiogalmet to maintain a higher level of carbon dioxide assimilation processes, growth and productivity is due to the photoprotection property of the preparation by intensifying the activity of the antioxidant enzyme system but the maintenance of water homeostasis (Ștefîrță *et al.*, 2022).

The effect of **Thiogalmet** on productivity of *Zea mays* plants compared to **Thiourea** and **Galmet** was tested in "Protuvim" SRL farm in Singerei city on a 0.35 ha area, which confirmed the experimental results obtained on small plots (*Figure 7*).


a b c d

Figure 7 – Degree of photooxidation damage in plants treated with **Thiourea** (a), **Galmet** (b) and **Thiogalmet** (c) and untreated plants (d). Singerei, August 2022

There were significant effects of plant pre-treatment with **Thiogalmet** on reducing the impact of complex drought and photooxidative death of plants, which were positively reflected on productivity.

The protection of plants pre-treated with Thiogalmet from photooxidation damage is explained as follows: 1) positive impact on the degree of hydration of leaf tissues, which protects the plant from excessive formation of SRO; 2) optimisation of synthesis processes and the accumulation of photoassimilates increases the water retention capacity with the same effect of weakening oxidative stress; 3) antioxidant properties of Thiourea, Galmet and, in particular, Thiogalmet, which manifests itself by increasing the activity of antioxidant enzymes.

The obtained results demonstrate the possibility of mitigating the adverse effects of drought on plant physiological responses and production by applying antioxidants.

CONCLUSIONS

The bioactive properties of **Thiogalmet** to regulate plant growth, productivity and yield were confirmed.

Thiourea, **Galmet** and **Thiogalmet** compositions ensured optimisation of carbon dioxide assimilation rate, transpiration, stomatal conductance and water use efficiency in plants throughout the vegetation period.

Treating seeds prior to sowing and foliage during vegetation with **Thiogalmet** had a beneficial effect on plant biological processes, conditioning a more thorough performance of growth and productivity, including the parts valuable for agriculture.

Novel **Thiogalmet** manifested a beneficial effect on plant growth, productivity and yield mainly by improving water status in tissues, photosynthesis and water use efficiency.

The effect of diminishing plant photooxidative death caused by drought, temperature and solar radiation was registered in plants treated with

Thiourea, **Galmet** and especially **Thiogalmet.**

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REFERENCES

Abid, M.; Shao, Y.; Liu, S.; Wang, F.; Gao, J.; Jiang, D.; Tian, Z.; Dai, T. Pre-drought priming sustains grain de-velopment under post-anthesis drought stress by regulating the growth hormones in winter wheat (*Triticum aes-tivum* L.). *Planta*. **2017**, 246, 509-524. https://doi.org/10.1007/s00425-017-2698-4

Aimar, D.; Calafat, M.; Andrade, A.; Carassay, L.; Abdala, G.I.; Molas, M.L. Drought Tolerance and Stress Hormones: From Model Organisms to Forage Crops. *Plants and Environment.* **2011**, 137-164. https://doi.org/10.5772/24279

Asada, K. Production and Scavenging of Reactive Oxygen Species in Chloroplast and Their Functions. *Plant Physiology.* **2006**, 141, 391-396. https://doi.org/10.1104/pp.106.082040

Chaves, M.; Maroco, J.; Pereira, J. Understating plant response to drought: from genes to the whole plant. *Functional Plant Biology*. **2003**, 30, 239-264. http://dx.doi.org/10.1071/FP02076

Davidescu, D.; Davidescu, V. *Potassium in agriculture* (in *Romanian*). Ed. Acad. R.S. România, **1979**, 269 p.

FAO. FAO *Strategy on Climate Change 2022–2031.* Food and Agriculture Organization of the United Nations, Rome. https://www.fao.org/3/cc2274en/cc2274en.pdf (accesed on 20 September 2023).

Gudvin, T.; Merser, E.I. *Introduction to Biochemistry.* Second Edition. Oxford. New York. Toronto. Sydney. Paris. Frankfurt: Pergamon Press, 1983, p. 123-126.

IPCC. *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. H.-O. Pörtner, D.C. Roberts, M. Tignor, et al. (eds.). Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 2022, 3056 pp. https://doi.org/10.1017/9781009325844

Hamann, F.A.; Fiebig, A.; Noga, G. Influence of water shortage on apple seedling growth under different radiation composition. *Biologia plantarum,* **2021**, 65, 88-99. https://doi.org/10.32615/bp.2020.086

Kushnirenko, M.D.; Pecherskaya, S.N. *Physiology of water exchange and drought resistance of plants* (in *Russian*). House publishing Shtiintsa, Chisinau, 1991**,** 480 p.

Larcher, B. *Plants ecology (*in *Russian*)*.* Ed: Mir, Moscow, 1978, 382

Lesk, C.; Rowhani, P.; Ramankutty, N. Influence of extreme weather disasters on global crop production. *Nature*. **2016**, 529, 84-87. https://doi.org/10.1038/nature16467

Leufen, G.; Noga, G.; Hunsche, M. Drought Stress Memory in Sugar Beet: Mismatch Between Biochemical and Physiological Parameters. *Journal of Plant Growth Regulation*. **2016**, 35, 680-689. https://doi.org/10.1007/s00344-016-9571-8

Levitt, J. Recovery of turgor by Wilted, excised cabbage leaves in the absence of water uptake. A new factor in drought acclimation. *Plant Physology*. **1986**, 82, 1945-1952.

Ovchinnikov, Yu.A. *Bioorganic chemistry (*in *Russian*)*.* Ed: Education, Moscow, **1987**, 795 p.

Sharp, R.E.; Davies, W.J. Regulation of growth and development of plants growing with a restricted supply of water. In: *Plants Under Stress*, HG Jones, TL Flowers, MB Jones (eds.), Cambridge University Press, Cambridge, UK. 1989, pp. 71-93.

Schildknecht, H. Turgorins –new chemical messengers for plants behaviour. *Endeavour*. **1984**, 8, 113 -117. https://doi.org/10.1016/0160-9327(84)90003-6

Şişcanu, Gh.; Piscorscaia, V. *Donor-acceptor relationships and soybean plant productivity* (in *Romanian*)*.* Chişinău 2001, Civitas, p. 163.

Ştefîrţă, A.; Brînza, L.; Toma, S.; Buceaceaea, S.; Melenciuc, M.; Bulhac, I.; Turta, C.; Barba, A.; Robu, Ş. Physiological options for strengthening plants in conditions of insufficient moisture (in *Romanian*). In *Reducing the impact of extreme pedoclimatic factors on crop plants.* Chişinău, 2008, p. 166-202.

Ștefîrță, A.; Bulhac, I.; Cocu, M.; Brînză, L.; Zubarev, V. Exogenous optimization of the antioxidant protection capacity of plants in moderate drought conditions. *International Journal of Advanced Research (IJAR)*. **2022**, 10, 1109-1119. http://dx.doi.org/10.21474/IJAR01/14654

Ștefîrță, A.; Bulhac, I.; Coropceanu, E.; Voloșciuc, L.; Brînză, L. Effect of Cytokinin-Type Compounds on The Self-Regulation of Plant Water Status Under Conditions of Adverse Humidity Variation and Repeated Water Stress. *SSRG International Journal of Agriculture and Environmental Science*. **2021**, 8, 1-7. https://doi.org/10.14445/23942568/IJAES-V8I3P101

Tardieu, F.; Davies, W.J. Roots communication and whole-plant regulation of water flux. In *Water deficits plant responses from cell to community*. Editor Davies W J. Lancaster: University of Lancaster, 1993, p. 147-162.

Tardieu, F.; Simoneau, T. Variability among Species of Stomatal Control under Fluctuating Soil Water Status and Evaporative Demand: Modelling Isohydric and Anisohydric Behaviours. *Journal of Experimental Botany*. **1998**, 49, 419-432.

Vasseu, T.L.; Sharkey, T.D. Mild water stress of Phaseolus vulgaris plants leads to reduced starch synthesis and extractable sucrose phosphate syntheses activity. *Plant Physiology.* **1989**, 89, 1066-1070. https://doi.org/10.1104/pp.89.4.1066

Virlouvet, L.; Fromm, M. Physiological and Transcriptional Memory in Guard

Cells during Repetitive Dehydration Stress. *New Phytologist*. **2015**, 205, 596-607. https://doi.org/10.1111/nph.13080

Wahid, A.; Basra, S.M.A.; Farooq, M. Thiourea: a molecule with immense biological significance for plants. *International Journal of Agriculture and Biology*. **2017**, 19, 911-920. https://doi.org/10.17957/IJAB/15.0464

Walter, J.; Jentsch, A.; Beierkuhnlein, C.; Kreyling, J. Cross-stress tolerance and stress "memory" in plants. *Environmental and Experimental Botany*. **2013**, 94, 3-8. https://doi.org/10.1016/j.envexpbot.2012.02.009

Yakhin, O.I.; Lubyanov, A.A.; Yakhin, I.A.; Brown, P.H. Biostimulants in Plant Science: A Global Perspective. *Frontiers in Plant Science*. **2017**, 7, 2049. https://doi.org/10.3389/fpls.2016.02049

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