PHOTOSYNTHETIC PROCESSES AND USES DIFFERENT FORMS OF FATTY ACIDS IN CORN PLANTS DURING THE PERIOD OF INTENSIVE GROWTH AND UNDER THE INFLUENCE OF FERTILIZER AND GROWTH REGULATOR

Yosyp RIVIS[1], Vasyl FEDAK[1],Oksana MAMCHUR[2], Volodymyr BALKOVSKYI[3], Ivan SHUVAR[3], Olena BEZALTYCHNA[4], Bogdan GUTYJ[5], Olha STADNYTSKA[1], Hanna KORPITA[3], Antin SHUVAR[1], Khrystyna LESKIV[5]

[1]Institute of Agriculture of the Carpathian Region of NAAS of Ukraine,
5 Grushevskogo Street, Obroshino, 81115, Ukraine
[2]Ivan Franko National University of Lviv, 1 Universytetska Street, Lviv, 79000, Ukraine
[3]Lviv National Agrarian University, 1 V. Velykiho Street, Dublyany, 80381, Ukraine
[4]Odessa State Agrarian University, 13 Panteleymonyvska Street, Odessa, 65012, Ukraine
[5]Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies Lviv,
50 Pekarska Street, Lviv, 79010, Ukraine

Corresponding author email: bvh@ukr.net

Abstract

The aim of the research was to identify quantitative changes in the processes of photosynthesis and fatty acid composition of the maize plants vegetative mass during ontogenesis and under the influence of mineral fertilizers and growth regulators. It is established that the functional activity of the photosynthetic apparatus in the leaves of maize plants increases with their age and depends on soil fertilizer and the influence of growth regulators. It was found that the increase in the functional activity of the photosynthetic apparatus of maize plants in the phase of intensive growth is accompanied by an increase in the concentration of esterified fatty acids and an increase in the ratio of more valuable linolenic polyunsaturated fatty acid to less valuable linoleic polyunsaturated fatty acid in stems and leaves. It is established that the formation of generative organs of maize plants leads to a gradual decrease in the concentration of esterified fatty acids and a decrease in the ratio of linolenic polyunsaturated fatty acid to linoleic polyunsaturated fatty acid in the stem and leaves.

Key words: corn, phases of vegetation, fertilizer, regulator of growth, photosynthetic processes.

INTRODUCTION

The coordinated functioning of biological membranes ensures plant cell homeostasis. Along with proteins, the main components of natural membranes are lipids and fatty acids. The action of exogenous or endogenous factors induces a change in the conformation of these molecules. Thus, the course and direction of metabolic functions in the cell change. The level of fertilization and biologically active substances play an essential role in the regulation of metabolic processes in the cell (Kramarov, 2003; Kovalchuk et al., 2019; Sobolev et al., 2020).

However, there needs to be more data on the influence of the level of fertilizer and biologically active substances of different classes on the metabolism of lipids and fatty acids, particularly in plants, in the scientific literature. In individuals, the effect of fertilizer and growth stimulants on the metabolism of phospholipids, primarily phosphatidylcholine, in the plasma membrane of corn seedlings has been shown (Storozhenko, 2004; Dalal & Tripathy, 2012). There are also incomplete reports on the metabolism of fatty acids in the ontogeny of corn (Bates et al., 2013; Wang et al., 2020). In these studies, it was established that the fatty acid composition of lipids in the leaves changes due to the proportion of linoleic acid during the corn-growing season.

Based on the above, the goal of our work was to reveal quantitative changes in the processes of photosynthesis and the fatty acid composition of the vegetative mass of corn plants during the period of intensive growth and under the

influence of mineral fertilizers and growth regulators.

MATERIALS AND METHODS

In the research, a simple mid-ripening corn hybrid Zbruch (FAO-310) was used, which was entered into the State Register of Plant Varieties of Ukraine in 2008. The hybrid is recommended for cultivation and is zoned in the Forest Steppe and Steppe. This maize hybrid of intensive type with high yield potential responds well to improved growing conditions. The main morphometric characteristics of hybrid plants: the average height of the plant is 210-220 cm, the length of the cob is 20-22 cm, the height of the cob attachment is 70-80 cm, the cob is cylindrical with a red stem, contains 14-16 rows of grains and 38-40 grains in a row. The kernel is yellow and tooth-shaped. The average weight of 1,000 kernels is 280-290 g. Corn plants of the Zbruch hybrid are characterized by resistance (out of 9 points): before lodging - 8; to the cold - 8; before drought - 8; before being affected by the major diseases - 8; before damage by pests - 8. The grain yield is 11.0-13.0 t/ha.

The plant growth regulator Zeastimulin, developed by the Research Institute of Bioorganic Chemistry and Petrochemistry of the National Academy of Sciences of Ukraine, was also used in the research, and its effectiveness meets world standards. According to the sanitary and hygienic classification, this drug belongs to low-toxic substances of the III-IV hazard class (GOST 12.1.007-76), has a positive effect on the microflora, and is quickly transformed by soil microorganisms and plant cells (Ponomarenko, 2003).

Zeastimulin (TU U 88.264.036-97) is a balanced composite plant growth regulator containing a complex of ivin with formic acid in combination with emistim C. It is a colorless liquid with a weak alcohol smell, unlimitedly soluble in water and polar solvents. The Ukrgosphimkomisi registers it as a corn growth regulator. The drug helps to increase the yield of corn grain by 7-10 t/ha, green mass - by 50-70 t/ha and increases the number of fats and proteins in the grain.

Field research was carried out in the barley-clover crop rotation (plowing of the II slopes) - winter wheat-corn of the laboratory of grain and fodder crop seed production of the Institute of Agriculture of the Carpathian region of the National Academy of Sciences. For liming, we used limestone flour (GOST 14050-93) with a content of $CaCO_3+MgCO_3$ - 93.5% of local production (JSC Pustomytivske Zavodopravlinia Vapnovyh Zavod).

The experiments were conducted on gray forest surface-glazed soils. The following agrochemical parameters characterize the arable layer (0-20 cm) of the soil: the pH of the salt extract is 4.8-5.2, the content of humus (according to Tyurin) is 2.26-2.53%, the content of easily hydrolyzed nitrogen is 9.24- 12.6 mg per 100 g of soil, mobile Phosphorus (according to Kirsanov) - 7.11-9.8 mg, exchangeable Potassium (by flame photometry) - 10.2-12.2 mg/100 g of soil.

Weather conditions during the experiment generally contributed to the formation of a high yield of green mass of corn and grain.

The technology of growing corn in the experiment is generally accepted for the soil and climate zone conditions. The predecessor is winter wheat with the harvesting of post-harvest residues and sowing of siderat (oil radish) with subsequent plowing for frost (25-27 cm).

The scheme of the experiment has the following form: 1 - control (without fertilizers), 2 - experiment (fertilizer $N_{60}P_{45}K_{45}$), 3 - experiment (growth regulator Zeastimulin). The sowing area is 39 m^2, and the accounting area is 25 m^2.

Corn seeds were sown in wide rows with a row width of 60 cm to a depth of 5-6 cm. Sowing was carried out from the end of April - the beginning of May. The optimal temperature of warming the soil was at a depth of 10 cm to 8-10ºC, which contributed to the appearance of friendly seedlings at a rate of 63,000 units/ha (50-55 thousand units/ha + 15% insurance premium - 63 thousand units/ha).

For the first spring cultivation, mineral fertilizers of the following composition were applied: ammonium nitrate (34% N), granulated superphosphate (19.5% P), and potassium salt (40% K) in a dose $N_{60}P_{45}K_{45}$. In the II experimental plot, corn plants in the 5-6 leaf phase were treated with an aqueous solution of the growth stimulator Zeastimulin (20 ml/ha) according to the manufacturer's recommendations. In addition, the plants were treated using a knapsack sprayer. The consumption of the mixture was 200 l/ha, and

the control plants were treated with distilled water.

Phenological observations were carried out according to the instructions "Conducting and state testing of plant varieties of grain, cereal and leguminous crops" with the following phenophase of vegetation: seedling, shedding of panicles, the beginning and full flowering of panicles and cobs.

Harvesting and accounting of the harvest of green mass of corn were carried out during the phenophase of 8-9 leaves, panicle shedding, and cob flowering.

The content of chlorophylls a and b were determined in plant leaf samples taken during the phenophase of 8-9 leaves, panicle shedding, cob flowering, and non-esterified and esterified fatty acids in stem and leaf samples taken during ontogenesis. The content of chlorophyll a and c was determined spectrophotometrically (Deeva, 2008). For this, pigments were extracted from medium leaf samples with acetone (according to Holm-Wettstein), and the resulting solutions were spectrophotometer. Determination of the content of non-esterified (so-called free) and esterified (found in the studied material in the composition of phospholipids, esterified phytosterol, mono-, di- and triacylglycerols) fatty acids was carried out by the method of gas-liquid chromatography (Rivis, 2017). For this, total lipids from the average samples of stems and leaves were extracted with a chloroform-methanol mixture (2: 1 by volume). First, the obtained lipids were dissolved in hexane. Next, a solution of sodium metal in methyl alcohol was added to the hexane solution of lipids in a test tube, and after that, the test tube was vigorously shaken. The methyl esters of fatty acids obtained in this way were injected into the evaporator of the gas-liquid chromatographic apparatus using a microsyringe. Peaks of esterified fatty acids were obtained on chromatograms.

Next, a few drops of glacial acetic acid and a few milliliters of hexane were added to the sediment in the test tube. After that, the test tube was intensively shaken. After its contents stratification, the upper hexane layer was removed with a pipette with a retracted nozzle and transferred to a special test tube with a grinding wheel. Hexane from this test tube was evaporated in a vacuum cabinet at a temperature of 40-45°C. A few drops of methyl alcohol and, as a catalyst, a few drops of acetyl chloride were added to the fatty acids. After that, the test tube was closed with a polished cork and placed for one and a half hours in a converted thermostat, in which the upper, larger part of the test tube was cooled by running water from the tap, and the lower, smaller part was in a water bath at the boiling temperature of methanol (65°C). After completion of methylation, the remaining methanol in the test tube was evaporated in a vacuum cabinet at a temperature of 40-45°C. The methyl esters of fatty acids obtained in this way were dissolved in a few drops of hexane and introduced into the evaporator of the gas-liquid chromatographic apparatus using a microsyringe. Peaks of non-esterified fatty acids were obtained on the chromatograms. To obtain quantitative data on esterified and non-esterified fatty acids, internal normalization and standard internal methods were used.

Field experiments were carried out over three years in four repetitions. Biochemical experiments were carried out in three biological and three analytical replicates. The obtained digital material was processed by the method of variational statistics using the Student's criterion. Average arithmetic values (M) and their errors ($\pm$ m) were determined. Changes were considered probable at $p<0.05$. The computer program Origin 6.0, and Excel (Microsoft, USA) was used for calculations.

RESULTS AND DISCUSSIONS

The pigment system of higher plants consists of many optically active substances, but only pigments localized in chloroplasts are directly involved in photosynthesis (Andrianova & Tarchevsky, 2000).

The high functional activity of chloroplasts is the essential feature of the formation of the photosynthetic apparatus, which determines the level of the plant's vital activity in general and contributes to its better response to optimal conditions. As a result, to obtain high yields since it is known that between the number of pigments and the productivity of plants, their viability, and stability, there is a direct dependence on adverse environmental factors (Guidi et al., 2019).Furthermore, the level of mineral nutrition and the effect of growth

regulators significantly influence the formation, structure, and activity of the photosynthetic apparatus of plants (Kramarov, 2003; Fromme et al., 2019; Ali, 2021).

It was established that different types of plants, depending on environmental conditions, have different chlorophyll content (Chotewutmontri & Barkan, 2016). Plants form a system that ensures the creation of the most optimal synthesizing apparatus in specific conditions, the main parameters of which can become criteria for optimality or inadequacy of growth conditions (Dalal & Tripathy, 2012). Studies of the dynamics of the content of chlorophyll a, a molecule directly involved in the accumulation of light energy, and chlorophyll b. The molecule a, indirectly related to photosynthesis, allows us to estimate the volume of energy conversion by chloroplast membranes during photosynthesis (Cook et al., 2021). The transformation of chlorophyll a into chlorophyll b is reversible, which allows to quickly change both the total content of chlorophyll in the plant and the ratio of chlorophyll a to chlorophyll b (Ruan et al., 2017).

In the field, we investigated the content of chlorophylls a and b in the leaves of Zbruch hybrid corn during the period of intensive growth and under the influence of the level of fertilizer and the growth regulator Zeastimulin. It was established that during the period of intensive growth of corn plants, the content of chlorophyll in leaves naturally increases (Table 1), which is consistent with existing facts that indicate the accumulation of the maximum content of photosynthetic pigments in plant leaves before the beginning of their flowering (Shumskaya & Wurtzela, 2013; Li et al., 2020).

Table 1. Chlorophyll content in the leaves of Zbruch hybrid corn plants during the period of intensive growth, $g \cdot 10^{-3}$/kg of natural weight ($M \pm m$, $n = 3$)

The investigated indicators	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Phase 8-9 leaves			
Chlorophyll a	209.2±3.24	224.9±16.31	246.2±20.37*
Chlorophyll b	60.2±0.59	61.5±1.23	73.0±1.53*
Sum a i b	269.5±2.72	286.3±8.49	319.2±10.33*
a/b	3.54	3.67	3.38
The phase of throwing out the panicle			
Chlorophyll a	211.4±2.02	233.0±3.36*	259.5±3.41*
Chlorophyll b	59.9±0.85	60.7±0.52	70.7±0.44*
Sum a i b	271.0±1.25	291.5±1.07*	330.2±3.57*
a/b	3.51	3.86	3.67
Flowering phase of cobs			
Chlorophyll a	214.9±2.12	240.6±1.23*	263.1±5.41*
Chlorophyll b	59.9±0.47	61.1±0.44	68.8±0.20*
Sum a i b	274.8±2.32	301.7±1.74*	331.3±5.54*
a/b	3.59	3.93	3.82

Note: here and hereafter* $p<0.02-0.05$, ** $p<0.01$, *** $p<0.001$.

The level of soil fertilization, along with other exogenous factors, has a significant impact on the formation, structure, and activity of the photosynthetic apparatus of plants, which is quantitatively expressed in the increase in the content of chlorophyll. The content of chlorophyll in the leaves of corn due to the action of fertilizers compared to the control increases by 7-12% during the growing season, ensuring a maximum increase in the number of pigments in the flowering phase by 10% (Table 1).

It is worth noting that under these conditions, chlorophyll turned out to be less sensitive to the conditions of soil fertilization. Therefore, its content practically did not change during the researched vegetation phase and remained at control values. Along with this, due to the effects of fertilizers, an increase in the ratio of the content of chlorophyll a to chlorophyll c in the investigated vegetation phase by 7-10% and by 3-9% compared to the control was found, which indicates a better adaptation of corn plants to external influences in these conditions.

Changes in the content and ratio of photosynthetic pigments detected by us under the action of fertilizers are consistent with data from the literature (Zhu et al., 2014; Fromme et al., 2019). In addition, the components of the pigment fund of plants react differently to the lack of mineral nutrition. Thus, the chlorophyll content under lack of mineral nutrition, especially nitrogen, sharply decreases, which is visually manifested in plant chlorosis (Dalal & Tripathy, 2012).

Biologically active substances of various nature cause changes in the pigment fund of leaves, remarkably increasing chlorophyll content (Pshibytko et al., 2003; Wang et al., 2018). Our research results prove that treating corn plants with the growth regulator Zeastimulin caused additional activation of biosynthesis and accumulation of chlorophyll *a* and chlorophyll *c* in plant leaves.

The use of exogenous phytohormones, which shift the phytohormonal balance of the plant in the direction of stimulator phytohormones, helps to activate the functioning of the photosynthetic apparatus, increase the stability of the pigment complex of plants and, therefore, the productivity and yield of plants, as evidenced by the literature (Wang et al., 2018; Guidi et al., 2019).

It was established that the content of chlorophyll *a* in the leaves of corn plants under the influence of the growth regulator Zeastimulin increases during intensive growth by 17-22% compared to the control. In contrast to the effect of soil fertilization, under the influence of Zeastimulin, an increase in the chlorophyll *b* content of these plants was also found - by 16-20% compared to the control values in the corresponding phases of vegetation, which can be explained by the onto genetic adaptation of plants in these conditions (Guidi et al., 2019). The better ontogenetic adaptation of corn plants is also indicated by a slight (6-10%) increase in the ratio of chlorophyll *a* to chlorophyll *b* content in the panicle shedding and plant flowering phases compared to the corresponding control values.

Thus, optimal conditions for the biosynthesis and accumulation of chlorophyll in the leaves of Zbruch hybrid corn plants were created under the influence of Zeastimulin. Somewhat lesser extent - under the impact of the applied mineral fertilizer, which contributed to the effective functioning of the pigment system during intensive growth, high intensity of photosynthesis, and, respectively, accumulation of raw and dry mass.

Positive changes in the content of non-esterified and esterified forms of fatty acids in the stem and leaves of corn leaves during the period of intensive growth accompany the detected changes in the concentration of chlorophyll *a* and *b*.

Non-esterified fatty acids in the stem and leaves of corn are primarily included in the composition of phospholipids, which in turn are used to form cell membranes (Qin et al., 2013). At the same time, biologically active substances are synthesized in plant tissues from non-esterified fatty acids, primarily oxylipins (Wang et al., 2020). Secondly, non-esterified fatty acids in the composition of triacylglycerols are deposited in the stem and leaves of corn (Wang et al., 2005).

Among other forms of fatty acids, non-esterified ones have significant metabolic and energetic activity, high lability, and reactivity. Based on the above, the quantitative and qualitative composition of non-esterified fatty acids in plant cells and tissues is susceptible to their energy and metabolic needs and readily responds to changes in the homeostasis of a cell, organ, or organism.

Given the importance of the functions performed by non-esterified fatty acids in the plant body, in the conditions of field research, we studied the peculiarities of changes in their content in the green mass of corn plants. The phases of the formation of above-ground vegetative organs, shedding of panicles, and flowering of panicles and cobs constitute the period of intensive growth of corn (Guidi et al., 2019). We found that during the intensive growth phase of corn plants, the content of non-esterified forms of saturated, monounsaturated, and polyunsaturated fatty acids in the control areas in its stem and leaves gradually and slightly decreases (Tables 2, 3, and 4). It can be seen due to their greater inclusion in the composition of phospholipids, esterified cholesterol, and triacylglycerols. The content of non-esterified saturated and polyunsaturated substances sharply decreases only in the flowering phase of the cobs. Perhaps this is related to the formation of grain cell membranes.

It should be noted that during the flowering phase of the cobs, highly oxidized and reactive non-esterified linolenic acid is used to a greater extent than the less oxidized and less reactive non-esterified linoleic acid for the formation of grain cell membranes. This is indicated by a sharp decrease in the ratio of highly oxidized and highly reactive non-esterified linolenic acid to less oxidized and less reactive non-esterified linoleic acid.

The decrease in the content of non-esterified saturated fatty acids in the stem and leaves of control corn plants during growth is caused in particular by a decrease in the total content of saturated fatty acids with an even number of carbon atoms in the chain by 10% and an insignificant decrease in the level of acids with an odd number. On the other hand, the reduction in the content of non-esterified monounsaturated fatty acids in the green mass of corn plants of the control variant during growth occurs, in particular, due to a decrease in the level of oleic acid by 16%. In contrast, the content of palmitoleic acid practically does not decrease.

Table 2. The content of non-esterified fatty acids in the stem and leaves of corn in the phase of 8-9 leaves, $g \cdot 10^{-3}$/kg natural weight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Kaprynic, 10:0	0.24±0.01	0.20±0.01*	0.29±0.01*
Laurynic, 12:0	0.48±0.02	0.41±0.01	0.56±0.02
Miristynic, 14:0	0.79±0.03	0.68±0.02	0.90±0.02
Pentadekanic, 15:0	0.47±0.02	0.39±0.02	0.55±0.02
Palmytynic, 16:0	2.36±0.11	1.94±0.09*	2.73±0.09
Palmitooleinic, 16:1	0.25±0.01	0.20±0.01*	0.30±0.01*
Stearinic, 18:0	1.32±0.06	1.10±0.06	1.60±0.08
Oleinic, 18:1	2.72±0.13	2.25±0.12	3.15±0.10
Linolinic, 18:2	5.40±0.23	4.69±0.23	6.41±0.19*
Linolenic, 18:3	10.34±0.52	8.50±0.43	12.22±0.51
The total fatty acid content	24.37	20.36	28.71
including saturated	5.66	4.72	6.63
monounsaturated	2.97	2.45	3.45
polyunsaturated	15.74	13.19	18.63
linolenic/linoleic	1.91	1.81	1.91

Non-esterified forms of fatty acids perform several functions in plant organisms, of which special attention is paid to their role in forming plant resistance to adverse environmental conditions. However, there are practically no studies that explain the change in the content of non-esterified forms of fatty acids in the plant organism under the influence of exogenous factors. So, we investigated the nature of the change in the content of non-esterified forms of fatty acids in the grain of Zbruch hybrid corn during ripening and the effects of mineral fertilizers and the growth regulator Zeastimulin. It was established that the content of non-esterified forms of saturated, monounsaturated, and polyunsaturated fatty acids in the stem and leaves of corn plants in all phases of intensive growth decreased more intensively compared to the control variant (Tables 2, 3, 4, and 5). This may indicate that mineral fertilization in the

phase of intensive growth of maize plants intensifies the use of non-esterified fatty acids in the stem and leaves for synthesizing phospholipids, esterified cholesterol, and triacylglycerols, which are necessary for cell membranes and storage.

It should be noted that only in the phase of 8-9 leaves and panicle shedding under the influence of mineral fertilizer, compared to the control variant, the ratio of the content of highly oxidized and highly reactive non-esterified linolenic acid to less oxidized and less reactive non-esterified linoleic acid in the stem and leaves of corn plants is sharply reduced. It can be seen in the synthesis of biologically active substances that change the hormonal balance of plant tissues highly oxidized and highly reactive non-esterified linolenic acid is used to a greater extent than less oxidized and less reactive non-esterified linoleic acid.

Table 3. The content of non-esterified fatty acids in the stem and leaves of corn in the panic phase, g·10^{-3}/kg natural weight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Kaprynic, 10:0	0.23±0.01	0.19±0.01*	0.28±0.01*
Laurynic, 12:0	0.47±0.02	0.39±0.02	0.55±0.02
Miristynic, 14:0	0.65±0.02	0.55±0.02*	0.76±0.02*
Pentadekanic, 15:0	0.46±0.02	0.38±0.02*	0.55±0.02*
Palmytynic, 16:0	2.26±0.11	1.86±0.09	2.68±0.11
Palmitooleinic, 16:1	0.24±0.01	0.19±0.01*	0.29±0.01*
Stearinic, 18:0	1.13±0.05	0.96±0.04	1.35±0.06
Oleinic, 18:1	2.35±0.10	2.28±0.35*	2.71±0.09
Linolinic, 18:2	5.48±0.19	4.75±0.20	6.22±0.18*
Linolenic, 18:3	10.13±0.55	8.52±0.37	12.08±0.52
The total fatty acid content	23.40	20.07	27.47
including saturated	5.20	4.33	6.17
monounsaturated	2.59	2.47	3.00
polyunsaturated	15.61	13.27	18.30
linolenic/linoleic	1.85	1.79	1.94

Zeastimulin, applied by us to treat corn plants according to the manufacturer's recommendations, caused the accumulation of non-esterified forms of saturated, monounsaturated, and polyunsaturated fatty acids in the stem and leaves of corn plants during their intensive growth, namely in the phase of 8-9 leaves, panicle shedding, flowering panicles and cobs (Tables 2, 3, 4 and 5).

The detected changes in the content of non-esterified forms of unsaturated fatty acids under Zeastimulin were accompanied by a gradual change in the ratio of highly oxidized and highly reactive non-esterified linolenic acid to less oxidized and less reactive non-esterified linoleic acid. In particular, it was established that during the phase of panicle shedding, panicle and cob flowering in the stem and leaves of corn plants, the ratio of highly oxidized and highly reactive non-esterified linolenic acid to less oxidized and less reactive non-esterified linoleic acid increases. In these phases of intense growth of corn plants, under the influence of the mentioned growth stimulator on the synthesis of biologically active substances that change the hormonal balance of plant tissues, highly oxidized and reactive non-esterified linolenic acid is used to a greater extent than less oxidized and less reactive non-esterified linoleic acid.

Table 4. The content of non-esterified fatty acids in the stem and leaves of corn in the panicle flowering phase, g·10^{-3}/kg of natural weight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Kaprynic, 10:0	0.23±0.01	0.19±0.01*	0.28±0.01*
Laurynic, 12:0	0.46±0.02	0.39±0.01*	0.53±0.02*
Miristynic, 14:0	0.70±0.02	0.61±0.02*	0.79±0.02*
Pentadekanic, 15:0	0.45±0.02	0.37±0.02*	0.50±0.02
Palmytynic, 16:0	2.33±0.09	1.95±0.09*	2.70±0.09*
Palmitooleinic, 16:1	0.22±0.01	0.18±0.01*	0.27±0.01*
Stearinic, 18:0	1.16±0.07	0.92±0.49	1.39±0.05
Oleinic, 18:1	2.30±0.08	1.93±0.10*	2.67±0.10*
Linolinic, 18:2	5.38±0.012	4.82±0.19	5.92±0.15*
Linolenic, 18:3	9.93±0.24	8.98±0.21*	11.10±0.42
The total fatty acid content	23.16	20.34	26.15
including saturated	5.33	4.43	6.19
monounsaturated	2.52	2.11	2.94
polyunsaturated	15.31	13.8	17.02
linolenic/linoleic	1.85	1.86	1.88

Thus, during the intensive growth of the green mass of corn plants in the stem and leaves, the content of non-esterified forms of saturated, monounsaturated fatty acids, and polyunsaturated fatty acids decreases. In general, this may be due to their greater use for cells' energy needs, the synthesis of lipids, phytohormones, and other biologically active substances.

The content of non-esterified forms of fatty acids in the stem and leaves of corn plants in the intensive growth phase generally decreases under the influence of mineral fertilizers and increases under the influence of Zeastimulin. This indicates differences in the biochemical action of fertilizer and growth stimulator on the plant cell. As you know, fats act on plant cells due to various amino acid and fatty acid metabolites, and growth stimulants are mainly due to synthesizing biologically active substances. There are data in the literature that as a result of the oxidation of fatty acid components in plant cells, such biologically active substances as oxylipins are formed. The latter has a wide range of regulatory influences and acts on the plant cell in minimal concentrations.

In the final phases of intensive growth (ejection of panicles, flowering of panicles and cobs) in the stem and leaves of corn plants under the action of a growth stimulator, an increase in the ratio of the content of the non-esterified form of linolenic acid to the non-esterified form of linolenic acid was noted, which indicates the possibility of the effect of the active components of Zeastimulin on lipids, in particular fatty acids, plant cell components. Polyunsaturated fatty acid linolenic acid has a wider range of biological effects on plant cells than polyunsaturated fatty acid linoleic acid.

Table 5. The content of non-esterified fatty acids in the stem and leaves of corn in the cob flowering phase, g·10^{-3}/kg of natural weight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
	0.20±0.01	0.17±0.01*	0.23±0.01*
Kaprynic, 10:0	0.46±0.02	0.39±0.02*	0.53±0.02*
Laurynic, 12:0	0.62±0.02	0.54±0.00	0.72±0.02*
Miristynic, 14:0	0.45±0.02	0.38±0.01*	0.53±0.02*
Pentadekanic, 15:0	1.78±0.07	1.42±0.06*	2.04±0.05*
Palmytynic, 16:0	0.21±0.01	0.18±0.01*	0.25±0.01*
Palmitooleinic, 16:1	1.24±0.01	0.95±0.06*	1.52±0.05
Stearinic, 18:0	2.40±0.01	2.04±0.08	2.79±0.09
Oleinic, 18:1	4.76±0.01	4.21±0.12*	5.33±0.12*
Linolinic, 18:2	8.32±0.18	7.53±0.21*	8.99±0.16*
Linolenic, 18:3	20.44	17.81	22.93
The total fatty acid content	4.75	3.85	5.57
including saturated	2.61	2.22	3.04
monounsaturated	13.08	11.74	14.32
polyunsaturated	0.57	0.56	0.59

It was found that the increase in the functional activity of the photosynthetic apparatus of corn plants in the phase of intensive growth is accompanied by an increase in the concentration of esterified fatty acids and the ratio of the content of the more valuable polyunsaturated fatty acid linoleic to the less valuable polyunsaturated fatty acid linoleic in the stem and leaves. Under the influence of mineral fertilizer and growth regulator Zeastimulin in the intensive growth phase of corn plants, esterified fatty acids accumulate, and the ratio of polyunsaturated linolenic fatty acid to polyunsaturated linoleic fatty acid in the stem and leaves increases. Esterified fatty acids in the composition of phospholipids in the green mass of corn primarily form cell membranes (Bates et al., 2013). Secondly, esterified fatty acids in the composition of triacylglycerols are deposited in the stem, leaves, and grain of corn, thereby creating their energy and biological value (Wang et al., 2020). The main poly saturated fatty acids of plant grains - linoleic and linolenic - play an essential role in the complete nutrition of humans and animals (Taran et al., 2006).

Given the importance of the functions performed by fatty acids in the plant organism in the conditions of field research, we studied the peculiarities of changes in their content in the green mass of corn plants. We established that during the control plots' intensive growth of corn plants, esterified fatty acids accumulated in their green mass (stems and leaves) (Tables 6, 7, and 8). Furthermore, their content increases due to saturated, monounsaturated, and polyunsaturated fatty acids.

The above is possibly related to the fact that in plant tissues from acetate and propionate, under the influence of synthase enzymes, saturated fatty acids are first synthesized, respectively, with an even (capric, lauric, myristic, palmitic, and stearic) and odd (pentadecane) number of carbon atoms in the chain. Then monounsaturated fatty acids are formed from saturated fatty acids under a specific desaturate enzyme (from palmitic to palmitooleic, and from stearic to oleic) (Taran et al., 2006). Only in plant tissues, under the influence of other specific desaturase enzymes, linoleic polyunsaturated fatty acid, which is valuable for plants, humans, and animals, is first formed from the monounsaturated fatty acid oleic. Then the latter forms an even more valuable unsaturated fatty acid, linolenic acid (Taran et al., 2006; Qin et al., 2013).

It should be noted that the increase in the concentration of unsaturated fatty acids in the stem and leaves of control corn plants in the phase of panicle ejection and flowering, compared to the phase of 8-9 leaves, is observed mainly due to polyunsaturated fatty acids linoleic and linolenic. A gradual growth in the ratio of linolenic acid content to linoleic acid accompanies this. This increases the functional activity of plant tissues.

Compared to the control, applying soil fertilizer significantly raised the intensity of accumulation of saturated, monounsaturated, and polyunsaturated fatty acids of total lipids in the stem and leaves of corn during intensive growth. It is worth noting the increase in the ratio of the content of the very valuable polyunsaturated fatty acid linolenic acid to the less valuable linoleic acid in the stems and leaves of corn plants under the action of fertilization, the nature of which is very pronounced in the phase of flowering and, especially, the shedding of the panicle.

It was investigated that the peculiarities of the dynamics of the accumulation of esterified fatty acids in the stem and leaves of corn during the period of intensive growth under the influence of the growth regulator Zeastimulin did not differ from those described by us under the action of fertilizers, their growth occurred equally due to saturated, monounsaturated and polyunsaturated fatty acids. At the same time, the ratio of the content of polyunsaturated fatty acid linolenic acid to polyunsaturated fatty acid linoleic acid gradually increased.

Table 6. The content of esterified fatty acids in the stem and leaves of corn in the phase of 8-9 leaves, $g \cdot 10^{-3}$/kg of natural weight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Kaprynic, 10:0	2.4±0.11	2.9±0.14*	3.0±0.11*
Laurynic, 12:0	4.8±0.20	5.9±0.29*	6.0±0.32*
Miristynic, 14:0	7.2±0.32	8.5±0.32*	8.8±0.35*
Pentadekanic, 15:0	4.8±0.23	5.7±0.23	5.8±0.26*
Palmytynic, 16:0	24.2±1.24	29.9±1.56*	30.4±1.66*
Palmitooleinic, 16:1	2.4±0.145	3.2±0.17*	3.1±0.17*
Stearinic, 18:0	12.2±0.61	15.5±0.72*	15.5±0.81*
Oleinic, 18:1	26.8±1.57	32.7±1.56*	34.0±1.68*
Linolinic, 18:2	55.3±2.48	65.7±2.54*	67.0±2.77*
Linolenic, 18:3	102.5±4.69	124.3±6.67	125.2±6.54*
The total fatty acid content	242.6	294.3	298.8
including saturated	55.6	68.4	69.5
monounsaturated	29.2	35.9	37.1
polyunsaturated	157.8	190.0	192.2

Table 7. Thecontentofesterifiedfattyacidsinthestemandleavesofcorninthepanicphase, $g \cdot 10^{-3}$/kgofnaturalweight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Kaprynic, 10:0	2.6±0.17	3.4±0.17*	3.5±0.21*
Laurynic, 12:0	5.2±0.26	6.3±0.26*	6.4±0.20*
Miristynic, 14:0	7.8±0.35	9.2±0.32*	9.4±0.29*
Pentadekanic, 15:0	5.1±0.23	6.0±0.20*	6.2±0.20*
Palmytynic, 16:0	26.2±1.24	32.3±1.68*	33.7±1.91*
Palmitooleinic, 16:1	2.6±0.145	3.4±0.17*	3.4±0.20*
Stearinic, 18:0	12.6±0.61	15.1±0.66*	15.5±0.65*
Oleinic, 18:1	26,4±1,38	31.8±1.34*	32.8±1.65*
Linolinic, 18:2	60.1±2.19	70.4±2.63*	71.7±2.46*
Linolenic, 18:3	111.7±5.05	136.6±7.28*	138.5±7.28*
The total fatty acid content	260.3	314.5	321.1
including saturated	59.5	72.3	74.7
monounsaturated	29.0	35.2	36.2
polyunsaturated	171.8	207.0	210.2

Table 8. The content of esterified fatty acids in the stem and leaves of corn in the panicle flowering phase, $g \cdot 10^{-3}$/kg of natural weight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Kaprynic, 10:0	2.9±0.17	3.6±0.17*	3.8±0.20*
Laurynic, 12:0	5.8±0.26	7.0±0.23*	7.2±0.23*
Miristynic, 14:0	8.7±0.34	10.2±0.34*	10.4±0.40*
Pentadekanic, 15:0	5.6±0.20	6.6±0.23*	6.7±0.23*
Palmytynic, 16:0	29.4±1.76	36.1±1.56*	36.8±1.6*
Palmitooleinic, 16:1	2.8±0.17	3.5±0.14*	3.7±0.17*
Stearinic, 18:0	14.5±0.72	17.4±0.81	17.6±0.75*
Oleinic, 18:1	28.4±1.07	34.1±1.50*	34.7±1.51*
Linolinic, 18:2	66.7±2.68	78.8±3.29*	80.4±3.44*
Linolenic, 18:3	124.5±6.61	150.6±6.90	152.6±6.75*
The total fatty acid content	289.3	347.9	353.9
including saturated	66.9	80.9	82.5
monounsaturated	31.2	37.6	38.4
polyunsaturated	191.2	229.4	233.0

In the ontogenesis of plants, in each period of their development, the course and direction of the main metabolic processes are determined by the actual requests of the plant organism (Kobyletska, 2020). During the transition of a plant from the juvenile period of development, which is characterized by an intensive accumulation of vegetative mass, to the generative one, an ontogenetic restructuring of metabolism takes place, due to the appearance and formation of generative organs, which in this period become integration centers and the main acceptors of plastic and energy resources of the plant (Miyazaki et al., 2013; Perlikowski et al., 2016).

We found that when corn plants transition to the generative phase of development when grain formation occurs, the content of esterified fatty acids in the stem and leaves decreases (Table 9).

It is shown that the decrease in their content under these conditions occurs mainly due to saturated and polyunsaturated fatty acids. At the same time, the ratio of the content of the precious polyunsaturated fatty acid linolenic acid to the less valuable polyunsaturated fatty acid linoleic acid also begins to decrease in the stalk and leaves of corn due to the greater use of highly oxidized and highly active linolenic acid for synthesizing biologically active derivatives. Plant growth, as an integral process of vital activity, is closely related to its metabolism, in particular, to protein and lipid exchanges, thanks to which the genetic information of deoxyribonucleic acids is implemented in the corresponding structural and enzymatic proteins that regulate the functional activity of cells (Yang et al., 2013).

Table 9. The content of esterified fatty acids in the stem and leaves of corn in the cob flowering phase, g·10^{-3}/kg of natural weight (M ± m, n = 3)

Fatty acids and their code	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
Kaprynic, 10:0	2.5±0.11	3.2±0.14*	3.1±0.17*
Laurynic, 12:0	5.8±0.23	6.9±0.26*	6.8±0.26*
Miristynic, 14:0	7.8±0.32	9.4±0.32*	9.2±0.32*
Pentadekanic, 15:0	5.6±0.23	6.9±0.26*	6.7±0.23*
Palmytynic, 16:0	26.2±1.36	33.0±1.47*	32.1±1.56*
Palmitooleinic, 16:1	2.6±0.17	3.4±0.09*	3.3±0.11*
Stearinic, 18:0	15.4±0.62	18.6±0.69*	18.1±0.72*
Oleinic, 18:1	31.3±1.50	38.6±1.43*	38.0±1.33*
Linolinic, 18:2	59.4±2.81	71.9±2.11*	70.2±2.37*
Linolenic, 18:3	104.1±5.17	127.3±6.00*	125.4±5.92
The total fatty acid content	260.7	319.2	312.9
including saturated	63.3	78.0	76.0
monounsaturated	33.9	42.0	41.3
polyunsaturated	163.5	199.2	195.6

The basis of plant growth is correlational relationships, both between individual organs and between individual processes. The visible results of plant growth are, in particular, a change in size and biomass accumulation. This complex physiological process directly or indirectly depends on many exo- and endogenous factors, often interconnected (Zhu et al., 2014; Guidi et al., 2019).

The peculiarity of the growth of corn plants is that, unlike other cereals, they can absorb elements of mineral nutrition before the grain is fully ripe, and the central mass of organic matter is accumulated after the panicles are thrown out and during the maturation of the reproductive organs (Kramarov, 2003; Deeva, 2008).

Plant height is an essential biometric indicator of growth and development and, therefore, productivity. We have shown in field studies that the intensity of growth of hybrid Zbruch corn plants varied depending on their morphological and individual characteristics and depended on the vegetation phase, the action of fertilizers, and the growth regulator Zeastimulin (Table 10).

Table 10. TheheightofthestemofcornplantsoftheZbruchhybridduringtheperiodofintensivegrowth, see (M ± m, n = 10)

Phases vegetation	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
8-9 leaves	65.8±2.19	73.0±1.12	71.9±2.40
Ejection of the panicle	197.1±2.57	207.5±2.29	210.5±2.75*
Flowering cabbage	199.3±2.98	221.0±2.64*	223.0±2.87*

As the above table shows, corn plants' growth intensity naturally increases with age, reaching maximum values in the panicle ejection and flowering phase. Under the influence of soil fertilizer, there is an increased rate of corn plants in the tillering phase by 10% compared to the control, while under the action of the growth regulator Zeastimulin - by 9%. In the following phases of vegetation, growth rates of corn plants were found to increase by 9-12% under Zeastimulin, while under the action of soil fertilizer - by 5-10%.

To understand the features of productivity formation processes, in addition to linear growth intensity parameters, quantitative indicators of plant growth and development are used, one of which is the dynamics of the accumulation of raw mass or dry matter during the growing season. That is why, to evaluate the influence of the Zeastimulin regulator and fertilizer, we studied the change in the raw mass of corn plants (Table 11).

Table 11. Accumulation of raw mass by corn plants during the period of intensive growth, g/plant (M ± m, n = 10)

Phases growth	Control	Experiment	
		$N_{60}P_{45}K_{45}$	Zeastimulin
8-9 leaves	298.8±19.00	340.1±6.80*	341.3±7.30*
Ejection of the panicle	670.0±54.85	756.3±12.90	736.4±11.15*
Flowering cobs	1285.5±103.50	1340.4±15.00	1315.7±14.65

As you can see, the intensity of accumulation of raw mass by corn plants naturally increases with age, reaching maximum values during panicle shedding and cob flowering. Under the influence of soil fertilizer, there is an increase in the rate of accumulation of raw mass by corn plants in the tilling phase by 10% relative to the control, while under the action of the growth regulator Zeastimulin - by 9%. In the following phases of the growing season, an increase in the accumulation rate of raw mass by corn plants was found under the action of Zeastimulin by 9-12%, while under the action of soil fertilizer - by 5-10%.

The marked increase in the intensity of growth of corn plants under the influence of fertilizer can be explained, in particular, by their physiological features since they, as representatives of the C-4 type of photosynthesis of trophic origin, have a high genetic potential for growth, which is more fully realized under conditions of optimal and intensive root nutrition, which is especially relevant for new varieties and hybrids (Ponomarenko, 2003).

The activation of the accumulation of raw mass by corn plants under the influence of the growth regulator Zeastimulin is explained by its ability, similar to other active analogs of phytohormones, to impact growth by replenishing the endogenous pool of phytohormones, thereby changing the phytohormonal balance of the plant and activating, in particular, the processes of cell division (Storozhenko, 2004; Cook et al., 2021). As a result of the formation of a significant number of cells, stretching and linear maturation of the plant organism is accelerated.

As we can see from the given data, corn plants quite intensively accumulate raw mass in all investigated phases of intensive growth. The most optimal of the investigated factors was the effect of soil fertilizer, under the influence of which an increase in the raw mass of 1 corn plant by 50-69 g was observed, while under the influence of Zeastimulin this effect was less pronounced - an rise of 30-40 g was shown.

In general, the active growth of corn plants in height and their accumulation of raw mass under the action of plant growth regulators can be activated, in particular, due to the acceleration of cell growth by stretching in the longitudinal and isodiametric directions, the increase in the permeability of cell membranes, which is activated explicitly by auxin-like components of biologically active compounds (Miyazaki et al., 2013). The increase in the intensity of the growth of corn plants due to the action of mineral fertilizers is due to the additional optimization of the soil nutrition of these plants associated with this better supply of nutrients and the opportunity to realize the productive potential (Ali, 2021) more fully.

CONCLUSIONS

The functional activity of the photosynthetic apparatus in the leaves of corn plants increases with their age and depends on soil fertilization and the influence of growth regulators. This is confirmed by the fact that the leaves of corn plants accumulate photosynthetic pigments during intensive growth and under the influence of mineral fertilizers and the growth regulator Zeastimulin.

The increase in the functional activity of the photosynthetic apparatus of corn plants during the period of intensive growth is accompanied by a slight and gradual decrease in the concentration of non-esterified fatty acids but an increase of esterified ones, in the stem and leaves, from the phase of 8-9 leaves to the phase of panicle flowering. During the cob flowering phase, the concentration of non-esterified and esterified fatty acids in the stem and leaves of corn sharply decreases. In the same phase, the ratio of the content of the more valuable linoleic fatty acid to the less valuable linoleic fatty acid also sharply decreases in the stalk and leaves of corn.

The general pattern of changes in the concentration of non-esterified and esterified fatty acids and the ratio of the content of the

more valuable linoleic fatty acid to the less valuable linoleic fatty acid in the stem and leaves in all phases of the vegetation phase of corn plants under the influence of mineral fertilizer and the growth regulator Zeastimulin resembles the changes in the control version. But changes in the concentration of non-esterified fatty acids in the stem and leaves of corn plants under the influence of mineral fertilizers occur at a lower level and under the influence of the growth regulator Zeastimulin - at a higher level. Only in the flowering phase of cobs under the influence of mineral fertilizer and growth regulator Zeastimulin in the stem and leaves of corn plants does the concentration of non-esterified and esterified fatty acids increase without changing the ratio of linoleic acid to linoleic acid.

The height of corn plants and the intensity of their accumulation of raw mass increases with age and reaches maximum values during panicle shedding and cob flowering. Under the influence of soil fertilizer and the growth regulator Zeastimulin, the rate of accumulation of raw mass by corn plants increases.

REFERENCES

Ali, A. A. (2021). Maize Productivity in the New Millennium. In: Mitigating Environmental Stresses for Agricultural Sustainability in Egypt. *Springer Water*, 509–535. doi: 10.1007/978-3-030-64323-2_19.

Andrianova, Yu. S., & Tarchevsky, I. A. (2000). Chlorophyll and plant productivity. Moscow.

Bates, P. D., Stymne, S., & Ohlrogge, J. (2013). Biochemical pathways in seed oil synthesis. *Current Opinion in Plant BiologyonScienceDirect,* 16(3), 358–364.

Chotewutmontri, P., & Barkan, A. (2016). Dynamics of chloroplast translation during chloroplast differentiation in maize. *PLoS Genet.*, 12(7), e1006106. doi: 10.1371/journal.pgen.1006106.

Cook, R., Lupette, J., & Benning, C. (2021). The Role of Chloroplast Membrane Lipid Metabolism in Plant Environmental Responses. *Cells*, 10(3), 706. doi: 10.3390/cells10030706.

Dalal, V. K., & Tripathy, B. C. (2012). Modulation of chlorophyll biosynthesis by water stress in rice seedlings during chloroplast biogenesis. *Plant, Cell and Environment,* 35, 1685-1703. doi:10.1111/j.1365-3040.2012.02520.x

Deeva, V. P. (2008). Plant growth regulators: mechanisms of action and use in agricultural technologies. Minsk.

Fromme, D. D., Spivey, T. A., & Grichar, W. J. (2019). Agronomic Response of Corn (*Zea mays* L.) Hybrids to Plant Populations.*International Journal of Agronomy*, 3589768. doi: 10.1155/2019/3589768.

Guidi, L., Lo Piccolo, E., & Landi, M. (2019). Chlorophyll Fluorescence, Photoinhibition and Abiotic Stress: Does it Make Any Difference the Fact to be a C3 or C4 Species? *Front. Plant Sci., 10*. 174. doi:10.3389/fpls.2019.00174.

Guo, Q., Liu, L., & Barkla, B. J. (2019). Membrane Lipid Remodeling in Response to Salinity. *International Journal of Molecular Sciences*, *20*(17), 4264. doi: 10.3390/ijms20174264.

Hadingham,S. A., Li,Y., & Bevan, M. W. (2006). Sugar and ABA response pathways and the control of gene expression. *Plant, Cell & Environment,* 29(3), 426–465.

Kobyletska, M.S. (2020). Fatty acid composition of corn and wheat plant shoots under the action of salicylate in drought conditions. *Biol. Stud.*, *14*(3), 91–104. doi: 10.30970/sbi.1403.629.

Kovalchuk, I., Dvylyuk, I., Lecyk, Y., Dvylyuk, I., & Gutyj, B. (2019). Physiological relationship between content of certain microelements in the tissues of different anatomic sections of the organism of honey bees exposed to citrates of argentum and cuprum. *Regulatory Mechanism sin Biosystems*, *10*(2), 177–181. doi:10.15421/021926.

Kramarov, S. M. (2003). Influence of optimized fertilizer system on biochemical indicators of grain quality of maize hybrids of different maturity groups. *Kormyikormovyrobnytstvo, 51.* 92–96.

Li, Y., Ma, L., Wu, P., Zhao, X., Chen, X., & Gao, X. (2020). Yield attributes and photosynthetic physiological characteristics of dryland wheat (*Triticum aestivum* L.) / maize (*Zea mays* L.) strip intercropping. *Field Crops Research, 248*. 412–421. doi: 10.1016/j.fcr.2019.107656.

Liu, Z., Gao, J., Gao, F., Liu, P., Zhao, B., & Zhang, J. (2018). Photosynthetic Characteristics and Chloroplast Ultrastructure of Summer Maize Response to Different Nitrogen Supplies. *Fronties in Plant Science,* 9, 576. doi: 10.3389/fpls. 2018.00576.

Miyazaki, M., Araki, M., & Okamura, K. (2013). Assimilate translocation and expression of sucrose transporter, OsSUT1, contribute to high-performance ripening under heat stress in the heat-tolerant rice cultivar Genkitsukushi. *J. of Plant Physiol., 170*(18), 1579–584.

Perlikowski, D., Kierszniowska, S., Sawikowska, A., Krajewski, P., Rapacz, M., Eckhardt, Ä. & Kosmala, A. (2016). Remodeling of Leaf Cellular Glycerolipid Composition under Drought and Re-hydration Conditions in Grasses from the Lolium-Festuca Complex. *Frontiers in Plant Science, 7*. 1027. doi: 10.3389/fpls.2016.01027.

Ponomarenko, S. P. (2003). Plant growth regulators. Kiev.

Pshibytko, N. L., Kalitukho, L. N., & Volkova, Ye. V. (2003). The role of sugars in the adaptation of the photosynthetic apparatus to stress factors. *Fiziologia ibiokhimiakulturnykhrasteniy, 35*(4), 330–341.

Qin, A., Huang, G., Chai, Q., Yu, A., & Huang, P. (2013). Grain yield and soil respiratory respons e ointercropping system sonarid land. *Crops Research., 144*, 1–10. doi: 10.1016/j.fcr.2012.12.005.

Rogowski, P., Wasilewska-Dębowska, W., Krupnik, T., Drożak, A., Zienkiewicz, M., Krysiak, M. &

Romanowska, E. (2019). Photosynthesis and organization of maize mesophyll and bundle sheath thylakoids of plants grown in various light intensities. *Environmental and Experimental Botany, 162*. 72–86.doi: 10.1016/j.envexpbot.2019.02.006.

Ruan, Y. Y., Li, X. Y., Wang, Y. P., Jiang, S. Q., Song, B., Guo, Z. Y., Zhang, A., Qi, Q., Zhang, L. J., Fan, J. J., Guan, Y. X., Cui, Z. H., & Zhu, Y. S. (2017). Photoinhibition of Leaves with Different Photosynthetic Carbon Assimilation Characteristics in Maize (*Zea mays*). *American J. of Plant Sci.*, *8*, 328–339. doi: 10.4236/ajps.2017.83023.

Rivis, J. F. (2017). Quantitative chromatographic methods for the determination of individual lipids and fatty acids in biological material. Lviv: Spolom.

Shumskaya, M., & Wurtzela, E. (2013). The carotenoid biosynthetic pathway: thinking in all dimensions. *Plant Sci.,* 208. 58–63. doi: 10.1016/j.plantsci.2013.03.012.

Sobolev, O.I., Gutyj, B.V., Sobolieva, S.V., Borshch, O.O., Kushnir, I.M., Petryshak, R.A., Naumyuk, O.S., Kushnir, V.I., Petryshak, O.Y., Zhelavskyi, M.M., Todoriuk, V.B., Sus, H.V., Levkivska, N.D., Vysotskij, A.O., & Magrelo, N.V. (2020). Review of germanium environmental distribution, migration and accumulation. *Ukrainian Journal of Ecology*, *10*(2), 200–208.

Storozhenko, V. O. (2004). Key antioxidant enzymes of the photosynthetic apparatus of higher plants under the action of stressors. *Fiziologia I biokhimia kulturny khrasteniy, 36*(1), 36–42.

Taran, N. Yu., Kosyk, O. I., Okanenko, O. A., & Batsmanova, L. M. (2006). Lipids of plants. Kyiv.

Wang, Y., Ying, J., Kuzma, M. et al. (2005). Molecular tailoring of farnesylation for plant drought tolerance and yield protection. *The Plant J., 43*(3), 413. doi: 10.1111/j.1365-313X.2005.02463.x.

Wang, Y., Zhang, X., Huang, G. et al. (2020). Dynamic changes in membrane lipid composition of leaves of winter wheat seedlings in response to PEG-induced water stress. *BMC Plant Biol., 20*. 84. doi: 10.1186/s12870-020-2257-1.

Wang, Z., Li, G., Sun, H., Ma, L., Guo, Y., Zhao, Z., Gao, H., & Mei, L. (2018). Effects of drought stress on photosynthesis and photosynthetic electron transport chain in young apple tree leaves. *Biology Open*, *7*(11), bio.035279. doi:10.1242/bio.035279.

Yang, Z., Wang, T., & Wang, H. (2013). Patterns of enzyme activities and gene expressions in sucrose metabolism in relation to sugar accumulation and composition in the aril of Litchi chinensis Sonn.*J. of Plant Physiol., 170*(8), 731–740.

Zhu, K.-L., Jin, L.-B., Dong, S.-T., Zhao, B., Liu, P., & Zhang, J.-W. (2014). Effects of Integrated Agronomic Practices on Leaf Senescence Physiological Characteristics of Summer Maize. *Sci. Agricultura Sinica, 47*(15), 2949-2959. doi: 10.3864/j.issn.0578-1752.2014.15.005.