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NEW PROMISING CORN GROWTH REGULATORS BASED ON AMMONIUM SALTS OF ALIPHATIC DICARBOXYLIC ACIDS OF THE C_2-C_6 SERIES

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Abstract. Corn is the second most widely sold grain crop in the world (after wheat). Sweet corn is a valuable vegetable crop, which ranks among the top vegetable crops in terms of nutritional value and taste. It has a significant list of useful substances: high content of vitamins A, B, C and E, especially a large amount of vitamin folate (B9), slightly less niacin (B3) and thiamine (B1). Of the macro- and microelements, corn has the most potassium (270 milligrams) and magnesium (37 milligrams). An element rare in other products, contained in corn, is gold, which is contained in corn in microportions, but this is enough to feed our brain with the rare metal necessary for its best work. Corn is balanced in the composition of fats, proteins and carbohydrates, rich in fiber and does not contain gluten. Fiber helps intestinal motility, prevents cancer. In addition, the absence of gluten makes corn the most universal food, which does not have the "contraindications" inherent in wheat, equally suitable for healthy people and people with health problems. Corn as a silage crop has great fodder value. Silage from cobs in the milky-wax ripeness phase of grain is considered one of the best in terms of nutritional value. Preparations from corn silk are used as a diuretic, anti-inflammatory, choleretic, hemostatic agent in the treatment of kidneys, liver, urological diseases, edema of various origins. Preparations from corn silk have a moderately calming effect, and can also reduce appetite. Corn oil, obtained from the germs of corn seeds, regulates the level of cholesterol in the blood, reduces its deposition on the walls of blood vessels, reduces the risk of thrombosis and has a choleretic effect. The share of corn in the world starch production is about 75%. Given the high importance of corn, it is necessary to conduct systematic research in the field of developing new effective growth regulators for this plant. In this work we show the results of our own research in the field of development of promising phytohormones for accelerating the growth of corn based on ammonium salts of aliphatic dicarboxylic acids. It is shown that the compounds synthesized by us contribute to the increase of the above-ground and root parts of corn and accelerate the growth of corn.

Key words: corn, growth regulators, phytohormones, growth stimulants, growth substances

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1. Introduction

Abiotic stresses including drought, salinity, heat, cold, flooding and ultraviolet radiation cause crop losses worldwide [1]. Recently, preventing these crop losses and producing more food and feed to meet the needs of an ever-growing population have gained unprecedented importance. However, the proportion of agricultural land facing multiple abiotic stresses is expected to only increase under a changing global climate fueled by anthropogenic activities. Thus, identifying the mechanisms developed and used by plants to counteract abiotic stresses and maintain their growth and survival under harsh conditions is of great importance. Recent studies have shown that phytohormones including the classical auxins, cytokinins, ethylene and gibberellins, as well as newer members including brassinosteroids, jasmonates and strigolactones, may prove to be important targets for metabolic engineering to create abiotic stress-tolerant crops. Recent review papers [2-11] summarize and critically evaluate the roles that phytohormones play in plant growth and development and abiotic stress tolerance, in addition to their engineering for abiotic stress tolerance in transgenic crops, in particular, the recent progress and future prospects including the limitations and challenges of engineering phytohormones to induce abiotic stress tolerance in crop plants are shown. Among the numerous agricultural crops, corn has the greatest importance and application. Corn (*Zea mays*), also known as maize, is a staple crop that plays a key role in the global agricultural economy, serving as a major source of food, feed, and biofuel. The cultural significance of corn spans many civilizations, with its origins dating back to ancient Mesoamerica over 7,000 years ago. The United States is the largest corn producer in the world, with an annual production exceeding 14 billion bushels, and Iowa is the leading corn producing state. Corn exhibits remarkable adaptability to a variety of climate conditions, making it a versatile crop in a variety of agricultural zones. However, it grows best in well-drained, fertile soils with adequate moisture levels. Corn is sensitive to drought conditions, relying heavily on consistent rainfall or irrigation for optimal growth and yield. It also requires significant nutrient inputs, especially nitrogen, to maintain its rapid growth and high productivity.

In this regard, the development and synthesis of new effective growth regulators and the improvement of already known classical phytohormones for increasing the productivity of corn are of great theoretical and practical interest. In the presented work, we review the results of studies conducted in this area, and also propose new effective corn growth regulators based on ammonium salts of some aliphatic dicarboxylic acids synthesized by us.

2. Analysis of research results

Thus, the objective of the study [12] is to determine the growth and yield of sweet corn based on the concentration of phytohormones sprayed during the day and night, and to find out which concentration of phytohormones gives the best effect on the parameters of plant height, leaf number, flowering age, fruit weight and fruit number. A two-factor completely randomized design (CRD) was used in

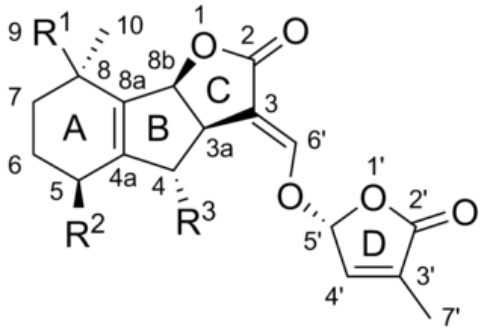
this study. The first factor of phytohormone concentrations consisted of T_0 = 0 ml/L, T_1 = 6 ml/L, T_2 = 8 ml/L, T_3 = 10 ml/L, T_4 = 12 ml/L with 3 replications and 27 experimental units. The subject of this study is phytohormone and the object of this study is sweet corn of the *Bonanza F1* variety. Data collection in this study is done by direct observation and documentation. The data were analyzed using ANOVA (analysis of variance) followed by DMRT (diffusion spectral tomography) test if there was an effect. Based on the DMRT test results, T_4=12 ml/L treatment had an effect on plant height and fruit weight with values of 195.4 cm and 162 g, respectively. T_3=10 ml/L treatment had an effect on leaf count with a value of 18.7, and T_1=6 ml/L treatment had an effect on flowering age with a value of 46.2. The best utilization of the phytohormone is achieved by applying the phytohormone sprayed during the day.

The work [13] noted that phytohormones such as gibberellins, auxins and cytokinins are plant growth promoting factors which when added to foliar fertilizers can modulate plant growth and development of crop species. This work was carried out to study the effects of exogenously applied phytohormones both individually and in mixtures on legumes and cereals grown in chambers with controlled conditions of humidity, temperature and light/dark cycle. It was found that the application of phytohormones resulted in significant increase in plant growth of soybean and maize plants. A mixture of phytohormones formulated with the lowest concentration of each required to enhance plant growth resulted in significant improvement in several growth parameters related to productivity. Thus, the addition of this mixture to commercial products as foliar fertilizers may have potential to improve the yield of legumes and cereals.

The grain set of maize (*Zea mays L.*) at maturity is mainly determined during pollination. Grain abortion often occurs during this period, resulting in reduced grain yield. Plasma membrane (PM) H^+-ATPase has been identified as a key enzyme responsible for the supply of assimilates to developing maize grains soon after pollination. The aim of this study [14] was to stimulate the PM H^+-ATPase activity in grains by in vivo application of the auxin indole-3-acetic acid (IAA) to maize plants during anthesis, resulting in improved hexose uptake and ultimately better grain set. *Maize* plants were grown under well-watered conditions using container technology. IAA was applied to unstressed maize plants twice, 2 days before controlled pollination and during pollination (application rate per plant: 1.9 ml of 1.5 mM IAA). Developing grains were harvested 2 days after pollination and PM vesicles were isolated and purified by two-phase separation. The hydrolytic activity of PM H^+-ATPase in vitro was significantly stimulated by 22% by IAA treatment *in vivo* (control: 0.99 ± 0.05, IAA treatment: 1.21 ± 0.03* μmol inorganic phosphate/mg protein min^{-1}). Vmax was significantly increased by IAA treatment, whereas K_m was decreased. The maximum pH gradient (ΔA492) in PM was increased by 10% (control: 0.071 ± 0.002, IAA treatment: 0.078 ± 0.002*). IAA caused a significant increase in the PM H^+-ATPase content in vesicles. The concentrations of sucrose and hexoses as well as the activity of acid invertase in the grains were not affected by IAA treatment. However, at maturity, the number

of grains per ear decreased significantly, resulting in a 19% decrease in grain yield. Thus, the authors showed that the increased PM H^+-ATPase activity could not be translated into an improvement in grain yield. It is likely that auxin application occurred too early during grain development. Since cytokinins play a key role during pollination, auxin application at this stage could have disrupted the balance of phytohormones, causing impaired cell division and a rather early onset of cell expansion due to elevated IAA concentrations.

Strigolactones are among the phytohormones that exert multiple effects on plant growth and development [15]. Since these activities of strigolactones are closely related to crop yield, the use of strigolactone could be a promising technology in modern sustainable agriculture. The major strigolactones in maize root exudates were identified as zealactone and zeapyranolactone. The authors of the work disclosed the first total synthesis of zealactone along with its biological activity in maize. They describe the design and synthesis of simplified analogues of both strigolactones obtained from maize with their bioavailability in soil and their biological activity. These compounds could be potential leads for the development of synthetic strigolactones for agronomic use in more sustainable crop production.



general structure of strigolactones

Indole-3-acetic acid (IAA), the major auxin of higher plants, and abscisic acid (ABA) have been shown [16] to play critical roles in the ability of maize (*Zea mays L.*) to adapt to various environmental conditions by mediating growth, development, defense, and nutrient allocation. Although the understanding of the biochemical reactions for IAA and ABA biosynthesis and signal transduction has advanced, the mechanisms by which auxin and ABA are synthesized and transduced in maize are still not fully understood. The synthesis and signal transduction pathway of IAA and ABA in maize can be analyzed using the existing model. This article focuses on the research progress toward understanding the synthesis and signaling pathways of IAA and ABA, as well as the regulation of maize growth by IAA and ABA, which provides insights into the future development and significance of IAA and ABA in maize improvement.

The aim of the work [17] is to reveal the regulatory mechanism of sweet corn seedling response to extreme temperature stress; this study integrated

transcriptomics and metabolomics of volatiles and phytohormones. The results showed that low-temperature stress significantly affected 20 volatiles; abscisic acid and salicylic acid accumulated, while auxin and jasmonic acid decreased. The regulatory patterns of vp14 and ABF for abscisic acid accumulation and signal transduction were elucidated under low-temperature stress. High-temperature stress affected 31 volatiles and caused a decrease in zeatin, salicylic acid, jasmonic acid and auxin. The upregulation of ARR-B gene highlighted its function in zeatin signal transduction under high-temperature stress. The correlations between gene modules, phytohormones and volatiles were analyzed to construct a regulatory network of sweet corn seedlings under temperature stress. The result may provide a basis for improving the early development of sweet corn through biological intervention or modulation at the genomic level.

Azospirillum spp. are plant growth promoting bacteria used worldwide as inoculants for various crops [18]. Among the beneficial mechanisms associated with *Azospirillum inoculation*, the biological process of nitrogen fixation and phytohormone synthesis are of particular interest. In Brazil, the use of inoculants containing *A. brasilense* strains Ab-V5 and Ab-V6 to cereal crops has been increasing exponentially and in this study, the authors investigated the effects of maize inoculation with these two strains applied to seeds or by foliar spraying at the V2.5 growth stage, a strategy to eliminate incompatibility with pesticides used for seed treatment. The authors also investigated the effects of spraying with metabolites of these two strains at the V2.5 stage. Maize growth was stimulated by inoculation of bacteria and their metabolites. When applied via foliar spray, although survival of *A. brasilense* on leaves was confirmed by confocal microscopy and cell recovery, few cells were detected after 24 h, indicating that the effects of bacterial foliar spray may also be related to their metabolites. The main molecules detected in the supernatants of both strains were indole-3-acetic acid, indole-3-ethanol, indole-3-lactic acid and salicylic acid. RT-PCR of oxidative stress (APX1, APX2, CAT1, SOD2, SOD4) and plant defense (pathogenesis-related PR1, prp2 and prp4)-related genes was assessed in maize leaves and roots. Differences were observed depending on the gene, plant tissue, strain and application method, but overall, *Azospirillum* inoculation resulted in up-regulation of oxidative stress genes in leaves and down-regulation in roots; In contrast, overall, PR genes were downregulated in leaves and upregulated in roots. Particular attention should be paid to the application of metabolites, especially Ab-V5 + Ab-V6, which overall resulted in the highest regulation of oxidative stress and PR genes in both leaves and roots. The authors suggest that the benefits of *Azospirillum* inoculation on seeds or by foliar sprays, as well as foliar sprays with *Azospirillum* metabolites, are closely related to the synthesis of phytohormones and the identification of genes associated with plant stress tolerance and pathogen defense.

Researchs in the field of development of new phytoregulators for corn was also reported in works [19-27].

3. Discussion of the obtained results

Thus, summarizing the results of the above-described studies in the field of developing new effective growth regulators of corn, we can conclude that in this direction, along with classical phytohormones (abscisic acid, cytokinins, gibberellins), new synthetic phytoregulators are currently widely used, as a rule, obtained on the basis of nitrogen-containing organic compounds, in particular amines and ammonium salts. In this direction, we have proposed new effective regulators of corn growth based on ammonium salts of aliphatic dicarboxylic acids of the C_2-C_6 series. The studies conducted in Petri dishes showed that tris(2-hydroxyethyl)ammonium hydrosuccinate succinate relatively exceeded tris(2-hydroxyethyl)ammonium succinate, and both compounds of succinic acid synthesized with triethanolamine exceed the control variant in the effect on corn seeds in the stem part by 10.8-19.6%, and in the root part by 2.1-13% [28-30]. And also the study of the effect of the glutaric acid derivatives synthesized by us on seed germination and plant development in laboratory conditions show that these compounds are recommended for use as a growth substance for various agricultural crops [31,32]. The work done in field experiments to study the growth regulatory properties of these compounds provides a basis for the feasibility of its use in agriculture and landscaping. The effect of a number of organic acids shows that the use of these derivatives allows to increase the growth of the above-ground and root parts of corn by a certain percentage, which contributes to the acceleration of corn growth.

4. Conclusion

Thus, we have developed new effective growth regulators for corn based on derivatives of dicarboxylic acids of the C_2-C_6 series. It has been experimentally established that ammonium salts of succinic acid and ethanolamines can increase the growth of the above-ground and root parts of corn by 10.8-19.6% and 2.1-13%, respectively. It has been shown that the obtained compounds have good phytoregulatory activity and can be recommended for use in agronomy and agricultural practice.

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Conflict of Interest: All authors declare that they have no conflict of interest.

C_2-C_6 СЕРИЯЛЫҚ АЛИФАТТЫ ДИКАРБОН ҚЫШҚЫЛДАРЫНЫН АММОНИЙ ТУЗДАРЫНА НЕГІЗДЕЛГЕН ЖҮГЕРІ ӨСУІНІҢ ЖАҢА БОЛАШАҚТЫ РЕТТЕУШІЛЕРІ

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Түйіндеме. . Жүгері дүние жүзінде ең көп сатылатын екінші дәнді дақыл (бидайдан кейін). Тәтті жүгері – құнды көкөніс дақылы, тағамдық құндылығы мен дәмі жағынан ең жақсы көкөніс дақылдарының бірі. Онда пайдалы заттардың маңызды тізімі бар: А, В, С және Е дәрумендерінің жоғары мазмұны, әсіресе фолий қышқылының көп мөлшері (В9), ниацин (В3) және тиамин (В1) сәл аз. Макро-және микроэлементтердің ішінде жүгеріде ең көп калий (270 мг) және магний (37 мг) бар. Жүгері құрамындағы басқа өнімдерде сирек кездесетін элемент - бұл жүгеріде микродозада бар алтын, бірақ бұл біздің миымызды оның жақсы жұмыс істеуі үшін қажет сирек металмен қоректендіруге жеткілікті. Жүгері майлардың, ақуыздардың және көмірсулардың құрамында теңдестірілген, талшыққа бай және құрамында глютен жоқ. Талшық ішек перистальтикасына көмектеседі, қатерлі ісіктің алдын алады. Сонымен қатар, глютеннің болмауы жүгеріні ең әмбебап тағамдық өнімге айналдырады, оның бидайға тән «қарсы көрсеткіштері» жоқ, дені сау адамдар үшін де, денсаулығында проблемалары бар адамдар үшін де бірдей қолайлы. Жүгері сүрлемдік дақыл ретінде үлкен азықтық құндылыққа ие. Дәннің сүтті-балауыз пісу фазасындағы қозалардан алынған сүрлем тағамдық құндылығы жағынан ең жақсылардың бірі болып саналады. Жүгері жібекінен жасалған препараттар несеп айдағыш, қабынуға қарсы, холеретикалық, гемостатикалық агент ретінде бүйрек ауруларын, бауырды, урологиялық ауруларды, әртүрлі шығу тегі ісінулерін емдеуде қолданылады. Жүгері жібекінен жасалған препараттар қалыпты седативті әсерге ие, сонымен қатар тәбетті төмендетуі мүмкін. Жүгері тұқымдарының ұрықтарынан алынған жүгері майы қандағы холестерин деңгейін реттейді, оның қан тамырларының қабырғаларына шөгуін азайтады, тромбоз қаупін азайтады және холеретикалық әсерге ие. Дүниежүзілік крахмал өндірісіндегі жүгерінің үлесі шамамен 75% құрайды. Жүгерінің маңыздылығын ескере отырып, осы өсімдіктің жаңа тиімді өсу реттегіштерін жасау саласында жүйелі зерттеулер жүргізу қажет. Бұл жұмыста алифатты дикарбон қышқылдарының аммоний тұздары негізінде жүгері өсімін жеделдету үшін перспективті фитогормондарды жасау саласындағы өз зерттеулеріміздің нәтижелері берілген. Бізде синтезделген қосылыстар жүгерінің жер үсті және тамыр бөліктерінің көбеюіне ықпал етіп, оның өсуін тездететіні көрсетілген.

Түйін сөздер: жүгері, өсу реттегіштері, фитогормондар, өсу стимуляторлары, өсу заттары

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НОВЫЕ ПЕРСПЕКТИВНЫЕ РЕГУЛЯТОРЫ РОСТА КУКУРУЗЫ НА ОСНОВЕ АММОНИЕВЫХ СОЛЕЙ АЛИФАТИЧЕСКИХ ДИКАРБОНОВЫХ КИСЛОТ РЯДА C_2-C_6

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Резюме. Кукуруза — вторая по объёму продаж зерновая культура в мире (после пшеницы). Сахарная кукуруза — ценная овощная культура, входящая в число лучших овощных культур по питательной ценности и вкусовым качествам. Она обладает значительным перечнем полезных веществ: высоким содержанием витаминов А, В, С и Е, особенно большого количества фолиевой кислоты (В9), немного меньше ниацина (В3) и тиамина (В1). Из макро- и микроэлементов в кукурузе больше всего калия (270 мг) и магния (37 мг). Редкий в других продуктах элемент, содержащийся в кукурузе — золото, которое содержится в кукурузе в микродозах, но этого достаточно, чтобы питать наш мозг редким металлом, необходимым для его лучшей работы. Кукуруза сбалансирована по составу жиров, белков и углеводов, богата клетчаткой и не содержит глютена. Клетчатка помогает перистальтике кишечника, предотвращает рак. Кроме того,

отсутствие глютена делает кукурузу наиболее универсальным продуктом питания, не имеющим «противопоказаний», присущих пшенице, одинаково подходящим как для здоровых людей, так и для людей с проблемами со здоровьем. Кукуруза как силосная культура имеет большую кормовую ценность. Силос из початков в фазе молочно-восковой спелости зерна считается одним из лучших по питательной ценности. Препараты из кукурузных рылец применяются как мочегонное, противовоспалительное, желчегонное, кровоостанавливающее средство при лечении заболеваний почек, печени, урологических заболеваний, отёков различного происхождения. Препараты из кукурузных рылец оказывают умеренное успокаивающее действие, а также могут снижать аппетит. Кукурузное масло, получаемое из зародышей семян кукурузы, регулирует уровень холестерина в крови, уменьшает его отложение на стенках сосудов, снижает риск тромбозов и обладает желчегонным действием. Доля кукурузы в мировом производстве крахмала составляет около 75%. Учитывая высокую значимость кукурузы, необходимо проводить систематические исследования в области разработки новых эффективных регуляторов роста этого растения. В данной работе представлены результаты собственных исследований в области разработки перспективных фитогормонов для ускорения роста кукурузы на основе аммонийных солей алифатических дикарбоновых кислот. Показано, что синтезированные нами соединения способствуют увеличению надземной и корневой частей кукурузы и ускоряют её рост.

Ключевые слова: кукуруза, регуляторы роста, фитогормоны, стимуляторы роста, ростовые вещества

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