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# METHODS FOR REDUCING SOYBEAN STRESS IN THE CONDITIONS OF THE LEFT-BANK FOREST-STEPPE OF UKRAINE

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# АНОТАЦІЯ

*Лі Жуйцзе*. Шляхи зниження стресу сої в умовах Лівобережного Лісостепу України. – Кваліфікаційна наукова праця на правах рукопису.

Дисертація на здобуття наукового ступеня доктора філософії за спеціальністю 201 «Агрономія». – Сумський національний аграрний університет, Міністерство освіти і науки України, Суми, 2025.

**Обґрунтування вибору теми дослідження**. Соя (*Glycine max* L.) – бобова рослина, що походить зі Східної Азії, Китаю та широко культивується в усьому світі. Вона є найважливішою олійною культурою та високобілковою зерновою кормовою культурою. Виробництво сої має багатовекторний характер, зокрема для продовольчої безпеки країни, економічного зростання, соціальної стабільності та стратегічного значення.

За сучасних змін кліматичних умов та інтенсифікації сільськогосподарського виробництва вплив стресових умов на ріст і розвиток рослин різко посилився. Тож актуальною є потреба в розробленні сучасних методів визначення стресових факторів із використанням експрес-діагностики та світових розробок. Вивчення природи стресів та визначення шляхів їх зниження забезпечить реалізацію біологічного потенціалу сільськогосподарських культур.

Для підвищення стабільності врожаїв сої необхідне комплексне використання сучасних технологій, зокрема сортового підбору з урахуванням агрокліматичних особливостей регіону та застосування регуляторів росту з антистресовою дією. Ці фізіологічно активні сполуки сприяють ефективнішій

мобілізації та утилізації рухомих форм мінеральних елементів, підвищуючи загальну стійкість рослин до біотичних і абіотичних стресів, що робить актуальними дослідження в цьому напрямі.

Зауважимо, що механізм впливу засоленості та регуляторів росту в умовах контрольованого середовища на біохімічні процеси та морфологічні індикатори не вивчався. Отже, вибрана тематика є важливою й актуальною, оскільки має комплексний лабораторно-польовий підхід і в умовах Лівобережного Лісостепу не досліджувалась.

**Зв'язок роботи з науковими програмами, планами, темами.** Науково-дослідна робота виконана за завданнями тематичних планів та в межах державних наукових тем Сумського національного аграрного університету – «Особливості формування продуктивності зернобобових культур в умовах Лісостепу та Степу України» (№ 0117U006536, 2017–2022 рр.) та «Розробити сучасні способи ідентифікації стресу сільськогосподарських культур та шляхи його зниження» (№ 0121U113642, 2021–2025 рр.)

**Мета досліджень** полягає у визначенні стресу та його впливу на ріст та розвиток рослин сої як у контрольованому середовищі, так і в польових умовах Лівобережного Лісостепу України. В основу досліджень у кліматичній камері покладено визначення динаміки вмісту основних сполук як індикаторів на стресові умови та стабілізаційної дії регуляторів росту. У польових умовах це аналіз морфологічних та структурних параметрів рослин для визначення впливу регуляторів росту на зниження стресових факторів та реалізацію біологічного потенціалу сучасних сортів сої.

Відповідно до мети були поставлені такі завдання:

– виявити фізіологічну реакцію *Glycine max* L. та вплив регуляторів росту на процес проростання за умови штучно створеного сольового стресу (у кліматичній камері Хенанського інституту науки і технологій, Сіньсян, Китай);

– визначити сортові особливості формування морфологічних параметрів *Glycine max* L. за застосування регуляторів росту з антистресовою дією в умовах Лівобережного Лісостепу України;

– установити вплив регуляторів росту з антистресовою дією на продуктивність та врожайність сортів сої в умовах Лівобережного Лісостепу України;

– визначити показники якості та біохімічний аналіз зерна сої залежно від сорту та регуляторів росту з антистресовою дією в умовах Лівобережного Лісостепу України;

– розрахувати економічну та енергетичну ефективність застосування регуляторів росту за вирощування сої в умовах Лівобережного Лісостепу України.

**Об'єктом дослідження** є оцінка адаптивності проростків *Glycine max* L. до сольового стресу в штучних умовах та впливу регуляторів росту. Реакція сої залежно від сортових особливостей, погодних умов та застосування регуляторів росту.

**Предметом дослідження** є *Glycine max* L., сорти, визначення стресу, регулятори росту рослин, абіотичний стрес (засолення), контрольоване середовище в кліматичній камері Хенанського інституту науки і технологій, Сіньсян, Китай, погодні умови, структура врожаю, економічна та енергетична ефективність застосування регуляторів росту за вирощування сої в умовах Лівобережного Лісостепу України.

**Наукова новизна отриманих результатів.** Уперше досліджено ферментативну активність та механізм морфологічної адаптації проростків *Glycine max* L. за штучно створених умов засоленості (0, 50, 75, and 100 mM NaCl). Уперше проведено комплексні дослідження щодо вивчення впливу регуляторів росту на ріст та розвиток *Glycine max* L. в умовах кліматичної камери та в польових умовах. Виявлено сортові (Амадеа, Ауреліна, Беттіна, Ментор, Навігатор) особливості формування продуктивності сої за використання регуляторів росту в умовах Лісостепу України. Оптимізовано технологію вирощування сої для умов Лісостепу України. Набули подальшого розвитку питання впливу погодних та стресових умов на особливості росту, розвитку та продуктивність сої залежно від сорту та позакореневого застосування регуляторів росту. Обґрунтовано економічну та енергетичну ефективність вирощування сортів сої за застосування регуляторів росту.

**Практичне значення отриманих результатів.** Основні компоненти досліджень перевірено в умовах Лівобережного Лісостепу України, зокрема на землях господарств СЛК-11 (Сумська обл.) та «Родина» (Полтавська обл.)

на площі 42 га.

Виробництву рекомендовано технологію вирощування сої, яка забезпечила врожайність зерна 2,89 та 2,91 т/га відповідно. Підтверджено її ефективність, а саме: умовно чистий прибуток – 24 928 та 25 534 грн/га; рентабельність виробництва – 140,2 та 146,7 % відповідно.

**Методи дослідження.** У процесі виконання досліджень було використано комплекс загальнонаукових і спеціальних методів. У штучній кліматичній камері листя *Glycine max* L. обробляли гліцин бетаїном (GB) концентрацією 100 мг/л та Amino VG ANTISRESS концентрацією 250 мл/год (дворазово). Зразки відбирали, коли в розсади виросли три листки, із триразовим повторенням для кожної групи. CK – контрольна група, Amino VG ANTISRESS та гліцин бетаїн (GB) – експериментальні групи. Фізіологічними показниками в штучній кліматичній камері були вміст хлорофілу, активність ферментів (SOD, CAT, APX), малоновий діальдегід та відносна провідність.

Візуальний метод застосовували для проведення фенологічних спостережень за проходженням основних фаз росту й розвитку рослин сої. Вимірювально-ваговий метод використовували для визначення біометричних показників, зокрема висоти рослин, площі листкової поверхні, кількості та маси бобів, маси насіння з однієї рослини (індивідуальної продуктивності), а також урожайності сої.

Хімічні методи застосовували для визначення вмісту хлорофілу (Ulab 502) та показників якості насіння, зокрема вмісту білка й жиру (SupNir 2700).

Математично-статистичний метод передбачав проведення дисперсійного аналізу для оцінювання достовірності отриманих результатів (Statistica 9.0). Розрахунково-порівняльний метод використовували для визначення економічної та енергетичної ефективності застосування регуляторів росту в посівах сої.

**Результати.** Узагальнено результати досліджень міжнародної наукової спільноти щодо впливу різних стресів на фізіологічні процеси та продуктивність рослин. Здійснено аналіз та узагальнення сучасних технологій вирощування *Glycine max*., зокрема використання систем живлення та регуляторів росту рослин. Із урахуванням змін клімату та факторів навколишнього середовища використання регуляторів росту рослин виявилося важливим резервом для стабілізації розвитку сільськогосподарських культур та підвищення врожайності, зокрема *Glycine max* L.

У дисертаційній роботі наведено теоретичне узагальнення й вирішення наукового завдання щодо вивчення сучасних методів визначення стресу та його впливу на ріст та розвиток рослин сої як у контрольованому середовищі, так і в польових умовах Лівобережного Лісостепу України. В основу покладено вивчення сортових особливостей формування продуктивності рослин сої за застосування різних регуляторів росту з антистресовою дією. Отримані результати 2021–2023 років досліджень дозволяють зробити такі висновки.

Виходячи з суми активних температур та кількості опадів, нами було розраховано ГТК для періодів вегетації сої (травень–вересень 2021–2023 рр.). Так, найбільш посушливі умови були в 2023 році, про що свідчить ГТК = 1,19. Нормальним за зволоженням був 2021 рік (ГТК = 1,23), тоді як 2022 рік був вологим, що підтверджує розрахований ГТК = 1,44.

Отже, були створені реальні умови для виявлення реалізації біологічного потенціалу рослин сої та формування врожаю та його якості за відмінних метеорологічних параметрів.

Новизна досліджень полягає в комплексному вивченні впливу стресових факторів на ріст та розвиток *Glycine max* L. Уперше проведено вегетаційні дослідження в кліматичній камері Хенанського інституту науки та технологій (м. Сіньсян, Китай) та польові дослідження в навчально-науковому комплексі Сумського НАУ (м. Суми, Україна). Змодельовано стресові умови (підвищена засоленість 0, 50, 75, 100 ммоль/л NaCl) та вивчено вплив регуляторів росту з антистресовою дією. Визначено динаміку вмісту основних сполук як індикаторів на стресові умови. Виявлено вплив регуляторів росту на зниження стресових факторів та реалізацію біологічного потенціалу сучасних сортів сої.

Виявлено, що в контрольованих умовах (кліматична камера) регулятор росту Amino VG-Antistress сприяв підвищенню стійкості до сольового стресу *Glycine max* L. сорту Zheng 196 на стадії сходів. Регулятор росту посилював антиоксидантну здатність молодих проростків сої та послаблював наслідки сольового стресу. Ефект був найбільш вираженим за концентрації солі

100 ммоль/л, що підтверджує здатність регулятора покращувати солестійкість сої.

За концентрацій солі 50 ммоль/л, 75 ммоль/л та 100 ммоль/л активність супероксиддисмутази, аскорбатпероксидази та каталази збільшилася. За концентрації солі 100 ммоль/л активність супероксиддисмутази збільшилася на 5,78 %, хоча це збільшення не було істотним порівняно з варіантом, де використовували регулятори росту. На противагу цьому, активність аскорбатпероксидази та каталази показала значне збільшення на 30 % та 35,96 % відповідно за тієї самої концентрації солі, тоді як вміст малонового діальдегіду помітно знизився на 33 %. Це продемонструвало, що за високих концентрацій солі регулятор значно посилює антиоксидантну здатність проростків *Glycine max* L. та зменшує окиснення мембран.

Нами було досліджено основні сполуки (ферменти), які є індикаторами стійкості рослинних організмів до підвищеної засоленості. Ключові результати продемонстрували ефективність регулятора росту Amino VG-Antistress та підтвердили його потенціал для підвищення стійкості *Glycine max* L. Водночас результати є актуальними для вчених, які прагнуть розробити речовини з подібним складом для створення нових, ефективніших регуляторів росту з антистресовими властивостями. Результати пропонують додаткові докази, що підтверджують фізіологічну роль мелатоніну та забезпечують теоретичну основу для його застосування в підвищенні солестійкості в сільськогосподарській практиці. Ці результати мають ключове значення для розроблення нових регуляторів росту та підтверджують їх доцільність у вирішенні актуальної проблеми засоленості ґрунту.

За результатами польових досліджень виявлено, що основні параметри габітусу та продуктивності *Glycine max* L. (висота, площа листкової поверхні) значно варіювали залежно від погодних умов, сортових особливостей та застосування регуляторів росту. Найбільшу висоту (71,4 см) сформував сорт Беттіна, а найвищий вміст хлорофілів (2,46 мг/г сирої маси) та найбільшу площу листкової поверхні (36,3 тис. м²/га) – сорт Ауреліна. Застосування препарату Antistress забезпечило найвищі показники всіх морфологічних параметрів.

Найвищі показники продуктивності були сформовані в 2023 році: кількість насіння (32,1 шт.); індивідуальна продуктивність (6,26 г). Серед сортів найбільшу кількість насіння (32,0 шт.) сформував сорт Навігатор, тоді як найбільшу масу насіння (5,63 г) – сорт Ауреліна. Застосування регулятора росту Sugar Mover забезпечило найбільший показник кількості насіння (31,6 шт.), а Antistress – найвищу індивідуальну продуктивність рослин (5,65 г).

У середньому найвищий показник урожайності *Glycine max* L. за умов 2023 року – 3,23 т/га. Лідер – сорт Ауреліна (2,90 т/га). Максимальну врожайність (2,91 т/га) отримали за застосування препарату Antistress. Умови 2023 року були найсприятливішими для формування маси 1 000 насінин – 194,8 г. Найбільшу масу 1 000 насінин сформував сорт Беттіна – 189,3 г. Застосування регуляторів росту, зокрема Amino VG Antistress, сприяло значному збільшенню цього показника (185,2 г).

За результатами біохімічного аналізу на інфрачервоному аналізаторі SupNir 2700 визначено, що на хімічний склад зерна сої впливають як генетичний потенціал сорту, так і агротехнічні прийоми. Найвищий вміст білка (42,0 %) було зафіксовано в сорту Ауреліна за застосування препарату Sugar Mover, а найвищий вміст жиру (19,5 %) – у сорту Ментор на контрольному варіанті, що свідчить про зворотну залежність між вмістом білка та жиру під впливом регуляторів росту. За результатами біохімічного аналізу найбільші показники вмісту як незамінних, так і замінних амінокислот були зафіксовані в сорту Ментор за використання препарату Sugar Mover, що свідчить про високу ефективність цієї комбінації для підвищення біологічної цінності зерна.

За результатами економічних розрахунків виявлено, що максимальний рівень рентабельності 161 % було отримано за вирощування сорту сої Ауреліна на контролі. Максимальну масу умовно чистого прибутку з одиниці площі (27 228 грн/га) було отримано за вирощування сої сорту Ауреліна та застосування регулятора росту з антистресовою дією Antistress. Максимальні середні значення коефіцієнтів енергоефективності було отримано за вирощування сої сорту Ауреліна та застосування регулятора росту з антистресовою дією Antistress (Кее 3,33).

Отже, за результатами досліджень в умовах контрольованого середовища доведено фізіологічну роль мелатоніну та ефективність його застосування в підвищенні солестійкості в сільськогосподарській практиці. Ці результати мають практичне значення для розроблення нових регуляторів росту та підтверджують їх ефективність у вирішенні актуальної проблеми засоленості ґрунту. Доцільно дослідити довгостроковий вплив регуляторів росту на ріст та врожайність сої за різних умов навколишнього середовища та вивчити його потенційну взаємодію з іншими стресовими факторами для розроблення комплексних підходів до підвищення стійкості культури.

Для отримання максимального врожаю сої з високими показниками якості зерна, найвищої економічної та біоенергетичної ефективності в умовах Лівобережного Лісостепу України технологія вирощування повинна передбачати використання сорту Ауреліна за позакореневого підживлення в $BBCH_{60–69}$ регулятором росту Антистрес (1,7 кг/га).

***Ключові слова:*** соя, сорти, регулятори росту, обробка насіння, позакореневе внесення, стресс, солестійкість, морфологія та параметри продуктивності, врожайність, якість, білок, жир, економічна та енергетична ефективність.

## ABSTRACT

***Li Ruijie.*** Methods for reducing soybean stress in the conditions of the Left-bank forest-steppe of Ukraine. – Manuscript.

Thesis for scientific degree of doctor of philosophy (PhD): Specialty 201 – Agronomy. – Sumy National Agrarian University, Ministry of education and science of Ukraine – Sumy, 2025.

**Rationale for choosing the research topic.** Soybean (*Glycine max* L.) is the most important global oil crop and high-protein grain-feeding crop. The soybean industry has three attributes of economy, politics and society at the same time, and is of great importance to the national food security, economic growth and social stability, as well as strategic significance. Soybean is a leguminous plant native to East Asia and China, and widely cultivated across the globe.

The outcomes of the research conducted by the international scientific community on the effects of different stresses on plant physiological processes and productivity have been summarized. The analysis and summary of modern *Glycine max* L. cultivation technology, especially the use of nutritional systems and plant growth regulators (PGR) have been made. With the impact of climate change and environmental factors, the use of plant growth regulators (PGRs) has proven to be an important reserve for stabilizing crop development and improving crop yields, especially in *Glycine max* L.

With modern changes in climatic conditions and intensification of agricultural production, the impact of stress conditions on plant growth and development has increased dramatically. Therefore, there is an obvious need to

develop modern methods for determining stress factors using the global developments. Studying the nature of stresses and developing the ways of their reduction will ensure the realization of the biological potential of agricultural crops.

To increase the stability of soybean yields, it is essential to use in its entirety modern technology, such as varietal selection taking into account the agroclimatic characteristics of the region and the use of growth regulators with anti-stress action. These physiologically active compounds contribute to more effective mobilization and utilization of mobile forms of mineral elements, increasing the overall resistance of plants to biotic and abiotic stresses, which makes research in this area relevant.

It should be noted that the study of the mechanism of influence of salinity and growth regulators in a controlled environment on biochemical processes and morphological indicators has not been carried out, which makes this research to be of current concern. Therefore, the selected topic is important and of great current interest, since it has a comprehensive laboratory-field approach and has not been studied in the conditions of the Left-Bank Forest-Steppe.

**Connection of the work with scientific programs, plans, topics.** The research was carried out according to the objectives outlined in the thematic plans and within the state scientific topics of Sumy National Agrarian University - “Features of the Formation of the Productivity of Leguminous Crops in the Conditions of the Forest-Steppe and Steppe of Ukraine”, (No. 0117U006536, 2017–2022) and “Development of Modern Methods for Identifying Stress in

Agricultural Crops and Ways of Its Reduction” (No. 0121U113642, 2021-2025).

**Goal of the research** is to determine stress and its impact on the growth and development of soybean, both in a controlled environment and in the field conditions of the Left-Bank Forest-Steppe of Ukraine. In the climatic chamber, the basis is the determination of the dynamics of the content of basic compounds as indicators of stress conditions and the stabilizing effect of growth regulators. In the field conditions, this is the analysis of morphological parameters to determine the influence of growth regulators on the reduction of stress factors and the realization of the biological potential of modern soybean varieties.

To solve the goal, the following objectives were set:

- To reveal the physiological reaction of *Glycine max* L. and the influence of growth regulators on the germination process under artificially created salt stress (in a controlled environment, PRC).
- To determine the varietal features of the formation of morphological parameters of *Glycine max* L. under the use of growth regulators with anti-stress effect;
- To establish the influence of growth regulators with anti-stress effect on the productivity and yield of soybean varieties;
- To determine the quality indicators and biochemical analysis of soybean grain depending on the variety and growth regulators with anti-stress effect;
- To calculate the economic and energy efficiency of the use of growth regulators for growing soybeans in the conditions of the Left-Bank Forest-Steppe of Ukraine.

**Object of the research** is to evaluate the adaptability of soybean seedlings to salt stress under artificial conditions and the effects of growth regulators. The response of soybeans depends on variety characteristics, growth regulators, and weather conditions.

**Subject of the research** is *Glycine max* L., determining stress, types of plant growth regulators, artificial conditions, abiotic stress (salinity), weather conditions, yield composition, and cultivation techniques, as well as the economic and energy efficiency of planting soybean growth regulators in the Left-Bank Forest Steppe of Ukraine and an artificial climatic chamber at the Henan Institute of Science and Technology, Xinxiang, China.

**Scientific novelty of the outcomes obtained.** For the first time, the enzymatic activity and the mechanism of morphological adaptation of *Glycine max* L. seedlings under the artificially created salinity conditions (0, 50, 75, and 100 mM NaCl) have been investigated. The comprehensive research has been firstly conducted to study the influence of regulators on the growth and development of *Glycine max.* under the climatic chamber and field conditions. The varietal (Amadea, Aurelina, Bettina, Mentor, Navigator) features of soybean productivity formation when using growth regulators in the conditions of the Forest-Steppe of Ukraine have been identified. The technology of soybean cultivation for the conditions of the Forest-Steppe of Ukraine has been optimized. The issue of the influence of weather and stress conditions on the characteristics of growth, development and productivity depending on the variety and the use of growth regulators for foliar application has been further developed. The economic and energy efficiency of growing soybean varieties using growth regulators has been substantiated.

**Practical significance of the outcomes obtained.** The main components of the research were verified in the conditions of the Left-Bank Forest-Steppe of Ukraine, in particular, on the lands of the following farms: SLK-11 (Sumy Region) and Rodina (Poltava Region) on an area of 42 hectares.

The soybean growing technology, which has ensured grain yields of 2.89 and 2.91 t/ha, respectively, is recommended for production. Its effectiveness has been confirmed as follows: conditional net profit – 24. 928 and 25. 534 UAH/ha; production profitability – 140.2 and 146.7%, respectively.

**Research methods.** In the process of conducting the research, a complex of general scientific and special methods was used. In artificial environmental chamber, leaves were treated with 100mg/L concentration of glycine betaine (GB) and Amino VG ANTISRESS at a concentration of 250 ml/h, once daily, twice. Samples were taken when the seedlings grew three leaves and one needle, with three-time repetition for each group. CK is the control group, Amino VG ANTISRESS and glycine betaine (GB) are the experimental groups. The physiological indicators in artificial climate chamber include chlorophyll content, enzyme activity (SOD, CAT, APX), malondialdehyde, and relative conductivity.

The visual method was used to conduct phenological observations of the main phases of growth and development of soybean plants. The measuring and weighing method was used to determine biometric indicators, in particular plant height, leaf surface area, number and mass of beans, mass of seeds from one plant (individual productivity), as well as soybean yield.

The chemical methods were used to determine the chlorophyll content and seed quality indicators, in particular protein and fat content. The mathematical and statistical method involved conducting a variance analysis to assess the reliability of the results obtained. The calculation and comparative method was used to determine the economic and energy efficiency of the use of mineral fertilizers and foliar feeding in soybean crops.

**Scientific outcomes.** The thesis provides for a theoretical generalization and resolution of the scientific task concerning the study of modern methods for determining stress and its impact on the growth and development of soybean plants, both in controlled environments and under the field conditions of the Left-Bank Forest-Steppe of Ukraine. The study is based on examining the variety-specific characteristics of soybean productivity formation when applying various growth regulators with anti-stress effects. The results obtained from the research conducted between 2021 and 2023 enable to make the following conclusions.

The research outcomes and their novelty consist in a comprehensive study of the influence of stress factors on the growth and development of *Glycine max*. The vegetative (in the climatic chamber) studies were conducted at the Henan Institute of Science and Technology (PRC) and field studies were conducted at the educational and scientific complex of Sumy National Agrarian University (Ukraine). The stress conditions (increased salinity) were modeled, and the effect of growth regulators with anti-stress action was studied. The dynamics of the content of basic compounds as indicators of stress conditions was determined. The influence of growth regulators on the reduction of stress factors and the realization of the biological potential of modern soybean varieties was revealed.

It has been established that the north-eastern Forest-Steppe zone of Ukraine is favorable for growing soybeans. According to the analysis of weather conditions, the years studied were excellent in terms of meteorological parameters, which made it possible to detect the realization of the biological potential of soybeans. The driest conditions were in 2023, as evidenced by GTK = 1.19. The normal humidity was 2021 (GTC=1.23). The year 2022 was humid, confirming the calculated GTC=1.44.

The research was conducted in an artificial climatic chamber at the Henan Institute of Science and Technology, Xinxiang, China. The Amino VG-Antistress regulator was evaluated for its ability to improve the salt tolerance of the Zheng 196 soybean variety at the seedling stage. The regulator enhanced the antioxidant capacity of Zheng 196 soybean seedlings and mitigated the effects of salt stress. The effect was most pronounced at a salt concentration of 100 mmol/L, confirming the regulator’s ability to improve soybean salt resistance.

According to the climatic chamber research under the salt concentrations of 50 mmol/L, 75 mmol/L, and 100 mmol/L, the activities of superoxide dismutase, ascorbate peroxidase, and catalase all increased. At a salt concentration of 100 mmol/L, superoxide dismutase activity increased by 5.78%, though this increase was not effect of a growth regulator significant. In contrast, ascorbate peroxidase and catalase activities showed significant increases of 30% and 35.96%, respectively, at the same salt concentration, while malondialdehyde content notably decreased by 33%. This demonstrated that under high salt concentrations, the regulator significantly enhanced the antioxidant capacity of soybean seedlings and reduced membrane oxidation.

The main compounds (enzymes) that are the indicators of resistance of plant organisms to increased salinity were studied. The key findings demonstrated the effectiveness of the regulator and highlighted its potential for increasing resistance. Along with this, the results are relevant for scientists seeking to develop substances with similar compositions to create newer, more effective growth regulators with anti-stress properties. The results offer additional evidence supporting the physiological role of melatonin and provide a theoretical foundation for its application in enhancing salt tolerance in agricultural practices. These findings are crucial for advancing the development of new growth regulators and provide scientific evidence supporting their feasibility in addressing the growing challenge of soil salinity.

The field research results revealed that the main plant morphology and productivity parameters (height, leaf area) varied significantly depending on weather conditions, variety characteristics, and growth regulator application. The Bettina variety achieved the greatest height (71.4 cm), while the Aurelina variety exhibited the highest chlorophyll content (2.46 mg/g fresh weight) and leaf area (36.3 $m^2$/ha). Application of the Antistress preparation yielded the highest values for all morphological parameters.

Another important indicator of crop structure is the mass and quantity of seeds from one plant. The highest productivity indicators were achieved in 2023: seed count (32.1 pieces); individual productivity (6.26 g). Among the varieties, Navigator produced the highest seed count (32.0 pieces), while Aurelia yielded the highest seed mass (5.63 g). The application of the growth regulator Sugar Mover resulted in the highest seed count (31.6 pieces), while Antistress achieved the highest individual plant productivity.

The average highest yield indicator under the conditions of 2023 was 3.23 t/ha. The leader was the variety Aurelina (2.90 t/ha). The highest yield (2.91 t/ha) was achieved at the level of applying the Antistress preparation. The conditions of 2023 were the most favorable for forming a 1000-grain weight of 194.8 g. The variety Bettina formed the largest 1000-grain weight at 189.3 g. The application of growth regulators, including Amino VG Antistress, significantly increased this indicator (185.2 g).

It was established that both the genetic potential of the variety and agronomic techniques influence the chemical composition of soybean grain. The highest protein content (42.0%) was recorded in the Aureliana variety with the application of Sugar Mover, while the highest fat content (19.5%) was observed in the Mentor variety under control conditions, indicating an inverse relationship between protein and fat content under the influence of growth regulators. Biochemical analysis results showed the highest levels of both essential and non-essential amino acids in the Mentor variety with the use of Sugar Mover, demonstrating the high effectiveness of this combination for enhancing the biological value of the grain.

The economic calculations revealed that the highest profitability level of 161% was achieved by cultivating the Aurelia soybean variety under control conditions. The maximum conditional net profit per unit area (27,228 UAH/ha) was obtained by growing the Aurelia soybean variety and applying the stress-protective growth regulator Antistress. The highest average energy efficiency coefficients were achieved by cultivating the Aurelia soybean variety and applying the stress-protective growth regulator Antistress (Kee 3.33).

**Keywords:** soybean, variety, growth regulators, seed treatment, foliar feeding, stress, salt tolerance, morphology and productivity parameters, yield, quality, protein, fat, economic and energy efficiency.

# LIST OF THE APPLICANT'S PUBLICATIONS

## Articles in scientific professional publications of Ukraine category «B»:

1. **Li RuiJie**, Dudka A. A. Varietal features of soybean productivity formation for the use of growth regulators with anti-stress action in the conditions of the Left-Bank Forest-Steppe of Ukraine. *Tavriiskyi Scientific Bulletin*. 2024. No. 138. Pp. 88–95. https://www.tnv-agro.ksauniv.ks.ua/archives/138_2024/13.pdf

2. **Li RuiJie**, Melnyk A. V., Dudka A. A., Romanko Yu. O., Melnyk T.I. Varietal features of formation of morphological parameters of soybean plants with the use of growth regulators with anti-stress action in the conditions of the Left-Bank Forest-Steppe of Ukraine. *Tavriiskyi Scientific Bulletin*. 2024. No. 139. Pp. 109–117. https://www.tnv-agro.ksauniv.ks.ua/archives/139_2024/part_1/17.pdf

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**CONTENT**

# LIST OF SYMBOLS AND ABBREVIATIONS

**GB**– glycine betaine

**APX**– ascorbic acid peroxidase

**CAT** – catalase

**MDA** – malondialdehyde

**POD** – peroxidase

**ROS**– reactive oxygen species

**SOD**– superoxide dismutase

# INTRODUCTION

Soybean (*Glycine max* L.) is the global most important oil crop and high-protein grain-feeding crop. The soybean industry has three attributes of economy, politics and society at the same time, and is of great importance to a country's food security, economic growth and social stability and strategic significance. Soybean is a leguminous plant native to East Asia, native to China, and widely cultivated across the globe.

Soybean can be processed into bean products such as tofu, soybean milk, rolls of dried bean milk creams, etc., and soybean isoflavones can also be extracted. Among them, fermented bean products include fermented bean curd, stinky tofu, bean paste, soy sauce, lobster sauce, natto, etc. Non fermented bean products include water tofu, dried tofu, bean sprouts, marinated bean products, fried bean products, smoked bean products, fried marinated bean products, frozen bean products, dried bean products, etc. In addition, soy flour is a high protein food that replaces meat, and can be made into various foods, including baby food [1, 2].

Soybean oil produced by soybean processing is an important type of oil used. It is an important source of unsaturated fat acids in the human body, can reduce cholesterol, and has an auxiliary therapeutic effect on hypertension and cardiovascular disease. Refined soybean oil extracted from soybean oil is mainly used in food. Soybean oil contains a large amount of linoleic acid. Linoleic acid is an essential fatty acid in the human body and has important physiological functions. Lack of linoleic acid in young children can lead to dry skin, thickened scales, and delayed growth and development; lack of linoleic acid in elderly people can lead to cataracts and cardiovascular and cerebrovascular diseases [3, 4].

Livestock feed is one of the main uses of soybeans, mainly in the form of soybean meal. About 85% of soybean meal is used for poultry and pig farming, and the various amino acids contained in soybean meal are suitable for the nutrition needs of poultry and pigs. For example, in the European Union, although soybean meal does not account for the majority of livestock feed weight, it provides about 60% of the protein in livestock feed. However, in the United States, 70% of soybean production is used for animal feed, and the poultry industry is the largest livestock industry for soybean consumption [5, 6, 7].

Soybeans are not only crops and strategic materials with high economic value, but also indispensable in our daily life and production, playing an important role in human health and industrial production. The improvement in the people’s living standards and the progress of production levels lead to a increase in the demand for soybeans, and therefore, improvement in the yield and quality of soybeans are crucial for agricultural production.

With modern changes in climatic conditions and intensification of agricultural production, the impact of stress conditions on plant growth and development has increased dramatically. Therefore, there is an obvious need to develop modern methods for determining stress factors using the global developments. Studying the nature of stresses and developing ways to reduce them will ensure the realization of the biological potential of agricultural crops.

To increase the stability of soybean yields, it is essential to comprehensively use modern technology, such as varietal selection taking into account the agroclimatic characteristics of the region and the use of growth regulators with anti-stress action. These physiologically active compounds contribute to more effective mobilization and utilization of mobile forms of mineral elements, increasing the overall resistance of plants to biotic and abiotic stresses, which makes research in this area relevant.

It should be noted that the study of the mechanism of the influence of salinity and growth regulators in a controlled environment on biochemical processes and morphological indicators has not been carried out, which makes these studies relevant. Therefore, the selected topic is important and relevant, since it has a comprehensive laboratory-field approach and has not been studied in the conditions of the Left-Bank Forest-Steppe.

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**Goal of the research** is to determine stress and its impact on the growth and development of soybean, both in a controlled environment and in the field conditions of the Left-Bank Forest-Steppe of Ukraine. In the climatic chamber, the basis is the determination of the dynamics of the content of basic compounds as indicators of stress conditions and the stabilizing effect of growth regulators. In the field conditions, this is the analysis of morphological parameters to determine the influence of growth regulators on the reduction of stress factors and the realization of the biological potential of modern soybean varieties.

To solve the goal, the following objectives were set:

- To reveal the physiological reaction of Glycine max. and the influence of growth regulators on the germination process under artificially created salt stress (in a controlled environment, PRC).

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- To establish the influence of growth regulators with anti-stress effect on the productivity and yield of soybean varieties;

- To determine the quality indicators and biochemical analysis of soybean grain depending on the variety and growth regulators with anti-stress effect;

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**Object of the research** is to evaluate the adaptability of soybean seedlings to salt stress under artificial conditions and the effects of growth regulators. The response of soybeans depends on variety characteristics, growth regulators, and weather conditions.

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production profitability – 140.2 and 146.7%, respectively.

**Personal contribution of the applicant**. The personal contribution of the applicant consists in searching, analyzing and systematizing scientific works of domestic and foreign scientists; performing the experimental part of the research, including conducting field and laboratory experiments; applying modern mathematical and statistical methods of data processing to generalize and interpret the results; forming scientifically sound conclusions and developing practical recommendations for production. An important component is the vegetation research in the controlled environment, which the applicant has conducted in the climatic chamber at the Henan Institute of Science and Technology, Xinxiang, China. Together with the scientific supervisor, all the main provisions of the PhD thesis submitted for defense have been summarized and worked out.

**Approbation of the results of the dissertation**. The main results of the PhD thesis research were approved at the international scientific and practical conferences, in particular: Honchariv Readings (Sumy, 2021–2025); Ukrainian Scientific Conference of Students and Postgraduates, dedicated to the International Student Day (Sumy, November 17–21, 2025).

**Publications.** The main provisions of the PhD thesis are covered in 8 scientific works, in particular: 1 article in a publication indexed in the Scopus database (Q-3); 3 articles in the Ukrainian professional scientific publications of Category B; 4 abstracts of reports of scientific and practical conferences.

**Structure and scope of the PhD thesis**. The PhD thesis consists of an introduction, five chapters, conclusions, recommendations for production, a list of used sources and appendices. The total volume of the work is 184 pages. The work contains 16 tables, 13 figures and 12 appendices. The list of used sources includes 237 names, 192 of which are given in Latin.

# LIST OF THE APPLICANT'S PUBLICATIONS

## Articles in scientific professional publications of Ukraine category «B»:

1. **Li RuiJie**, Dudka A. A. Varietal features of soybean productivity formation for the use of growth regulators with anti-stress action in the conditions of the Left-Bank Forest-Steppe of Ukraine. *Tavriiskyi Scientific Bulletin*. 2024. No. 138. Pp. 88–95.

https://www.tnv-agro.ksauniv.ks.ua/archives/138_2024/13.pdf

4. **Li RuiJie**, Melnyk A. V., Dudka A. A., Romanko Yu. O., Melnyk T.I. Varietal features of formation of morphological parameters of soybean plants with the use of growth regulators with anti-stress action in the conditions of the Left-Bank Forest-Steppe of Ukraine. *Tavriiskyi Scientific Bulletin*. 2024. No. 139. Pp. 109–117.

https://www.tnv-agro.ksauniv.ks.ua/archives/139_2024/part_1/17.pdf

5. **Ruijie, L**., Sorokolit, Ye., Melnyk, A., Dudka, A., & Butenko, S. Effect of a growth regulator on the salt resistance of soybean Zheng 196 at the seeding stage. Plant and Soil Science. *Plant and Soil Science***.** 2024. No. 4 (15). Pp. 40–49.

https://doi.org/10.31548/plant4.2024.40

## Scopus and WoS publications:

4. Andrii Melnyk, Anhelina Dudka, Yuriy Romanko, **Li Ruijie,** Yevhen Sorokolit, Tetiana Melnyk, Vika Chervona. Varietal features of the formation of quality indicators and amino acid composition of soybean grain under the conditions of the left-bank forest-steppe of Ukraine. // *Journal of Ecological Engineering* 2025, 26 (5), 366–376. (Q-3)

https://doi.org/10.12912/27197050/203372

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5. **RuiJie Li**., Brunov M.I., Dudka A.A. Factors affecting soybean yield under drought stress // International Scientific and Practical Conference “HONCHARIVSKI CHYTANNIA”, Ukraine, Sumy National Agrarian University, 25 May 2021. Pp. 108-109.

6. **Li Ruijie**, Brunov Maksym, Chen rui, Huang zhaoxin. Effecets of environment factor for the growth of soybean plant // Material of the International Scientific and Practical CONFERENCE “HONCHARIVSKI CHYTANNIA” dedicated to the 93th Anniversary of Doctor of Agricultural Sciences Professor Mykola Demianovych Honcharov, 25 May 2022. – Pp. 86–88.

7. Melnyk A.V., **Li Ruijie**, Sorokolit Ye. M. Influence of weather conditions on photosynthetic activity of soybean plants in the conditions of the Left-Bank Forest-Steppe of Ukraine // Material of the International Scientific and Practical CONFERENCE “HONCHARIVSKI CHYTANNIA” dedicated to the 96th Anniversary of Doctor of Agricultural Sciences Professor Mykola Demianovych Honcharov, 23–24 May 2025. – Pp. 74–75.

8. **Li Ruijie**, Sorokolit E. M., Yurchenko E. S. The level of realization of the biological potential of soybean varieties under different weather conditions // Materials of the Ukrainian scientific conference of students and postgraduates dedicated to the International Student Day – (November 17-21, 2025). – Sumy, 2025. – P. 23.

# SECTION 1
# COMPOSITION OF MODERN CULTIVATION TECHNIQUES OF SOYBEAN (*GLYCINE MAX*.L.) AND ITS REPONSE TO STRESS (LITERATURE REVIEW)

## 1.1. Status and prospects of growing soybean (*Glycine max.* L.)

At present, the soybean planting area in 98 countries and regions across the globe is 127 million hectares, with a yield of 353 million tons. The top five countries in terms of planting area are Brazil, the United States, Argentina, India, and China, with soybean planting area accounting for 85.8% of the global total soybean planting area [8]. Since 2000, the global soybean planting area has rapidly increased from 73.44 million hectares in 2000 to 113 million hectares in 2015, constituting an increase of 53.8%. Among them, American (mainly produced by the United States, Brazil, Canada, and Argentina) is the region with the largest soybean planting area in the world – a planting area of over 5000 $hm^2$, accounting for over 70% of the global planting area; the planting area in Asia exceeds 16 million hectares, accounting for approximately 24% of the global soybean planting area, with the main planting countries being China and India; the soybean planting area in Europe and Africa is less than 2 million hectares, accounting for approximately 2.5% of the global soybean planting area [9, 10, 11].

The American countries such as the United States, Brazil, and Argentina mainly focus on developing genetically modified soybeans. Due to their seasonal climate, genetic technology, and management measures, the future development trend will continue to develop genetically modified soybeans, leveraging their low planting costs and high yields. With the implementation of the Chinese Belt and Road Initiative, Ukraine, as the world's third largest grain exporter, is actively cooperating with China to increase its share of soybean exports [12]. Despite the fact that India has also the idea of exporting soybeans to China, its non-genetically modified soybean production is too low-scale to meet domestic demand, and cannot be achieved in the short term [13]. Countries across the globe have different attitudes towards genetically modified soybeans, and countries such as the Americas hold an open attitude. However, in July 2016, the United States signed the mandatory labeling of genetically modified foods bill stipulating for mandatory labeling of food containing genetically modified ingredients [14]. In addition, countries such as Canada and Argentina adopt voluntary labeling of genetically modified foods [15, 16]. The EU requires that genetically modified ingredients exceed 0.9%, and Brazil requires that genetically modified ingredients exceed 1% to be labeled [16]. In 2001, Japan passed regulations requiring the labeling of genetically modified foods [17]. Many countries in the European Union, China, Japan, South Korea, Russia, and Southeast Asia also impose strict restrictions on genetically modified soybean food.

## 1.2. Systematic and structural features of the soybean (*Glycine max*.L) plant

The soybean genus can be divided into two subgenus, Glycine and Soja. The Soja subgenus includes cultivated soybean G. max and wild soybean, which are considered separate species of G. soja or subspecies of G. max subsp. soja. Cultivated soybeans and wild soybeans are annual plants [18, 19].

Soybeans generally refer to their seeds. Soybeans are divided into five categories based on their seed coat color and shape: yellow soybeans, green soybeans, black soybeans, and feed soybeans. Yellow soybean is the most widely planted variety among soybeans [20, 21].

Yellow soybeans are most commonly used for making various soy products, brewing soy sauce, and extracting protein. Soybean residue or ground into coarse powder is also commonly used in poultry and livestock feed. Green soybeans are soybeans with a green seed coat. According to the color of its cotyledons, it can be further divided into two types: green skinned green kernel soybeans and green skinned yellow kernel soybeans [22]. Green soybean is rich in unsaturated fat acid and soybean lecithin, saponin, protease inhibitor, isoflavone, molybdenum, selenium and other anti-cancer ingredients, protein and fiber. It is also one of the main sources of vitamin A, vitamin C, vitamin K and vitamin B for human consumption [23]. Black beans are the black seeds of the soybean plant in the leguminous family. Black beans have a protein content of 36% and are easy to digest, which is of great significance for meeting the human body's protein needs, the fat content is 16%, mainly containing unsaturated fat acids, and the absorption rate is up to 95%. In addition to meeting the needs of the human body for fat, it also has the function of reducing cholesterol in the blood. Black beans are rich in vitamins, vitellin, and melanin, among which the B and E vitamins are high in content and have nutritional and health benefits. Black beans also contain abundant trace elements, which are essential for maintaining functional integrity, delaying aging, reducing blood viscosity, and meeting the brain's demand for trace substances [24, 25]. Forage beans are annual herbaceous plants in the leguminous family and a type of feed in the soybean genus with a developed root system where the stem is above 150cm in height, initially erect, with a trailing upper part, densely covered with yellow long hard hairs [26].

The first stage of soybean growth is germination. When the embryonic root of the seed appears, this is the first stage of root growth, which occurs within the first 48 hours under ideal growth conditions [27]. The first photosynthetic structure, namely cotyledons, develops from the hypocotyl, which is the first plant structure to appear in the soil. These cotyledons are both leaves and a source of nutrients for immature plants, providing seedling nutrition for the first 7 to 10 days.

Soybeans, as annual herbs, are 30-90 cm tall. The stem is thick and erect, or the upper part is nearly intertwined, with more or less edges on the upper part, densely covered with brown long hard hairs. Leaves usually have 3 leaflets; stipules broadly ovate, acuminate, 3-7 mm long, veined, covered with yellow pubescence; The petiole is 2-20 cm long, sparsely pilose or angular when young, and covered with long hard hairs. The leaflets are papery, broadly ovate, nearly circular or elliptically lanceolate, with a larger terminal leaflet, 5-12 cm in length and 2.5-8 cm in width. The apex is acuminate or nearly circular, rarely obtuse, with a small pointed protrusion. The base is wide cuneate or circular, and the lateral leaflets are smaller, obliquely ovate, usually sparsely hispid on both sides or glabrous below; 5 lateral veins are on each side; stipules lanceolate, 1-2 mm long. The petiole is 1.5-4 millimeters long and covered with yellowish brown long hard hairs [28, 29].

The raceme of soybean is short with few flowers and long with many flowers; The total length of the pedicel is 10 to 35 millimeters or longer, usually consisting of 5 to 8 sessile, tightly packed flowers. The lower flowers of the plant are sometimes solitary or paired in leaf axils; bracts lanceolate, 2-3 mm long, strigose; bracteoles lanceolate, 2-3 mm long, with appressed setae; calyx is of 4-6 millimeter long, densely covered with long hard or rough hairs, often deeply divided into two lips, 5 lobes, lanceolate, 2 upper lobes often connate to above the middle, 3 lower lobes are separated, all densely is covered with white villous hairs. Flowers are purple, light purple or white, 4.5-8 (10) mm long, flag petal obovate suborbicular, apex slightly concave and usually reflexed, base with a petiole, wing petal castor shaped, base narrow, petiole and ear, keel petal obliquely obovate, having a short petiole; stamen dimorphism. There are underdeveloped glands at the base of the ovary [30].

The soybean pods are plump, oblong, slightly curved, pendulous, chartreuse, 4-7.5cm long, 8-15mm wide, densely covered with brown yellow long hairs; 2-5 seeds, elliptical, nearly spherical, ovoid to oblong, approximately 1 cm long and 5-8 mm wide, with a smooth seed coat and a variety of light green, yellow, brown, and black colors, depending on the variety.

The shell of mature soybeans is hard and waterproof, which can protect the cotyledons and hypocotyls (or buds) from damage. If the seed coat cracks, the seed will not germinate. The visible scars on the seed coat are called gates (colors include black, brown, light yellow, gray, and yellow), and one end of the gate is a micropore, a small hole on the seed coat that can absorb water and germinate [31]. Some seeds, such as soybeans containing very high levels of protein, can be dried but survive and revive after absorbing water [32].

## 1.3. Impact of environmental factors on soybean (*Glycine max.*L)

Environmental factors are of particular importance for the growth and development of soybeans, as they directly affect their yield and quality. Therefore, it is important to understand the existence pattern of soybeans, mainly including the following 5 aspects:

**Lighting requirements.** Soybeans are photogenic and belong to the category of short day crops. Short day plants are plants that have less than a certain critical day length of sunlight to form flower buds, or to promote flower bud formation. Long nights and shorter days can promote the reproductive growth of soybean plants and inhibit nutritional growth. Shortening sunlight can promote flower bud differentiation and early flowering and maturation. When the first compound leaf of the seedling grows, it begins to respond to light. When the calyx primordium appears in the plant, it indicates that the light stage has been completed. The impact of light on soybean quality includes two aspects: light duration and light intensity. The length of light duration changes the growth period of soybeans, and light intensity affects their photosynthesis [33, 34]. According to the research, the effect of increasing light on soybean fat content after flowering shows that increasing light hours have increased fat content and decreased protein content [35-40]. With the decrease in light intensity, the protein content of soybean shows an upward trend, and the fat content decreases. The total protein and fat content increases [41, 42, 43].

**Temperature requirements.** Soybeans prefer warmth, and high temperatures within a certain temperature range are beneficial for their growth and development. Seeds begin to germinate at 10-12℃, with 15-20℃ being the optimal temperature for growth at 20-25 ℃. The optimal temperature for flowering and podding is 20-28℃. At low temperatures, podding is delayed, and plants cannot bloom below 14℃. Plants with high temperatures end their growth early. Seed germination must occur at a temperature of 10-12℃, and around 15-20℃ is the most suitable temperature for germination. The temperature for growth should be between 20-25℃, and during the flowering and podding period, the temperature should be controlled between 20-28℃. If the temperature does not reach 20-28℃, the time for podding will be delayed. If it is below 14℃, it is not possible to bloom [44, 45]. Therefore, when planting soybeans, if the temperature is too high, it will wait for the pillars of the soybean to end growing earlier. The temperature factor can be divided into two phases: high and low temperature and temperature difference. High temperature causes an increase in protein content, while lower and larger temperature difference is conducive to the formation of fat. The average temperature of soybeans during the podding and bulging stages is lower than 20℃, which is conducive to the formation and conversion of sugar into fat with low oil content; but if the temperature is higher than 35 ℃, especially when the temperature difference between day and night is little, it is not conducive to the reduction of oil content during photosynthesis [46, 47, 48, 49].

**Water requirements.** Soybeans are crops that require a lot of water, and drought during the podding and bulging stages is an important reason for soybean yield reduction. It requires a lot of water during its growth period, and its lifelong water demand pattern is "less, more, and less", that is, the first one-third period requires less water, the middle one-third period requires the most water, and the last one-third period requires less water [50]. There are agricultural proverbs in China that say "Wet flowers and dry pods yield one hundred and eight per mu" and "Soybeans bloom and shrimp are touched in the ditch", reflecting the water demand characteristics of soybeans. Soybean seeds require more water during germination, and during the flowering period, they frantically absorb nutrients and water. During the flowering and podding period, more than 80% of the total nutrients are absorbed, which means that during the podding period, it is necessary to provide all the nutrients and water needed for soybean growth to ensure normal growth. The soil moisture content should be maintained at 70-80%, otherwise the flower buds may easily fall off [51, 52]. According to the research, precipitation is positively correlated with protein content and negatively correlated with fat content, indicating that sufficient water supply is beneficial for the synthesis of soybean protein, while less rainfall is beneficial for the synthesis of soybean fat.

This is one of the reasons why the protein content of soybeans is high in the south and low in the north, while the fat content is high in the north and low in the south. The protein content increased during the flowering and fruiting stages, while the fat content decreased. The egg fat content slightly decreased, with the most significant impact of drought during the fruiting stage. The experiment of waterlogging stress on summer soybean during the flowering stage showed that with the extension of waterlogging time, the middle fat content increased and the protein content decreased [53, 54].

**Nutrient requirements.** Soybeans require a lot of nutrients throughout their lifetime. Soybeans are crops that require a large amount of mineral nutrients and a wide range of varieties. The rhizobia produced by their roots can fix nitrogen in the air, reduce nitrogen absorption in the soil, and promote fertility [55, 56]. Compared to rice and wheat, soybeans require two times more nitrogen and 0.5-1.0 times more phosphorus and potassium to produce one unit of dry matter. The situation in which soybean needs fertilizer throughout its life is that from emergence to flowering, the absorption of nitrogen, phosphorus, and potassium accounts for 25-35% of the total absorption. Nitrogen, phosphorus, and potassium are the three main nutrients necessary for soybean growth and development, their functions cannot be replaced by each other, and they are indispensable. The nitrogen requirement from flowering to granulation is about 54% of the total nitrogen requirement, phosphorus requirement is about 52%, and potassium requirement is about 62%. Soybeans absorb less than 15% of the total fertilizer before flowering, while the flowering and podding stage accounts for over 80% of the total fertilizer absorption. That is to say, the absorption of nitrogen and potassium in the later stage of growth is greatly reduced, but the absorption of phosphorus has not yet stopped [57, 58, 59]. Soybeans mainly require trace elements such as molybdenum, manganese, zinc, boron, etc. The applyication of molybdenum can generally increase yield by 5-10%. According to the research, many farmers in China are currently choosing to apply 225-450 $kg/h^2$ of diammonium phosphate during the flowering and podding stages of soybeans. Combining the prevention and control of diseases and pests during the bulging stage, spraying potassium dihydrogen phosphate with plant growth regulators and trace element fertilizers have achieved good results in increasing soybean yield and improving soybean quality [60]. Applying nitrogen fertilizer has the effect of increasing protein content and reducing fat conten. The research has shown that phosphorus has the effect of increasing fat content, while potassium application has a trend of increasing soybean fat content and reducing protein content. Nitrogen fertilizer has a significant impact on protein content, while phosphorus and potassium fertilizer have a significant impact on fat content. An increase in the total amount of nitrogen, phosphorus, and potassium fertilizers helps to increase the protein content. The fat content increases from a low to a high period, but both periods have the best fertilization content. Trace elements require a very small amount, but their physiological effects are very obvious. The impact of trace elements on quality is indispensable, and cannot be excessive [61-76].

**Soil requirements.** Soybeans have a wide adaptability, and the requirements for soil conditions are not very strict. The loam or sandy loam with deep soil layer, good drainage, rich calcium humus, and good structure are the most suitable sapects. Soybeans are not resistant to acid and alkali, and acidic soil is not conducive to the development of soybean rhizobia. Soil pH scale should ranges from 6.8 to 7.5.

### 1.4. Modern technologies for growing soybean (*Glycine* max. L)

**Soil preparation.** Pre-sowing land preparation: pre-sowing land preparation includes soil cultivation, raking, plowing, pressing, etc. carried out prior to sowing, such as flat plowing, ridge planting, raking, deep loosening, etc. When turning the land, the turning depth should be controlled at about 20 cm, which is mainly used to prevent the land surface from caking and to avoid affecting the cellular respiration of plants [77].

Pre-sowing irrigation: For plots with poor soil moisture, if irrigation conditions are available, watering can be done once 1-2 days before sowing, soaking the soil to facilitate seed germination after sowing.

Pre-sowing closed weeding: If not managed in a timely manner, weeds can be severely damaged, and mechanical spraying of herbicides is often used before sowing for field closed weeding [78].

**Selected seeds.** The selection of soybean seeds is particularly important, as it relates to whether soybean plants can thrive in the future. Therefore, it is necessary to choose excellent seeds, which can lay the foundation for high yield and quality of soybeans [79]. Thus, prior to sowing, diseased seeds, insect eaten seeds, small seeds, blighted seeds, and broken petals should be picked out. At the same time, it is required to eliminate mixed seeds of different varieties based on the inherent typical characteristics of this variety, such as grain type, grain color, seed size, navel size, and color depth, in order to improve seed purity. The effect of using manual seed selection is very good [80]. If a large amount of seeds are used, a spiral soybean seed selection machine can be used. Its mechanical structure is simple, easy to move, and suitable for soybean planting professionals to apply. The purity requirement for selected products is over 97%, and the purity is over 98%. The purchased seeds should be fully dried, spread out, and stirred in a timely manner. They should not be exposed to sunlight and stored in a cool and damp place to avoid mold, which can affect the quality of the seeds and affect the germination rate [81]. In order to reduce the possible diseases and pests of soybean during planting, appropriate coating treatment should be taken, and 50% carbendazim or metronidazole emulsifiable concentrates should be selected for proper seed dressing [82].

**Seed determination and germination test.** The selected seeds should be tested for grain weight and germination rate before sowing. These two tasks are the basis for calculating the sowing rate. Randomly sample contains 3 selected seeds, with 100 seeds randomly selected from each sample. It is required to weigh each seed and calculate the average, which is the weight of the 100 seeds of the variety. Its unit is expressed in grams. Seed germination rate measurement is as follows: it is necessary to place 100 seeds from each of the above 3 portions into 3 small plates or germination dishes, and place them on straw paper or river sand.

Secondly, it is essential to add water to a thin layer of water, then evenly arrange the seeds and place them in a warm place around 20 ℃ to absorb water, expand and germinate. After 5 to 7 days, to calculate the number of seeds that can grow and germinate normally, and average the three samples to obtain the germination rate of the seed. The germination rate required is of over 95% [83, 84].

**Seed processing.** Currently, sun drying, seed mixing, and seed coating are the three main methods for treating soybean seeds. Suning seeds refers to the process of combining seeds that are difficult to store with seeds with high moisture content [85]. Prior to sowing, the soybean seeds should be exposed to sunlight for 3-5 days before being coated [86]. Seed dressing includes rhizobia seed dressing and micro fertilizer seed dressing. Rhizobia seed dressing refers to the use of 500 g of rhizobium agent per mu, which helps prevent seed diseases and pests and improve soybean yield. The micro fertilizer seed mixing method refers to the use of chemical fertilizers such as ammonium molybdate and borax to stir the seeds evenly and sow them in soil lacking trace elements. Seed coating refers to the use of proprietary seed coating agents that have been inspected and registered to encapsulate seeds, in order to enhance their resistance to pests and diseases. Before sowing, mechanical or manual selection should be carried out to remove broken petals, diseased seeds and insect eating seeds [87].

**Reasonable dense planting.** To improve the production efficiency of soybean cultivation, it is necessary to carry out reasonable close planting and ensure that soybean plants can grow and develop normally. Therefore, it is essential to reasonably control the planting density of soybeans [88]. The so-called reasonable dense planting refers to correctly handling the relationship between individuals and groups under local and specific conditions at that time, so as to maximize the development of the group and ensure the full development of individuals; Make full use of light energy and soil power per unit area; Under the same cultivation conditions, the best economic benefits can be achieved [89]. Therefore, a suitable density is not fixed and cannot simply be said to be thin for fertile land and dense for lean land. The following factors should be considered:

**Variety.** The richness of variety, such as plant height, number of branches, and leaf size, is closely related to its density. For varieties with tall and branching plants, well-developed plant types, and large leaf types, the planting density should be small; varieties with short and poor lush plants, or varieties with higher plants but fewer branches and converging plant types, should use higher densities [90].

**Fertilizer and water conditions.** When the fertilizer and water conditions are good for the same variety, the plant growth should be lush and the density should be small. On the contrary, if the fertilizer and water conditions are poor, the density should be higher. Throughout the entire growth process, fertilization of soybeans has a serious impact on production efficiency, which to some extent determines the yield and plant benefits of soybeans [91]. Thus, we cannot save on the investment of fertilizers, but we cannot waste them to avoid affecting the growth of the entire plant. During the fertilization process, the ratio of nitrogen, phosphorus, and potassium should be maintained at 3:2:1, and the amount of fertilization should be adjusted reasonably according to different soybean varieties. In addition, during the fertilization process, the depth of fertilization should be increased on the original basis, which can increase the stability of soybean roots, while providing more water and nutrients, and enhancing the lodging resistance of the entire plant [92].

**Variety type and planting season**: Summer soybeans in general have a longer growth period, tall plants, and sparse planting density. Spring soybeans have a shorter growth period, while autumn soybeans have the shortest growth period, and their plants are also relatively short. It is advisable to plant them in close proximity [93].

**Sowing period.** The sowing time has a significant impact on yield and quality. Planting too early or too late is detrimental to the growth and development of soybeans. The important aspects are timely sowing, high seedling preservation rate, neat and robust emergence, good growth, and thick stems. If sown too late, although the seedlings may emerge quickly, they may not be robust and appear evenly. In the northern region, late maturing varieties are susceptible to early frost damage, posing a risk of green and late maturing to reduce production [94].

**Bird prevention.** The most effective way to prevent birds at present is still to directly cover the entire grain field with nylon mesh. In addition, it can be manually watched over and repelled by birds or sprayed with bird fumigants, but the effect is not very ideal [95, 96].

**Timely harvest.** Soybeans should be harvested in a timely manner after the completion of the production period to ensure that the soybean yield reaches its maximum value. If the soybean harvest time is too early, the growth period of the soybean becomes shorter, which can easily lead to incomplete development of the soybean and may result in a large number of withered seeds, affecting the quality of the soybean. If the harvest time is too late, it is easy to cause most mature varieties to fall naturally leading to a decrease in yield. Therefore, the soybean harvest time should be neither too early nor too late, and the golden harvest period is generally 3-7 days after the soybean matures. If the soybean contains a lot of water during harvesting, it can be picked together with the pods, and then fully dried in the sun before finally threshing [97, 98, 99].

### 1.4.1. Effect of Adversity Stress on Plant Reactive Oxygen Metabolism

Reactive oxygen species (ROS) refer to several metabolites of oxygen with high chemical reactivity, such as superoxide anion radicals ($O_2^-$), hydroxyl radicals ($OH^-$), hydrogen peroxide ($H_2O_2$), etc. They have always been considered toxic byproducts in plant metabolism, which can cause damage to macromolecular substances such as lipids, proteins, and DNA in plants. Correspondingly, in order to protect cells from the potential harm of ROS, plants have developed a complete defense system, including enzymatic antioxidant systems (such as SOD, CAT, POD, etc.) and non enzymatic antioxidant systems (such as AsA, GSH, etc.) [100, 101]. Since the production and removal of ROS in plants are in a state of dynamic balance, they generally do not cause harm to plants. However, under adverse conditions, this balance of plant cells will be broken and a large amount of reactive oxygen species will be produced. These reactive oxygen species will cause cell membrane lipid peroxidation with their extremely strong oxidizing properties, leading to membrane system damage and cell oxidation, causing serious damage to plants [102].

Malondialdehyde (MDA) is a product of plant cell membrane lipid peroxidation, and its content is an important indicator of plant cell membrane lipid peroxidation and plasma membrane damage. Under different concentrations of NaCl treatment, the MDA content in the roots of soybean seedlings does not increase significantly, but it increases in the leaves. Only the MDA content in the roots of soybeans with strong salt tolerance increases significantly compared with the control under high salt stress, while the MDA content in the roots and leaves of soybeans with weak salt tolerance increases, and as the intensity of salt stress increases [103]. Therefore, it is speculated that halophytic soybeans and soybean varieties with strong salt tolerance are better able to tolerate salt stress, but the stress resistance of their organs is different.

Superoxide dismutase (SOD) plays an extremely important role in the reactive oxygen species scavenging system. It is the first line of defense of the reactive oxygen species free radical scavenging system in plants. It can catalyze the disproportionation reaction of $O_2^-$, and its activity is considered to be an important indicator of plant resistance to stress [104]. Relevant experiments have shown [105] that different types of wheat have different changing trends in SOD activity in vivo under different degrees of high temperature stress. Under mild high temperature stress, the SOD activity of wheat leaves showed a slowly increasing and eventually decreasing trend as the treatment time was extended. In general, SOD activity is positively correlated with plant antioxidant capacity. Under mild or short-term water stress, SOD activity in plants gradually increases, while it shows a downward trend under severe or long-term stress conditions. However, some studies have found that the changes in SOD activity under adverse stress are pervasive. For example, as the stress intensity increases, SOD activity decreases, first decreases and then increases, or remains unchanged [106, 107].

Catalase (CAT) is an important active oxygen scavenging enzyme in plants. High concentrations of $H_2O_2$ in plant tissues are mainly decomposed and removed by CAT. Under ozone stress, the CAT activity of winter wheat leaves increased. As the stress intensity further increased, its activity was inhibited and gradually decreased. When the ozone concentration increased again, the CAT activity decreased rapidly [108].

The main function of POD is to reduce excess H2O2 in plants to H2O and O2, thereby eliminating the harm of active oxygen to plants. An increase in POD isoenzyme activity can reduce the damage of reactive oxygen species to cell membranes to a certain extent, thus protecting plants from damage. POD isoenzymes are called plant stress proteins. It is one of the important protective enzymes in the free radical defense system of plants against external stress [109]. Studying the changes of POD enzymes under water stress, it was found that the POD enzyme activity and the number of enzyme bands in Atractylodes macrocephala leaves increased with the intensification of water stress. However, under excessive water stress, the enzyme activity decreased and the number of enzyme bands reduced. After water stress, enzyme bands not expressed under normal conditions were detected in the leaves, indicating that drought stress can induce a new POD isoenzyme encoded by the gene in atractylodes macrocephala to remove excessive reactive oxygen species produced in the body due to an unfavorable ecological environment, thereby reducing the damage to the plant itself [110]. However, excessive water stress will cause the activity of some enzyme bands to decrease or even disappear. This may be due to the severe water deficit reaching the minimum tolerance limit of the plant, and the defense mechanism in the plant being destroyed. POD isoenzyme is inactivated.

### 1.5. For more fertilizers processing of soybean (*Glycine max*. L)

Trace elements are essential for plant growth and development, and can regulate various physiological and metabolic activities in plants, playing an important role in the stability and integrity of plant cell membranes [111]. The research has shown that elements such as calcium, magnesium, and sulfur can participate in plant particle absorption and affect crop growth, development, and stress resistance [112]. Molybdenum is involved in the synthesis of nitrogenase and nitrate reductase in leguminous crops, as well as in soybean nitrogen metabolism and nodule nitrogen fixation [113]; calcium can stabilize cell walls, promote cell elongation and division, prevent premature aging of crops, and improve the quality of soybean seeds [114]; silicon has a good regulatory effect on soybean photosynthesis rate, root activity, stress resistance, and yield [115]. For a long time, various trace elements in the soil have been continuously consumed, but have not been effectively supplemented, resulting in a continuous decrease in the content of effective trace elements in the soil. Trace elements have become a limiting factor for high yield and quality of crops [116].

During the main growth period of soybeans, especially before and after flowering and podding, there is a high demand for nutrients such as phosphorus, potassium, calcium, magnesium, and zinc [117]. The expansion and filling of soybean pods mainly rely on the photosynthesis of leaves to produce organic nutrients. Therefore, supplementing nutrients and enhancing photosynthesis in the leaves are crucial for preventing premature leaf senescence. The repeated application of medium and trace element fertilizers can promote leaf strength, plump soybean pods, and achieve high yield [118, 119].

Plants can regulate various physiological effects within their bodies through growth regulators to achieve yield increase [120]. For example, plant growth regulators can regulate seed germination and growth, preserve flower buds, promote growth, and enhance crop stress resistance [121]. They have the advantages of broad-spectrum, high efficiency, low residue, and convenient use, and are often widely used in field crops such as soybeans [122, 123].

### 1.5.1 Effect of regulators on soybean (*Glycine max.* L)

Researchers discovered melatonin (MT, molecular formula C13N2H16O2) in plants in 1995 [124, 125, 126], and elucidated that melatonin could regulate plant growth and increase crop yield. Under drought stress, the nutritional growth of leguminous crops in the seedling stage is hindered, plant height growth slows down, and leaf area decreases. In severe cases, it can directly cause permanent plant wilting [127]. At the same time, drought stress will also slow down the growth and development of big tofu pudding in the flowering and pod stage, resulting in the shedding of flowers and pods, affecting the formation of grains in the grain filling stage, and thus causing yield reduction [128]. Melatonin can help plants resist various stress suppressions. The research has found that melatonin can promote root growth and development under drought stress [129]. Melatonin also has a strong ability to scavenge reactive oxygen species (ROS), which can improve the resistance of legume crops under drought stress [130].

Betaine is a class of quaternary amine compounds. Its chemical name is N-methyl-glycine. There are mainly 12 kinds of betaine in plants. The simplest and earliest one to be found and studied is glycine betaine, or betaine for short. Many higher plants under stress accumulate a large amount of glycine betaine, they are mainly concentrated in the cytoplasm, as a non-toxic osmotic regulator to maintain cell osmotic pressure, stabilize the structure of biological macromolecules and cell membranes, maintain normal physiological functions [131], relieve the effect of salt concentration on enzyme activity and protect respiratory enzymes and participate in the process of energy metabolism. Exogenous betaine can maintain the function of soybean PSII under water stress and reduce the adverse effects of water stress on PSII [132]. Moreover, the studies have shown that the reproductive yield of soybean plants grown under drought stress is significantly reduced, and their leaf area growth rate and biomass accumulation are significantly reduced [133]. This is due to the weakened photosynthetic capacity and reduced $N_2$ fixation ability [134]. However, the application of betaine to soybean plants under drought stress showed that betaine increased yield and leaf area growth rate by increasing photosynthesis rate and $N_2$ fixation process [135].

### 1.5.2. Prevention and control of pests and diseases

Seeding period: Reasonable selection of resistant (tolerant) varieties for major pests and diseases, avoiding continuous use of a single variety for many years [136]. At the same time, sun drying seeds can reduce the incidence of pests and diseases in the seedling stage, and conducting seed germination rate testing before sowing can also help predict the risk of pests and diseases [137, 138, 139]. Coating or seed dressing with compound seed coating agent is a key measure to prevent seed borne diseases, soil borne diseases and underground and seedling pests of soybean. To pay attention to selecting active ingredient for the disease, for example, when controlling root rot, stem like spot seed rot and other diseases, you can choose the compound ingredients of oocides and fungi such as fludioxonil [140, 141]. Thiamethoxam, imidacloprid, bromocyanoxamide and chloramphenicol Benzamide can be used to control underground pests such as grubs and golden needle worms and seedling pests such as aphids, leaf beetles and weevils [142, 143]. Active ingredient such as methylamino avermectin can be selected to control cyst nematode disease.

Seedling stage to branching stage: in large contiguous soybean fields, insecticidal lamp combined sex attractants and food attractants can be used to monitor and trap the adults of Scarabaeidae (grub adults), cotton bollworm, Spodoptera litura and other pests, and biological agents such as Bacillus thuringiensis and Beauveria bassiana can be used in combination for spraying treatment. When the occurrence density of aphids, whitefly, Liriomyza leguminosae and Spodoptera litura is high, insecticides such as Benzamide, carbaryl salt, Fenvalerate, Thiamethasone and perchlorofluoride can be used for spray control at the initial stage of larvae. In addition, according to the occurrence of soybean stem and leaf diseases such as stem blight, anthrax and leaf spot, fungicides such as pyrazolidinoxystrobin and fenoxystrobin were selected for spray control. In addition, spraying immune activators such as amino oligosaccharides and chain proteins may help improve the immunity of soybean plants to viral diseases and pests [144].

Flowering and pod stage: on the basis of early prevention and control, fungicides such as azoxystrobin, benzometh propiconazole and azometh fluconazole can be sprayed to prevent and control fungal leaf diseases such as rust, stem and pod blight and Anthrax and other stem and pod diseases according to the occurrence of soybean diseases and pests. Spiking pests such as Bemisia tabaci and aphids are the main transmission of viral diseases. Insecticides such as chlorinsect Benzamide and thiamethoxam can be used for spraying control. During the peak period of adult pests such as soybean heartworms and bean pod borers, the strip method can be used to spray biological food attractants to lure and kill them. Insecticides such as Bacillus thuringiensis, Deltamethrin and Beta-cypermethrin can also be used to control adults and newly hatched larvae, combining the growth status of soybeans, applying foliar fertilizers, growth regulators, or immune inducers to control plant growth, enhancing or maintaining the resistance of soybean plants to diseases and pests, including preventing premature aging caused by root rot [142].

## Conclusions to section 1

1. The directions of use and prospects for the cultivation of *Glycine max*. L. in the world and Ukraine have been drawn.

2. The research results of the international scientific community on the effects of different stresses on plant physiological processes and productivity are summarized.

3. The analysis and summary of modern *Glycine max*. L. cultivation technology, especially the use of nutritional systems and plant growth regulators (PGR) have been made.

4. With the impact of climate change and environmental factors, the use of plant growth regulators (PGRs) has proven to be an important reserve for stabilizing crop development and improving crop yields, especially in *Glycine max*. L.

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# SECTION 2

# OBJECT, SUBJECT, AND METHODOLOGY OF THE RESEARCH

## 2.1. Object, scheme, and methods of the research

**The object of the research** is to evaluate the adaptability of soybean seedlings to salt stress under artificial conditions and the effects of growth regulators. The response of soybeans depends on variety characteristics, growth tissues, growth regulators, and weather conditions.

**The subject of the research is** *Glycine max* L., vapplication methods, types of plant growth regulators, abiotic stress (salinity), weather conditions, yield composition, and cultivation techniques, as well as the economic and energy efficiency of planting soybeans growth regulators in the Left-Bank forest grasslands of Ukraine and an artificial climate chamber at the Henan Institute of Science and Technology, Xinxiang, China.

On the topic of the study, the research was conducted according to the following scheme.

**Experiment 1.** Effects of salt stress on the growth and physiological features of *Glycine max* L. seedlings.

**Scheme of experiment 1.** Factor A – varieties of *Glycine max*. (ZHENG196, ZHENG1307); Factor B – plant growth regulators: control, Amino VG-ANTISTRESS，Glycine Betaine; Factor C – The level of exposed salt stress *Glycine max (*L.*)* Merr. seedlings: control (CK, water), low salt stress (50 mM

NaCl), moderate salt stress (75 mM NaCl), and severe salt stress (100 mM NaCl).

**Experiment parameters 1:** la = 2; lb = 3; lc = 4; n=12. Soybean seeds were grown in 7 x 7 cm nutrient pots using vermiculite. Culture conditions: light time 16 h, light intensity 8000 lumens, day and night temperature 25°C/18°C. After the seedlings grew two leaves and one needle, the seedlings were irrigated with 50, 75, 100 mmol·$L^{-1}$ sodium chloride (NaCl) solutions respectively for stress treatment, and the seedlings in the other group were irrigated with distilled water as a control. Leaves were treated with 100mg/L concentration of glycine betaine (GB) and Amino VG ANTISRESS at a concentration of 250 ml/h, once daily, twice. Samples were taken when the seedlings grew three leaves and one needle, with three-time repetition for each group. CK is the control group, Amino VG ANTISRESS and glycine betaine (GB) are the experimental groups.

Physiological indicators include chlorophyll content, enzyme activity (SOD, CAT, APX), malondialdehyde, and relative conductivity.

**Research methods.**

Physiological indicators of salt treated seedlings

Chlorophyll content: using the SPAD-502 chlorophyll meter (Japan) to measure the SPAD value of leaves, select uniformly sized blades and measure the same area three times.

Enzyme assays: measure superoxide dismutase (SOD) using NBT photoreduction method [1]. It is required to remove 0.1g of fresh leaves and add 130mmol/L methionine to 3mL of reaction solution; 750 μmol/L NBT; 20 μ mol/L riboflavin; 100 μmol/L EDTA-2Na; 50 mmol/L phosphate buffer solution (pH 7.5), The enzyme solution to be tested (blank is replaced with buffer solution, and the tube is zeroed without illumination) is irradiated under 4000 lx light for 20 minutes, The blue methylhydrazine produced by NBT photochemical reduction has a maximum absorption at 560 nm. Under these conditions, the enzyme required to inhibit the reaction by 50% is 1 activity unit.

Ascorbate peroxidase (APX): take 0.1g of fresh leaves, add 2.5ml of enzyme extract (50mmol/L phosphate buffer, pH 7.8, 2mmol/L ascorbic acid, 5mmol/L EDTA), grind in an ice bath, freeze centrifuge 12000g for 20 minutes, and obtain the supernatant. Ascorbate peroxidase (APX) activity assay was performed using the Asada's method [2], and the changes in A290 were continuously recorded at room temperature.

Catalase (CAT): take 0.1g of fresh leaves, 5ml of enzyme extract (50mmol/L phosphate buffer, pH 7.0, 10g/L polyvinylpyrrolidone PVP), grind in an ice bath, freeze centrifuge 12000g for 20 minutes, and take the supernatant for later use. Catalase (CAT) activity assay was performed using the method of chance [3] to continuously record the changes in A240 at 25℃.

Lipid peroxidation (MDA): the content of MDA was determined using TBA [4]. The assay mixture was heated at 95°C for 30 min and then quickly cooled in an ice bath. After centrifugation at 10000 g for 20 min, the absorbance of the supernatant was measured at 450 nm, 532 nm, and 600 nm.

Relative conductivity: Following the method of Niu Lixin [5], wash the collected leaves with deionized water and cut them into rectangular shapes of similar size. Weigh 1 g per part and take 3 parallel samples per part. After constant temperature treatment in the dark for 1 hour, add 20 mL of deionized water, immerse the material, and measure the conductivity $R_1$ with a conductivity F3-meter (Mettler Toledo. Inc., Columbus, USA). Heat in a constant temperature boiling water bath for 20 minutes and cool at room temperature to measure the total conductivity $R_2$. Finally, use the formula $(R_1/R_2) \times 100$ to represent the relative conductivity (%) of the leaves.

Statistical analysis was conducted using SPSS 22 (IBM, Armonk, NY, USA). According to Duncan's multiple variance test, there is a significant difference in the use of different lowercase letters, with $P<0.05$ indicating the level of significance.

**Experiment 2:** Varietal features of the formation of *Glycine max* (L.) productivity depending on growth regulators in the conditions of the forest-steppe of Ukraine.

**Scheme of experiment 2.** Factor A – soybean varieties (Amadea, Aurelina, Bettina, Mentor, Navigator); Factor B – various growth stimulants with anti-stress action (Control, Amino VG Antistress, Antistress, Sugar Mover).

The agrotechnics of the study was based on the typical methods of soybean cultivation for the Left-Bank Forest Steppe, with the exception of experimental factors. The sowing was carried out in the usual row way (with row spacing of 15 cm) and the norm of sowing 650 thousand. seeds per hectare. Seeds before sowing were inoculated with the drug Histik Soya (4 kg/t). Mineral nutrition was provided by the introduction of nitrogen, phosphorus and potassium fertilizers at a dose of 45 kg of active substance per hectare of each element.

## 2.2. Soil and climate conditions over the years of conducting research

Field research was conducted on the arable lands of Sumy National Agrarian University during 2021–2023 (coordinates: 50°52.742N latitude, 34°46.159E longitude 137.7 m above sea level). Laboratory research was carried out on the instrument base of the Center for Collective Use (CCU) of Sumy National National University (Ukraine) and an artificial climate chamber at the Henan Institute of Science and Technology, Xinxiang, China.

The research was carried out according to the objectives outlined in the thematic plans and within the state scientific topics of Sumy National Agrarian University - "Features of the Formation of the Productivity of Leguminous Crops in the Conditions of the Forest-Steppe and Steppe of Ukraine", (No. 0117U006536, 2017–2022) and "Development of Modern Methods for Identifying Stress in Agricultural Crops and Ways of Its Reduction" (No. 0121U113642, 2021-2025).

The main components of the research were checked in the conditions of the Left Bank Forest Steppe of Ukraine, in particular on the lands of farms: SLK-11 (Sumy Region) and Rodina (Poltava Region) on an area of 42 hectares.

The direct field research was carried out in the research field near the greenhouse complex of the University (NSVK Sumy NAU). The soil of the research area is represented by a typical deep medium-carbon black earth on forest rocks. Grouping of soils by properties (degree of acidity and alkalinity, humus content and nutrient content) determined according to DSTU 4362:2004 Soil

Quality Soil Fertility Indicators. The agrotechnical analysis shows: humus content ranges from 4.2 to 4.4% (according to Turin); salt pH ranges from 6.0 to 6.1. The nutrient content for the years of study is shown in Table 2.1. According to the analysis of the data table, the average nutrient content over the years of research is within the following range: nitrogen (according to Cornfield) – 133.7 mg/kg of soil; phosphorus and potassium (according to Chirikov) – 205.6 and 78.0 mg/kg of soil, respectively. These values were then used to calculate the calculated fertilizer rate and to adjust the recommended fertilizer rate [1].

In general, according to the recent trends of climate change towards an increase in the temperature regime, the Sumy Region is conducive to soybean cultivation and a promising region for the cultivation of chicken pox [4, 133]. This trend has been observed for the last 10–15 years and makes research into the choice of research subject relevant.

Weather and climate conditions were characterized by data obtained by the Institute of Agriculture of the North East of the National Academy of Sciences of Ukraine, located at a distance of 4 km from the research site.

Thus, 2021 was characterized by sufficient moisture during the period of sowing of soybeans and nutmeg, which contributed to the rapid swelling of the grain and the appearance of single shoots. But it should be noted that excessive humidity and low temperature mode slowed the climbs of heat-wavy juvenile plants of soybeans and nuts. Thus, in May it fell up to 168.3 mm, and in June – 101.9 mm with an average monthly temperature of 15.5–21.4 °C. The conditions in July were also unfavorable, including a shortage of precipitation (7.0 mm) and a sharp increase in the temperature regime to 25.0°C, which was 4.8°C higher than the multi-year average. Only August and September were characterized by the conditions within the medium-long range. But their impact on the formation of the crop was minimal, since the critical stages of development were in the previous months. We calculated the sum of active temperatures (over 5°C) – 2950.7 °C, and moisture supply by precipitation – 377.8 mm. In other words, it is the same.

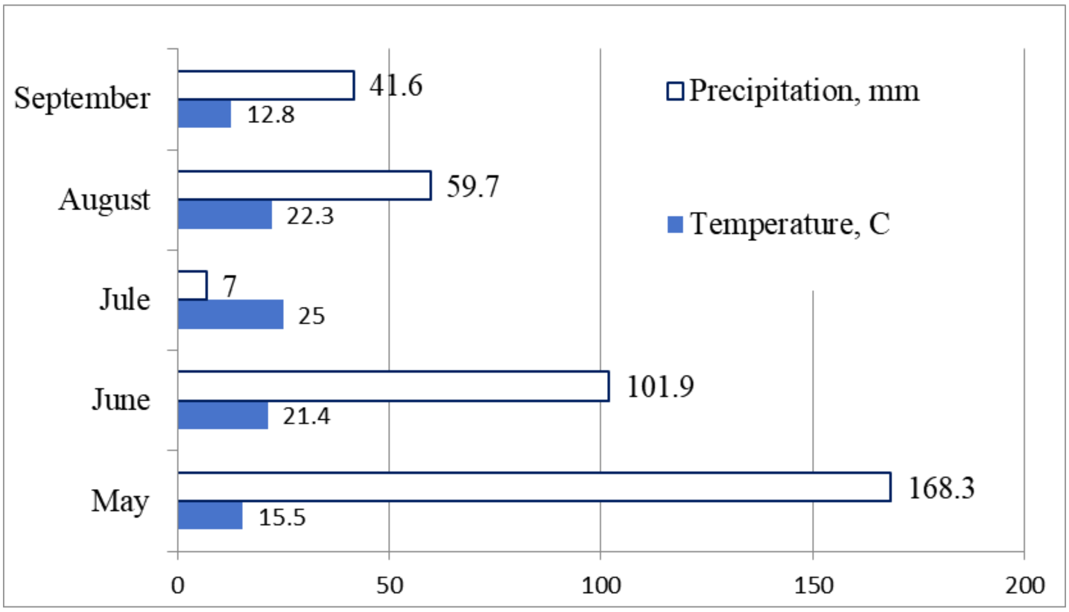


**Fig. 2.1. Meteorological parameters of the soybean vegetation period in 2021 (average monthly rainfall (mm) and temperature (°C))**

Thus, the weather conditions in 2022 differed in the direction of increasing the provision of precipitation and reducing the temperature regime. The record rainfall fell in June (155.3 mm) and September (125.0 mm). It should be noted that the average monthly temperature in May (13.3 °C) and September (11.6 °C) was lower than the multi-year average. In total, during the period of May-September 342.3 mm of precipitation fell, for the sum of active temperatures 2490.5 °C. As a result of the above differences, namely excessive humidification at low temperatures, there is a slowdown in the growth and development of nutmeg plants and a delay in the occurrence of calendar phases of development, in particular flooding and economic maturity.

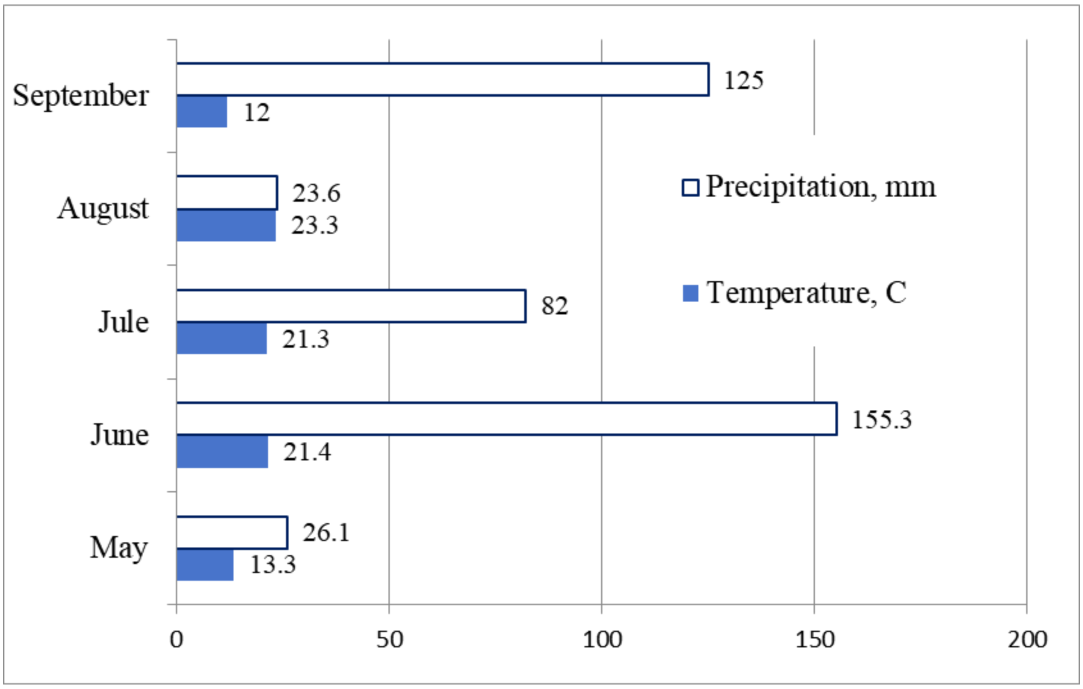


**Fig. 2.2. Meteorological parameters of soybean vegetation period in 2022 (average monthly rainfall (mm) and temperature (°C))**

The conditions in 2023 differed somewhat from the multi-year average, particularly in May, which was 13.3°C cooler compared to the average of 15.6°C. Precipitation was only 26.1 mm, 27.9 mm below the multi-year average. In June and July, soil moisture was above the multi-year average of 155.3 mm and 82.0 mm, respectively. It should be noted that precipitation in August was low (23.6 mm). This situation negatively impacted the grain filling process. Meanwhile, September was wet, with 125 mm of precipitation, exceeding the multi-year average of 50.0 mm. Regarding temperature, monthly average temperatures increased, except for May as mentioned earlier. From May to September, the monthly average temperature ranged between 15.6–22.8°C. It was calculated that during the vegetation period, the sum of active temperatures was 2439.0°C, and the total precipitation – 292.5 mm.

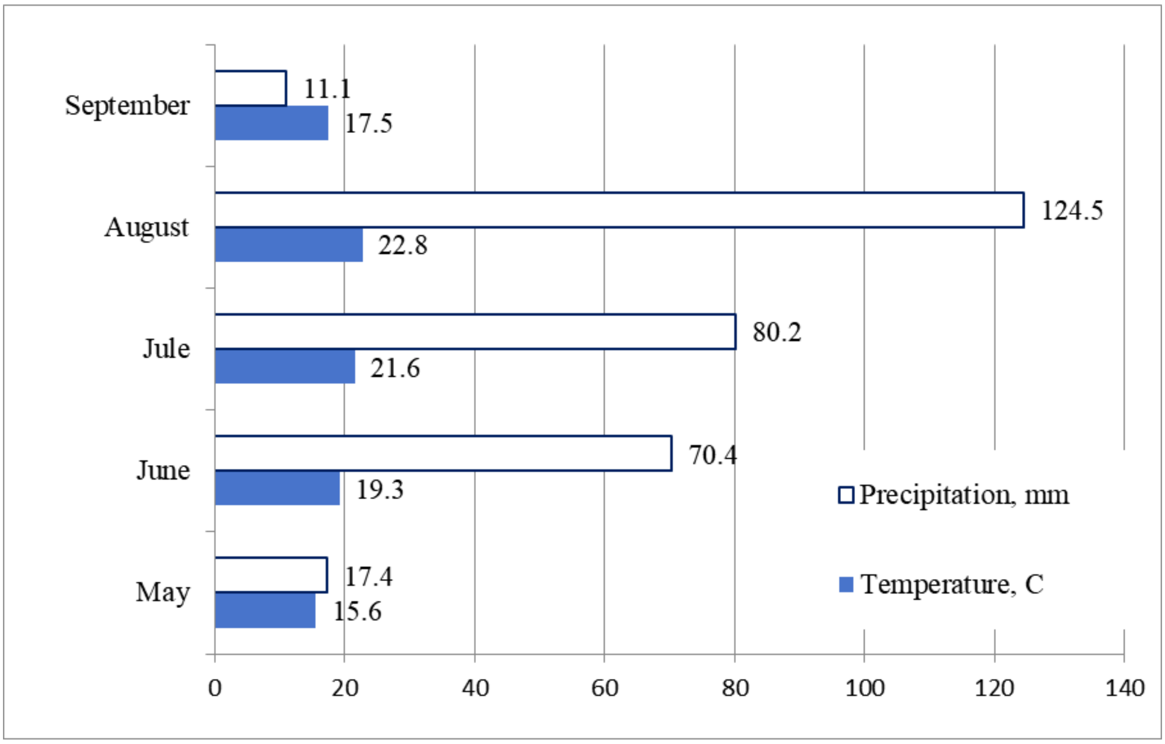


**Fig. 2.3. Meteorological parameters of the soybean growing period in 2023 (average monthly precipitation (mm) and temperature (°C))**

A more presentable parameter for assessing annual moisture conditions is the widely accepted hydrothermal coefficient of Selianinov, i.e., GTC [4]. Based on the sum of active temperatures and precipitation amounts, we calculated the HTC for the soybean growing periods (May–September 2021–2023). The obtained data are presented in Table 2.1.

Thus, the driest conditions were recorded in 2023, indicated by a GTC of 1.19. The year 2021 had normal moisture levels (GTC=1.23). In contrast, 2022 was a wet year, confirmed by the calculated GTC of 1.44.

*Table 2.1*

**Sumy of active temperatures, sum of precipitation, and hydrothermal coefficient during the research period (May–September, 2021–2023)**

| Year | Sum of active temperatures, °C | Sum of precipitations, mm | GTC | Year by moisture |
|---|---|---|---|---|
| 2021 | 2871.7 | 355.0 | 1.23 | Normal |
| 2022 | 2774.8 | 399.5 | 1.44 | Wet |
| 2023 | 2439.0 | 292.5 | 1.19 | Normal |
| Average annual (1989–2019) | 2829.3 | 334.2 | 1.2 | Normal |

Thus, we had the actual conditions to observe the realization of the biological potential of soybean plants and the formation of yield and its quality under favorable meteorological parameters.

## Conclusions to section 2

1. The research plan envisions a comprehensive task approach that involves observing and recording the use of regulators during the seedling stage and under salt stress, combined with transcriptome differential analysis, to deeply explore the effects of regulator use on soybean growth.

2. The field research scheme provided for a comprehensive study of the influence of the variety, weather conditions and growth regulators on the realization of the biological potential of soybeans.

3. The years studied were excellent in terms of meteorological parameters, which made it possible to detect the realization of the biological potential of soybeans. The driest conditions were in 2023, as evidenced by GTK = 1.19. The normal humidity was 2021 (GTC=1.23). The year 2022 was humid, confirming the calculated GTC=1.44.

4. The modern methods and methodologies used have enabled to conduct a comprehensive and reliable analysis of the influence of the investigated factors on the development of soybean plants and the formation of their productivity.

5. The results obtained will optimize the technology for planting soybeans (Glycine max.) in the Left-Bank forest grasslands of Ukraine.

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## SECTION 3

## PHYSIOLOGICAL RESPONSE OF SOYBEAN (*GLYCINE MAX*.) TO SALT STRESS AND THE EFFECT OF PLANT GROWTH REGULATORS ON SEEDLINGS

Salt content in soil is an important environmental factor that affects plant growth and yield. Salt stress can reduce water potential and lead to ion imbalance, resulting in toxicity and causing plant yield reduction or death [1]. The response of plants to salt stress involves physiology, biochemistry, cells, etc [2, 3]. Multiple changes aim at maintaining high osmotic pressure in the external environment. Maintaining water balance and normal photosynthetic activity can lead to salt stress. Although the growth of all plants is inhibited under salt stress, the tolerance level and degree of growth reduction to lethal salt concentration vary among different plants [4, 5].

Soil salinization is an important abiotic factor that affects crop yield. With the deterioration of the environment and unreasonable cultivation, soil salinization is becoming increasingly severe, affecting the quality and yield of soybeans. There is a dynamic balance between the production and elimination of reactive oxygen species and free radicals produced by plants in their life activities. Salt stress can disrupt the dynamic balance of reactive oxygen species in plants [6]. The accumulation of reactive oxygen species such as superoxide anions and hydrogen peroxide can induce membrane lipid peroxidation, increase membrane permeability, and damage the membrane system, causing serious damage to plants. The reactive oxygen species scavenging system is coordinated by substances such as superoxide dismutase (SOD), catalase (CAT), and acid peroxidase (APX) [7, 8, 9]. Under salt stress, antioxidant enzymes play an important role in clarifying plant reactive oxygen species [11]. In order to cope with the obstruction of water absorption caused by salt stress, plants will carry out osmotic regulation. However, excessive salt concentration can interfere with the osmotic regulation mechanism of plants, leading to an imbalance of intracellular and extracellular osmotic pressure, and affecting plant growth and development [12]. Malondialdehyde (MDA) is one of the commonly used indicators to measure the degree of oxidative stress, which can reflect the degree of membrane lipid peroxidation of plants [13, 14].

The increase in salt content in the soil environment can disrupt the ion stability of plants, resulting in a high permeability state, often accompanied by secondary harmful effects such as oxidative damage and photosynthesis damage [15]. Salt stress leads to an increase in the concentration difference of ions inside and outside plant cells, disrupting the ion balance state. Excessive salt entering plant cells disrupts the ion balance within the cells, leading to metabolic disorders. Meanwhile, salt stress can also affect the absorption and utilization of essential elements such as potassium, calcium, and magnesium by plants, further exacerbating the disruption of ion balance [16, 17]. Under salt stress, chlorophyll enzyme activity may increase. Chlorophyllase is an enzyme that can degrade chlorophyll, and an increase in its activity leads to a decrease in chlorophyll content. This degradation effect may be an adaptive response of plants to salt stress, which reduces the absorption of light energy by reducing the content of chlorophyll, thereby reducing the damage of reactive oxygen species produced by excess light energy to cells [10, 18]. Photosynthesis is an extremely important metabolic process in plants, and its strength has a significant impact on plant growth, yield, and stress resistance. Chlorophyll content is a physiological indicator that reflects the intensity of plant photosynthesis [19]. Among plant factors, changes in the permeability and ion flow rate of the cell membrane itself can directly lead to the rapid accumulation of active oxygen elements in the plant body, which further affects the osmotic regulation and photosynthesis ability of the plant itself, and disrupts the metabolic process and order of the plant during growth [20, 21]. During the process of absorbing mineral nutrients in plants under salt stress, salt ions compete with other mineral elements, resulting in imbalanced ion absorption, leading to a lack of mineral nutrients, disrupting the homeostasis of ions in the body, and seriously hindering normal plant growth. High concentrations of $Na^+$ in saline soil severely inhibit the absorption and transportation of $K^+$ by the root system, leading to a deficiency of $K^+$ [22]. High levels of $Na^+$ can also replace $Ca^{2+}$ bound to the cell plasma and liquid cell membranes, resulting in a decrease in the $Ca^{2+}/Na^+$ ratio on the membrane, disrupting the structure and function of the membrane, leading to the leakage of intracellular $K^+$ and organic solutes, a decrease in the $K^+/Na^+$ ratio within the cell, and a decrease in the pH gradient across the vacuole membrane, which hinders the accumulation of $Na^+$ within the vacuole [23, 24, 25].

**Superoxide Dismutase (SOD) activity.** For soybean variety 196, as the salt concentration increases, the SOD activity gradually increases. When treated with 0, the use of regulators GB and VG increases the SOD content to 4% and 6%. When treated with 50 mmol/L salt, the use of regulators GB and VG increases the SOD activity by 1.2% and 2.5%. When treated with 75 mmol/L salt, the use of regulators GB and VG increases the SOD activity by 1.3% and 5.7%. When treated with 100 mmol/L salt, the use of regulators GB and VG increases the SOD activity by 2.8% and 7.5%. For soybean variety 1307, as the salt concentration increases, the SOD activity gradually increases. When treated with 0, the use of regulators GB and VG increases the SOD activity to 5.3% and 7.4%. When treated with 50mmol/L salt, the use of regulators GB and VG increases the SOD activity by 7.7% and 9%. When treated with 75 mmol/L salt, the use of regulator GB SOD reduces the activity by 1.5% and increases the VG to 1.3%. When treated with 100 mmol/L salt, the use of regulators GB and VG can increase SOD activity by 6% and 11.9%.Under higher salt stress, the use of two regulators has a greater impact on the SOD activity of soybean seedlings during the two leaf and one needle period (Figure 3.1).

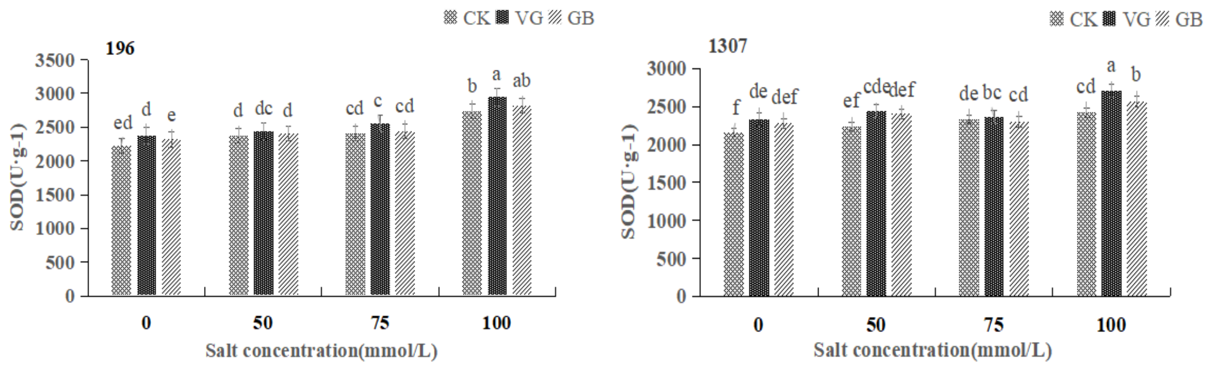


**Figure 3.1.** Changes in SOD in the leaves of two soybean varieties under salt stress (0, 50, 75, and 100 mM NaCl). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 3.

**Acid Peroxidase (APX) activity.** For soybean variety 196, when treated with 0, the use of regulators GB and VG increased APX activity to 24.4% and 33.6%, respectively. When treated with 50 mmol/L salt, the use of regulators GB and VG can increase APX activity by 28.3% and 41.2%. When treated with 75 mmol/L salt, the use of regulators GB and VG can increase APX activity by 22.5% and 36.2%. When treated with 100 mmol/L salt, the use of regulators GB and VG can increase APX activity by 32.8% and 42.8%. For soybean variety 1307, APX activity gradually increases with increasing salt concentration. When treated with 0, the use of regulators GB and VG increased APX activity to 7% and 12.9%. When treated with 50 mmol/L salt, the use of regulators GB and VG can increase APX activity by 2.6% and 10%. When treated with 75 mmol/L salt, the APX activity increased by 5.5% and 12% with the use of regulators GB and VG. When treated with 100 mmol/L salt, the use of regulators GB and VG can increase APX activity by 7.1% and 21.5% (Figure 3.2).

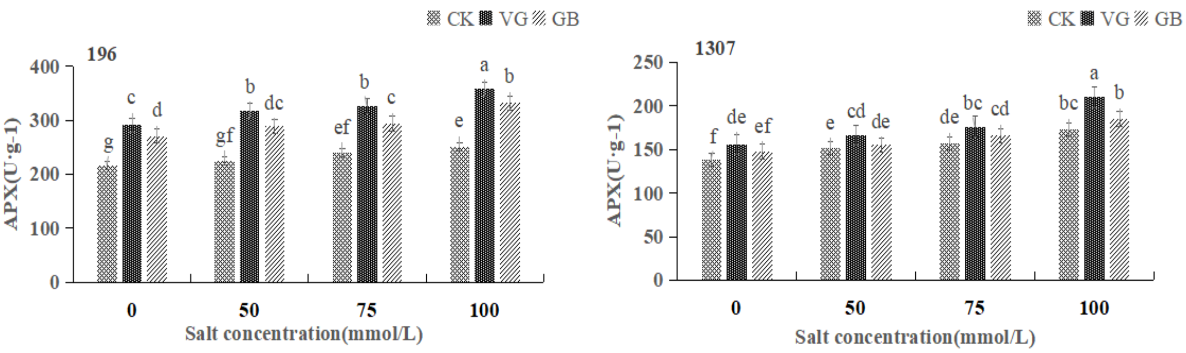


**Figure 3.2.** Changes in APX in the leaves of two soybean varieties under salt stress (0, 50, 75, and 100 mM NaCl). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, $P<0.05$, n = 3.

**Catalase (CAT) activity.** For soybean variety 196, when treated with 0, the use of regulators GB and VG increased CAT activity to 12.2% and 25.2%. When treated with 50mmol/L salt, the use of regulators GB and VG can increase CAT activity by 10.3% and 20.33%. When treated with 75mmol/L salt, the use of regulators GB and VG can increase CAT activity by 6.5% and 11.9%. When treated with 100mmol/L salt, the use of regulators GB and VG can increase CAT activity by 14.5% and 58.5%. For soybean variety 1307, when treated with 0, the use of regulators GB and VG increased CAT activity to 8.5% and 29.2%. When treated with 50 mmol/L salt, the use of regulators GB and VG can increase CAT activity by 9.6% and 30.5%. When treated with 75mmol/L salt, the CAT activity increased by 4.7% and 30.9% after the use of regulators GB and VG. When treated with 100mmol/L salt, the use of regulators GB and VG can increase CAT activity by 12% and 44.2% (Figure 3.3).

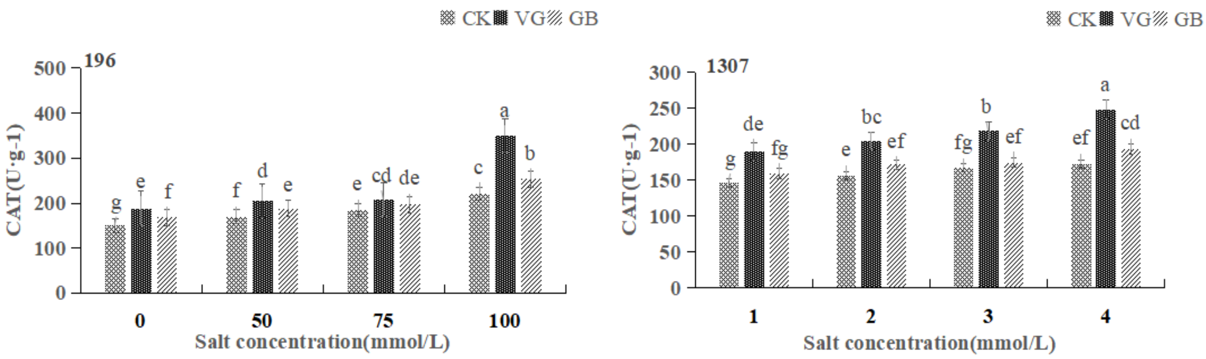


**Figure 3.3.** Changes in CAT in the leaves of two soybean varieties under salt stress (0, 50, 75, and 100 mM NaCl). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 3.

**Malondialdehyde (MAD) content.** For soybean variety 196, when treated with 0, the MAD content decreased by 7.0% and 13.6% respectively with the use of regulators GB and VG. When treated with 50mmol/L salt, the MAD content decreased by 3.6% and 6% after the use of regulators GB and VG. When treated with 75mmol/L salt, the MAD content decreased by 3.8% and 9.4% after the use of regulators GB and VG. When treated with 100mmol/L salt, the MAD content decreased by 18.33% and 25% after the use of regulators GB and VG. For soybean variety 1307, when treated with 0, the MAD content decreased by 6.3% and 12.5% after the use of regulators GB and VG. When treated with 50mmol/L salt, the MAD content decreased by 5.7% and 19.1% after the use of regulators GB and VG. When treated with 75mmol/L salt, the MAD content decreased by 11.6% and 19.8% after the use of regulators GB and VG. When treated with 100mmol/L salt, the MAD content decreased by 18.4% and 26.2% after the use of regulators GB and VG (Figure 3.4).

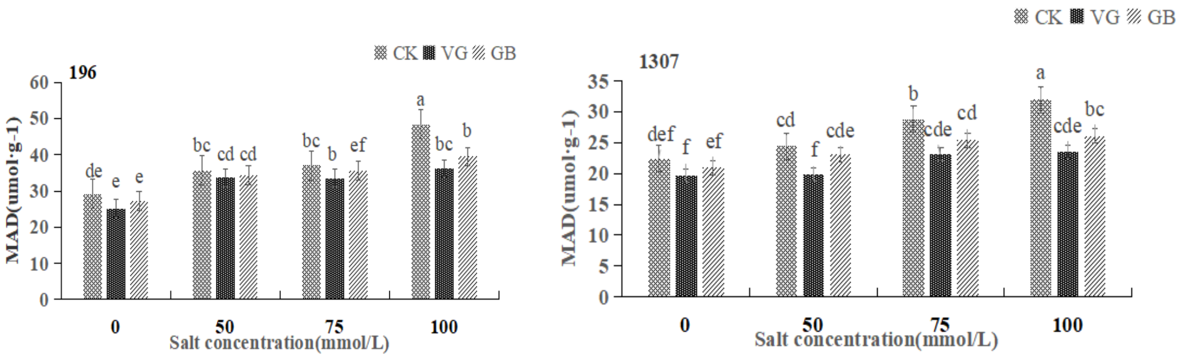


**Figure 3.4.** Changes in MAD in the leaves of two soybean varieties under salt stress (0, 50, 75, and 100 mM NaCl). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 3.

**Relative conductivity.** For soybean variety 196, when treated with 0, the relative conductivity decreased by 5.7% and 7.5% with the use of regulators GB and VG. When treated with 50mmol/L salt, the relative conductivity decreased by 5% and 8.1% with the use of regulators GB and VG. When treated with 75mmol/L salt, the relative conductivity decreased by 4.1% and 7.6% with the use of regulators GB and VG. When treated with 100 mmol/L salt, the relative conductivity decreased by 1.9% and 3% with the use of regulators GB and VG. For soybean variety 1307, when treated with 0, the relative conductivity decreased by 7.4% and 8.4% with the use of regulators GB and VG. When treated with 50mmol/L salt, the relative conductivity decreased by 5.1% and 7.4% with the use of regulators GB and VG. When treated with 75 mmol/L salt, the relative conductivity decreased by 10.4% and 14.2% respectively with the use of regulators GB and VG. When treated with 100mmol/L salt, the relative conductivity decreased by 4% and 19.3% with the use of regulators GB and VG (Figure 3.5).

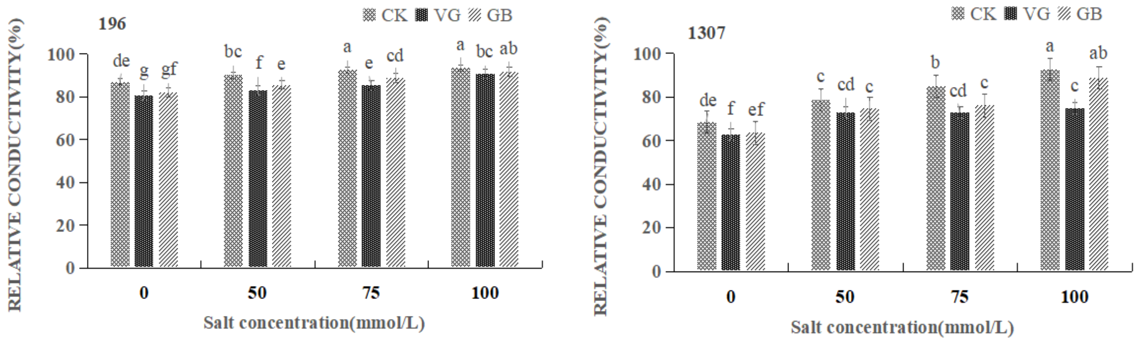


**Figure 3.5.** Changes in Relative conductivity in the leaves of two soybean varieties under salt stress (0, 50, 75, and 100 mM NaCl). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 3.

**Chlorophyll content.** For soybean variety 196, when treated with 0, the chlorophyll content increased by 2% and 5.4% after using regulators GB and VG. When treated with 50mmol/L salt, the chlorophyll content increased by 1.6% and 8% after the use of regulators GB and VG. When treated with 75mmol/L salt, the chlorophyll content increased to 2.7% and 5% after the use of regulators GB and VG. When treated with 100mmol/L salt, the chlorophyll content increased to 3% and 8% after the use of regulators GB and VG. For soybean variety 1307, when treated with 0, the chlorophyll content increased by 5.8% and 8% after using regulators GB and VG. When treated with 50mmol/L salt, the chlorophyll content increased by 10.9% and 13.9% after the use of regulators GB and VG. When treated with 75mmol/L salt, the chlorophyll content increased by 9.6% and 15.6% after the use of regulators GB and VG. When treated with 100mmol/L salt, the chlorophyll content increased by 13.6% and 24.5% after the use of regulators GB and VG (Figure 3.6).

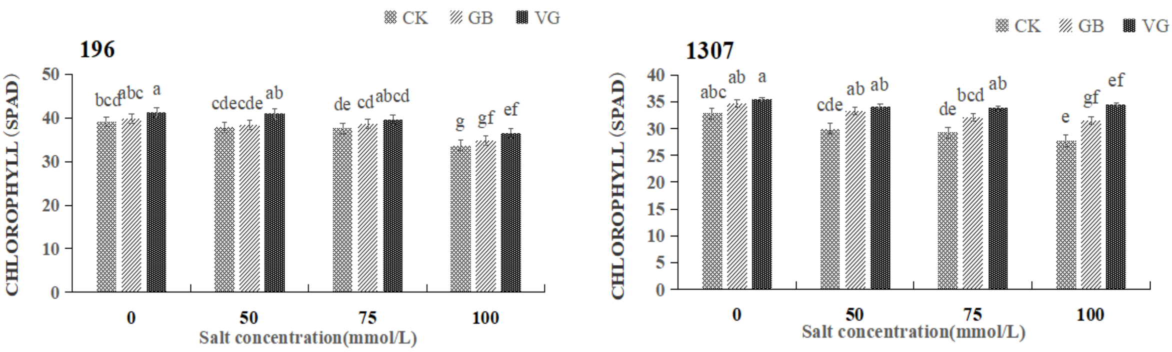


**Figure 3.6.** Changes in chlorophyll in the leaves of two soybean varieties under salt stress (0, 50, 75, and 100 mM NaCl). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, $P<0.05$, n = 3.

**Figure 3.7.** Soybean cultivation conditions in the incubator: light exposure time of 16 hours, light intensity of 8000 lumens, and day and night temperature of 25℃/18℃.

**Figure 3.8.** The left image shows the comparison between 100mmol/L NaCl treatment and CK 0 treatment. The middle image shows soybean seedlings treated with 100mm NaCl+100mg/L glycine betaine. The right image shows soybean seedlings treated with 100 mM NaCl+250 ml/h Amino VG ANTIRESS

*Table 3.1*

**Effects of Using Regulators under Salt Stress on the Physiology of Soybean Variety ZHENG 196 Seedlings**

| Varieties | Treatments | SOD($U \cdot g^{-1}$) | APX($U \cdot g^{-1}$) | CAT($U \cdot g^{-1}$) | MAD($umol \cdot g^{-1}$) | RELATIVE CONDUCTIVITY (%) | CHLOROPHYLL (SPAD) |
|---|---|---|---|---|---|---|---|
| ZHENG 196 | CK1 | 2227.35±12.44ed | 217.02±7.58g | 150.40±9.37g | 29.16±0.11de | 87.10±1.78de | 39.07±0.74bcd |
| | GB1 | 2317.77±20.59e | 270.50±2.54d | 168.77±8.33f | 27.13±0.88e | 82.16±1.88gf | 39.83±0.95abc |
| | VG1 | 2374.20±25.70d | 290.35±5.58c | 188.33±4.80e | 25.20±0.40e | 80.57±0.07g | 40.90±0.35a |
| | CK2 | 2375.73±26.63d | 224.42±7.74gf | 170.00±2.00f | 35.73±2.99bc | 90.16±0.89bc | 37.83±0.42cde |
| | GB2 | 2404.60±69.17d | 288.69±2.08dc | 187.43±3.07e | 34.45±0.55cd | 85.63±0.54e | 38.33±0.72cde |
| | VG2 | 2435.87±19.79dc | 317.64±2.41b | 204.57±14.63d | 32.93±0.49cd | 82.82±0.70f | 40.87±0.71ab |
| | CK3 | 2411.53±163.09cd | 239.59 ±3.89ef | 185.23±9.07e | 37.04±1.79bc | 92.63±1.27a | 37.60±1.32de |
| | GB3 | 2443.73±38.59cd | 293.57±2.75c | 197.27±3.04de | 35.64±0.89ef | 88.81±0.64cd | 38.60±1.32cd |
| | VG3 | 2550.81±144.55c | 326.40±7.35b | 207.27±5.72cd | 33.55±0.50b | 85.60±1.01e | 39.60±1.32abcd |
| | CK4 | 2736.29±0.53b | 249.99±13.4e | 221.27±2.06c | 48.34± 2.69a | 93.46± 0.73a | 33.70±1.73g |
| | GB4 | 2812.38±55.05ab | 332.13±7.73b | 243.33±11.5b | 39.48±7.65b | 91.72±0.55ab | 34.70±1.73gf |
| | VG4 | 2942.48±10.64bc | 357.13±24.16a | 350.73±2.37a | 36.26±2.26a | 90.59±0.57bc | 36.37±0.59ef |

Means ± SD, followed by different lowercase letters are significantly different according to Duncan's multiple range test, $P<0.05$, n = 3.CK1: water; CK2: 50 mM NaCl; CK3: 75 mm NaCl; CK4: 100 mm NaCl; GB1: 100mg/L glycine betaine; GB2: 50 mm NaCl + 100mg/L glycine betaine; GB3: 75mm NaCl + 100mg/L glycine betaine; GB4: 100mm NaCl + 100mg/L glycine betaine; VG1: 250 ml/h Amino VG ANTISRESS; VG2: 50 mm NaCl + 250 ml/h Amino VG ANTISRESS; VG3: 75 mm NaCl + 250 ml/h Amino VG ANTISRESS; VG4: 100 mm NaCl + 250 ml/h Amino VG ANTISRESS.

*Table 3.2*

**Effects of Using Regulators under Salt Stress on the Physiology of Soybean Variety ZHENG 1307 Seedlings**

| Varieties | Treatments | SOD($U \cdot g^{-1}$) | APX($U \cdot g^{-1}$) | CAT($U \cdot g^{-1}$) | MAD($umol \cdot g^{-1}$) | RELATIVE CONDUCTIVITY (%) | CHLOROPHYLL (SPAD) |
|---|---|---|---|---|---|---|---|
| ZHENG 1307 | CK1 | 2164.77±12.04f | 138.08±3.64f | 147.13± 2.50g | 22.40± 0.63def | 63.54± 1.43de | 32.80± 0.85abc |
| | GB1 | 2280.36±22.06def | 147.73±13.41ef | 159.60±15.63fg | 20.98±1.43ef | 62.89±0.62ef | 34.70±1.54ab |
| | VG1 | 2326.22±79.63de | 155.83±4.66de | 183.43±6.58de | 19.59±0.60f | 68.63±0.62f | 35.43±0.97a |
| | CK2 | 2232.01±38.35ef | 151.31±7.41e | 156.80±3.67e | 24.45±1.21cd | 78.63±9.56c | 30.00±1.93cde |
| | GB2 | 2299.60±85.04def | 155.35±5.36de | 171.87±0.23ef | 23.05±0.40cde | 74.63±1.95c | 33.27±0.55ab |
| | VG2 | 2363.40±29.46ced | 166.54±5.00cd | 204.60±4.53bc | 19.77±0.74f | 72.85±0.99cd | 34.17±0.40ab |
| | CK3 | 2333.73±112.45de | 157.38±7.88de | 166.80±8.88fg | 28.77±0.77b | 84.91±3.49b | 29.23±0.55de |
| | GB3 | 2356.96±108.79cd | 166.07±5.36cd | 174.67±2.42ef | 25.42±1.29cd | 76.05±0.87c | 32.03±0.42bcd |
| | VG3 | 2498.70±48.37bc | 176.19±2.38bc | 218.36±2.15b | 23.07±0.51cde | 73.34±0.95cd | 33.80±4.86ab |
| | CK4 | 2419.52±20.62cd | 172.90±3.19bc | 172.44±2.28ef | 31.99±4.43a | 92.58±0.78a | 27.70±0.53e |
| | GB4 | 2566.60±26.09b | 185.23±3.32b | 193.07±8.50cd | 26.08±0.61bc | 88.84±1.01ab | 31.47±1.31gf |
| | VG4 | 2707.84±80.24a | 209.99±1.86a | 248.64±27.01a | 23.59±0.25cde | 74.73±1.15c | 34.50±1.23ef |

Means ± SD, followed by different lowercase letters are significantly different according to Duncan's multiple range test, $P<0.05$, n = 3.CK1: water; CK2: 50 mM NaCl; CK3: 75 mM NaCl; CK4: 100 mM NaCl; GB1: 100mg/L glycine betaine; GB2: 50 mM NaCl + 100mg/L glycine betaine; GB3: 75mM NaCl + 100mg/L glycine betaine; GB4: 100mM NaCl + 100mg/L glycine betaine; VG1: 250 ml/h Amino VG ANTISRESS; VG2: 50 mM NaCl + 250 ml/h Amino VG ANTISRESS; VG3: 75 mM NaCl + 250 ml/h Amino VG ANTISRESS; VG4: 100 mM NaCl + 250 ml/h Amino VG ANTISRES.

## Conclusions to section 3

1. The results showed that for soybean variety 196, the use of GB resulted in a maximum increase of 4% in SOD activity under 0 treatment, while the use of VG resulted in a maximum increase of 7.5% under 100 mmol/L salt treatment. For variety 1307, the use of GB resulted in a maximum increase of 7% in SOD activity under 50 mmol/L treatment, while the use of VG resulted in a maximum increase of 11.9% under 100 mmol/L salt treatment.

2. The results showed that for soybean variety 196, the use of GB resulted in a maximum increase of 32.8% in APX activity under 100 mmol/L treatment, while the use of VG resulted in a maximum increase of 42.8% under 100 mmol/L salt treatment. For variety 1307, the use of GB resulted in a maximum increase of 7.1% in APX activity under 100 mmol/L treatment, while the use of VG resulted in a maximum increase of 21.5% under 100 mmol/L salt treatment.

3. The results showed that for soybean variety 196, the use of GB resulted in a maximum increase of 14.5% in CAT activity under 100 mmol/L treatment, while the use of VG resulted in a maximum increase of 58.5% under 100 mmol/L salt treatment. For variety 1307, the use of GB resulted in a maximum increase of 12% in CAT activity under 100 mmol/L salt treatment, while the use of VG resulted in a maximum increase of 44.2% under 100 mmol/L salt treatment.

4. The experimental results showed that under 100 mmol/L salt treatment, the MAD content of soybean variety 196 decreased by a maximum of 18.33% in GB,

while VG decreased by 25%. For variety 1307, the use of GB resulted in a maximum reduction of 18.4% in MAD content under 100 mmol/L salt treatment, while the use of VG resulted in a maximum reduction of 26.2% under 100 mmol/L salt treatment.

5. The results showed that under 0 treatment, the relative conductivity of soybean variety 196 decreased by a maximum of 5.7%, while under 50 mmol/L salt treatment, the relative conductivity of VG decreased by a maximum of 8.1%. For variety 1307, using GB resulted in a maximum decrease of 10.4% in relative conductivity under 75 mmol/L salt treatment, while using VG resulted in a maximum decrease of 19.3% under 100 mmol/L salt treatment.

6. The results showed that for soybean variety 196, the use of GB resulted in a maximum increase of 3% in chlorophyll content under 100 mmol/L treatment, while the use of VG resulted in a maximum increase of 8% under 100 mmol/L salt treatment. For variety 1307, the use of GB resulted in a maximum increase of 13.6% in chlorophyll content under 100 mmol/L treatment, while the use of VG resulted in a maximum increase of 24.5% under 100 mmol/L salt treatment.

7. The use of regulators GB and VG increased the activity of SOD, APX, and CAT antioxidant enzymes during the seedling stage of two soybean varieties, enhancing soybean antioxidant capacity and increasing leaf chlorophyll content. At the same time, the relative conductivity and MAD content decreased, reducing damage to the cytoplasmic membrane.

8. With the increase of salt stress, under different salt concentrations, the use of regulator VG resulted in a greater increase in APX, CAT, and chlorophyll

content than the use of regulator GB. The use of MAD and relative conductivity VG also decreased more than that of GB, indicating that regulator VG has a stronger ability to respond to salt stress in soybean seedlings than GB and can better improve their salt resistance.

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# SECTION 4

## SPECIFICATIONS OF THE FORMATION OF MORPHOLOGICAL PARAMETERS, PRODUCTIVITY OF PLANTS AND QUALITY OF SOY GRAIN FOR THE USE OF GROWTH REGULATORS WITH ANTISTRESS ACTION IN THE LEFT COAST FOREST OF UKRAINE

Cereal crops are the second largest group of agricultural plants after cereals (wheat, rice, corn). They play a crucial role in ensuring food security, especially in countries with animal protein deficiencies. The high content of plant proteins, fiber, vitamins and minerals makes legumes an indispensable component of a balanced human diet [43]. Soybean is one of the most adaptive oil crops suitable for cultivation in a wide range of climatic conditions. Its high yield and high protein content make it an important crop in the agricultural system of many countries in the world. However, in recent years, the adverse impact of climate change on agricultural production in the agrarian sector has become noticeable and is a reality worldwide. Climate change-induced abiotic stresses such as drought and temperature fluctuations destroy the physiological responses of crops, including soybeans, productivity and overall yield, ultimately posing a serious threat to global food security and agroecosystems [19, 27]. Increasing the stability of soybean crops requires the comprehensive use of modern technologies, such as variety selection taking into account the agro-climatic characteristics of the region and the use of growth regulators with anti-stress action [16].

Climate change, including rising temperatures, changing rainfall patterns and more frequent extreme events are increasingly affecting crop yields in Europe [26, 30]. An estimated extreme drought was recorded in August 2022. In the European Union (EU), maize, soybean and sunflower yields decreased by 12-16% compared to the 5-year period [25]. Therefore, the instability of weather conditions requires farmers and scientists across the globe to constantly adapt production processes to ensure stable soybean yields.

The soybean variety is a key element of its cultivation technology, which largely determines the level and stability of yield. Selection work aimed at creating new high-yielding varieties is one of the main directions of increasing the efficiency of soybean production. However, the most modern varieties have limited plasticity and require selection according to specific growing conditions [3, 4, 17]. Taking into account the diversity of agroclimatic conditions, the urgent task of modern agronomic research is the scientifically reasoned selection of soybean varieties, which will ensure their maximum productivity and resistance to unfavorable environmental factors [2, 15, 38].

Extreme weather conditions, in particular, prolonged periods of high temperatures without precipitation reinforce the need to develop innovative approaches to vegetation [13 , 28 , 32 ].

One of the promising strategies for optimizing soybean growing technology is the use of growth regulators. These physiologically active compounds contribute to more efficient mobilization and utilization of mobile forms of mineral elements, enhancing the overall resistance of plants to biotic and abiotic stresses [48].

## 4.1. Varietal characteristics of morphological parameter formation in soybean plants under the application of stress-resistant growth regulators

Morphological parameters of plants, such as height, photosynthetic pigment content, and leaf area are the key indicators of their physiological state and potential productivity. These metrics reflect the efficiency of the plants' assimilative activity, their ability to adapt to environmental conditions, and the effective utilization of available resources. Studying the dynamics of these parameters in response to the application of stress-protective growth regulators allows for an objective assessment of their impact on crop development and prediction of final yield. Specifically, optimal plant height ensures better leaf illumination and more efficient nutrient transport, while high chlorophyll content and sufficient leaf area guarantee maximum photosynthetic intensity. Thus, analyzing these morphological parameters is critically important for understanding the mechanisms of action of growth regulators and their contribution to enhancing the stress resistance and productivity of soybeans in the Left-Bank Forest-Steppe of Ukraine.

The height of soybean plants is a key selection criterion closely linked to the yield of the crop due to its role in transporting and transforming nutrients [14]. The analysis of data of 2022-2023 (Table 4.1.1) demonstrated a significant influence of meteorological conditions on the dynamics of the studied indicator. The highest plant height at full soybean flowering was recorded under the weather conditions of 2023 - 67.7 cm. Slightly lower heights were observed for the conditions prevailing in 2021 - 63.8 cm. The lowest plants were recorded under the conditions of 2022 - 61.8 cm.

The analysis by Factor A (varieties) revealed significant differences in soybean plant height among varieties. The tallest plants were recorded in the Betina variety at 71.4 cm. Slightly shorter and approximately similar heights were observed in the Aurelina and Amadea varieties, at 64.7 cm and 66.9 cm, respectively. The Navigator and Mentor varieties characterized by the shortest heights, at 58.9 cm and 60.0 cm, respectively.

For Factor B (growth regulators), it was determined that the tallest plants were formed using the Antistress preparation – 65.7 cm. The variants treated with Sugar Mover and GREEN HAS Amino VG Antistress had slightly shorter plant heights – 65.2 cm and 65.3 cm, respectively. The control variant showed the smallest height of 61.4 cm. $HIP_{05}$ values for Factor A=0.91; B=0.82; AB=1.83 cm.

Plant productivity is closely correlated with the efficiency of the photosynthetic apparatus, whose main components are chlorophylls a and b. These pigments absorb light in different spectral ranges, providing energy for photochemical reactions necessary to convert light energy into chemical bonds of organic compounds [8, 29]. During the research (Table 4.1.2), it was established that the weather conditions in 2023 had the greatest impact on the content of chlorophylls a+b during full flowering - 2.47 mg/g of fresh weight. The average value of this indicator was observed for the conditions of 2021 -2.38 mg/g of fresh weight. The lowest content of chlorophylls a+b was recorded for the conditions of 2022 - 2.25 mg/g of fresh weight.

*Table 4.1.1.*

**Varietal characteristics of soybean plant height formation depending on the application of stress-resistant growth regulators (average for 2021–2023, Sumy National Agrarian University, NNVK), cm**

| Variety (Factor A) | Growth regulator (Factor B) | Plant height, cm | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadeus | Control | 65,2 | 62,8 | 67,3 | 66,9 | 61,4 |
| | GREEN HAS Amino VG Antistress | 67,3 | 64,4 | 71,1 | | 65,3 |
| | Antistress | 68,2 | 65,1 | 70,5 | | 65,7 |
| | Sugar Mover | 66,9 | 64,0 | 70,5 | | 65,2 |
| Aureline | Control | 61,2 | 59,3 | 65,1 | 64,7 | |
| | GREEN HAS Amino VG Antistress | 65,0 | 62,8 | 68,2 | | |
| | Antistress | 67,1 | 63,8 | 67,3 | | |
| | Sugar Mover | 66,9 | 63,1 | 67 | | |
| Bettina | Control | 67,1 | 65,9 | 71,2 | 71,4 | |
| | GREEN HAS Amino VG Antistress | 70,9 | 68,4 | 77 | | |
| | Antistress | 72,2 | 69,5 | 77,4 | | |
| | Sugar Mover | 71,5 | 69,3 | 76,6 | | |
| Mentor | Control | 56,1 | 55,0 | 58,6 | 60,0 | |
| | GREEN HAS Amino VG Antistress | 58,6 | 57,9 | 65,7 | | |
| | Antistress | 60,0 | 60,3 | 64,4 | | |
| | Sugar Mover | 59,4 | 59,7 | 64,1 | | |
| Navigator | Control | 54,4 | 53,6 | 58,9 | 58,9 | |
| | GREEN HAS Amino VG Antistress | 59,2 | 57,5 | 65,0 | | |
| | Antistress | 58,2 | 56,7 | 64,4 | | |
| | Sugar Mover | 59,6 | 56,2 | 62,9 | | |
| Average per year | | 63,8 | 61,8 | 67,7 | 64,4 | |
| $HIP_{05}$ Factor A=0,91; B=0,82; AB=1,83 | | | | | | |

In terms of Factor A (varieties), it should be noted that the highest content of chlorophylls a+b was found in the Aureliana variety (2.46 mg/g fresh weight). Slightly lower chlorophyll content was observed in the Navigator and Bettina varieties (2.39 and 2.38 mg/g fresh weight, respectively). The lowest values were calculated for the Mentor (2.31 mg/g fresh weight) and Amadea (2.28 mg/g fresh weight) varieties.

The highest content of chlorophylls a+b under Factor B (growth regulators) was observed in the variant treated with Antistress, at 2.45 mg/g of fresh weight. The variants treated with GREEN HAS Amino VG Antistress and Sugar Mover showed slightly lower values - 2.39 and 2.40 mg/g of fresh weight, respectively. A significantly lower content of chlorophylls a+b was formed on the plots (varieties) without growth regulator application - 2.22 mg/g of fresh weight. The $NIP_{05}$ for Factor A=0.04; B=0.04; AB=0.09 mg/g.

The leaf surface area is a key factor determining the photosynthetic activity of plants, as leaves are the primary organs that absorb sunlight and perform photosynthesis, providing the plant with organic substances [6, 12]. The intensity of photosynthesis, which is the main source of energy and building materials for forming all elements of grain yield structure, directly depends on the size, quantity, and duration of leaf function. Achieving and maintaining optimal leaf surface area during critical growth phases, especially during grain filling, is essential for high productivity and the accumulation of nutrients in the final product [37].

*Table 4.1.2.*

**Varietal characteristics of chlorophyll a+b content formation in soybean plants depending on the application of stress-protective growth regulators (average for 2021–2023, Sumy National Agrarian University, NNVK), mg/g of fresh weight**

| Variety (Factor A) | Growth regulator (Factor B) | Content of chlorophyll a+b, mg/g of fresh weight | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 2,14 | 2,06 | 2,25 | 2,28 | 2,22 |
| | GREEN HAS Amino VG Antistress | 2,33 | 2,16 | 2,44 | | 2,39 |
| | Antistress | 2,41 | 2,21 | 2,49 | | 2,45 |
| | Sugar Mover | 2,39 | 2,1 | 2,4 | | 2,40 |
| Aureline | Control | 2,31 | 2,28 | 2,48 | 2,46 | |
| | GREEN HAS Amino VG Antistress | 2,4 | 2,38 | 2,53 | | |
| | Antistress | 2,56 | 2,41 | 2,7 | | |
| | Sugar Mover | 2,45 | 2,37 | 2,66 | | |
| Bettyna | Control | 2,21 | 2,19 | 2,36 | 2,38 | |
| | GREEN HAS Amino VG Antistress | 2,44 | 2,39 | 2,45 | | |
| | Antistress | 2,5 | 2,38 | 2,49 | | |
| | Sugar Mover | 2,44 | 2,33 | 2,4 | | |
| Mentor | Control | 2,12 | 2,02 | 2,27 | 2,31 | |
| | GREEN HAS Amino VG Antistress | 2,35 | 2,15 | 2,46 | | |
| | Antistress | 2,45 | 2,24 | 2,55 | | |
| | Sugar Mover | 2,41 | 2,2 | 2,51 | | |
| Navigator | Control | 2,2 | 2,13 | 2,34 | 2,39 | |
| | GREEN HAS Amino VG Antistress | 2,5 | 2,38 | 2,54 | | |
| | Antistress | 2,44 | 2,34 | 2,58 | | |
| | Sugar Mover | 2,51 | 2,29 | 2,48 | | |
| Average per year | | 2,38 | 2,25 | 2,47 | 2,37 | |
| $HIP_{05}$ Factor A=0,04; B=0,04; AB=0,09 | | | | | | |

During the research (Table 4.1.3), it was found that the largest leaf surface area during the full flowering phase of soybeans was recorded under the conditions of 2023 - 40.2 thousand m²/ha. A slightly smaller area was calculated in 2021 - 33.4 thousand m²/ha. The smallest assimilative surface formed under the conditions of 2022 - 32.3 thousand m²/ha.

Among the varieties (Factor A), the Aureline variety exhibited the largest leaf surface area at 36.3 thousand m²/ha. The Navigator and Bettina varieties showed slightly lower indicators, each at 36.0 thousand m²/ha. The smallest leaf surface areas among the studied varieties were observed in the Amadea (33.7 thousand m²/ha) and Mentor (34.3 thousand m²/ha) varieties.

For Factor B (growth regulators), it was determined that the largest leaf surface area was calculated with the use of the Antistress preparation - 36.8 thousand m²/ha. The use of Sugar Mover and GREEN HAS Amino VG Antistress resulted in slightly lower leaf surface area indicators -35.8 and 35.7 thousand m²/ha, respectively. A significantly smaller leaf surface area was formed in the control - 32.8 thousand m²/ha. The $HIP_{05}$ for Factor A=0.96; B=0.86; AB=1.92 thousand m²/ha. Numerous scientific studies have been devoted to investigating the influence of variety characteristics and the use of growth regulators on the morphological parameters of soybean plants. The results of these studies indicate a significant positive effect of the above Factors on soybean productivity [11, 18].

*Table 4.1.3.*

**Varietal characteristics of soybean leaf area formation depending on the application of anti-stress growth regulators (Average for 2021–2023, Sumy National Agrarian University, NNVK), thousand m²/ha**

| Variety | Growth regulator | Leaf surface area, thousand m²/ha | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 31,1 | 31,3 | 33,2 | 33,7 | 32,8 |
| | GREEN HAS Amino VG Antistress | 32,3 | 30,7 | 39,4 | | 35,7 |
| | Antistress | 33,0 | 31,7 | 40,5 | | 36,8 |
| | Sugar Mover | 31,5 | 30,6 | 39,2 | | 35,8 |
| Aureline | Control | 33,1 | 32,6 | 36,9 | 36,3 | |
| | GREEN HAS Amino VG Antistress | 34,5 | 32,7 | 41,9 | | |
| | Antistress | 34,2 | 33,9 | 44,5 | | |
| | Sugar Mover | 35,1 | 33,7 | 42,4 | | |
| Bettyna | Control | 30,7 | 30,1 | 38,7 | 36,0 | |
| | GREEN HAS Amino VG Antistress | 33,9 | 33,2 | 42,6 | | |
| | Antistress | 35,8 | 34,2 | 42,9 | | |
| | Sugar Mover | 35,7 | 32 | 41,9 | | |
| Mentor | Control | 30,4 | 30,0 | 35,8 | 34,3 | |
| | GREEN HAS Amino VG Antistress | 30,9 | 30,9 | 38,4 | | |
| | Antistress | 34,6 | 33,4 | 42,4 | | |
| | Sugar Mover | 33,1 | 31,0 | 40,9 | | |
| Navigator | Control | 30,9 | 30,1 | 36,6 | 36,0 | |
| | GREEN HAS Amino VG Antistress | 36,5 | 34,8 | 42,8 | | |
| | Antistress | 35,6 | 33,9 | 41,7 | | |
| | Sugar Mover | 34,5 | 34,2 | 40,7 | | |
| Average per year | | 33,4 | 32,3 | 40,2 | 35,3 | |
| $HIP_{05}$ Factor A=0,96; B=0,86; AB=1,92 | | | | | | |

## 4.2. Productivity and yield of soybean varieties depending on the variety and the application of stress-resistant growth regulators

The formation of agricultural crop yields is a complex multifactorial process that significantly depends on a set of yield structure indicators. These include the number of seeds per plant, seed mass per plant, and the mass of 1000 seeds. Analyzing these parameters allows for a comprehensive assessment of the plant's response to various influencing factors, including variety characteristics and the application of growth regulators with anti-stress effects [9]. The importance of studying these indicators lies in their direct impact on the final productivity and economic efficiency of soybean cultivation, as well as the potential to optimize technologies for improving yield stability and quality. Detailed research into the interrelationships between morphological parameters, yield structure elements, and final yield enables to determine the most effective strategies for managing the productive potential of soybeans under the conditions of the Left-Bank Forest-Steppe of Ukraine.

The seed number per plant is an indicator that significantly influences the yield of agricultural crops [7]. The research conducted during 2021 - 2022 (Table 4.2.1) revealed that annual conditions affected the formation of this parameter. The 2023 weather conditions proved the most favorable for soybean seed number per plant, with 32.1 seeds per plant recorded. A slightly lower count was observed in 2021 conditions – 29.9 seeds per plant. The lowest seed number per plant was calculated in 2022 – 27.9 seeds per plant.

*Table 4.2.1.*

**Variety features of the formation of the amount of seeds from one soybean plant depending on the use of growth regulators with anti-stress action (average for 2021-2023, NSVK Sumy NAU), pcs.**

| Variety (Factor A) | Growth regulator (Factor B) | Yield, pcs/plant | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 27,5 | 25,8 | 29,4 | 28,8 | 28,5 |
| | Amino VG Antistress | 28,3 | 26,7 | 31,7 | | 29,4 |
| | Antistress | 28,4 | 26,7 | 31,9 | | 30,5 |
| | Sugar Mover | 28,8 | 27,9 | 32,1 | | 31,6 |
| Aureline | Control | 28,4 | 26,5 | 30,9 | 30,3 | |
| | Amino VG Antistress | 30,9 | 26,7 | 32,1 | | |
| | Antistress | 31,2 | 27,9 | 33,5 | | |
| | Sugar Mover | 32,6 | 29,9 | 33,3 | | |
| Bettina | Control | 27,4 | 25,9 | 29,5 | 29,2 | |
| | Amino VG Antistress | 29,0 | 26,0 | 32,7 | | |
| | Antistress | 28,4 | 26,7 | 33,7 | | |
| | Sugar Mover | 28,7 | 28,5 | 33,9 | | |
| Mentor | Control | 33,6 | 26,0 | 28,0 | 29,6 | |
| | Amino VG Antistress | 28,1 | 24,0 | 29,8 | | |
| | Antistress | 30,1 | 26,8 | 34,6 | | |
| | Sugar Mover | 29,5 | 30,4 | 34,5 | | |
| Navigator | Control | 30,1 | 28,1 | 30,2 | 32,03 | |
| | Amino VG Antistress | 31,5 | 31,9 | 31,1 | | |
| | Antistress | 32,5 | 31,8 | 32,9 | | |
| | Sugar Mover | 33,2 | 34,4 | 36,5 | | |
| Average per year | | 29,9 | 27,9 | 32,1 | 30,0 | |
| $HIP_{05}$ Factor A=1,3; B=1,16; AB=2,59 | | | | | | |

Factor A (variety) can be used to trace the influence of variety characteristics on the number of seeds per plant. The highest value was recorded in the Navigator variety – 32.0 seeds/plant. Slightly lower and approximately similar quantities were observed in the Bettina, Mentor, and Aureliana varieties (29.2, 29.6, and 30.3 seeds/plant, respectively). The Amadea variety was characterized by the lowest seed count – 28.8 seeds/plant.

For Factor B (growth regulators), it was determined that the highest number of seeds was formed when using Sugar Mover – 31.6 seeds/plant. The variants with Amino VG Antistress and Antistress resulted in slightly fewer seeds – 29.4 and 30.5 seeds/plant, respectively. The lowest value was observed in the control variant – 28.5 seeds/plant. The $NIR_{05}$ for factor A=1.3; B=1.16; AB=2.59 seeds.

An equally important component of the crop structure is the individual productivity of soybean plants. In the course of the studies (Table 4.2.2), it was established that the greatest impact on the mass of seeds from the plant had the weather conditions that formed in 2023 – 6.26 g. The average value of the indicator was observed for the conditions of 2021 – 5.12 years. The smallest mass recorded in 2022 was 4.88 g.

In terms of Factor A (varieties), it should be worth noting that the largest seed mass from one plant was the Aurelina variety (5.63 g). Slightly less mass was collected on samples of varieties Navigator (5.53 g) and Bettina (5.50 g). The lowest value was calculated for Mentor (5.25 g) and Amadea (5.20 g).

*Table 4.2.2.*

**Variety features of the formation of individual productivity of soybean plants depending on the use of growth regulators with anti-stress action (average for 2021-2023, NSVK Sumy NAU), g**

| Variety (Factor A) | Growth regulator (Factor B) | Yield, g/plant | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 4,67 | 4,46 | 6,00 | 5,20 | 5,16 |
| | Amino VG Antistress | 4,97 | 4,72 | 6,06 | | 5,48 |
| | Antistress | 5,08 | 4,84 | 6,20 | | 5,65 |
| | Sugar Mover | 4,81 | 4,55 | 6,03 | | 5,41 |
| Aureline | Control | 5,09 | 4,86 | 6,45 | 5,63 | |
| | Amino VG Antistress | 5,27 | 5,03 | 6,43 | | |
| | Antistress | 5,54 | 5,21 | 6,74 | | |
| | Sugar Mover | 5,39 | 5,03 | 6,53 | | |
| Bettina | Control | 4,88 | 4,78 | 5,85 | 5,50 | |
| | Amino VG Antistress | 5,22 | 5,11 | 6,55 | | |
| | Antistress | 5,43 | 5,24 | 6,63 | | |
| | Sugar Mover | 5,03 | 4,92 | 6,35 | | |
| Mentor | Control | 4,83 | 4,30 | 5,71 | 5,25 | |
| | Amino VG Antistress | 4,75 | 4,55 | 5,91 | | |
| | Antistress | 5,31 | 4,99 | 6,53 | | |
| | Sugar Mover | 5,09 | 4,77 | 6,29 | | |
| Navigator | Control | 4,84 | 4,84 | 5,78 | 5,53 | |
| | Amino VG Antistress | 5,62 | 5,35 | 6,59 | | |
| | Antistress | 5,48 | 5,14 | 6,42 | | |
| | Sugar Mover | 5,16 | 4,95 | 6,18 | | |
| Average per year | | 5,12 | 4,88 | 6,26 | 5,42 | |
| $HIP_{05}$ Factor A=0,08; B=0,07; AB=0,17 | | | | | | |

The largest mass of seeds by Factor B (growth regulators) was found using Antistress – 5.65 g. Slightly lower indicators were characterized by options for the introduction of Amino VG Antistress and Sugar Mover – 5.48 and 5.41 g, respectively. As in the case of the amount of seeds per plant, the lowest productivity was observed in the control variants of the study – 5.16 g. NIR05 for Factor A=0.08; B=0.07; AB=0.17.

Fertility is a key indicator of agricultural production efficiency and an important factor in ensuring food security both at the level of the individual farm and the country as a whole [45]. Conditions of different years have affected soybean yield differently. During the studies (Table 4.2.3) it was established that the highest yield of soybeans was recorded under the conditions that were in 2023 – 3.23 t/ha. A slightly lower yield was harvested in 2021 – 2.63 t/ha. The lowest yield was formed in 2022 – 2.51 t/ha.

Among the varieties (Factor A), the highest yield was observed in the Aurelina variety - 2.90 t/ha, therefore, the seed mass index was more supported. The varieties Navigator (2.87 t/ha) and Bettina (2.86 t/ha) showed slightly lower yields. At the same time, from the previous conclusions, it can also be said that the yield of the Navigator variety was more affected by the amount of seeds, and in the Bettina variety there was a cumulative effect of the mass and amount of grains from the plant. The lowest yields among the varieties were Amadea (2.70 t/ha) and Mentor (2.62 t/ha). NIR05 for Factor A=0.04; B=0.04; AV=0.09 t/ha.

*Table 4.2.3.*

**Variety characteristics of the formation of soybean yield depending on the use of growth regulators with anti-stress action (average for 2021-2023, NSVK Sumy NAU), t/ha**

| Variety | Growth regulator | Yield, t/ha | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 2,41 | 2,32 | 3,14 | 2,70 | 2,66 |
| | Amino VG Antistress | 2,58 | 2,45 | 3,15 | | 2,82 |
| | Antistress | 2,63 | 2,51 | 3,22 | | 2,91 |
| | Sugar Mover | 2,49 | 2,36 | 3,13 | | 2,78 |
| Aureline | Control | 2,62 | 2,50 | 3,35 | 2,90 | |
| | Amino VG Antistress | 2,71 | 2,58 | 3,34 | | |
| | Antistress | 2,85 | 2,68 | 3,47 | | |
| | Sugar Mover | 2,77 | 2,61 | 3,37 | | |
| Bettina | Control | 2,54 | 2,49 | 3,05 | 2,86 | |
| | Amino VG Antistress | 2,71 | 2,65 | 3,41 | | |
| | Antistress | 2,82 | 2,72 | 3,48 | | |
| | Sugar Mover | 2,61 | 2,55 | 3,29 | | |
| Mentor | Control | 2,41 | 2,15 | 2,85 | 2,62 | |
| | Amino VG Antistress | 2,38 | 2,27 | 2,95 | | |
| | Antistress | 2,65 | 2,49 | 3,27 | | |
| | Sugar Mover | 2,54 | 2,39 | 3,14 | | |
| Navigator | Control | 2,51 | 2,51 | 3,01 | 2,87 | |
| | Amino VG Antistress | 2,91 | 2,79 | 3,42 | | |
| | Antistress | 2,85 | 2,68 | 3,34 | | |
| | Sugar Mover | 2,68 | 2,57 | 3,21 | | |
| Average per year | | 2,63 | 2,51 | 3,23 | 2,79 | |
| $HIP_{05}$ Factor A=0,04; B=0,04; AB=0,09 | | | | | | |

According to Factor B (growth regulators), it was established that the highest yield was collected using the drug Antistress – 2.91 t/ha, and this trend was largely due to the fact that this drug had a positive effect on the seed mass. Using Sugar Mover and Amino VG Antistress, slightly lower yields were formed – 2.78 and 2.82 t/ha. The lowest yield values belong to the control options of the study – 2.66 t/ha. It is also worth noting that the influence of the variety and use of growth regulators today is the subject of numerous studies by scientists, who in turn note their positive impact on this indicator [1, 5, 16].

## 4.3. Quality indicators and biochemical analysis of soybean seeds depending on variety and application of stress-resistant growth

The quality of soybean seeds is a key factor determining their value for the processing industry and consumers, as well as an important criterion for evaluating the effectiveness of cultivation technology.

The thousand-kernel weight is a component of yield structure that reflects the plant ability to efficiently accumulate assimilates in the grain. This indicator is closely correlated with final yield and serves as a measure of the variety response to weather conditions and agronomic practices. An increase in thousand-kernel weight indicates a highly efficient photosynthetic apparatus and effective transport of nutrients. Thus, this parameter is a crucial criterion for evaluating the effectiveness of applied agronomic measures [21].

The analysis of data from the studies conducted in 2021-2023 (Table 4.3.1) has demonstrated a significant influence of meteorological conditions on the formation of the mass of 1,000 grains. The highest mass of 1,000 grains was recorded in 2023 – 194.8 g. This indicates the optimal conditions for pouring grain formed during this year. In 2022, which was drier, the mass of 1,000 grains was 182.2 g, and in 2021 - 166.7 g.

In the Factor A section (varieties), the largest mass of 1,000 grains was the Bettina variety (189.3 g), indicating its high genetic potential for the formation of large seeds. Such varities as Aureline (182.7 g), Mentor (179.9 g) and Amadea (178.2 g) had slightly lower performance, but also demonstrated the ability to effectively pour grain under different conditions. The lowest mass of 1,000 grains was characterized by such variety as Navigator – 175.9 g.

The Factor B (growth regulators) found that extra-root feeding significantly increased the mass of 1,000 grains compared to control. The most effective was the growth regulator Amino VG Antistress, which provided an average of 185.2 g. This can be explained by its ability to improve the adaptation of plants to stressful conditions and stimulate photosynthesis, leading to greater accumulation of nutrients in the grain. Antistress (183.4 g) and Sugar Mover (180.1 g) also showed positive effects. The lowest indicator was recorded on the Control variant – 176.1g. The results of the dispersion analysis have proven that the influence of the variety ($NIR_{05}$ = 6.03 g), growth regulators ($NIR_{05}$ = 5.39 g) and their interaction ($NIR_{05}$ = 12.06 g) on the formation of the mass of 1,000 grains is statistically significant.

*Table 4.3.1.*

**Varietal characteristics of 1000-seed weight formation depending on the application of stress-protective growth regulators (Average for 2021–2023, Sumy National Agrarian University, NSVK), g**

| Veriety (Factor A) | Growth regulator (Factor B) | Weight of 1000 grains, g | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 162,5 | 172,9 | 187,6 | 178,2 | 176,1 |
| | Amino VG Antistress | 175,6 | 176,9 | 191,2 | | 185,2 |
| | Antistress | 169,0 | 181,2 | 192,1 | | 183,4 |
| | Sugar Mover | 167,2 | 172,8 | 189,5 | | 180,1 |
| Aureline | Control | 159,2 | 180,0 | 196,4 | 182,7 | |
| | Amino VG Antistress | 170,5 | 188,2 | 200,4 | | |
| | Antistress | 168,5 | 187,0 | 198,1 | | |
| | Sugar Mover | 165,2 | 182,4 | 196,0 | | |
| Bettina | Control | 178,0 | 184,0 | 197,8 | 189,3 | |
| | Amino VG Antistress | 179,9 | 196,2 | 200,1 | | |
| | Antistress | 180,3 | 196,5 | 196,9 | | |
| | Sugar Mover | 180,2 | 188,0 | 194,0 | | |
| Mentor | Control | 143,9 | 165,1 | 203,6 | 179,9 | |
| | mino VG Antistress | 169,0 | 189,7 | 198,2 | | |
| | Antistress | 169,9 | 186,1 | 188,9 | | |
| | Sugar Mover | 179,1 | 182,9 | 182,4 | | |
| Navigator | Control | 147,2 | 172,0 | 191,2 | 175,9 | |
| | Amino VG Antistress | 161,5 | 184,5 | 195,9 | | |
| | Antistress | 160,8 | 181,1 | 194,8 | | |
| | Sugar Mover | 145,6 | 176,0 | 200,1 | | |
| Average per year | | 166,7 | 182,2 | 194,8 | 181,2 | |
| $HIP_{05}$ Factor A=6,03; B=5,39; AB=12,06 | | | | | | |

The quality of soybeans is an important criterion that determines its consumer and industrial value. Protein and fat content are the main indicators that shape grain quality and depend on both the genetic potential of the variety and the influence of environmental factors and agrotechnical techniques [10, 23].

The analysis of the study data has shown a significant influence of weather conditions on the protein content of soybeans (Table 4.3.2). The highest average protein content was recorded in 2021 (42.6%), while in the somewhat drier 2022 this figure was the lowest (38.8%), indicating the negative impact of stressful conditions on protein accumulation. In 2023, which was characterized by favorable humidity, the average protein content was 42.2%.

In the category of Factor A (varieties), the highest average protein content was the Aurelina variety (42.0%), and the smallest - the Amadea variety (40.2%). Other varieties, such as Bettina, Mentor and Navigator, had similar values (41.2–41.3%).

The use of extra-root nutrition contributed to increasing the protein content in the grain. The most effective agent was Sugar Mover, providing for an average protein content of 42.0%, which may be due to its effect on improving the transport of nutrients to the grain. Amino VG Antistress and Antistress also showed a positive effect, providing protein content of 41.3% and 40.9% respectively, while the control version was the lowest at 40.7%.

*Table 4.3.2.*

**Variety features of formation of protein content in soybeans depending on the use of growth regulators with anti-stress action (average for 2021-2023, NSVK Sumy NAU), %**

| Veriety (Factor A) | Growth regulator (Factor B) | Protein content, % | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 40,5 | 37,7 | 40,1 | 40,2 | 40,7 |
| | Amino VG Antistress | 40,9 | 39,1 | 40,5 | | 41,3 |
| | Antistress | 40,8 | 38,9 | 40,2 | | 40,9 |
| | Sugar Mover | 43,5 | 39,0 | 41,8 | | 42,0 |
| Aureline | Control | 41,5 | 39,3 | 43,4 | 42,0 | |
| | Amino VG Antistress | 41,9 | 40,1 | 44,6 | | |
| | Antistress | 41,6 | 39,4 | 43,9 | | |
| | Sugar Mover | 43,8 | 39,9 | 45,1 | | |
| Bettina | Control | 42,2 | 38,9 | 41,0 | 41,2 | |
| | Amino VG Antistress | 43,0 | 39,8 | 41,8 | | |
| | Antistress | 42,7 | 39,1 | 41,1 | | |
| | Sugar Mover | 43,1 | 39,5 | 42,5 | | |
| Mentor | Control | 42,6 | 38,0 | 42,0 | 41,3 | |
| | Amino VG Antistress | 43,2 | 38,5 | 42,5 | | |
| | Antistress | 42,9 | 38,2 | 41,8 | | |
| | Sugar Mover | 44,2 | 38,3 | 43,1 | | |
| Navigator | Control | 42,6 | 38,0 | 42,0 | 41,3 | |
| | Amino VG Antistress | 43,2 | 38,5 | 42,5 | | |
| | Antistress | 42,9 | 38,2 | 41,8 | | |
| | Sugar Mover | 44,2 | 38,3 | 43,1 | | |
| Average per year | | 42,6 | 38,8 | 42,2 | 41,2 | |
| $HIP_{05}$ Factor A=0,74; B=0,66; AB=1,48 | | | | | | |

The results of the dispersion analysis have shown a statistically significant effect on the protein content of the variety ($NIR_{05}$ = 0.74%), growth regulators ($NIR_{05}$ = 0.66%) and their interaction ($NIR_{05}$ = 1.48%). This means that the difference in indicators is significant and not accidental.

The fat content of soybeans determines the food, feed and industrial value of the crop. Soybean oil has a high nutritional value, and is widely used in the food industry for the production of oil, margarine, as well as in the non-food sector, in particular for the manufacture of biodiesel, paints, varnishes and other technical products. Fat accumulation occurs in the cells of the seedlings during seed maturation, and is an important form of nutrients needed for germination. The optimal fat content, together with the high protein one, ensures the comprehensive quality characteristics of the grain, making it a valuable raw material in the global market. Therefore, studies aimed at increasing fat and protein content are of great importance for increasing the profitability of soybean production [23, 46].

The analysis of the fat content in soybeans for the period 2021-2023 has shown that this indicator is highly dependent on weather conditions and varietal characteristics (Table 4.3.3). On average, the highest fat content was recorded in 2023 (19.7%), which correlated with high yield and optimal grain pouring temperature regime. In 2021, the average fat content was 18.9%, and in 2022 was 18.8%, which might be due to the impact of stressful conditions on plant metabolism.

In the category of Factor A (varieties), the highest fat content was characterized by the Mentor variety (19.5%). The Amadeus was 19.2% and the

Navigator was 19.1%. The lowest figure was recorded in the varieties such as Aurelina and Bettina, which amounted to 19.0%. This indicates the genetic differences of the varieties in the synthesis of fats.

The use of anti-stress growth regulators did not lead to a significant increase in fat content, and in some cases it was observed to be slightly reduced compared to control. The highest fat content was in the control (19.2%), while when using drugs it ranged from 19.0% to 19.2%. This pattern can be explained by a known feedback in soybean metabolism, where the activation of protein synthesis caused by the action of drugs leads to the use of resources that could be spent on fat synthesis [35, 41].

The results of the dispersion analysis have proved that the effect of the variety ($NIR_{05}$ = 0.26), growth regulators ($NIR_{05}$ = 0.24) and their interaction ($NIR_{05}$ = 0.53) on the fat content of the grain is statistically significant.

The analysis of essential amino acid content is critical to assessing the biological integrity of soy protein, as these compounds are not synthesized by human and animal bodies. Assessing the range of fluctuations of these indicators enables to identify the most effective combination of varieties and agrotechnical techniques to improve grain quality [34, 40].

According to the results of the studies, it was established that the highest indicators of the content of most essential amino acids were recorded in the Mentor variety in the variant with the use of Sugar Mover. In particular, the maximum content of lysine was 2.71%, threonine – 1.63 g/100 g, valine – 2.10 g/100 g, isoleicin – 1.80 g/100 g, leucine – 3.15 g/100 g, and phenylalanine – 2.21 g/100 g.

*Table 4.3.3.*

**Variety features of the formation of fat content in soybeans depending on the use of growth regulators with anti-stress action (average for 2021-2023, NSVK Sumy NAU), %**

| Variety (Factor A) | Growth regulator (Factor B) | Fat content, % | | | Average | |
|---|---|---|---|---|---|---|
| | | 2021 | 2022 | 2023 | Factor A | Factor B |
| Amadea | Control | 18,9 | 18,8 | 19,9 | 19,2 | 19,2 |
| | Amino VG Antistress | 19,0 | 19,1 | 20,2 | | 19,2 |
| | Antistress | 18,8 | 18,9 | 19,2 | | 19,1 |
| | Sugar Mover | 18,5 | 18,6 | 20,3 | | 19,2 |
| Aureline | Control | 18,8 | 18,7 | 19,9 | 19,0 | |
| | Amino VG Antistress | 19,1 | 18,7 | 19,6 | | |
| | Antistress | 18,7 | 18,1 | 19,2 | | |
| | Sugar Mover | 19,0 | 19,0 | 19,6 | | |
| Bettina | Control | 18,9 | 18,7 | 19,8 | 19,0 | |
| | Amino VG Antistress | 18,7 | 18,9 | 19,6 | | |
| | Antistress | 18,7 | 18,9 | 19,0 | | |
| | Sugar Mover | 19,0 | 18,6 | 19,4 | | |
| Mentor | Control | 18,5 | 18,9 | 20,3 | 19,5 | |
| | Amino VG Antistress | 19,4 | 19,4 | 20,3 | | |
| | Antistress | 19,4 | 19,3 | 20,2 | | |
| | Sugar Mover | 18,5 | 19,3 | 20,1 | | |
| Navigator | Control | 18,9 | 18,5 | 20,0 | 19,1 | |
| | Amino VG Antistress | 18,8 | 18,4 | 18,4 | | |
| | Antistress | 19,6 | 18,6 | 19,7 | | |
| | Sugar Mover | 19,1 | 19,1 | 20,1 | | |
| Average per year | | 18,9 | 18,8 | 19,7 | 19,2 | |
| $HIP_{05}$ Factor A=0,26; B=0,24; AB=0,53 | | | | | | |

The highest methionine content was recorded at 0.56 g/100 g also in Mentor, but in the control variant. These data indicate the high genetic potential of Mentor and the effectiveness of Sugar Mover in improving the amino acid composition of the grain.

In contrast, the lowest values were predominantly observed in the Amadea variety at the control sites, underlining the importance of extra-root nutrition. The minimum content of lysine was 2.40 g/100 g, treonin – 1.44 g/100 g, and leucine – 2.85 g/100 g. The lowest methionine content (0.50 g/100 g) was observed in Amadea with the application of Antistress. Minimum values of valine (1.90 g/100 g), isoleicin (1.62 g/100 g) and phenylalanine (1.98 g/100 g) were recorded in Amadea in the control. The general trend indicates the positive effect of agents with anti-stress action on the accumulation of essential amino acids, which emphasizes their role in increasing the biological value of the crop.

The content of substitute amino acids involved in key metabolic processes is an important indicator that reflects the overall metabolic state of the plant and influences the formation of quality protein [31]. The analysis of the data has shown clear trends regarding the impact of varieties and preparations on their content in soybeans.

According to the results of the studies, it was established that the highest indicators of the content of all substitute amino acids were recorded in the Mentor variety in the variant with the use of the agent Sugar Mover.

*Table 4.3.4.*

**Variety features of formation of essential amino acid content in soybeans depending on the use of growth regulators with anti-stress action (average for 2021-2023, NSVK Sumy NAU), g/100 g**

| Variety (Factor A) | Growth regulator (Factor B) | Irreplaceable amino acids, g/100 g | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Lyzin** | **Treonin** | **Methionine** | **Walin** | **Isolecin** | **Leizin** | **Phenylalanine** |
| Aureline | Control | 2,52 | 1,51 | 0,55 | 1,98 | 1,69 | 2,95 | 2,05 |
| | Amino VG Antistress | 2,65 | 1,59 | 0,54 | 2,04 | 1,75 | 3,08 | 2,15 |
| | Antistress | 2,59 | 1,55 | 0,53 | 2,01 | 1,72 | 3,02 | 2,10 |
| | Sugar Mover | 2,68 | 1,62 | 0,55 | 2,08 | 1,78 | 3,12 | 2,18 |
| Bettina | Control | 2,48 | 1,48 | 0,54 | 1,95 | 1,67 | 2,90 | 2,02 |
| | Amino VS Antistress | 2,61 | 1,56 | 0,53 | 2,02 | 1,73 | 3,05 | 2,12 |
| | Antistress | 2,55 | 1,52 | 0,52 | 1,99 | 1,70 | 2,98 | 2,07 |
| | Sugar Mover | 2,60 | 1,54 | 0,55 | 2,01 | 1,71 | 3,02 | 2,10 |
| Amadea | Control | 2,40 | 1,44 | 0,52 | 1,90 | 1,62 | 2,85 | 1,98 |
| | Amino VS Antistress | 2,51 | 1,51 | 0,51 | 1,97 | 1,68 | 2,98 | 2,08 |
| | Antistress | 2,48 | 1,48 | 0,50 | 1,95 | 1,66 | 2,95 | 2,05 |
| | Sugar Mover | 2,54 | 1,53 | 0,52 | 2,00 | 1,71 | 3,01 | 2,11 |
| Mentor | Control | 2,55 | 1,53 | 0,56 | 2,00 | 1,72 | 2,98 | 2,08 |
| | Amino VS Antistress | 2,68 | 1,61 | 0,55 | 2,07 | 1,78 | 3,11 | 2,18 |
| | Antistress | 2,62 | 1,57 | 0,54 | 2,03 | 1,75 | 3,05 | 2,13 |
| | Sugar Mover | 2,71 | 1,63 | 0,56 | 2,10 | 1,80 | 3,15 | 2,21 |
| Navigator | Control | 2,45 | 1,47 | 0,53 | 1,94 | 1,65 | 2,88 | 2,00 |
| | Amino VS | 2,58 | 1,54 | 0,52 | 2,01 | 1,72 | 3,01 | 2,10 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Antistress | | | | | | | |
| | Antistress | 2,52 | 1,50 | 0,51 | 1,98 | 1,69 | 2,95 | 2,05 |
| | Sugar Mover | 2,61 | 1,56 | 0,54 | 2,04 | 1,75 | 3,08 | 2,15 |

In particular, the maximum content of alanine was 1.71%, proline - 1.67 g/100 g, glutamic acid - 6.05 g / 100 g, asparaginic acid - 4.30 g/100 g, serine - 2.03 g/100 g, arginine - 3.00 g/100 g, and histidine - 1.61 g/100 g. This indicates the high effectiveness of the combination of the genetic potential of this variety and the stimulating action of the agent Sugar Mover on the synthesis of protein compounds.

In contrast, the lowest values of the content of most substitute amino acids were mainly observed in the Navigator variety in the control. The minimum content of alanine was 1.45 g/100 g, glutamic acid – 5.20 g/100 g, asparaginic acid – 3.70 g/100 g, serine – 1.70 g/100 g, arginine – 2.50 g/100 g, and histidine – 1.30 g/100 g. The exception was proline, whose minimum value (1.42 g/100 g) was also recorded in the Navigator variety, but when using the agent Amino VG Antistress. The general trend indicates the positive effect of extra-root nutrition on the accumulation of substitute amino acids, underlining their role in improving the qualitative characteristics of the grain.

The effect of weather conditions on the protein content of soybeans is the subject of discussion in the scientific community. Some researchers believe that high temperatures (>20 to <28 °C) during vegetation contribute to increased protein content [44, 47].

*Table 4.3.5.*

**Variety features of formation of substitute amino acid content in soybeans depending on the use of growth regulators with anti-stress action (average for 2021-2023, NSVK Sumy NAU), g/100 g**

| Variety (Factor A) | Growth regulator (Factor B) | Replacement amino acids, g/100 g | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Alanin | Prolin | Glutaminic acid | Asparaginic acid | Serene | Arginine | Histidine |
| Aureline | Control | 1,55 | 1,52 | 5,50 | 3,85 | 1,85 | 2,65 | 1,42 |
| | Amino VG Antistress | 1,65 | 1,61 | 5,80 | 4,10 | 1,95 | 2,85 | 1,52 |
| | Antistress | 1,60 | 1,56 | 5,65 | 3,98 | 1,90 | 2,75 | 1,47 |
| | Sugar Mover | 1,68 | 1,64 | 5,95 | 4,25 | 2,00 | 2,95 | 1,58 |
| Bettina | Control | 1,52 | 1,49 | 5,40 | 3,80 | 1,80 | 2,60 | 1,39 |
| | Amino VS Antistress | 1,62 | 1,58 | 5,70 | 4,05 | 1,90 | 2,80 | 1,49 |
| | Antistress | 1,58 | 1,54 | 5,55 | 3,90 | 1,85 | 2,70 | 1,44 |
| | Sugar Mover | 1,65 | 1,61 | 5,85 | 4,15 | 1,95 | 2,90 | 1,55 |
| Amadea | Control | 1,48 | 1,45 | 5,30 | 3,75 | 1,75 | 2,55 | 1,35 |
| | Amino VS Antistress | 1,58 | 1,55 | 5,60 | 4,00 | 1,85 | 2,75 | 1,45 |
| | Antistress | 1,54 | 1,51 | 5,45 | 3,88 | 1,80 | 2,65 | 1,40 |
| | Sugar Mover | 1,61 | 1,58 | 5,75 | 4,10 | 1,90 | 2,85 | 1,51 |
| Mentor | Control | 1,58 | 1,55 | 5,60 | 3,95 | 1,88 | 2,70 | 1,45 |
| | Amino VS Antistress | 1,68 | 1,64 | 5,90 | 4,20 | 1,98 | 2,90 | 1,55 |
| | Antistress | 1,64 | 1,60 | 5,75 | 4,08 | 1,93 | 2,80 | 1,50 |
| | Sugar Mover | 1,71 | 1,67 | 6,05 | 4,30 | 2,03 | 3,00 | 1,61 |
| Navigator | Control | 1,45 | 1,42 | 5,20 | 3,70 | 1,70 | 2,50 | 1,30 |
| | Amino VS | 1,55 | 1,51 | 5,50 | 3,95 | 1,80 | 2,70 | 1,40 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Antistress | | | | | | | |
| | Antistress | 1,51 | 1,48 | 5,35 | 3,82 | 1,75 | 2,60 | 1,35 |
| | Sugar Mover | 1,58 | 1,55 | 5,65 | 4,05 | 1,85 | 2,80 | 1,46 |

At the same time, other scientific papers indicate an inverse dependence – a negative correlation between temperature and protein content [36]. Scientists from the Eastern Forest Steppe of Ukraine confirm that the best accumulation of protein occurs under conditions of stable heat supply during pouring and ripening of beans [20].

In addition to climatic factors, the protein content is significantly influenced by varietal features. According to the researchers of V. Ya. Yuriev Plant Production Institute of NAAN, the highest protein content was recorded in such varieties as Adamos (41.23%), Malvina (40.12%), Melody (39.69%) and Veresneva (39.52%), while the lowest figure was in the variety Biliavka (31.72%) [22].

Foreign scientists also note that the amino acid composition of soybeans depends on the total protein concentration. It is observed that the relative content of such amino acids as lysine, methionine, cysteine, tryptophan and threonine decreases with an increase in the concentration of protein in the seed. On the contrary, the content of arginine and glutamic acid increases [39, 42]. This indicates that the ratio between the seed protein and the content of individual amino acids is changing.

## Conclusions to section 4

1. Soybean plant height and leaf surface area varied greatly depending on weather conditions, varietal characteristics and application of growth regulators. The highest height (71.4 cm) was formed by the Bettina variety, and the highest content of chlorophylls (2.46 mg/g of raw mass) and leaf surface area (36.3 thousand $m^2$/ha) - the Aurelina variety. The use of the agent Antistress provided the largest indicators of all morphological parameters.

2. The number of seeds and individual productivity of plants were significantly dependent on weather conditions – in 2023 when the varieties formed the highest indicators: the number of seeds (32.1 pieces); individual productivity (6.26 g). The largest number of seeds (32.0 pieces) was formed by the Navigator variety, while the largest seed mass (5.63 g) was the Aurelina variety. The use of the Sugar Mover growth regulator provided the highest seed count (31.6 pieces) and Antistress – the highest individual plant productivity (5.65 g).

3. The highest yield indicators were formed in 2023 – 3.23 t/ha. Among the varieties studied, the highest yield was Aurelina (2.90 t/ha), outperforming other varieties such as Navigator (2.87 t/ha) and Bettina (2.86 t/ha), as well as Amadea (2.70 t/ha) and Mentor (2.62 t/ha). The maximum yield (2.91 t/ha) was obtained at the level for the use of the agent Antistress.

4. It turns out that the conditions in 2023 were the most favorable for the formation of a mass of 1,000 grains – 194.8 g. The largest mass of 1000 grains was

formed by the Bettina variety – 189.3 g. The use of growth regulators, in particular Amino VG Antistress, contributed to a significant increase in this figure (185.2 g).

5. It has been established that the quality of soybeans is influenced by both the genetic potential of the variety and agrotechnical techniques. The highest protein content (42.0%) was recorded in Aurelina with Sugar Mover and the highest fat content (19.5%) in Mentor in the control, indicating an inverse relationship between protein and fat content under the influence of growth regulators.

6. According to the results of biochemical analysis, the largest indicators of the content of both essential and substitutable amino acids were recorded in Mentor variety using Sugar Mover, which indicated the high effectiveness of this combination to increase the biological value of grain.

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# SECTION 5

# ECONOMIC AND ENERGY EFFICIENCY OF GROWTH OF SOY DEPENDING ON THE TYPE AND APPLICATION OF GROWTH REGULATORS WITH ANTI-STRESS ACTION

## 5.1. Economic efficiency of soybean cultivation depending on the variety and application of growth regulators with anti-stress action

In recent years, there has been a trend of climate change in Ukraine, with such factors as an increase in average annual temperature, an increase in the frequency of droughts and other abiotic stresses, significantly complicating the cultivation of agricultural crops, including soybeans. With this in mind, farmers should improve their cultivation technology to minimize the impact of adverse environmental factors.

An effective technological approach is the use of growth regulators with anti-stress action, since they not only improve physiological and biochemical processes, but also increase the adaptive potential of soybeans, which for growing in stressful conditions enables to maintain productivity. The use of such a technological approach should be economically justified, as cost optimization will allow the cultivation of competitive products, thereby ensuring the sustainable development of the agrarian sector [1].

A comprehensive indicator that enable to assess the feasibility of introducing a method to soybean cultivation technology is economic efficiency. The most informative indicators of economic efficiency are the level of profitability and the mass of profits [2].

The relative efficiency of production, namely what portion of the profit is derived from each unit of expenditure, demonstrates the level of profitability. The financial result of the cultivation of a crop shows profit, as it reflects the amount of the enterprise net income after covering production costs. Therefore, analyzing these indicators, it is possible to conclude about the economic effectiveness of the technological solution, which allows its widespread implementation in agricultural production [3].

On the basis of complex technological maps of cultivation and current prices for material resources and labor remuneration as of 2023, indicators of economic efficiency of cultivation of soybean varieties in the conditions of the Left-Bank Forest Steppe of Ukraine were calculated. The sale price of soybeans for October 2023 was 14 800 UAH/ton.

The Appendices attached contain detailed calculations of the economic efficiency of the cultivation of soybean varieties studied depending on the application of growth regulators with anti-stress action. The profitability indicators of cultivation of soybean varieties under study using growth regulators with anti-stress action at prices as of October 2023 are shown in Table 5.1.

*Table 5.1.*

**Profitability of cultivation of soybean varieties studied using growth regulators with anti-stress action (at October 2023 prices), %**

| Variety (Factor A) | Growth regulators with anti-stress action (Factor B) | | | |
|---|---|---|---|---|
| | Control | Amino VS Antistress | Antistress | Sugar Mover |
| Amadeus | 149 | 124 | 146 | 120 |
| Aurelina | 161 | 132 | 159 | 136 |
| Bettina | 145 | 131 | 155 | 132 |
| Mentor | 131 | 106 | 143 | 119 |
| Navigator | 148 | 144 | 155 | 129 |

From Table above, it can be concluded that the cultivation of soybean varieties using growth regulators with anti-stress action is effective, since each study option guarantees a profitability of more than 100%, indicating a high level of cost recovery. It is worth noting that almost all control options have a high rate of profitability, which is in the range of 131-161%. This is due to the lack of cost on growth regulators, which significantly reduces the cost, and as a result increases profitability.

Among the soybean varieties studied using growth regulators with anti-stress action, the highest profitability indicators were recorded for the Aurelina variety. Thus, the cost-effectiveness of the control option was 161%, and the use of Antistress, Amino VS Antistress, Antistress and Sugar Mover regulators – 132%, 159% and 136%, respectively. The obtained indicators demonstrate the significant economic potential of this variety both by standard cultivation technology and the modified one.

Among the studied growth regulators with anti-stress action, the highest profitability was obtained by using Antistress, namely for Bettina and Navigator varieties by 155%, and for Mentor soybean variety by 143%. Other growth regulators with an anti-stress effect have resulted in lower profitability, demonstrating their inefficiency from an economic point of view.

Thus, the maximum level of profitability was obtained for the cultivation of soybean variety Aurelina without the use of growth regulators with atri-stress effect, which was explained by the absence of additional costs for growth regulatory agents.

For a complete picture of the economic efficiency of growing soybean varieties using growth regulators with anti-stress action will help to obtain a mass of conditionally net profit. It is of key importance as it shows the actual financial result of production in cash equivalent, as opposed to profitability, which demonstrates the relative efficiency of the production activity.

That is why the analysis of the mass of conditional net profit is a crucial component of the economic justification of crop cultivation technology, as it helps in management decision-making in agricultural production.

Data on the mass of conditional net profit for soybean cultivation and application of anti-stres growth regulators are given in Table 5.2. The above Table shows that all experimental variants are profitable. Among the soybean varieties studied, the most profitable was the Aureliana variety, with a net profit ranging from UAH 24,232 to 27,228 per hectare.

*Table 5.2.*

**Mass of conditionally net profit of cultivation of soybean varieties studied using growth regulators with anti-stress action (at October 2023 prices), UAH/ha**

| Varietys (Factor A) | Growth regulators with anti-stress action (Factor B) | | | |
|---|---|---|---|---|
| | Control | Amino VS Antistress | Antistress | Sugar Mover |
| Amadeus | 23 179 | 22 386 | 24 516 | 21 504 |
| Aurelina | 25 744 | 24 232 | 27 228 | 24 932 |
| Bettina | 23 556 | 24 489 | 27 054 | 24 614 |
| Mentor | 20 744 | 19 232 | 24 386 | 21 658 |
| Navigator | 23 664 | 26 611 | 26 731 | 23 572 |

Other varieties yielded slightly lower results. Specifically, the Amadea variety had a profit of UAH 21,504 to 24,156 per hectare, the Bettina variety – UAH 23,556 to 27,054 per hectare, the Mentor variety – UAH 19,232 to 24,386 per hectare, and the Navigato variety – UAH 23,572 to 26,731 per hectare.

The application of stress-resistant growth regulators ensured an increase in profit compared to the control in almost every experimental variant. The highest values of conditional net profit were achieved with the use of the Antistress regulator, which demonstrated a 5-15% higher profitability than the controls. For example, the profit for the Aureliana variety was 27,228 UAH/ha, for the Bettina variety - 27,054 UAH/ha, for the Navigator variety - 26,731 UAH/ha, for the Amadea variety - 24,516 UAH/ha, and for the Mentor variety - 24,386 UAH/ha. It is worth noting that the application of growth regulators such as Antistress, Amino VS Antistress, and Sugar Mover resulted in lower profits compared to the controls, indicating their lower economic efficiency.

Thus, the maximum value of mass conditionally pure profit was achieved by cultivating the Aurelina soybean variety and applying the Antistress Anti-Stress Growth Regulator.

To comprehensively evaluate the economic efficiency of soybean cultivation technology elements, analyzing the cost structure is a material condition. To visually represent the cost structure information, a pie chart was constructed, showing the proportions of major cost items for the most profitable experimental variant (Fig. 5.1).

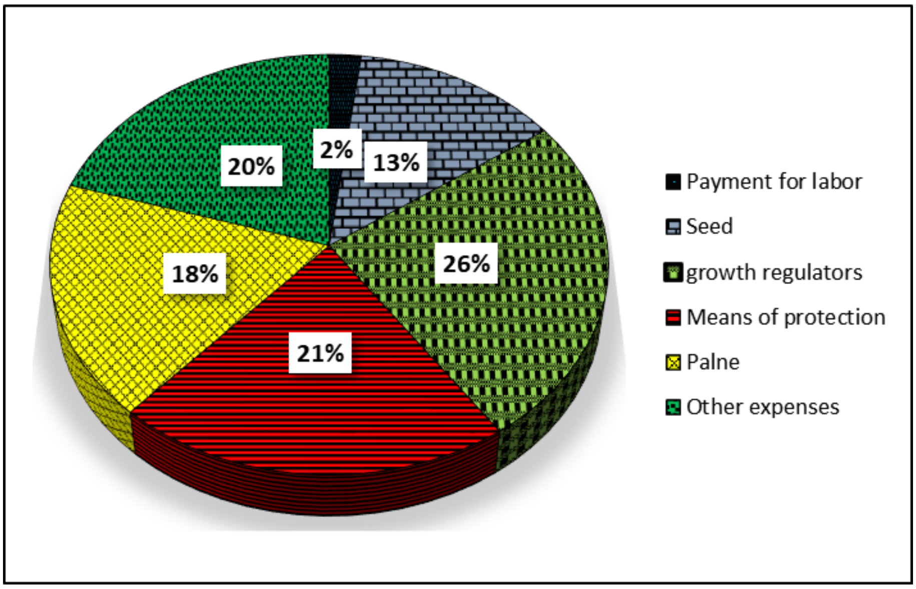



**Fig. 5.1. Structure of costs per 1 hectare, %**

Analyzing the diagram, we can draw the following conclusions: the largest share in the overall structure of expenses is occupied by growth regulators at 26%, protective measures at 21%, and other expenses at 20%, which include general costs for the maintenance and repair of non-current assets, depreciation provisions, and other production-related expenses.

## 5.2. Energy efficiency of soybean cultivation depends on the variety and application of stress-resistant growth regulators

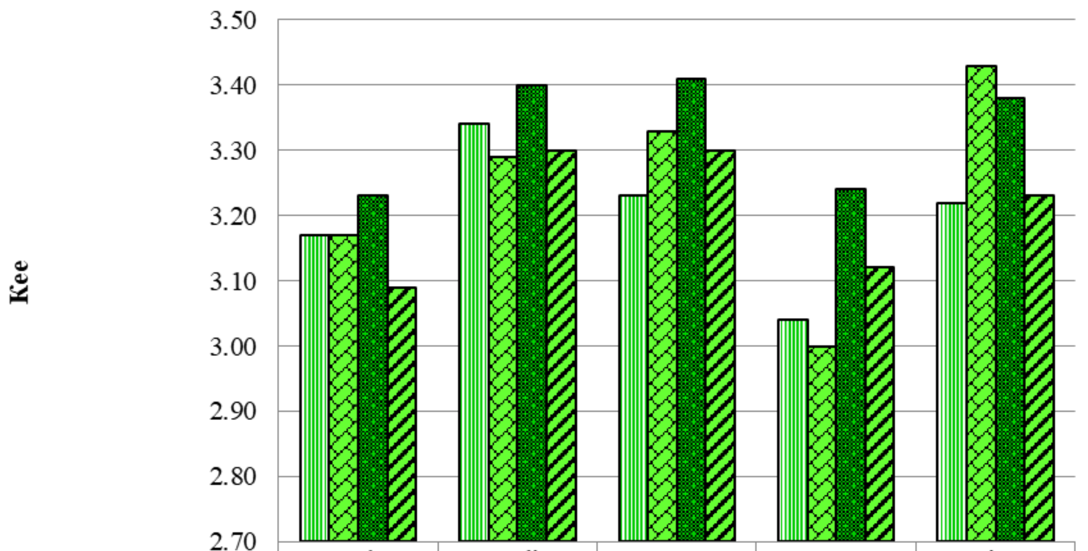
Global climate change, coupled with rising energy costs and increasing demand for high-quality raw materials, is compelling modern agricultural production to enhance the energy efficiency of growing crops, including soybeans. To achieve this, each new element of cultivation technology should be evaluated from an energy perspective. Such an assessment is more comprehensive than an economic evaluation, as it is not tied to market conditions or pricing mechanisms. In this context, energy expenditures are expressed in joules [4].

To evaluate a specific element of cultivation technology, it is essential to calculate the energy efficiency coefficient by dividing the total energy accumulated in the crop yield by the total energy spent on growing and harvesting the crop [5].

The energy indicators presented in Appendix A demonstrate the direct impact of the studied factors on energy efficiency metrics. The energy efficiency coefficients calculated for each experimental variant exceed 1, proving their energy-saving nature.

The evaluation of energy efficiency in soybean cultivation depending on the variety, with the application of stress-resistant growth regulators, is presented in Figure 5.2 as a bar chart.

From the graph, we can see that for Factor A, the most energy-efficient option from an energy perspective was the cultivation of the Aurelia variety, as its Kee value ranged between 3.29-3.40. Regarding Factor B, the growth regulator that achieved the highest energy efficiency index of 3.43 for the Navigator variety was Amino VS Antistress. It is important to note that the growth regulator Antistress had the highest average index for all varieties.




| | Amadeus | Aureline | Bettyna | Mentor | Navigator |
|---|---|---|---|---|---|
| Control | 3.17 | 3.34 | 3.23 | 3.04 | 3.22 |
| Amino VS Antistress | 3.17 | 3.29 | 3.33 | 3.00 | 3.43 |
| Antistress | 3.23 | 3.40 | 3.41 | 3.24 | 3.38 |
| Sugar Mover | 3.09 | 3.30 | 3.30 | 3.12 | 3.23 |

**Fig. 5.2. Energy efficiency coefficients depending on the variety when applying growth regulators with anti-stress effects.**

Thus, the analysis of energy efficiency helped identify the general trend in forming the Kee coefficient. Based on the average coefficient values, it can be concluded that the most energy-efficient variety was Aureliana, as it consistently provided high energy output from the yield, resulting in minor Kee coefficient fluctuations (3,29-3,40) depending on the use of growth regulators. Among the studied stress-resistant growth regulators, the highest value was achieved with Amino VS Antistress, which yielded a Kee coefficient of 3,43 for the Navigator variety, but performed worse on other varieties. Therefore, it is advisable to determine the most energy-efficient variety based on the average Kee coefficient when applying growth regulators. Hence, the maximum average energy efficiency coefficient of 3,33 was obtained using the stress-resistant growth regulator Antistress.

## Conclusions to section 5

Analyzing the economic and energy efficiency of soybean cultivation based on variety and the application of stress-resistant growth regulators, the following conclusions were drawn:

1. Growing soybeans in the Left-Bank Forest-Steppe of Ukraine is economically and energetically advantageous. This is confirmed by calculated economic indicators (masses of net conditional profits and levels of profitability), as well as energy efficiency coefficients.

2. The maximum profitability level of 161% was achieved by cultivating the Aurelia soybean variety without the use of growth regulators with atrazine-like effects, which is explained by the absence of additional costs for growth-controlling agents

3. The maximum conditional pure profit per unit area (27,228 UAH/ha) was achieved by growing the Aureliana soybean variety and applying the Antistress Stress-Resistant Growth Regulator.

4. The structure of soybean cultivation costs is distributed as follows: average labor costs account for ≈ 2–2.5%; seeds ≈ 10–15%; protective agents ≈ 17–27%; fuel ≈ 16–19%; other costs ≈ 20%. The application of stress-resistant growth regulators accounts for ≈ 22–27%.

5. The highest average values of energy efficiency coefficients were obtained for growing the Aurenella soybean variety (Kee 3.33) and applying the Antistress Stress-Resistant Growth Regulator (Kee 3.33).

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# CONCLUSIONS

The PhD thesis presents a theoretical generalization and resolution of the scientific task concerning the study of modern methods for determining stress and its impact on the growth and development of soybean plants, both in controlled environments and under field conditions in the Left-Bank Forest-Steppe of Ukraine. The study is based on examining the variety-specific characteristics of soybean productivity formation when applying various growth regulators with anti-stress effects. The results obtained from the research conducted between 2021 and 2023 allow the following conclusions to be drawn:

1. The result research was conducted in an artificial climate chamber at the Henan Institute of Science and Technology, Xinxiang, China. The Amino VG-Antistress regulator was evaluated for its ability to improve the salt tolerance of the Zheng 196 soybean variety at the seedling stage. The Regulator enhanced the antioxidant capacity of Zheng 196 soybean seedlings and mitigated the effects of salt stress. The effect was most pronounced at a salt concentration of 100 mmol/L, confirming the regulator’s ability to improve soybean salt resistance.

2. Under salt concentrations of 50 mmol/L, 75 mmol/L, and 100 mmol/L, the activities of superoxide dismutase, ascorbate peroxidase, and catalase all increased. At a salt concentration of 100 mmol/L, superoxide dismutase activity increased by 5.78%, though this increase was not effect of a growth regulator significant. In contrast, ascorbate peroxidase and catalase activities showed significant increases of 30% and 35.96%, respectively, at the same salt

concentration, while malondialdehyde content notably decreased by 33%. This demonstrated that under high salt concentrations, the Regulator significantly enhanced the antioxidant capacity of soybean seedlings and reduced membrane oxidation.

3. The main compounds (enzymes) that are indicators of the resistance of plant organisms to increased salinity were studied. The key findings demonstrated the effectiveness of the regulator and highlighted its potential for increasing resistance. Along with this, the results are relevant for scientists seeking to develop substances with similar compositions to create newer, more effective growth regulators with anti-stress properties. The results offer additional evidence supporting the physiological role of melatonin and provide a theoretical foundation for its application in enhancing salt tolerance in agricultural practices. These findings are crucial for advancing the development of new growth regulators and provide scientific evidence supporting their feasibility in addressing the growing challenge of soil salinity.

4. Field research results revealed that the main plant morphology and productivity parameters (height, leaf area) varied significantly depending on weather conditions, variety characteristics, and growth regulator application. The Bettina variety achieved the greatest height (71.4 cm), while the Aurelina variety exhibited the highest chlorophyll content (2.46 mg/g fresh weight) and leaf area (36.3 $m^2$/ha). Application of the Antistress preparation yielded the highest values for all morphological parameters.

5. The highest productivity indicators were achieved in 2023: seed count (32.1 pieces); individual productivity (6.26 g). Among the varieties, Navigator produced the highest seed count (32.0 pieces), while Aurelia yielded the highest seed mass (5.63 g). The application of the growth regulator Sugar Mover resulted in the highest seed count (31.6 pieces), while Antistress achieved the highest individual plant productivity.

6. The average highest yield indicator under the conditions of 2023 was 3.23 t/ha. The leader was the variety Aurelina (2.90 t/ha). The highest yield (2.91 t/ha) was achieved at the level of applying the Antistress preparation. The conditions of 2023 were the most favorable for forming a 1000-grain weight of 194.8 g. The variety Bettina formed the largest 1000-grain weight at 189.3 g. The application of growth regulators, including Amino VG Antistress, significantly increased this indicator (185.2 g).

7. It was established that both the genetic potential of the variety and agronomic techniques influence the chemical composition of soybean grain. The highest protein content (42.0%) was recorded in the Aureliana variety with the application of Sugar Mover, while the highest fat content (19.5%) was observed in the Mentor variety under control conditions, indicating an inverse relationship between protein and fat content under the influence of growth regulators. Biochemical analysis results showed the highest levels of both essential and non-essential amino acids in the Mentor variety with the use of Sugar Mover, demonstrating the high effectiveness of this combination for enhancing the biological value of the grain.

8. The economic calculations revealed that the highest profitability level of 161% was achieved by cultivating the Aurelia soybean variety under control conditions. The maximum conditional net profit per unit area (27,228 UAH/ha) was obtained by growing the Aurelia soybean variety and applying the stress-protective growth regulator Antistress. The highest average energy efficiency coefficients were achieved by cultivating the Aurelia soybean variety and applying the stress-protective growth regulator Antistress (Кее 3.33).

# RECOMMENDATION

**For the laboratory research:**

To further build upon these findings, future research should explore the longterm effects of the growth regulator on soybean growth and yield under diverse environmental conditions and examine its potential interactions with other stress factors to develop comprehensive strategies for enhancing crop resilience.

**For the field research**

For high performance, economic and bioenergetic efficiency of the cultivation of soybean in the conditions of the Left-Bank Forest, the technology should provide for the use of the Aurelina of foliar application: Antistress (1.7 kg/ha). The term for foliar application in micro stages $BBCH_{60–69}$.

# APPENDICES

Appendice A

| Economic efficiency of soybean cultivation | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Growth regulators with anti-stress effects | yield, centner per hectare | payment for work, UAH | seed | Good | means of protection | fueling | other expenses | total expenses | the cost of gross output, UAH | cost of 1 centner, UAH | profit, UAH/ha | profitability, % |
| **Amadeus** | | | | | | | | | | | | |
| Control | 26,2 | 369,3 | 1968 | 4298 | 2784 | 3058 | 3119 | 15597 | 38776 | 595,31 | 23179 | 149 |
| Amino VS Antistress | 27,3 | 377,7 | 1968 | 4298 | 4684 | 3087 | 3604 | 18018 | 40404 | 659,99 | 22386 | 124 |
| Antistress | 27,9 | 382,3 | 1968 | 4298 | 3668 | 3102 | 3355 | 16773 | 41292 | 601,17 | 24519 | 146 |
| Sugar Mover | 26,6 | 372,4 | 1968 | 4298 | 4584 | 3069 | 3573 | 17864 | 39368 | 671,57 | 21504 | 120 |
| **Average** | 27 | 375,4 | 1968,0 | 4298,0 | 3930 | 3079 | 3413 | 17063 | 39960 | 632,0 | 22897 | 134 |
| **Aureline** | | | | | | | | | | | | |
| Control | 28,2 | 384,6 | 2218 | 4298 | 2784 | 3110 | 3198 | 15992 | 41736 | 567,10 | 25744 | 161 |
| Amino VS Antistress | 28,8 | 389,1 | 2218 | 4298 | 4684 | 3125 | 3678 | 18392 | 42624 | 638,61 | 24232 | 132 |
| Antistress | 30 | 398,3 | 2218 | 4298 | 3668 | 3156 | 3434 | 17172 | 44400 | 572,39 | 27228 | 159 |
| Sugar Mover | 29,2 | 392,2 | 2218 | 4298 | 4584 | 3135 | 3657 | 18284 | 43216 | 626,15 | 24932 | 136 |
| **Average** | 29,1 | 391,1 | 2218 | 4298,0 | 3930 | 3131 | 3492 | 17460 | 42994 | 601,1 | 25534 | 146 |
| **Bettina** | | | | | | | | | | | | |
| Control | 26,9 | 374,6 | 2472 | 4298 | 2784 | 3076 | 3251 | 16256 | 39812 | 604,32 | 23556 | 145 |
| Amino VS Antistress | 29,2 | 392,2 | 2472 | 4298 | 4684 | 3135 | 3745 | 18727 | 43216 | 641,32 | 24489 | 131 |
| Antistress | 30,1 | 399,1 | 2472 | 4298 | 3668 | 3158 | 3499 | 17494 | 44548 | 581,19 | 27054 | 155 |
| Sugar Mover | 29,2 | 392,2 | 2472 | 4298 | 4584 | 3135 | 3720 | 18602 | 43216 | 637,04 | 24614 | 132 |
| **Average** | 28,9 | 389,5 | 2472 | 4298,0 | 3930 | 3126 | 3554 | 17770 | 42698 | 616,0 | 24928 | 140 |
| **Mentor** | | | | | | | | | | | | |
| Control | 24,7 | 357,8 | 2190 | 4298 | 2784 | 3020 | 3162 | 15812 | 36556 | 640,17 | 20744 | 131 |
| Amino VS Antistress | 25,3 | 362,4 | 2190 | 4298 | 4684 | 3035 | 3642 | 18212 | 37444 | 719,85 | 19232 | 106 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Antistress | 28 | 383,0 | 2190 | 4298 | 3668 | 3104 | 3411 | 17054 | 41440 | 609,08 | 24386 | 143 |
| Sugar Mover | 26,9 | 374,6 | 2190 | 4298 | 4584 | 3076 | 3631 | 18154 | 39812 | 674,86 | 21658 | 119 |
| **Average** | 26,2 | 369,5 | 2190 | 4298,0 | 3930 | 3059 | 3462 | 17308 | 38813 | 661,0 | 21505 | 124 |
| **Navigator** | | | | | | | | | | | | |
| Control | 26,8 | 373,9 | 2270 | 4298 | 2784 | 3074 | 3200 | 16000 | 39664 | 597,01 | 23664 | 148 |
| Amino VS Antistress | 30,5 | 402,1 | 2270 | 4298 | 4684 | 3168 | 3706 | 18529 | 45140 | 607,49 | 26611 | 144 |
| Antistress | 29,7 | 396,0 | 2270 | 4298 | 3668 | 3148 | 3445 | 17225 | 43956 | 579,98 | 26731 | 155 |
| Sugar Mover | 28,3 | 385,3 | 2270 | 4298 | 4584 | 3112 | 3662 | 18312 | 41884 | 647,08 | 23572 | 129 |
| **Average** | 28,8 | 389,3 | 2270 | 4298,0 | 3930 | 3126 | 3503 | 17517 | 42661 | 607,9 | 25144 | 144 |

Appendice A

| **Cost structure, %** | | | | | | | | **Energy efficiency of soybean cultivation** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PPP | payment pr. | seed | fertilizers | means of protection | palne | other costs. | total expenses | tractors and agricultural machinery | good. | the pest. | palne | seed | labor costs | total expenses | energy output from the crop, MJ | Cost per 1 centner | Kee |
| **Amadeus** | | | | | | | | | | | | | | | | | |
| Control | 2,37 | 12,62 | 27,56 | 17,85 | 19,61 | 20,00 | 100,00 | 1562 | 5147 | 1895 | 2195 | 2123 | 1703 | 14623 | 46348 | 558 | 3,17 |
| Amino VS Antistress | 2,10 | 10,92 | 23,85 | 26,00 | 17,13 | 20,00 | 100,00 | 1627 | 5147 | 2325 | 2232 | 2123 | 1775 | 15228 | 48294 | 558 | 3,17 |
| Antistress | 2,28 | 11,73 | 25,63 | 21,87 | 18,49 | 20,00 | 100,00 | 1663 | 5147 | 2260 | 2252 | 2123 | 1814 | 15258 | 49355 | 547 | 3,23 |
| Sugar Mover | 2,08 | 11,02 | 24,06 | 25,66 | 17,18 | 20,00 | 100,00 | 1585 | 5147 | 2433 | 2208 | 2123 | 1729 | 15225 | 47055 | 572 | 3,09 |
| Average | 2,20 | 11,53 | 25,19 | 23,03 | 18,04 | 20,00 | 100,00 | 1609 | 5147 | 2228,08 | 2222 | 2123 | 1755 | 15083 | 47763 | 559 | 3,17 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aureline** | | | | | | | | | | | | | | | | | |
| Control | 2,40 | 13,87 | 26,88 | 17,41 | 19,44 | 20,00 | 100,00 | 1681 | 5147 | 1895 | 2262 | 2123 | 1833 | 14940 | 49886 | 530 | 3,34 |
| Amino VS Antistress | 2,12 | 12,06 | 23,37 | 25,47 | 16,99 | 20,00 | 100,00 | 1716 | 5147 | 2325 | 2283 | 2123 | 1872 | 15465 | 50947 | 537 | 3,29 |
| Antistress | 2,32 | 12,91 | 25,03 | 21,36 | 18,38 | 20,00 | 100,00 | 1788 | 5147 | 2260 | 2323 | 2123 | 1950 | 15591 | 53070 | 520 | 3,40 |
| Sugar Mover | 2,15 | 12,13 | 23,51 | 25,07 | 17,15 | 20,00 | 100,00 | 1740 | 5147 | 2433 | 2296 | 2123 | 1898 | 15636 | 51655 | 535 | 3,30 |
| Average | 2,24 | 12,70 | 24,62 | 22,51 | 17,93 | 20,00 | 100,00 | 1731 | 5147 | 2228,08 | 2291 | 2123 | 1888,25 | 15408 | 51389,45 | 530 | 3,34 |
| **Bettina** | | | | | | | | | | | | | | | | | |
| Control | 2,30 | 15,21 | 26,44 | 17,13 | 18,92 | 20,00 | 100,00 | 1603 | 5147 | 1895 | 2219 | 2123 | 1749 | 14734 | 47586 | 548 | 3,23 |
| Amino VS Antistress | 2,09 | 13,20 | 22,95 | 25,01 | 16,74 | 20,00 | 100,00 | 1740 | 5147 | 2325 | 2296 | 2123 | 1898 | 15529 | 51655 | 532 | 3,33 |
| Antistress | 2,28 | 14,13 | 24,57 | 20,97 | 18,05 | 20,00 | 100,00 | 1794 | 5147 | 2260 | 2326 | 2123 | 1957 | 15606 | 53247 | 518 | 3,41 |
| Sugar Mover | 2,11 | 13,29 | 23,11 | 24,64 | 16,85 | 20,00 | 100,00 | 1740 | 5147 | 2433 | 2296 | 2123 | 1898 | 15636 | 51655 | 535 | 3,30 |
| Average | 2,19 | 13,91 | 24,19 | 22,12 | 17,59 | 20,00 | 100,00 | 1719 | 5147 | 2228,08 | 2284 | 2123 | 1875,25 | 15376 | 51035,65 | 533 | 3,32 |
| **Mentor** | | | | | | | | | | | | | | | | | |
| Control | 2,26 | 13,85 | 27,18 | 17,61 | 19,10 | 20,00 | 100,00 | 1472 | 5147 | 1895 | 2144 | 2123 | 1606 | 14386 | 43694 | 582 | 3,04 |
| Amino VS Antistress | 1,99 | 12,02 | 23,60 | 25,72 | 16,67 | 20,00 | 100,00 | 1508 | 5147 | 2325 | 2165 | 2123 | 1645 | 14911 | 44756 | 589 | 3,00 |
| Antistress | 2,25 | 12,84 | 25,20 | 21,51 | 18,20 | 20,00 | 100,00 | 1669 | 5147 | 2260 | 2256 | 2123 | 1820 | 15274 | 49532 | 546 | 3,24 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sugar Mover | 2,06 | 12,06 | 23,68 | 25,25 | 16,95 | 20,00 | 100,00 | 1603 | 5147 | 2433 | 2219 | 2123 | 1749 | 15272 | 47586 | 568 | 3,12 |
| Average | 2,13 | 12,65 | 24,83 | 22,71 | 17,67 | 20,00 | 100,00 | 1563 | 5147 | 2228,08 | 2196 | 2123 | 1704,625 | 14961 | 46392,025 | 570 | 3,10 |
| **Navigator** | | | | | | | | | | | | | | | | | |
| Control | 2,34 | 14,19 | 26,86 | 17,40 | 19,21 | 20,00 | 100,00 | 1597 | 5147 | 1895 | 2215 | 2123 | 1742 | 14718 | 47409 | 549 | 3,22 |
| Amino VS Antistress | 2,17 | 12,25 | 23,20 | 25,28 | 17,10 | 20,00 | 100,00 | 1818 | 5147 | 2325 | 2340 | 2123 | 1983 | 15734 | 53955 | 516 | 3,43 |
| Antistress | 2,30 | 13,18 | 24,95 | 21,29 | 18,28 | 20,00 | 100,00 | 1770 | 5147 | 2260 | 2313 | 2123 | 1931 | 15543 | 52539 | 523 | 3,38 |
| Sugar Mover | 2,10 | 12,40 | 23,47 | 25,03 | 16,99 | 20,00 | 100,00 | 1687 | 5147 | 2433 | 2266 | 2123 | 1840 | 15494 | 50063 | 547 | 3,23 |
| Average | 2,22 | 12,96 | 24,54 | 22,44 | 17,84 | 20,00 | 100,00 | 1718 | 5147 | 2228,08 | 2283 | 2123 | 1873,625 | 15372 | 50991,425 | 533 | 3,32 |

Appendices B.1

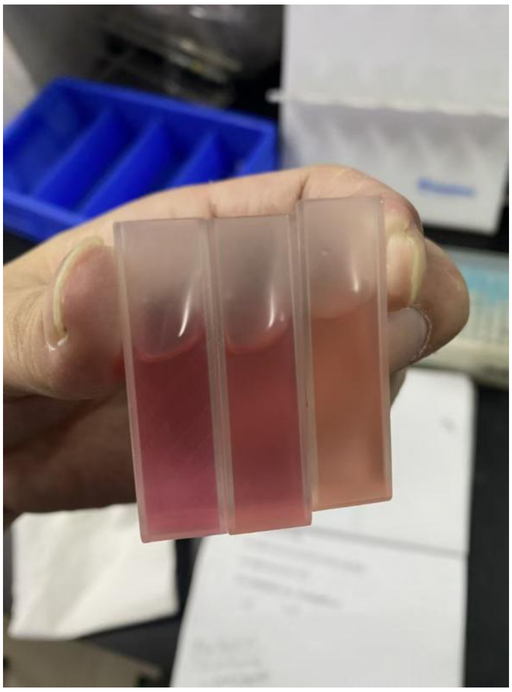
**A**

**B**

The photo of laboratory research (experiment 1) at Henan Institute of Science and Technology, Xinxiang, China: A – effects of salt stress on the growth of soybean under Greenhouse conditions; B – Three weeks after the salt treatment of soybean seedlings

Appendices B.2

**A**



**B**

The photo of laboratory research (experiment 1) at Henan Institute of Science and Technology, Xinxiang, China: A – Extraction of enzyme solution from leaves; B – Determination of antioxidant enzyme activity

Appendices C.1

**A**

**B**

The photo of field research (experiment 2), Sumy National Agrarian University (latitude 50o52.742N, 34o46.159E Longitude, and 137.7 m above sea level):
A – soybean seeds sowing; B – field fertilization

Appendices C.2

**A**

**B**

The photo of field research (experiment 2), Sumy National Agrarian University (latitude 50o52.742N, 34o46.159E Longitude, and 137.7 m above sea level):
A – determination of soybean leaf indicators; B – soybean seed measurement

Appendices D.1.1

**Узгоджено**
Проректор з наукової та
міжнародної діяльності
д. е. н., професор Данько Ю. І.
_______________
"12" "11" 2025 р.

**Затверджую**
Директор ТОВ «ЛСК -11»,
Нагорнєва Т. В.
_______________
"14" "11" 2025 р.

# Акт впровадження

## Результатів науково-дослідних і технологічних розробок

Замовник: *ТОВ «ЛСК -11», Сумська область, м. Лебедин, вул. Сумська, 94*
Керівник організації (директор): *Нагорнєва Тетяна Володимирівна*
Цим актом підтверджується, що результати роботи: *Ефективність застосування регуляторів росту за вирощування сої сорту Ауреліна*
яка виконана *аспірантом Сумського національного аграрного університету Лі Жуйцзе*
впровадженні на землях *ТОВ «ЛСК -11», Сумський район, Сумська область.*

1. Вид впровадження результатів: *Вивчали ефективність застосування регуляторів росту (контроль, Antistress, Sugar Mover) за вирощування сої сорту Ауреліна.*

*Встановлено, що найбільший прибуток з одиниці площі отримали за вирощування сої сорту Ауреліна за застосування Antistress (1,7 кг/га). Прибуток з одиниці площі 27 228тис. грн., рентабельність 159 %*

2. Характеристика масштабу впровадження 22 га.
3. Новизна науково-дослідних робіт: *Вперше в умовах північного Лісостепу України (Сумський район, Сумська область) встановлена найвища ефективність вирощування сої сорту Ауреліна за позакореневого внесення регулятору росту Antistress (1,7 кг/га) в мікростадії ВВСН60–69.*
4. Впроваджені: у сільськогосподарське виробництво *ТОВ «ЛСК -11», Сумська область, м. Лебедин, вул. Сумська, 94 .*

Appendices D.1.2

5. Річний економічний ефект *(додатковий прибуток в порівнянні з контролем – 1484 грн/га):*

6. Питома економічна ефективність впровадження: *чистий прибуток на 1 гектар посіву – 27 228 грн.; розрахунковий рівень рентабельності – 159 %; загальний прибуток з поля - 599,2 тис. грн.*

7. Соціально-науковий ефект: *зростання об'єму сировини для харчової та переробної промисловості, покращення фінансово економічного стану господарства та агропромислового комплексу України.*

*Цей акт завіряється гербовими печатками з боку Замовника і Виконавця*

**Від ВНЗ:**

*Завідувач науково-дослідною частиною Сумського НАУ, к. с.-г. н., доцент*

______________________ *Ярощук Р. А.*

*Виконавець, аспірант*

______________________ *Лі Жуйцзе*

**Від підприємства:**

*Головний бухгалтер*

______________________ *Захарченко О.О.*

*Відповідальний за впровадження, агроном*

______________________ *Новак С. І.*

*Розроблено відповідно до „Положення про науково-дослідні, дослідно - конструкторські та технічні роботи у вищих навчальних закладах"*

Appendices D.2.1

**Узгоджено**

Проректор з наукової та міжнародної діяльності

д. е. н., професор Данько Ю. І.

„21" „11" 2025 р.

**Затверджую**

Директор ФГ «Родина-2017»,

Білокінь В. О.

„18" „11" 2025 р.

# Акт впровадження

## Результатів науково-дослідних і технологічних розробок

Замовник: *Фермерське господарство «Родина-2017», Полтавська область, Кобеляцький район, село Канави, вулиця Центральна, б.1*

Керівник організації (директор): *Білокінь Віталій Олегович*

Цим актом підтверджується, що результати роботи: *Підбір сортів сої для вирощування в умовах Лівобережного Лісостепу України (Полтавська область)*

яка виконана *аспірантом Сумського національного аграрного університету Лі Жуйцзе*

впровадженні на землях *Фермерського господарства «Родина-2017», Полтавська область, Кобеляцький район, село Канави, вулиця Центральна, б. 1.*

1. Вид впровадження результатів: *Вивчали ефективність вирощування сої сортів Ауреліна, Беттіна, Ментор.*

*Встановлено, що найбільш економічно вигідно вирощувати сої* ***сорту Ауреліна*** *(за максимального прибутку з одиниці площі понад 25 744 тис. грн. та рівня рентабельності 161%).*

2. Характеристика масштабу впровадження *20 га.*

3. Новизна науково-дослідних робіт: *Вперше в умовах Лівобережного Лісостепу України (Полтавська область) встановлена найвища ефективність вирощування сої сорту Ауреліна.*

Appendices D.2.2

4. Впроваджені: у сільськогосподарське виробництво *Фермерського господарства «Родина-2017», Полтавська область, Кобеляцький район.*

5. Річний економічний ефект *(додатковий прибуток в порівнянні з варіантами де вирощували сорт Ментор – 5000 грн/га):*

очікуваний – *65,0 тис. грн.*

фактичний – *100,0 тис. грн. (з 20 га)*

6. Питома економічна ефективність впровадження: *чистий прибуток на 1 гектар посіву – 25 744 грн.; розрахунковий рівень рентабельності – 161 %.*

7. Соціально-науковий ефект: *зростання об'єму сировини для харчової промисловості, покращення фінансово економічного стану агропромислового комплексу та працівників.*

*Цей акт завіряється гербовими печатками з боку Замовника і Виконавця*

**Від ВНЗ:**

*Завідувач науково-дослідною частиною Сумського НАУ, к. с.-г. н., доцент*

________________ *Ярощук Р. А.*

*Виконавець, аспірант*

Li Ruijie *Лі Жуйцзе*

**Від підприємства:**

*Головний бухгалтер*

________________ *Смирнова В. В.*

*Відповідальний за впровадження, агроном*

________________ *Білокінь В. О.*

*Розроблено відповідно до „Положення про науково-дослідні, дослідно - конструкторські та технічні роботи у вищих навчальних закладах"*