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DISSERTATION

Varietal features of development and performance of *Brassica Juncea* L. according to growth regulators in terms of the Forest-Steppe of Ukraine

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АНОТАЦІЯ

Цзя ПейПей. Сортові особливості розвитку та продуктивність *Brassica Juncea* L. залежно від регуляторів росту в умовах 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, 2022.

Обґрунтування вибору теми дослідження. Гірчиця є культурою багатовекторного промислового значення завдяки різноманітному використанню. У насінні *Brassica Juncea* L. міститься 41–48% високоякісної олії, яку можна використовувати для технічних та харчових цілей. Сучасні тенденції глобальної зміни клімату та збільшення стресових ситуацій зумовили актуальність використання регуляторів росту рослин для стабілізації розвитку гірчиці. Також слід зазначити, що вивчення механізму впливу регуляторів росту в умовах контрольованого середовища наріст та розвиток рослин гірчиці не проводилось, що робить ці дослідження особливо актуальними.

Наукова новизна одержаних результатів. Уперше проведено комплексні дослідження щодо вивчення впливу регуляторів росту на ріст та розвиток *Brassica Juncea* L. в умовах контрольованого середовища (кліматична камера) та польових умовах. *Уперше* досліджено антиоксидантну ферментативну активність та механізм морфологічної адаптації коренів і пагонів проростків гірчиці за штучно створених умов посухи та засоленості.

Виявлено сортові особливості формування продуктивності гірчиці сизої за використання регуляторів роству умовах Лісостепу України. *Оптимізовано* технологію вирощування гірчиці сизої для умов Лісостепу України. *Набули подальшого розвитку* питання впливу погодних та стресових умов на особливості росту, розвитку та продуктивність залежно від сортута комбінованого застосування регуляторів росту для обробки насіння та позакореневого застосування. *Обґрунтовано* економічну та енергетичну ефективність вирощування гірчиці сизої за застосування досліджуваних елементів технології.

Практичне значення одержаних результатів. Основні елементи досліджень пройшли виробничу перевірку та впроваджені в господарствах Сумської та Полтавської областей, зокрема в ФГ «Еліта» та ФГ «Родина-2017» на загальній площі 50 га. Виробництву рекомендовано технологію вирощування гірчиці сизої, яка забезпечила врожайність насіння 1,77 та 1,91 т/га відповідно. Підтверджено її ефективність, а саме: умовно-чистий прибуток – 1345 та 4350 грн/га; рентабельність виробництва –9,5 та 133 % відповідно.

У дисертаційній роботі наведено теоретичне узагальнення і новее вирішення наукової проблеми щодо стабілізації впливу стресових факторів та підвищення продуктивності *Brassica Juncea* L. В основу досліджуваної технології покладено вивчення комбінованого використання регуляторів росту для обробки насіння та позакореневого застосування в умовах Лісостепу України.

Проаналізовано світові наукові розробки щодо виявлення оптимальних способів та видів застосування регуляторів росту для рослин гірчиці сизої. Доведено, що за сучасних змін клімату та виникнення стресових умов комбіноване використання регуляторів росту для обробки насіння та позакореневого застосуванняє важливим резервом стабілізації розвитку та підвищення продуктивності *Brassica Juncea* L.

У кліматичній камері Хенанського науково-технічного інституту науки та технологій (КНР) вивчали реакцію проростків гірчиці на абіотичністреси та ефективність застосування сучасних регуляторів росту рослин. Соляний і посушливий стрес є найпоширенішими абіотичними стресами, що пригнічують ріст рослин та зменшують продуктивність або призводять навітьдо їх загибелі. Регулятори росту можуть певною мірою зменшити пригнічення рослин під час стресу та стабілізувати їх розвиток.

Солеадаптивні механізми проростків і коренів *Brassica Juncea* L. вивчали шляхом установлення параметрів їх росту, біомаси, фотосинтезу, вмісту МДА (малоновогодіальдегіду) та деяких ключових антиоксидантів. Проростки гірчиці обробляли чотирма концентраціями солі (0, 50, 100 і 200 мМ NaCl). За результатами обліків, проведених за допомогою Epson Perfection V800 Photoscanner (Epson, lnc., LongBeach, CA, USA), виявлено, що обробка 200 мМ NaCl значно пригнічувала ріст пагонів, викликаючи зменшення площі листя, сухої та свіжої маси. Інгібітуюча дія солі на пагони позитивно корелювала зі зниженням вмісту хлорофілу і індексу продуктивності та негативно корелювала з вмістом МДА у листках. Доведено, що підвищена солоність розчину позитивно впливала на ріст кореневої системи. Співвідношення кількості бічних коренів першого порядку та щільність бічних коренів були вищими за показники контрольної групи на 26,1 %, 28,7 % та 58,5 % на 10-ту добу відповідно. Рівні МДА залишились незмінними. Координація антиоксидантних ферментів забезпечує високу ефективність рослин у видаленні АФК (активних форм кисню). Ці результати переконливо свідчать про те, що антиоксидантна система бере участь у адаптивній регуляції росту коренів, щоб уникнути шкідливих наслідків високої засоленості ґрунту.

У другому лабораторному досліді сорт гірчиці сизої (*Brassica Juncea* L.) Феліція використовувався для аналізу ефектів компенсації процесів росту в умовах посухового стресу та регідратації на стадії проростків. Паростки зазнавали різних рівнів посухового стресу (0, 10 %, 15 % і 20 % PEG). Вимірювали параметри росту, свіжу масу, флуоресценцію хлорофілу та антиоксидантну систему. Опрацьовані результати за допомогою WinRHIZO 2007 (Regent Instruments. Inc., Quebec, Canada) показали, що посуховий стрес пригнічує ріст коренів і пагонів та знижує продуктивність фото системи (використано портативний флюорометр PEA, Hansatech Instruments Ltd, King's Lynn, UK). Після регідратації довжина коренів і свіжа маса рослин швидко збільшувалися, а індекс продуктивності (PI_{ABS}) виявився вищим порівняно з контролем, що свідчить про компенсуючий ефект. Визначений за допомогою Dualex Scientific (Force-A, Orsay, France) вміст хлорофілу значно знижувався під час помірного та сильного посухового стресу. Однак він збільшився в умовах легкого стресу. Після регідратації вміст хлорофілу за помірного та сильного стресу не повертався до рівнів контролю і не було істотної різниці між легким стресом і контролем. Під час посухового стресу активність антиоксидантних ферментів і вміст МДА в листках значно підвищилися. Після регідратації МДА та активність антиоксидантного ферменту були вищими, ніж у контрольній групі, особливо за помірного та сильного стресу. За результатами виявлено, що *Brassica Juncea* L. сильно адаптована до помірного стресу від посухи завдяки ефективній активності антиоксидантних ферментів і фотосинтезу, а також її швидкому відновленню після регідратації.

Третій дослід мав на меті оцінити вплив регуляторів росту рослин (РРР) на швидкість проростання, морфологію проростків двох сортів (Феліція та Пріма) гірчиці сизої (*Brassica Juncea* L.) за умов симуляції посухового стресу за допомогою ПЕГ-6000 (PEG-6000). Застосування РРР сприяло росту проростків в умовах посухового стресу, але не мало помітного впливу на швидкість проростання обох сортів. Сира маса та довжина кореня, площа листків, довжина та об’єм стебла сорту Феліція суттєво зросли за обробки Антистресом на 24,28 %; 3,3 %; 24,7 %; 19,4% та 30,9 %. Крім того, кількість бічних коренів досягала максимуму за застосування Агріносу і Регоплану порівняно з рослинами без РРР в умовах посухи, які становили 135,55 % і 121,20 % відповідно. Для Пріми застосування Фаст старту мало значний вплив на сиру вагу та загальну довжину кореня, кількість бічних коренів і довжину основного кореня, площу поверхні коренів, площу листків та об’єм стебла на 17,62 %; 18,12 %; 211,2 %; 53,75 %; 28,57 %; 15,9 % і 32,3 % відповідно.

Результати польових досліджень, проведених упродовж 2019–2021 рр. в умовах Лівобережного Лісостепу України, показали, що застосування PPP мало вплив на висоту рослин, кількість гілок, площу листкової поверхні, кількість стручків, урожайність насіння та масу 1000 насінин обох сортів. Це дослідження продемонструвало, що поєднання обробки насіння та позакореневого обприскування рослин ефективно сприяло росту гірчиці порівняно з одноразовою обробкою насіння або позакореневим обприскуванням. Урожайність насіння сорту Феліція (1,78 т/га) була значно вищою, ніж у сорту Пріма (1,67 т/га). Максимальну врожайність для сорту Пріма отриманона варіантах комплексного застосування Фаст старту (1,76 т/га) та Регоплану (1,77 т/га); для Феліції: Агрінос (1,89 т/га); Антистрес (1,91 т/га). Усі регулятори росту рослин збільшували середню масу 1000 шт. насінин обох сортів. Для Пріми вплив Фаст старту і Регоплану на масу 1000 насінин мав максимальний ефект (9,5 % порівняно з контролем). За винятком Альбіту та Вермістиму Д, інші регулятори росту збільшили масу 1000 шт. насінин Феліціїна 5,8–11,7 %.

Застосування регуляторів росту підвищило середню олійність насіння *Brassica Juncea* L. на 1,18–5,61 %. Визначений за допомогою інфрачервоного аналізатора (SupNir 2700, China) істотний вплив на олійність насіння у сорту Прімаспостерігався від застосування Агрінос, Фаст Старт і Регоплан. У сорту Феліціяне було суттєвої різниці олійності насіння за фактором «Спосіб застосування РРР» та «Вид РРР». За вмістом білкарізниці між двома сортами, способами та видами використаних регуляторів росту не виявлено. За результатами кореляційного аналізу виявлено, що врожайність насіння мала позитивні тісні ($p<0,01$) залежності індивідуальних середніх значень з кількістю стручків, кількістю гілок, площею листкової поверхні та масою насіння на одній рослині. Маса 1000 шт. насінин тісно корелювала з вмістом хлорофілу та висотою рослини. Ці результати показали, що кількість гілок, індивідуальна продуктивність рослин, кількість стручків і площа листкової поверхні були основними факторами, що визначали врожайність з притаманними сортовими особливостями реакції на застосування регуляторів росту рослин. Вміст олії негативно корелював із білком.

Аналіз показників економічної та енергетичної ефективності виявив, що вирощування гірчиці сизої (*Brassica Juncea* L.) в Лівобережному Лісостепу України є доцільним. Для гірчиці сизої максимальний рівень рентабельності (147–151 %) та коефіцієнт енергоефективності (2,74–2,77) отримано за вирощування сорту Феліція та позакореневого підживлення регуляторами росту Регоплан та Агрінос відповідно.

Ключові слова: гірчиця сиза, регулятори росту рослин, стрес, обробка насіння, позакореневе підживлення, морфологічні та біологічні параметри, кліматична камера, фотосинтетична активність, урожайність, продуктивність, економічна та енергетична ефективність.

LIST OF THE APPLICANT'S PUBLICATIONS

Articles in scientific professional publications of Ukraine:

1. Мельник А. В., Жердецька С. В., Шабір Г., **Цзя Пей Пей**. Оптимізація системи живлення гірчиці сизої в умовах північно-східного Лісостепу України. *Вісник Сумського НАУ*. 2018. № 9 (36). С. 60–63.

2. Бутенко С. О., **Цзя Пей Пей**. Вплив регуляторів росту рослин на якість зерен гірчиці в умовах північно-східного Лісостепу України. *Таврійський науковий вісник*. 2022. № 124. С. 10–18.

DOI: https://doi.org/10.32851/2226-0099.2022.124.2

Scopus and WoS publication:

3. **Jia P.,** Melnyk A., Zhang Z. Effects of different plant growth regulators in a vegetative chamber on seedling morphology parameters of yellow mustard (*Brassica Juncea* L.). *AgroLife Scientific Journal*. 2020. № 9 (1). P. 180–185.

ISSN 2285-5718; ISSN ONLINE 2286-0126; ISSN-L 2285-5718

4. **Jia P.**, Melnyk A., Li L., Kong X., Dai H., Zhang Z., Butenko S. Effects of drought and rehydration on the growth and physiological features of mustard seedlings. *Journal of Central European Agriculture.* 2021. 22(4). P. 836–847.

DOI:https://doi.org/10.5513/JCEA01/22.4.3246.

5. **Jia P.,** Melnyk A., Zhang Z., Butenko S., Kolosok V. Effects of seed pre-treatment with plant growth compound regulators on seedling growth under drought stress. *Agraarteadus.*2021. 32(2). P. 251–256.

DOI: https://doi.org/10.15159/jas.21.35.

6. **Jia P.,** Melnyk A., Zhang Z. Differential adaptation of root and shoot to salt stress correlates with antioxidant capacity in mustard. *Pakistan journal of botany.* 2022. № 54 (6). P. 2001–2011.

DOI: http://dx.doi.org/10.30848/PJB2022-6(32)

Conferences

7. Мельник А. В., Бутенко С. О., **Цзя Пей Пей**. Перспективи використання регуляторів росту з антистресовою дією для олійних культур родини *Brassicaceae* за умов зміни клімату в лівобережному лісостепу України. *Науково-практична конференція «Кліматичні зміни та сільське господарство».* (Миколаїв, 1–12 квітня 2019 р.). Миколаїв, 2019. С. 212–213.

8. Melnyk A. V., **Jia Peipei**, Butenko S. O. Influence of seeds tretment with growth regulators for the getermination of mustard seeds. *Міжнародна науково-практична конференція «Гончарівські читання».* (Суми, 24–25 травня 2019 р.). Суми, 2019. С. 80–81.

9. Melnyk A. V., **Jia P.**, Butenko S. O. The role of melatonin in salt stress on mustard. *Матеріали міжнародної науково-практичної конференції «Гончарівські читання».* (Суми, 25-26 травня 2020 р.). Суми, 2020. С. 99.

10. **Jia P.**, Li R. Different responses of morphology, chlorophyll fluorescence and antioxidant enzyme activity to salt stress of mustard (*Brassica Juncea* l.) seedling. *Матеріали міжнародної науково-практичної конференції*

«Наукові засади підвищення ефективності сільськогосподарського виробництва». (Харків, 26–27 листопада 2020 р.). Харків, 2020. С. 35.

11. Melnyk A., **Jia P.**, Li R., Kubrak T., Shyian M., Bobonych V. Impact of growth regulators on the yield capacity of brown mustard in Ukraine. *VII International Scientific and Practical conference "The world of science and innovation".* (United Kingdom, London, 10–12 February). London. 2021. P. 114–119.

12. Бутенко С. О., **Цзя П.,** Колосок В. Г. Особливості використання фотоситнетично активної радіації рослинами гірчиці ярої в умовах Лівобережного Лісостепу України. *Матеріали міжнародної науково-практичної конференції «Гончарівські читання».* Суми, 2021. С. 78–79.

13. Melnyk A., **Jia P.** Growth and physiological compensation of mustard seedling after drought stress and rehydration. *International scientific and practical conference "Ideas and innovation in natural sciences".* (Lublin, the Republic of Poland, March 12–13, 2021). Lublin, 2021. P. 11–13.

DOI https://doi.org/10.30525/978-9934-26-047-6-2.

14. Melnyk A., **Jia P.**, Butenko S. Effect of Seed treatment with Plant Growth regulators under Stress conditions in Mustard. *Метеріали Міжнародній науково-практичній конференції «Розвиток аграрної галузі на впровадження наукових розробок у виробництво».* (Миколаїв, 18 листопада 2021 р.). Миколаїв: МНАУ, 2021. С. 80–81.

15. Melnyk A. V., **Jia P**., Kolosok V. Response of growth and yield

components of two varieties of oilseed mustard (*Brassica Juncea* L.) to growth regulators under the agro-ecological conditions of the northeastern Forest-Steppe of Ukraine. *Materials of the International Scientific and Practical Conference "Honcharivski readings" dedicated to the 93-th anniversary of Doctor of Agricultural Sciences professor Mykola Demyanovych Honcharov.* (Sumy, 25 May 2022). Sumy, 2022. P. 83–84.

ABSTRACT

***Jia PeiPei.* Varietal features of development and performance of *Brassica Juncea* L. according to growth regulators in terms of the Forest-Steppe of Ukraine.** – Manuscript.

Dissertation for a Doctor of Philosophy degree (PhD): Specialty 201 – Agronomy. – Sumy National Agrarian University, Ministry of Education and Science of Ukraine – Sumy, 2022.

The rationale for choosing the research topic. Mustard is a crop of multivector industrial significance due to its diverse uses. The seeds of *Brassica Juncea* L. contain 41–48 % of high-quality oil for technical and food purposes. Modern trends of global climate change and more frequent occurrence of stressful situations determined the urgency of using plant growth regulators to stabilize the development of mustard. It is also worth noting that no study of the mechanism of the growth regulators effect in terms of a controlled environment on the growth and development of mustard plants has been conducted, which makes the research data particularly relevant.

The scientific novelty of the obtained results. Comprehensive research was *first* conducted to study the influence of growth regulators on the growth and development of *Brassica Juncea L.* in a controlled environment (climate chamber) and field conditions. The antioxidant enzymatic activity and the mechanism of morphological adaptation of roots and shoots of mustard seedlings under artificially created conditions of drought and salinity were *first* investigated. Varietal features of brown mustard performance were identified using growth

regulators in terms of the forest-steppe of Ukraine. The technology of growing brown mustard is *optimized* for the conditions of the forest steppe of Ukraine. The issue of the influence of weather and stress conditions on the features of growth, development, and performance according to the variety and the combined use of growth regulators for seed treatment and foliar application *have been further developed.* The economic and energy efficiency of the cultivation of brown mustard with the use of the studied elements of the technology *has been substantiated.*

The practical significance of the obtained results. The technology of growing brown mustard was recommended for production, which ensured a seed yield capacity of 1.77 and 1.85 t/ha, accordingly. The main elements of the research were tested in the production and implemented on the farms of the Sumy and Poltava regions, in particular, at the Elita and Rodina 2017 farming enterprises on a total area of 60 hectares. Their efficiency has been confirmed, namely: net operating profit – 1345 and 1420 UAH/ha; profitability of production – 59.5 and 65.3 %, accordingly.

The dissertation provides theoretical generalizations and a new solution to the scientific issue of stabilizing the impact of stress factors and increasing the performance of *Brassica Juncea* L. The research technology is based on the study of the combined use of growth regulators for seed treatment and foliar application in terms of the forest steppe of Ukraine.

The world’s scientific developments regarding the identification of optimal methods and types of application of growth regulators for brown mustard plants have been analyzed. Under current climate changes and the emergence of stressful conditions, the combined use of growth regulators for seed treatment and foliar application have been proven to be an important reserve for stabilizing the development and increasing the performance of *Brassica Juncea* L.

The response of mustard seedlings to abiotic stresses and the efficiency of modern plant growth regulators were studied in the climate chamber of the Henan Scientific and Technical Institute of Science and Technology (PRC). Salt and drought stresses are the most common abiotic stresses that suppress plant growth and reduce performance or even cause plants' death. To some extent, plant growth regulators can reduce plant inhibition during stress.

The salt adaptive mechanisms of mustard seedlings and roots were studied by determining their growth parameters, biomass, photosynthesis, MDA content, and some key antioxidants. Mustard seedlings were treated with four salt concentrations (0, 50, 100, and 200 mM NaCl). The results of calculations carried out with the help of Epson Perfection V800 Photoscanner (Epson, lnc., LongBeach, CA, USA) showed that the treatment with 200 mM NaCl significantly inhibited the growth of shoots, causing a decrease in leaf area, as well as dry and fresh matter. The inhibitory effect of salt on shoots correlated positively with the decrease in chlorophyll content and performance index and correlated negatively with MDA content in leaves. Increasing salinity has been shown to have a positive effect on root growth. The ratio of the number of lateral roots of the first order and the density of lateral roots were higher than those of the control group by 26.1 %, 28.7 %, and 58.5 % on day 10, accordingly. MDA levels remained unchanged. The coordination of antioxidant enzymes ensures the high efficiency of plants in removing NPK. These results persuade that the antioxidant system is involved in the adaptive regulation of root growth to avoid the deleterious effects of high soil salinity.

In the second laboratory experiment, the brown mustard variety (*Brassica Juncea* L.) of Felicia was used to analyze the response and compensation effects of growth and physiology under drought stress and rehydration at the seedling stage. The seedlings were exposed to different levels of drought stress (0, 10%, 15%, and 20% PEG). Growth parameters, fresh weight, chlorophyll fluorescence, and antioxidant system were measured. The processed results showed that drought stress suppresses the growth of roots and shoots (WinRHIZO 2007, Regent Instruments. Inc., Quebec, Canada) and reduces the performance of the photosystem (a portable fluorometer PEA, Hansatech Instruments Ltd, King'sLynn, UK was used). After rehydration, root length and plant fresh weight increased rapidly, and the performance index (PI_{ABS}) was higher compared to the control, indicating a compensatory effect. Chlorophyll content as determined by DualexScientific (Force-A, Orsay, France) decreased significantly under moderate and severe drought stress. However, it increased under mild stress. After rehydration, chlorophyll content under moderate and severe stress did not return to control levels, and there was no significant difference between mild stress and control. During drought stress, the activity of antioxidant enzymes and MDA content in leaves increased significantly. After rehydration, MDA and antioxidant enzyme activity were higher than in the control group, especially under moderate and severe stress. According to the results, mustard is highly adapted to moderate drought stress due to the effective activity of antioxidant enzymes and photosynthesis, as well as its rapid recovery after rehydration.

The third experiment aimed at evaluating the effect of plant growth regulators (PGRs) on the germination rate and seedling morphology of two varieties of blue mustard (*Brassica Juncea* L.) (Felicia and Prima) under simulated conditions of drought stress using PEG-6000. The application of PGRs contributed to the growth of seedlings under drought stress conditions but did not have a noticeable effect on the germination rate of both varieties. Raw mass and root length, leaf area, stem length, and volume of the Felicia variety significantly increased by 24.28 %, 3.3 %, 24.7 %, 19.4 %, and 30.9 % under Antistress treatment. Besides, the number of lateral roots reached its maximum with the use of Agrinos and Regoplan compared to plants without PGR under drought conditions, which were 135.55 % and 121.20 %, respectively. For Prima, the application of Fast Start had a significant effect on raw root weight, total root length, the number of lateral roots and main root length, root surface area, and leaf area and stem volume by 17.62 %, 18.12 %, 211.20 %, 53.75 %, 28.57 %, 15.9 %, and 32.3 %, accordingly.

The results of the field research conducted during 2019-2021 in terms of the Left-Bank Forest-Steppe of Ukraine showed that the use of PGR affected the height of plants, the number of branches, the area of the leaf surface, the number of pods, seed yield capacity, and the weight of 1000 seeds of both varieties. This study demonstrated that a combination of seed treatment and foliar spray was effective in promoting mustard growth compared to a single seed treatment or foliar spray. The seed yield capacity of the Felicia variety (1.78 t/ha) was significantly higher than that of Prima (1.67 t/ha). The maximum yield capacity for Prima was obtained on the variants of complex application of Fast Start (1.76 t/ha) and Regoplan (1.77 t/ha); for Felicia it was Agrinos (1.89 t/ha) and Antistress (1.91 t/ha). All plant growth regulators increased the average weight of both varieties. For Prima, the influence of Fast Start and Regoplan on the weight of 1000 seeds had the maximum effect (9.5% compared to the control). Except for Albit and Vermistim D, other growth regulators increased the weight of 1000 Felicia seeds by 5.8-11.7 %.

The use of growth regulators increased the average oil content of *Brassica Juncea* L. seeds by 1.18-5.61%. A significant effect on the oiliness of seeds in the Prima variety, determined with the help of an infrared analyzer (SupNir 2700, China), was due to the use of Agrinos, Fast Start, and Regoplan. There was no significant difference in the seed oiliness of the Felicia variety by the factor of “Method of application of PGR” and “Type of PGR”. In terms of protein content, no difference was found between the two varieties, as well as methods and types of growth regulators used. According to the results of the correlation analysis, seed yield capacity had positive and close ($p<0.01$) correlations of individual mean values with the number of pods, number of branches, leaf surface area, and seed weight per plant. The weight of 1000 seeds was closely correlated ($p<0.01$) with chlorophyll content and plant height. These results showed that the number of branches, individual plant performance, the number of pods, and the leaf surface area were the main factors that determined the yield with inherent varietal features of the response to the application of plant growth regulators. Oil content correlated negatively with protein.

The analysis of economic and energy efficiency indicators revealed that the cultivation of brown mustard (*Brassica Juncea* L.) in the Left-Bank Forest-Steppe of Ukraine is expedient. For brown mustard, the maximum level of profitability (149%) and energy efficiency ratio (2.75) was obtained for the cultivation of the Felicia variety and foliar fertilization with the growth regulator Regoplan.

Keywords: brown mustard, plant growth regulators, stress, treatmemt, foliar, morphological and biological parameters, climate chamber, photosynthetic activity, yield, productivity, economic and energy efficiency.

CONTENT

LIST OF SYMBOLS AND ABBREVIATIONS

ABA– abscisic acid

APX– ascorbic acid peroxidase

BR – brassinosteroids

CAT – catalase

CTK – cytokinin

ETH – ethylene

F_v/F_m– maximal photochemical efficiency

GA – gibberellin

HI – harvest index

HTC – hydrothermal coefficient

IAA – auxin

MDA – malondialdehyde

PEG- polyethylene glycol

PGR – plant growth regulator

PI_{ABS} – performance index

POD – peroxidase

PVPP – polyvinylpyrrolidone

ROS– reactive oxygen species

RSA– root system architecture

SOD– superoxide dismutase

INTRODUCTION

The rationale for choosing the research topic. Mustard is a crop of multivector industrial importance due to its diverse uses. The seeds of *Brassica Juncea* L. contain 41–48% of high-quality oil for technical and food purposes.

Research by scientists N. Khan, N. Iqbal, R. Setia, K. Ahuja, E. Lionneton, G. Aubert, C. Cailin.; P. Gupta; H. Guangfan, F. Yonghong, K. Mandal; A. Sinha, Gh. Sabbir, S. Ali, etc. significantly increased the level of fulfillment of mustard biological potential in the world. Thanks to the works of V. D. Haydash, V. V. Lykhochvor, O. I. Polyakov, P. S. Vyshnivskyi, A. V. Melnyk, N. P. Zhernova, O. G. Zhuikov, T. V. Kozina, O. L. Oksymets, A. V. Chekhov, Yu. V. Vovchenko, S. V. Zherdetska, and other scientists, success in solving several issues related to mustard cultivation in Ukraine have been achieved. Concurrently, just a small number of scientific developments are devoted to the issue of stabilizing the impact of stress factors that may seriously affect the performance of *Brassica Juncea* L. Factors that can cause stress responses in plant organisms can be different: lack or excess of moisture, temperature, illumination, radioactive radiation, chemical salts, the acidity of the environment, herbicides, wind, pressure, and damage. Today, agricultural production pays primary attention to the system of protection of crops from adverse factors. It should also be noted that the mechanism of the influence of growth regulators on the growth and development of mustard plants under the conditions of a controlled environment has not been studied, which makes the research data particularly urgent.

Connection of the research with scientific programs, plans, and topics. The research was carried out according to the tasks of the thematic plans and within the framework of the state scientific topics of the Sumy National Agrarian University for 2019–2021 – "Optimization of the elements of mustard cultivation technology in the conditions of the North-Eastern Forest Steppe of Ukraine", state registration number 0115U001051 and "The development of modern methods of identification of the stress of crops and forest plantation and ways to reduce it", state registration number 0121U113642. This work was also supported by the Innovative Research Group Program (in Science and Technology) at Henan Provincial University (21IRTSTHN023), China.

The purpose of the research is to determine the effect of the combined use of growth regulators for the seed treatment and foliar application on the growth and development of *Brassica Juncea* L. in a controlled environment (climatic chamber, P. R. China) and field conditions of the Left-Bank Forest-Steppe of Ukraine.

According to the specified goal, the following tasks were set:

- To determine growth and development indicators according to the varietal features of *Brassica Juncea* L. and growth regulators under artificially created salt stress (in a controlled environment, P. R. China).
- To determine growth and development indicators according to varietal features of *Brassica Juncea* L. and growth regulators under artificially created drought stress (in a controlled environment, P. R. China).

- To identify the features of performance formation depending on the varietal features of *Brassica Juncea* L. and growth regulators in terms of the Left-Bank Forest-Steppe of Ukraine.
- To determine the effectiveness of the application of growth regulators on the yield capacity and quality of *Brassica Juncea* L. seeds in the conditions of the Left-Bank Forest-Steppe of Ukraine.
- To calculate the economic and energy efficiency of the application of plant growth regulators for the cultivation of *Brassica Juncea* L. in terms of the Left-Bank Forest-Steppe of Ukraine.

The object of the research is the process of adaptation of *Brassica Juncea* L. roots and seedlings under artificially created conditions of salinity and drought with the use of plant growth regulators. Formation of performance of *Brassica Juncea* L. according to varietal features, a combined application of growth regulators, and weather conditions.

The subject of the research is brown mustard (*Brassica Juncea* L.) varieties of Prima and Felicia, methods of application and types of plant growth regulators (PGR), artificially created stress factors (salinity and drought), weather conditions, economic and energy efficiency of plant growth regulators in *Brassica Juncea* L. cultivation in terms of the Left-Bank Forest-Steppe of Ukraine.

Research methods. In the process of performing the research, general scientific (hypothesis, analysis, synthesis, extrapolation, and generalization), as well as special research methods were used. Visual – for phenological observations of plant growth and development phases; measuring and weighing – to determine morphological parameters and performance of plants; chemical – for conducting enzyme analyses and determining the seed quality; mathematical and statistical – the dispersion and correlation analysis of research results; calculation and comparative – to establish the economic and energy efficiency of the use of plant growth regulators for the cultivation of brown mustard (*Brassica Juncea* L.).

The scientific novelty of the obtained results. Comprehensive research was *first* conducted to study the influence of growth regulators on the growth and development of *Brassica Juncea* L. in a controlled environment (climate chamber) and field conditions. The antioxidant enzymatic activity and the mechanism of morphological adaptation of roots and shoots of mustard seedlings under artificially created conditions of drought and salinity were *first* investigated. Varietal features of brown mustard performance were identified using growth regulators in terms of the forest-steppe of Ukraine. The technology of growing brown mustard is *optimized* for the conditions of the forest steppe of Ukraine. The issue of the influence of weather and stress conditions on the features of growth, development, and performance according to the variety and the combined use of growth regulators for seed treatment and foliar application *have been further developed.* The economic and energy efficiency of the cultivation of brown mustard with the use of the studied elements of the technology *has been substantiated.*

The practical significance of the obtained results. The technology of growing brown mustard was recommended for production, which ensured a seed yield capacity of 1.77 and 1.91 t/ha, accordingly. The main elements of the research were tested in the production and implemented on the farms of the Sumy and Poltava regions, in particular, at the Elita and Rodina 2017 farming enterprises on a total area of 50 hectares. Their efficiency has been confirmed, namely: net operating profit – 1345 and 4350 UAH/ha; profitability of production – 9.5 and 133%, accordingly.

The doctoral candidate's contribution is in the study, generalization, and systematization of the world and Ukrainian research; the performance of the main scope of the experimental part of the research (in particular, under the conditions of a controlled environment, P. R. China), implementation of generalization, as well as mathematical and statistical processing of data, formulation of conclusions, and recommendations for production. The scientific provisions of the dissertation were worked out by the author in consultation with the scientific supervisor.

Approbation of the dissertation results. The results of the dissertation research were made public and discussed at International Scientific and Practical Conferences "Honcharivski readings" (Sumy, 2019–2022); Scientific and Practical Conference "Climate change and agriculture" (Mykolaiv, 2019); International Scientific and Practical Conference Scientific principles of increasing the efficiency of agricultural production" (Kharkiv, 2020); VII International Scientific and Practical Conference "World of Science and Innovation" (London, Great Britain, 2021); The International Practical Conference "Development of the agricultural industry for the implementation of scientific developments in production" (Mykolaiv, 2021); International Scientific and Practical Conference "Ideas and Innovations in Natural Sciences" (Lublin, Poland, 2021).

Publications. The main provisions of the thesis are presented in 15 scientific works, including 2 articles in professional publications of Ukraine; included in the international scientometric citation databases Scopus and WoS – 4; abstracts of reports at international scientific and practical conferences and symposia – 9 (abroad – 2).

Structure and scope of the dissertation. The dissertation consists of an introduction, 5 sections, conclusions, practical recommendations, and a list of references and appendices. The materials of the dissertation are presented on 237 pages of printed text and contain 20 tables, 24 figures, and 17 appendices. The list of references includes 311 sources.

SECTION 1

RESPONSE OF MUSTARD (*BRASSICA JUNCEA* L.) TO STRESS AND COMPONENTS OF MODERN CULTIVATION TECHNIQUES (LITERATURE REVIEW)

1.1. Economic significance of mustard (*Brassica Juncea* L.)

Mustard (*Brassica Juncea* L.) belongs to the family of *Brassicaceae*, with a long history of cultivation and strong adaptability, and has been cultivated all over the world. According to the FAO in 2020, mustard has a large harvest area and production. Ukraine has the fifth largest harvest area in the world.

Mustard is an important cash crop. It is one of the world's major sources of vegetable oil and protein. The oil is consumed for both edible and non-edible purposes. Many studies have shown that mustard oil is considered one of the healthiest cooking oils. It's worth noting that mustard oil is high in ω-3 fatty acids, which protect the heart and blood vessels, compared to other vegetable oils [10]. Isocyanates, enriched in mustard seeds, have been shown to play an essential role in preventing cancer and bacteria [11, 12]. Besides, mustard oil is widely used in food processing, such as canning and baking, as well as in the production of candy and margarine [13]. Mustard oil, on the other hand, has been developed as a potential biofuel, which is favored by most researchers because of its ability to reduce air pollution and greenhouse gas emissions [14].

The potential benefits of *B. Juncea* have been recognized by several countries. All over the world, mustard is favored because of its unique ingredients and medicinal value. The essential oil obtained from mustard seeds is used to make condiments or medicine. Previous reports have shown that mustard has significant effects on traditional diet medicines such as painkillers, aperitifs, diuretics, emetic, redness, and stimulants [15]. All parts of the mustard plant are edible. The leaves of the plant, known as mustard greens, are delicious in salads when they are young and tender. Older leaves with stems may be eaten fresh as a vegetable. The flowers can be enjoyed as edible decorations.

Mustard has more vigorous seedling growth, faster ground covering ability along with better resistance to adversity [16]. It is a more adaptable oilseed crop than *Brassica napus* in stressful environments associated with low rainfall, high temperature, and late sowing [17]. Moreover, *B. Juncea* seed pods shatter less readily, and seeds potentially contain a higher percentage of oil plus protein [18]. *B. Juncea* was found to be particularly effective for the elimination of copper by phytoextraction, but also demonstrated potential for additional metal uptake from soils including cadmium, nickel, lead, and zinc [19]. Regarding the fact that rape plants improve soil structure, and clear it from radionuclides, the Chornobyl zone seems to be especially attractive for crop growing. According to the analysts, about 100 thousand ha of contaminated land in Ukraine are suitable for growing technical crops [20].

1.2. Origin, status, and prospects of growing mustard (*Brassica Juncea* L.) in the world and Ukraine

Mustard is a natural allopolyploid of *Brassica rapa* (AA) and *Brassica nigra* (BB) [21]. Mustard was one of the first domesticated crops. Thus, archaeologists and botanists believe it has been found in Stone Age settlements. Ancient Greeks and Romans used mustard not only as a condiment but also medicinally, applying it externally to relieve a variety of aches and pains. In about 1300, the name "mustard" was given to the condiment made by mixing mustum, which is the Latin word for unfermented grape juice, with ground mustard seeds. Researchers have proposed different ideas about the geographical origins of mustard. According to the geographical location of the parents of Black mustard and Chinese cabbage, the origin of mustard is most likely from the Middle East and India. However, Chinese researchers generally believe that mustard originated in the east, south, or west of China and that Sichuan Basin is the differentiation center of vegetable mustard [22-23].

Based on morphology, origin, and the place of growth classification, mustard can be broadly divided into four groups around the globe. (1) White mustard (*Sinapis hirta*), a mild variety, grows wild in North Africa, the Middle East, and Mediterranean Europe and has long been cultivated widely. In Europe, yellow mustard is also known as white mustard (*Sinapis alba* – an older botanical name). (2) Oriental mustard (*Brassica Juncea*), the basis of American and European mustards as well as hot Chinese mustard, grows wild in the foothills of the

Himalayas. (3) Black mustard (*Brassica nigra*) is believed to be native to the southern Mediterranean regions. (4) Abyssinian mustard (*B. carinata* Braun): This plant is restricted to Ethiopia and neighboring territories, where it has been cultivated for seed oil and as a vegetable from ancient times [24].

Due to ecological geographical variation and human selection, mustard has formed many varieties of different forms, including oil, semi-oil, root, and leaf vegetable types. Mustard is grown as an oil crop in India, Canada, Australia, Russia, and Ukraine, as a vegetable in China, and as a condiment in Canada and Europe. Among the oilseed crops, mustard and rape seed is in the second position after soybean. The increase in the area and performance of mustard is limited by policy, technology, and the environment. Currently, mustard plants are mainly produced in Canada, Hungary, India, China, the United States, Ukraine, and areas suitable for mustard cultivation. In China, mustard is widely known as the product of "Zha cai", "Datou cai", and "Ya cai" [22]. High-quality low erucic acid oil obtained by genetic engineering plays an important role in increasing the performance and area of mustard [25].

In recent years, the cultivation area of mustard and rape has increased significantly in Ukraine, based on favorable climatic conditions and strong adaptability. Considering the lack of bioenergy in Ukraine, mustard and oilseed have the potential to become one of the most popular oilseed crops and an alternative to biodiesel products [20]. The market for oilseeds in Ukraine is a large segment of the general market for agricultural products. Mustard (*Brassica Juncea* L.) is an oilseed crop that can restore the optimal ratio of crops in crop rotation without reducing the efficiency of economic activity. Ukraine is among the top ten world leaders in its cultivation. The warming trends observed over the last 30 years in the world and Ukraine, allow the growing of mustard throughout the country. Consequently, it became necessary to develop varietal technologies for growing mustard for specific soil and climatic conditions.

1.3. Systemic and structural features of mustard (*Brassica Juncea* L.)

Mustard is known to be categorized under brassica in the cruciferous family. This morphological variation results from long-term selection with varying objectives in the different parts of the world where the species were initially domesticated. Up to now, mustard has been classified in a variety of ways, including the purpose of use, morphology, and molecular techniques.

Mustard can be divided into oil and leaf vegetables according to its use. Previous research has found that genetically distinct between the oilseed group and the vegetable varieties [26]. As an oil crop, mustard varieties were evaluated by using agronomic traits such as flowering time, plant height, seed color, seed weight, oil content, protein, fiber, fatty acid, and glucosinolates levels. As a leafy vegetable, the following traits, such as large leaf size, late flowering, many leaves per plant, and tolerance to diseases and pests are preferred [27].

The classification based on morphological differences is one of the commonly used methods. The morphological features mainly include leaf blade colour, leaf blade margin; plant growth habit; plant height at 50% flowering; plant diameter at 50% flowering; leaf number per plant at 50% flowering; leaf length at 50% flowering (largest leaf including petiole); leaf blade width at 50% flowering (widest point of the largest leaf); leaf blade blistering; leaf angle (angle of petiole and horizontal); leaf bloom; leaf lamina attitude, petiole length at 50% flowering (petiole of the largest leaf); petiole width at 50% flowering (petiole of the largest leaf) and days from sowing to 50% flowering. The plant growth habit is upright, prostrate, and intermediate; the leaf color includes light green, green, and dark green; the leaf edges include Undulate, Dentate, Remove Dentate, and Serrate; the leaf angle is Prostrate (<30°), Semi prostrate (~45°), Open (~67°), Erect (>87°); the leaf number per plant is 20>, 20-40, 40<; the previous studies of 36 accessions in Ethiopia found that they were 149-226 cm in height, 2.85-4 g in 1000-seed weight, 140-178 days to mature, and 179-352 pods per plant [28]. A field survey of 66 accessions of *Brassica carinata* at Saskatoon found that the average plant height was 140 cm, the maturity period was 100 days, the average 1000-grain weight was 3.1 g, and the time from sowing to flowering was 51 days [29].

DNA molecular marker refers to the fragment that can reflect the features of some differences in the genomes of individuals or populations. Therefore, molecular technology provides a new strategy for studying the genetic relationship, variety identification, as well as further exploration and utilization of mustard resources. Lionneton et al.. used the AFLP method to map the agronomic and yield-related traits of mustard, including flowering time, plant height, 1000-seed weight, and seed oil content [30]. The mapping of genes related to agronomic traits and yield in the genome will provide a new breeding strategy for breeders [31].

1.4. Effects of abiotic stresses on the growth and physiological parameters of mustard (*Brassica Juncea* L.)

Abiotic and biotic stresses restrict regular crops, leading to inferior grain quality and a devastating impact on crop yield. In agricultural production, abiotic stresses mainly include drought, salinity, extreme temperatures, flooding, pollutants, and poor or excessive irradiation [32,33]. As the global climate changes, the effects of abiotic stress on plants are becoming a more frequent and increasingly severe problem. In addition to abiotic stresses, plants face the threat of infection by pathogens (including bacteria, fungi, viruses, and nematodes) and attack by herbivore pests [34].

Among the various abiotic stresses, salinity and drought stress are increasing problems in global agriculture, which inhibit plant growth and reduce crop performance. Twenty percent of the 230 million hectares of irrigated croplands are affected by salts, and this proportion increases dramatically each year owing to unsuitable irrigation practices [35]. It is estimated that 50% of the world's arable land will be salinized by 2050 [36]. At present, the arid and semi-arid areas in the world account for 36% of the total land area and 43% of the cultivated land area. Moreover, global climate change will likely add to water scarcity, making it a greater limitation for sustainable agricultural performance. The adverse effects of abiotic stress on crops include seed germination rate, early seedling growth, plant height, seed yield capacity, and oil quality, as well as physiological and biochemical features of crops.

1.4.1. Effects of abiotic stress on seed germination and plant growth

Seed germination and seedling emergence are critical stages in crop production, particularly sensitive to environmental factors. A comfortable environment includes adequate moisture, oxygen, sunlight, and the right temperature, which are necessary for the germination and growth of healthy seeds. The germination stage for those plants which reproduce through their seeds is crucial because of its indirect influence on plant concentration [37]. Therefore, it is of great significance to study the effects of seed germination and plant growth in complex and diverse environments.

Water is the primary condition for seed germination, and successful seedling establishment depends on the amount of water [38]. Extensive literature suggested that polyethylene glycol (PEG) can be used to simulate drought conditions and study the effects of drought stress on plants [39,40]. Polyethylene glycol (PEG) is an inert long-chain polymer with high molecular weight, with little effect on cells. A study of drought on wild almonds showed that the germination rate decreased with increasing stress [41]. Similar results have been observed for maize varieties [42]. In 14 rapeseed varieties, drought stress reduced seedling height by 40.68 %, and fresh weight by 34.2 %, and a survival rate by 18 % on average [43].

Generally, there is a temperature threshold for plant growth, and it is favorable for plant development and growth rate under optimum temperature conditions. Temperatures for germination and growth above or below this threshold cause various physiological damage in plants. Low temperatures not only retard germination, emergence, and vegetative growth but also affect morphogenesis. The germination energy, germination rate, and germination index of maize dropped to a minimum with the treatment of -25℃ and 12 hours [44]. Low-temperature stress during reproductive development induced flower abscission, pollen sterility, pollen tube distortion, ovule abortion, and reduced fruit set, which ultimately lowered yield [45]. High temperatures can also cause serious damage to plants. A study of sugarcane found that heat stress significantly reduced the length of the first internode and resulted in premature plant death [46]. The high temperature was closely related to pollen development and pollen tube elongation in rice [47].

Salt stress increases the concentration of sodium and chloride ions, thus, leading to nutritional imbalance and even plant death [48]. Salinity stress inhibits plant growth for two reasons: the first is to reduce the plant's ability to absorb water from the surrounding soil, and the second is excessive ions that move into the leaves to damage the cells further and ultimately slow the plant’s growth [49]. The germination rate of tomatoes was negatively correlated with salt concentration, and all seedling growth parameters, except plant height, decreased with the increase in salt concentration [50]. Severe salt stress resulted in a significant decrease in maize germination percentage (77.4 %), germination rate (32.4 %), length of radicle (79.5 %) and plumule (78 %), seedling length (78.1 %), and seed vigor (95 %) [51].

Plant roots are closely associated with nutrients and water uptake and are the first contact tissue that responds to stress signals. Multiple figures determine the root system architecture (RSA), particularly, abiotic stresses [52, 53]. Plants have established a sophisticated mechanism to adapt to abiotic stresses, such as regulating the plant RSA [53]. A study in Arabidopsis thaliana reported that salt stress markedly promotes the elongation of lateral roots [4]. In Brassica napus, stress stimulates changes in root morphology, including the growth and development of root hairs on lateral roots, which leads to an additional increase in the root surface area compared with plants that are not stressed. To some extent, an increase in root surface area indicates that plants can absorb more water and nutrients from the surrounding rhizosphere, and this change induced by stress in root morphology serves as an adaptation strategy [54]. The natural variation of RSA enables its use as a modern breeding strategy to improve the efficiency of uptake of water and nutrients, and further increase crop yields [5, 6].

1.4.2. Effects of abiotic stress on plant photosynthesis

Photosynthesis is undoubtedly the most important physiological process that affects plant growth and biomass. Adverse environmental factors including light, temperature, water, nutrients, and carbon dioxide can affect photosynthesis and reduce plant growth [55].

Water is one of the important factors in photosynthesis. Previous studies have shown that drought restricts photosynthesis through stomatal and non-stomatal processes [56, 57]. Controlling water loss through stomatal regulation has been considered an early response of plants to drought [58]. With the aggravation of drought stress, the factor affecting the photosynthetic rate changed towards the critical value from the stomatal limitation to the non-stomatal limitation, and the photosynthetic system was damaged [59]. Chloroplasts are highly sensitive to stress, and the decrease of chlorophyll content is a common phenomenon under drought stress [60, 61]. The reduction in chlorophyll content may be due to its decomposition rate exceeding the synthesis [62].

Photosynthesis is also inhibited when high concentrations of Na^+ and/or Cl^- are accumulated in the plants. High concentrations of Na^+ reduced K^+ and Ca^{2+} uptake and photosynthesis by reducing stomatal conductance, while high Cl^- concentration reduced the photosynthetic capacity due to non-stomatal effects and chlorophyll degradation [63]. Salinity accelerates the degradation of chloroplasts and then inhibits chlorophyll synthesis [64]. Leaf chlorophyll is involved in the capture, absorption, and transfer of light energy in photosynthesis, and the decreased chlorophyll content correlated negatively with plant yield capacity [65]. In addition to the above-mentioned environmental factors, light limits photosynthetic rate by regulating photosynthetic activity and stomatal opening of leaves [66].

1.4.3. Effects of abiotic stress on reactive oxygen species metabolism of plants

Oxidative stress is a general response of living organisms to many harmful environmental factors [67]. During oxidative stress, several reactive oxygen species (ROS), like superoxide anion ($O_2^{\cdot -}$), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH) are commonly generated [33]. As toxic byproducts of aerobic metabolism, ROS are primarily formed in chloroplasts, mitochondria, and peroxisomes. Previous studies have shown that stress induces a significant increase in ROS and causes lipid peroxidation [68, 69]. High levels of ROS and RNS can cause lipid and protein oxidation, damage to nucleic acids, enzyme inhibition, and activation of the programmed cell death pathway (PCD), ultimately leading to cell death [70]. Recent studies suggested ROS is necessary for cellular proliferation and differentiation, even though excessive amounts of ROS inhibit the synthesis of proteins and chlorophyll, resulting in wilting or death under severe stress [71]. A recent study in Brassica napus revealed that in addition to hormones, ROS can also regulate the growth and development of roots [33].

To keep the ROS in balance and not harm the plant, the plant activates its antioxidant system to eliminate the deleterious ROS. The antioxidant system can be divided into the enzymatic antioxidant system and non-enzymatic protection system, among which the enzymatic antioxidant system includes superoxide dismutase (SOD), catalase (CAT), ascorbic acid peroxidase (APX), and peroxidase (POD). The non-enzymatic antioxidant defense system mainly includes ascorbic acid (ASA), glutathione, and carotenoids [72, 73]. It has been documented that the antioxidant enzyme activity was positively related to salt resistance in rice (Oryzae sativa) [7], chickpea (Cicer arietinum) [8], and maize (Zea may) [9]. Khan showed that the SOD, POD, and CAT activities of rapeseed seedlings increased rapidly under drought stress growth conditions, and might have limited the ROS production [74]. GSH-AsA cycle is an important non-enzymatic antioxidant defense system and has attained considerable attention [75]. Many studies have shown that high concentrations of AsA and GSH can reduce ROS accumulation in plants [76, 77]. Under high-temperature conditions, Wang showed ascorbate (AsA, DAsA) and glutathione (GSH, GSSG) content increased in early cauliflower leaves [78].

1.4.4. Effects of abiotic stress on osmotic adjustment substances

Osmotic adjustment is generally an important physiological mechanism for plants to endure and resist abiotic stress [79]. Plants will actively accumulate some osmotic adjustment substances to maintain osmotic balance and protect cell structure under stress [80, 81]. There are four main classes of solutes that could have an osmotic or protective role. They are as follows: the N-containing solutes such as proline and glycine betaine; sugars such as sucrose and raffinose; straight-chain polyhydric alcohols (polyols) such as mannitol and sorbitol; and cyclic polyhydric alcohols (cyclic polyols) [82].

Saccharide is an important dehydrating protectant in plants. Wang demonstrated that increasing soluble sugar content can resist drought stress in Apocynum species [83]. Li showed that the contents of soluble sugar and proline in maize seedlings were significantly increased under drought stress, indicating that drought stress could induce osmotic regulation of substance accumulation in maize seedlings [84]. Previous studies have suggested a positive correlation between the accumulation of proline and plant stress resistance [84, 85]. Mansour et al.. reported that NaCl stress resulted in the accumulation of glycinebetaine (GB) and free proline (Pro) in shoots of the two maize varieties [86]. Proline facilitates water uptake, maintains osmotic balance, and protects cells against ROS under salt stress [87]. The role of soluble protein content in osmotic regulation is controversial under the stress of adversity. Some studies suggested that soluble protein content decreased under water stress [88]. On the contrary, an increase in the soluble proteins may be due to the rapid synthesis of an osmotin-like protein or structural protein mainly involved in cell wall modification [89]. In addition to organic osmotic regulators, inorganic substances including Ca^{2+}, Mg^{2+}, and Na^{+} are also used to maintain cellular homeostasis to increase stress resistance in plants. Ca^{2+} is a universal second messenger of diverse signaling pathways, involved in biotic and abiotic stresses.

1.4.5. Effects of abiotic stress on phytohormones

Phytohormones are the key endogenous factors mediating plant stress response and play an important role in the defense response [90]. There are six major classes of plant endogenous hormones, auxin (IAA), cytokinin (CTK), gibberellin (GA), abscisic acid (ABA), ethylene (ETH), and brassinosteroids (BR). Plant hormones have a wide range of effects on plant growth and development, from cell division, elongation, and differentiation to germination, rooting, flowering, fruiting, sex determination, dormancy, and shedding. Plant hormones can mitigate stress due to the complex interactions of different plant hormones and their ability to control a wide range of physiological processes.

Extensive studies have demonstrated a close relationship between phytohormones and stress resistance in plants. The prominent contribution of ABA in plant resistance against abiotic stress has been studied extensively [91-94]. Therefore, ABA is known as the stress hormone. ABA can stimulate stomatal closure under drought conditions, resulting in the maintenance of water balance [95]. ABA induced the synthesis of LEA proteins, dehydrins, and other stress-induced proteins that maintained water status and protected enzymes and organelles from damage under water stress [96, 97]. Besides, the interaction of plant hormones to regulate root development is considered an adaptive strategy for plants during adverse environments [98]. A large number of studies have proved that auxin is involved in plant morphology and development, especially in root growth regulation [99]. Auxin associates with ethylene to regulate root development and architecture, and contribute to drought and salt stress tolerance [100]. However, Auxin and cytokinin play opposite effects in lateral root formation induced by low phosphate conditions [101].

1.5. The components of modern technologies for growing mustard (*Brassica Juncea* L.)

Mustard has outstanding economic value and is commonly used as an oil crop, source of leafy greens, spice, fodder, and green manure [102]. In recent years, abiotic stresses, including a limited supply of moisture, high transpiration, and continuous high temperature, have been detrimental to the healthy growth of mustard [103]. Under fluctuating environmental conditions, favorable cultivation and management practices play an important role in mustard growth and yield.

1.5.1. Seeding time

Mustard is mainly cultivated in temperate climates. It is also grown in certain tropical and subtropical regions as a cold weather crop [104]. Generally, the growth features of mustard varieties vary from region to region. Selecting suitable varieties for the local climate is the first step in ensuring high yields. The timing of sowing determines the level of moisture and nutrients available for the plants. The change of climate conditions in Ukraine over the past decades had an impact on the soil maturity and allowed sowing all the crops as well as mustard at earlier dates.

Seed germination is an important stage in the life cycle of crops. Sowing time influences the morphological development of crop plants through temperature and heat units. Mustard is reported to tolerate annual precipitation of 500 to 4200 mm, and an annual temperature of 6 to 27°C. Mustard follows the C_3 pathway for carbon assimilation. Therefore, it has an efficient photosynthetic response at 15–20°C temperatures. At this temperature, the plant achieves the maximum CO_2 exchange range, which declines after that.

To ensure the yield and quality of mustard, a detailed investigation and understanding of the local climate and temperature conditions should be conducted to select before sowing. Throughout the world, sowing times vary for different varieties, but appropriate planting times are necessary to improve crop yield and quality [105]. Chinese mustard is usually planted in August [106], while the most suitable planting time in Ukraine is from April to May, and harvested in August.

1.5.2. Land and seedbed preparation

Generally, mustard plants have well-developed roots, and deep soil is necessary to produce vigorous seedlings. Mustard prefers good sandy loamy soil, chernozem, and chestnut soils. Moreover, the field requires a complete drainage system and a high content of soil organic matter. Mustard has a low water requirement (240–400 mm) and a certain drought resistance, which fits well in the rainfed cropping systems. The seedbed should be firm and moist to ensure good contact between the seeds and the soil. Weeds and gravel should be removed from the soil to ensure good conditions for mustard growth.

Tillage affects both crop growth and grain yield. The conventional tillage includes moldboard plowing followed by disc harrowing; reduced tillage includes disc plowing followed by disc harrowing and complete zero tillage (crop is sown under uncultivated soil). Minimum tillage, with or without straw, enhances soil moisture conservation and moisture availability during crop growth [104]. Proper crop rotations include beans, alfalfa, rice, and tobacco, but not mustard, rape, and cabbage. PH is also very important. White mustard is sensitive to the acid reaction, so the soil for its crops must be slightly acid or neutral (pH of about 7). Finally, weeds need to be removed. Weeds compete with crops for water, light, space, and nutrients. Therefore, timely and appropriate weed control greatly increases crop yield. Studies have shown that the effective application of herbicide combined with nitrogen fertilizer is an effective strategy to achieve weed control and yield increase in winter rape [107].

1.5.3. Seeds and sowing

High yield traits of mustard mainly include vigorous seedling growth, good root development, early stem elongation, rapid ground covering ability, early flowering, optimum plant population, and strong resistance to stress and disease.

Plant population and row spacing. Density is an essential factor affecting the rational planting structure of crops and coordinating the physiological features of source and sink [108]. A suitable population structure is the basis of high crop yield. The individual production capacity of Brassica is poor, so it is necessary to give full play to the population advantage through proper planting [109]. A study on rapeseed showed a significant positive correlation between planting density and branch height and yield, and a significant negative correlation between first-order branch number and yield. The potential of a high yield of rapeseed could be achieved by controlling individual growth and compressing low-efficient branches at the lower position [110]. Previous studies on rape planting densities have shown that seed yield increased and then decreased as plant density continuously improved ($15 \times 10^4 – 60 \times 10^4$ plant/hm^2). The highest seed yield was obtained at the plant density of 30×10^4 plants/hm^2, and it significantly decreased when plant density increased to 60×10^4 plants/hm^2. The effect of plant density on seed quality was not significant [111]. Lodging was one of the main factors of yield decline, which hindered nutrient absorption and material transport, and was not conducive to grain formation and filling [112]. The lodging resistance of crops decreased with the increase in planting density. Moreover, lodging is not conducive to mechanized harvesting.

With an increase in rape planting density, competition for space and resources will be intensified. Reasonable row spacing can coordinate the contradiction between population and individual under high density, ensure a reasonable distribution of leaf area, make full use of light energy and soil fertility, and further improve yield. It was believed that there was no significant difference in yield between wide row (36 cm) and narrow row (18 cm) under mechanized planting of rapeseed [113], other studies indicated that narrow row spacing (7.5 cm) had an advantage in yield increase compared with wide row spacing (15 cm and 23 cm) [114]. Reasonable row spacing and planting density can not only achieve high yield but are also suitable for mechanized agriculture and field management.

Seed priming is an effective technology to enhance rapid and uniform emergence and achieve high vigor. Various seed priming techniques have been developed, including hydro-priming, halo-priming, osmo-priming and hormonal priming, etc. [115]. Hydropriming is defined as the soaking of seeds in water. Halo-priming is a pre-sowing soaking of seeds in salt solutions to enhance germination and seedling emergence uniformly under adverse environmental conditions. NaCl, KCl, KNO_3, and $CaCl_2$ are used. Osmopriming is known as a pre-sowing treatment that involves the exposure of seeds to lower external water potential [116]. Hormonal priming is the soaking of seed in hormone solution is referred to as hormonal priming. GA_3, Salicylic acid, Ascorbic acid, Cytokinins, etc. can be used for this.

Due to priming, germination rates increase and the emergence of uniform seedlings and greater stress tolerance compared to non-primed seeds under different adverse environmental circumstances [117]. Previous studies have used a variety of materials for seed priming. A study of rapeseed showed melatonin-priming alleviated the damage of drought stress [74]. The soaking of mustard seeds in 0.025% aqueous pyridoxine hydrochloride solution for 4 hours improved germination [118]. In addition to the effect on germination rate and abiotic stress, seed priming with plant hormones can increase the biological resistance of plants [119].

Planting technique. The sowing technique depends upon land resources, soil conditions, and management levels. Broadcast sowing, line sowing, ridge sowing, and furrow sowing are standard techniques. At higher soil moisture regimes, broadcast sowing is beneficial to the early emergence of seedlings. Under regular and conserved moisture regimes, line sowing becomes the most suitable seeding method for crops. Ridge and furrow sowing is superior to conventional flat sowing for growth parameters and yield. Under the saline conditions, grain yield in ridge sowing was higher by 45, 31, and 28 % than the broadcast, drill, and furrow sowing methods, respectively [120]. Transplanting is also considered a way to save time and resources. With the rise of labor costs, direct seeding has become the main development direction because of its simple operation, labor-saving and time-saving, and ease to mechanize sowing and harvesting. In addition, direct seeding seedlings also had the advantages of a developed main root system and strong lodging resistance [111].

1.5.4. Fertilizer management

Fertilizer has brought unprecedented prosperity and increased production to world agriculture to a certain extent. It is considered that some 30 to 50% of the increase in world food production since the 1950s is attributable to fertilizer use. Six macronutrients (N, K, P, Ca, Mg, and S) and seven micronutrients (Fe, Mn, Zn, Cu, B, Cl, and Mo) are required by plants. Optimal fertilizer management plays a crucial role in high photosynthesis, nutrient utilization, and biological yield. Nitrogen (N), phosphorus (P), and potassium (K) are considered to be three major elements in plant growth. Oilseed crops require adequate availability of fertilizers for maximum performance [121]. The previous study had shown that the plant height, the number of branches per plant, the number of siliqua per plant, the number of seeds per siliquae, 1000-seed weight, and seed and oil yield of mustard increased under optimal NPK management [122].

Nitrogen is one of the essential nutrient elements for crop growth. Adequate nitrogen nutrition is vital to maintaining plant photosynthesis and development [123]. About 75 % of the nitrogen in the plant leaves is located in the chloroplasts, which is conducive to photosynthesis. Increasing leaf nitrogen content could increase the content of the Rubisco enzyme and other photosynthesis-related enzymes [124]. In addition, nitrogen supply could improve leaf structure [125]. In a rape study, high nitrogen was conducive to forming the maximum leaf area index, which ultimately led to higher seed yield. Field studies in India indicated that the grain yield of both mustard crops significantly increased with increased N rates [126]. Nitrogen is also a component of vitamins and hormones and plays an important role in regulating physiological processes. However, excessive nitrogen fertilizer application will cause various harm to the growth and development of plants [127]. The previous report showed a negative correlation between nitrogen and oil content in rapeseed. Therefore, it is necessary to adjust the amount of nitrogen application to prevent excess nitrogen from harming crops.

Phosphorus (P) is the second essential mineral element in plants, closely related to energy metabolism, nucleic acid, and membrane biosynthesis [128]. Plant performance relies on photosynthesis, and the photosynthetic process relies on P-containing compounds. Thus, the efficient use of P in photosynthesis is a potentially important determinant of the crop. An increase in soil phosphorus application led to a rise in rape yield, oil content, and phosphorus content in seeds [129]. In the study of the effect of phosphorus on soybean, it was found that the number of pods per plant, pod length, the number of seeds per pod, biological yield, harvest index, and oil yield increased significantly when the soil phosphorus level was 100 kg ha^{-1}[130]. Plant biomass of maize and P content were positively related to root length, root surface area, and bacteria number, but did not correlate with the dry weight of the root [131]. In agriculture, however, phosphorus is easily lost to water, causing eutrophication. Therefore, the reasonable management of phosphorus is of great significance to achieve a balance between food production and environmental pollution.

Potassium (K) is one of the essential nutrient elements in plants and acts as a coenzyme or activator of many enzymes. Potassium is an important inorganic component of osmotic potential in plant cells. In addition to the three essential elements, plants also have a relatively high demand for sulfur (S), especially the cruciferous family. Previous studies showed that most other parameters of oil crops had a positive response to sulfur fertilizer, and the magnitude of the response varied with species/variety and year [132]. The branches plant^{-1}, seed pod^{-1}, seed weight, and seed and oil yields increased significantly with the applications of sulfur up to 40 kg ha^{-1} [133]. The sulfur application can increase the content of glucosinolate in rape seeds [134]. In addition, the combination of sulfur and nitrogen fertilizer is essential in maintaining sufficient oil levels and fatty acid quality [135].

Mustard, in general, is very sensitive to micronutrient deficiency, especially zinc and boron. Zn fertilizer could significantly increase the aboveground biomass of rape by 7.9-114.3 % and had a significant effect on rape yield [136]. Boron (B) is an essential element for plants and the only non-metal among the seven plant micronutrient. B deficiency is one of the worldwide agricultural problems and a major drawback to crop production [137]. B deficiency hampers flowering and fruiting by retarding pollen germination and pollen tube development processes. Deformed flowers are a common symptom of boron deficiency [138].

According to the results of the research conducted by S. V. Zherdetska at the Sumy National University of Science and Technology in 2015-2017, a significant increase in the yield capacity of the yellow mustard variety of Prima after applying $N_{30}P_{30}K_{30}$ to 1.89 t/ha, which is 0.47 t/ha more than the control variant, was established (without fertilizers). The maximum yield was obtained on the variant with the $N_{60}P_{60}K_{60}$ fertilizer rate – 2.03 t/ha, which is 0.61 t/ha more than the control variant. In the Retro variety, a significant increase in the yield capacity by 0.41 and 0.53 t/ha was also found in variants with the $N_{30}P_{30}K_{30}$ and $N_{60}P_{60}K_{60}$ fertilizer rate compared to the control variant [139].

For steppe conditions, O. H. Zhuykov proved that the highest effect was obtained with pre-sowing incrustation of seeds and foliar feeding of mustard plants. The priority algorithm for carrying out the mentioned event is the use of "Gilea" TM preparations two times during the budding and flowering phase of yellow mustard [140].

1.5.5. Agricultural applications of plant biostimulants

Plant biostimulant refers to any substance or microorganism used by plants, regardless of their nutrient content, for the purpose to improve nutrient efficiency, abiotic stress tolerance, and/or crop quality traits. By extension, plant biostimulants also designate commercial products containing mixtures of such substances and/or microorganisms [141]. Numerous studies have shown that biostimulants promote plant growth, increase yield, and enhance plant resistance to a variety of adverse conditions. Currently, there are many types of biostimulants used in production, mainly including (1) Organic components, such as amino acids, humic acid, seaweed extract, organic carbon, acetic acid, sugar alkyd, chitin, chitosan, etc. (2) Biological components, such as nitrogen-fixing microorganisms, promoting microorganisms, control, and remediation of contaminated soil microorganisms. (3) Inorganic components, such as iron, boron, calcium, magnesium, silicon, titanium, as well as other nutrients and phosphate. (4) Other components, such as plant endogenous hormones, and plant growth regulators [142].

Biostimulants control crop growth and development. Plant biostimulants can promote root growth, regulate the flowering period, promote flower bud differentiation, and fruit development, and increase fruit setting rate. Setia revealed that GA_3 significantly increased plant height of mustard, number of fertile siliqua/plant, number of flowers/plant, setting of siliqua/plant, dry matter yield, number of seeds/siliqua, harvest index, and the number of flowers/plant [143]. Foliar spraying humic substances enhanced the aerial part and root system of watermelon seedlings [144]. Exogenous application of spermidine in maize increased plant height, promoted root development, and increased dry matter accumulation, leading to the increase in maize yield [145]. Mixtalol foliar spraying on mustard increased the number of second and third branches, as well as starch, protein, and oil content [143].

The research conducted by G. Shabbir in 2016-2019 proved that for the conditions of the forest-steppe of Ukraine, the technology should provide for the application of $N_{60}P_{60}K_{60}$ mineral fertilizers combined with 2-fold foliar fertilization in the 14–18 and 45–53 micro stages according to BBCH. It is advisable to use Basfoliar 12-4-6+S (6.0 l/ha) + Soliu Bor (3.0 l/ha) or Vuksal boron (3.0 l/ha) + Vuksal bioaminoplant (3.0 l/ha) [146].

Regulation of photosynthetic and physiological activities of plants by biostimulant. Chlorophyll is a photosynthetic pigment, which is essential to absorb and utilize light energy. Thus, measuring chlorophyll indirectly explains the efficiency of photosynthesis and photosynthate production. Two biostimulants, AZAL5 and HA7, which are derived from seaweed and black peat, can stimulate chloroplast division and promote the absorption efficiency of macronutrients in the rapeseed root system [147]. Furthermore, a large number of studies have shown that the application of biostimulants can effectively improve the activity of a variety of enzymes in crops, regulate the action of a variety of biological factors, and participate in a variety of enzymatic reactions and body metabolism. Brassinolide induced an increase in nitrate reductase activity [148]. The activities of SOD and POD were significantly increased after soybean foliar spraying with SOD simulation material (SODM), Choline chloride (Cc), and Diethyl aminoethyl hexanoate (DTA-6) [149].

Induction of crop resistance to stress. Biostimulants are highly effective in mitigating the effects of abiotic and biological stresses on plants. The application of Salicylic acid (SA) and Putrescine (Put) can effectively alleviate drought stress by maintaining the water budget of canola plants, accumulating proline, and protecting photosynthetic pigments [150]. Silicon (Si) can improve drought tolerance via enhancing root hydraulic conductance and water uptake in tomato plants [151]. Inoculation with plant growth regulators has been known to modulate abiotic stress via direct and indirect mechanisms [152-154].

1.5.6. Crop protection (weeds, diseases, and insects)

Weeds significantly affect the growth of oil crops, especially in the early growth stage. Weeds cause direct yield losses through competition for light, nutrients, and space. Weeds can also interfere with harvesting. Some weeds such as chickweed, cleaves, and speedwells grow at lower temperatures and threaten to smother the oilseed crop in early spring. In general, weeds in the winter oilseed rape fields of Europe are volunteer cereal grasses and botanically similar, closely related brassica weeds, which include Chalock, Wild mustard, Stinkweed, ball mustard, wormseed mustard, and shepherd's purse [155]. In general, weed control is a combination of agricultural practices and herbicides [156]. Cultural practices include rotation, sowing time, inversion tillage, crop management, as well as hand and mechanical weeding.

Numerous diseases may cause production losses to a greater or lesser extent in different areas of the world. Sclerotinia stem rot (*Sclerotinia sclerotiorum*), Alternaria blight (*Alternaria brassicae*), White rust (*Albugo candida*), Downy mildew (*Hyaloperonospora parasitica*), Powdery mildew (*Erysiphe cruciferarum*), and Blackleg (*Leptoshaeria maculans*), are the major diseases of oil crops [157]. Control of disease has involved a range of strategies. Black leg and light leaf spot are most effectively controlled by the use of resistant varieties. Cultural control methods, particularly rotation, are important means of controlling diseases such as sclerotinia and clubroot [155].

A range of insects attack oil crops throughout their growth and cause reduced yields or even death. Cabbage-stem flea beetle (*Psylliodes chrysocephala*) is one of the important insects on winter rape seed in Europe. Several species of aphids can also cause damage. Flea beetles (*Phyllotreta spp*) are considered very adverse insects for spring rapeseed. The pollen beetle (*Meligethes spp*), seed weevil (*Ceuthorhynchus assimilis*), and pod midge (*Dasinaura brassicae*) [155]. Traditionally, neonicotinoid and pyrethroid insecticides have been widely used for control [158]. Cultivation control practices such as crop rotation, adjustment to seedling date, and cultivation practice are effective controlling measures.

1.5.7. Components of grain yield

Seed yield is the result of many characters, which are interdependent [159]. The yield of mustard includes the number of siliques per plant, the number of seeds per silique, and 1000-seed weight [160]. The remaining yield-related features, such as the number of primary and secondary branches per plant, seed yield per 100 siliquae, seed yield per plant, biologic yield per plant, and harvest index, provide more opportunities for increasing the yield capacity [161]. A previous study showed that high density (5.2×10^5 plants per hectare) significantly increased yield by increasing the number of branches per unit area, main branches per unit area, and branch racemes. The oil content and glucosinolide content were increased by reducing nitrogen application [162]. Environmental conditions have significant differences in yield capacity and yield components of oil crops. There was a very significant correlation between numbers of pods per plant, PAI (pod area index), main inflorescence yield, and branch yield, as well as accumulated temperature and daylight hours but no significant correlation for 1000-seed weight and SNPA (seed numbers per unit pod area). Seeding date mainly affected branch development, growth, and branch yield formation resulting in a highly significant effect on the yield capacity [163].

1.5.8. Maturity and harvesting

Mustard is a raceme with unlimited inflorescence, which results in inconsistent pod maturation. When more than 75% of the pods turn yellow and the seeds show mature color, we consider it the mature stage [164]. Timely harvesting depends on maturity. Thus, the maturity index is necessary for a high yield capacity of mustard. Harvest index (HI), also known as an economic coefficient, refers to the ratio between crop economic yield capacity and biological yield capacity and is one of the universal indicators for comprehensively evaluating the conversion of photosynthetic products into the economic yield capacity. The harvest index for winter oilseed rape ranges from 0.25 to 0.3, equal to the above-ground dry matter yield of 20 $t \cdot ha^{-1}$, accompanied by a seed yield of 5 $t \cdot ha^{-1}$ [165]. The harvest index of varieties varies to a certain extent according to climatic conditions and soil features [166]. Natural shedding and mechanical harvesting are the main causes of seed loss in oil crops. Previous studies have shown that rape losses averaged 4% of yield during 1974-6, 22-224 kg/ha after strapping and 45-353 kg/ha after drying on 26 farms in Yorkshire and N. Humberside [167].

1.5.9. Selection and production of mustard

Mustard is an industrial crop that is primarily cultivated for oil. As edible oil, yield capacity and quality are key factors in mustard development. The isocyanate, which is rich in mustard seeds, plays an important role in preventing cancer. In terms of nutrition, mustard oil contains a large number of essential fatty acids but the high content of erucic acid reduces the use of mustard oil. Therefore, developing varieties with high nutritional quality has become an important goal in the quality cultivation of mustard. Traditionally, plant breeders obtained desired genes quickly through interspecific and intergeneric hybridization. In recent years, more specialized tools like mutagenesis, marker-assisted selection (MAS), and genetic engineering (transgenic) have revolutionized the way, in which quality selection was undertaken. The related genes and quantitative trait loci of erucic acid and glucosinolates content were mapped and cloned by a molecular marker array [25]. The combination of traditional and modern selection will provide strategies for novel mustard varieties.

Selection for phenotypic plasticity in traits other than seed or oil yield will potentially provide resilience under increasingly unpredictable environmental conditions. These varieties need not only high yield capacity but also strong stress resistance. The features like early maturity, flowering, reduced plant height, and length of the main axis are preferred in Brassicagroup, which enable plant breeders to produce varieties evading or tolerating abiotic stresses like heat and lodging [168].

Conclusions to section 1

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

2. The results of research by the international scientific community on the impact of stress factors on physiological processes and plant productivity have been summarized.

3. The components of the modern technology of growing *Brassica Juncea* L. have been analyzed, in particular, the nutrition system and the use of plant growth regulators (PGR).

4. Under modern climate changes and the emergence of stressful situations, the complex use of plant growth regulators (PGRs) has been proven to be the main reserve for stabilizing development and increasing the performance of crops in general, as well as *Brassica Juncea* L. in particular.

References to section 1

1. Husen A., Iqbal M., Aref I. M. Growth, water status, and leaf features of brassica carinata under drought and rehydration conditions. *Brazilian Journal of Botany*. 2014. 37. P. 217–227.

2. Cao F., Shan S., Gao W., Li Z., Zou Y., Zhang H. Effects of xinqing attapulgite microbial compound fertilizer and conditioning agent on growth and cadmium content in rice. *Tillage and Cultivation*. 2017. 04. P. 4-6.

3. Rademacher W. Plant growth regulators: Backgrounds and uses in plant production. *J Plant Growth Regul.* 2015. *34*. P. 845–872.

4. Wang Y., Li K., Li X. Auxin redistribution modulates plastic development of root system architecture under salt stress in *Arabidopsis Thaliana*. *J Plant Physiol.* 2009. 166. P. 1637–1645.

5. White P. J., George T. S., Gregory P. J., Bengough A. G., Mckenzie B.M. Matching roots to their environment. *Ann Bot-London.* 2013. 112. P. 207–222.

6. He Y., Hu D., You J., Wu D., Cui Y., Dong H., Li J., Qian W. Genome-wide association study and protein network analysis for understanding candidate genes involved in root development at the rapeseed seedling stage. *Plant Physiol Bioch.* 2019. 137. P. 42–52.

7. Khan M., Singha K. L., Panda S. Changes in antioxidant levels in *Oryza Sativa* L. Roots subjected to NaCl-salinity stress. *Acta Physiol Plant.* 2002. 24. P. 145–148.

8. Rasool S., Ahmad A., Siddiqi T.O., Ahmad P. Changes in growth, lipid peroxidation and some key antioxidant enzymes in chickpea genotypes under salt stress. *Acta Physiol Plant.* 2013. 35. P. 1039–1050.

9. Neto A., Prisco J. T., Enéas-Filho J., Abreu C.B., Gomes-Filho E. Effect of salt stress on antioxidative enzymes and lipid peroxidation in leaves and roots of salt-tolerant and salt-sensitive maize genotypes. *Environmental & Experimental Botany.* 2006. 56. P. 87–94.

10. Singh R. B., Niaz M. A., Sharma J. P., Kumar R., Rastogi V., Moshiri M. Randomized, double-blind, placebo-controlled trial of fish oil and mustard oil in patients with suspected acute myocardial infarction: The indian experiment of infarct survival – 4. *Cardiovascular drugs and therapy.* 1997. 11. P. 485–491.

11. Delaquis P., Mazza G. Antimicrobial properties of isothiocyanates in food preservation. *Food Technol.* 1995. 49. P. 73–84.

12. Trachootham D., Zhou Y., Zhang H., Demizu Y., Chen Z., Pelicano H., Chiao P. J., Achanta G., Arlinghaus R.B., Liu J. Selective killing of oncogenically transformed cells through a ros-mediated mechanism by β-phenylethyl isothiocyanate. *Cancer cell.* 2006. 10. P. 241–252.

13. Raymer P. L. Canola: An emerging oilseed crop. *Trends in new crops and new uses.* 2002. 1. P. 122–126.

14. Jham G. N., Moser B. R., Shah S. N., Holser R. A., Dhingra O. D,. Vaughn S. F., Berhow M. A., Winkler-Moser J. K., Isbell T. A., Holloway R. K. Wild brazilian mustard (*Brassica Juncea* L.) seed oil methyl esters as biodiesel fuel. *Journal of the American Oil Chemists' Society.* 2009. 86. P. 917–926.

15. Thirumalai T., Therasa S. V., Elumalai E., David E. Hypoglycemic effect of *Brassica Juncea* (seeds) on streptozotocin induced diabetic male albino rat. *Asian Pacific Journal of Tropical Biomedicine.* 2011. 1. P. 323–325.

16. Wright P., Morgan J., Jessop R. Comparative adaptation of canola (*Brassica Napus*) and indian mustard (*B. Juncea*) to soil water deficits: Plant water relations and growth. *Field Crop Res.* 1996. 49. P. 51–64.

17. Gunasekera C., Martin L., Siddique K., Walton G. Genotype by environment interactions of indian mustard (*Brassica Juncea* L.) and canola (b. Napus l.) in mediterranean-type environments: 1. Crop growth and seed yield. *Eur J Agron.* 2006. 25. P. 1–12.

18. Burton W., Salisbury P., Potts D. The potential of canola quality brassica Juncea as an oilseed crop for australia. *Proceedings 13-Th Biennial Australian Research Assembly on Brassicas, Tamworth, NSW.* 2003. P. 62–64.

19. Johnson A., Gunawardana B., Singhal N. Amendments for enhancing copper uptake by brassica Juncea and lolium perenne from solution. *Int J Phytoremediat.* 2009. 11. P. 215–234.

20. Kurbatova T., Khlyap H. State and economic prospects of developing potential of non-renewable and renewable energy resources in ukraine. *Renewable & sustainable energy reviews.* 2015. P. 217-226.

21. Pradhan A. K., Pental D.. "Genetics of Brassica juncea." *Genetics and Genomics of the Brassicaceae*. Springer, New York, NY, 2011. P. 323-345.

22. Cailin C., Guangfan Z., Yonghong F., Yuan Z., Xuequn C. In Discussion on the origin of mustard (*Brassica Juncea*) in China. *International*

Symposium on Variety Improvement of Horticultural Crops. Part 1: Vegetable Crops. 402. 1993. P. 431–433.

23. Gómez-Campo C., Prakash S. 2 origin and domestication. *Developments in Plant Genetics & Breeding.* 1999. 4. P. 33–58.

24. Vaughan, J. A multidisciplinary study of the taxonomy and origin of brassica crops. *BioScience.* 1977. 27. P. 35–40.

25. Priyamedha, B. K., Thomas, L., Bala, M., Singh, V. V., Singh, D.. Status and perspective of canola quality rapeseed-mustard cultivation in India: a review. *Journal of Oilseed Brassica*, 2016. 1(1), P. 142-151.

26. Rabbani M. A., Iwabuchi A., Murakami Y., Suzuki T., Takayanagi K. Phenotypic variation and the relationships among mustard (*Brassica Juncea* L.) germplasm from pakistan. *Euphytica.*1998. 101. P. 357–366.

27. Jane, M. Characterization of Ethiopian mustard (*Brassica carinata* A. *Braun*) lines for vegetative agromorphological traits at Arusha, Tanzania. *Journal of Horticulture and Forestry*, 2010. 2(1). P. 1-6.

28. Alemayehu N., Becker H. Genotypic diversity and patterns of variation in a germplasm material of ethiopian mustard (*brassica carinata* A. *Braun*). *Genetic Resources and Crop Evolution.* 2002. 49. P. 573–582.

29. Warwick S., Gugel R., McDonald T., Falk K. Genetic variation of ethiopian mustard (*brassica carinata* A. *Braun*) germplasm in western canada. *Genetic Resources and Crop Evolution.* 2006. 53. P. 297–312.

30. Lionneton E., Aubert G., Ochatt S., Merah O. Genetic analysis of agronomic and quality traits in mustard (*Brassica Juncea*). *Theoretical & Applied*

Genetics. 2004. *109*. P. 792–799.

31. Gupta, V., Pradhan, A. K., Bisht, N. C., Sodhi, Y. S., Arumugam, N., Mukhopadhyay, A., Pental, D. Mapping and tagging of agrnomically important genes in *Brassica Juncea*. *International Rape Congress*. 2007. P. 231-245.

32. Mittler R. Abiotic stress, the field environment and stress combination. *Trends in plant science*. 2006. 11. P. 15 ‑ 19.

33. Feigl G., Molnár A., Szőllősi R., Ördög A., Törőcsik K., Oláh D., Bodor A., Perei K., Kolbert Z. Zinc-induced root architectural changes of rhizotron-grown b. Napus correlate with a differential nitro-oxidative response. *Nitric Oxide*. 2019. 90. P. 55 ‑ 65.

34. Atkinson N. J., Urwin P. E. The interaction of plant biotic and abiotic stresses: From genes to the field. *J Exp Bot*. 2012. 63. P. 3523 ‑ 3543.

35. Deinlein U., Stephan A. B., Horie T., Luo W., Xu G., Schroeder J. I. Plant salt-tolerance mechanisms. *Trends in plant science*. 2014. 19. P. 371 ‑ 379.

36. Jamil A., Riaz S., Ashraf M., Foolad M. R. Gene expression profiling of plants under salt stress. *Critical Reviews in Plant Sciences*. 2011. 30. P. 435 ‑ 458.

37. Hamidi H., Safarnejad A. Effect of drought stress on alfalfa varieties (*Medicago Sativa* L.) in germination stage. *American-Eurasian Journal of Agricultural & Environmental Sciences*. 2010. 8. P. 705 ‑ 709.

38. Bybordi, A., Tabatabaei, J. Effect of salinity stress on germination and seedling properties in canola cultivars (*Brassica Napus* L.). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*. 2009 37(2), P. 71-76.

39. Bressan R., Hasegawa P., Handa A. K. Resistance of cultured higher plant cells to polyethylene glycol-induced water stress. *Plant Science Letters.* 1981. 21. P. 23–30.

40. Berg L. V., Zeng Y. J. Response of south african indigenous grass species to drought stress induced by polyethylene glycol (PEG) 6000. *S Afr J Bot.* 2006. 72. P. 284–286.

41. Gholami M., Rahemi M., Kholdebarin B. Effect of drought stress induced by polyethylene glycol on seed germination of four wild almond species. *Australian Journal of Basic and Applied Sciences.* 2010. 4. P. 785–791.

42. Zahra K., Mohammad M. Evaluation of drought and salinity stress effects on germination and early growth of two varieties of maize (*Zea Mays* L.). *African Journal of Biotechnology.* 2011. 10. P. 14868–14872.

43. Yang C., Zhang X., Zou C. Effects of drought simulated by PEG-6000 on germination and seedling growth of rapeseed (*Brassica Napus* L.). *Chinese Journal of Oil Crop Sciences.* 2007. 29(4), P. 425-430.

44. Zheng Q., Wang H. N., Wang W., Ren G. S., Ding Z. Y., Xu. C.Y. Effect of freezing injury on germination features of maize seeds. *Journal of Maize Sciences.* 2011. P. 58-61.

45. Waraich E., Ahmad R., Halim A., Aziz T. Alleviation of temperature stress by nutrient management in crop plants: A review. *Journal of soil science and plant nutrition.* 2012. 12. P. 221–244.

46. Hall A. E. Breeding for heat tolerance. *Plant Breed. Rev.* 1992. 10. P. 129–168.

47. Prasad P., Boote K., Allen Jr L., Sheehy J., Thomas J. Species, ecotype and variety differences in spikelet fertility and harvest index of rice in response to high temperature stress. *Field Crop Res.* 2006. 95, P. 398–411.

48. Zahedi A. M., Fazeli I., Zavareh M., Dorry H., Gerayeli N. Evaluation of the sensitive components in seedling growth of common bean (*Phaseolus Vulgaris* L.) affected by salinity. *Asian Journal of Crop Science.* 2012. 4. P. 159–164.

49. Munns R. Genes and salt tolerance: Bringing them together. *New Phytol.* 2005. 167. P. 645–663.

50. Kaveh H., Nemati H., Farsi M., Jartoodeh S.V. How salinity affect germination and emergence of tomato lines. *J Biol Environ Sci.* 2011. 5. P. 159–163.

51. Khodarahmpour Z., Ifar M., Motamedi M. Effects of NaCl salinity on maize (*Zea Mays* L.) at germination and early seedling stage. *African Journal of Biotechnology.* 2012. 11. P. 298–304.

52. Osmont K. S., Sibout R., Hardtke C. S. Hidden branches: Developments in root system architecture. *Annual review of plant biology.* 2007. 58. P. 93–113.

53. Galvan-Ampudia C.S., Testerink C. Salt stress signals shape the plant root. *Current Opinion in Plant Biology.* 2011. 14. P. 296–302.

54. Arif M. R., Islam M. T., Robin A. H. K. Salinity stress alters root morphology and root hair traits in *Brassica Napus*. *Plants.* 2019. *8*. P. 192.

55. Marcelle R, Clijsters H, Poucke M. Effects of stress on photosynthesis;

proceedings // Conference on Effects of Stress on Photosynthesis 22-27 Ago 1982 Diepenbeek (Bélgica). Limburgs Universitair Centrum, Diepenbeek (Bélgica), 1983 (581.13342063 E27 1982). P. 102.

56. Izanloo A, Condon A G, Langridge P, et al. Different mechanisms of adaptation to cyclic water stress in two South Australian bread wheat cultivars. *Journal of experimental botany*. 2008, 59(12). P. 3327-3346.

57. Zhao W., Liu L., Shen Q., Yang J., Wu J. Effects of water stress on photosynthesis, yield, and water use efficiency in winter wheat. *Water.* 2020, 12(8), 2127.

58. Harb A., Krishnan A., Ambavaram M. M., Pereira A. Molecular and physiological analysis of drought stress in arabidopsis reveals early responses leading to acclimation in plant growth. *Plant physiology.* 2010. 154. P. 1254–1271.

59. Zlatev Z., Lidon F. C. An overview on drought induced changes in plant growth, water relationsand photosynthesis. *Emirates Journal of Food and Agriculture.* 2012. P. 57–72.

60. Din J., Khan S., Ali I., Gurmani A. Physiological and agronomic response of canola varieties to drought stress. *J Anim Plant Sci.* 2011. 21. P. 78–82.

61. Mafakheri A., Siosemardeh A., Bahramnejad B., Struik P., Sohrabi Y. Effect of drought stress on yield, proline and chlorophyll contents in three chickpea varieties. *Australian journal of crop science.* 2010. 4(8). P. 580-585.

62. Harpaz-Saad S., Azoulay T., Arazi T., Ben-Yaakov E., Mett A., Shiboleth Y. M., Hörtensteiner S., Gidoni D., Gal-On A., Goldschmidt E. E.

Chlorophyllase is a rate-limiting enzyme in chlorophyll catabolism and is posttranslationally regulated. *The Plant Cell.* 2007. 19. P. 1007–1022.

63. Tavakkoli E., Fatehi F., Coventry S., Rengasamy P., McDonald G. K. Additive effects of Na^{+} and cl–ions on barley growth under salinity stress. *J Exp Bot.* 2011. 62. P. 2189–2203.

64. Ma Q., Yue L.-J., Zhang J.-L., Wu G.-Q., Bao A.-K., Wang S.-M. Sodium chloride improves photosynthesis and water status in the succulent xerophyte zygophyllum xanthoxylum. *Tree Physiol.* 2012. 32. P. 4–13.

65. Feng Z. T., Deng Y. Q., Fan H., Sun Q. J., Sui N., Wang B. S. Effects of NaCl stress on the growth and photosynthetic features of *Ulmus Pumila* L. Seedlings in sand culture. *Photosynthetica.* 2014. 52. P. 313–320.

66. Fu Q., Zhang J., Qiao T., Liu Y., Hou C., Xu W., MA H., Wang B., Hou Y. Research progress and prospect on the effects of abiotic stress on plant photosynthesis. *Agricultural Biotechnology.* 2020. P. 2164-4993.

67. Piacentini D., Falasca G., Canepari S., Massimi L. Potential of PM-selected components to induce oxidative stress and root system alteration in a plant model organism. *Environment International.* 2019. 132. 105094. P. 1-13.

68. Sairam R. K., Rao K. V., Srivastava G. Differential response of wheat genotypes to long term salinity stress in relation to oxidative stress, antioxidant activity and osmolyte concentration. *Plant Sci.* 2002. 163. P. 1037–1046.

69. Nazar R., Umar S., Khan N. A. Exogenous salicylic acid improves photosynthesis and growth through increase in ascorbate-glutathione metabolism and s assimilation in mustard under salt stress. *Plant signaling & behavior.* 2015.

10. P. 1-10.

70. Pallavi S., Bhushan J. A., Shanker D. R., Mohammad P. Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. *Journal of Botany.* 2012. 2012. P. 1–26.

71. Mittler R. Ros are good. *Trends in plant science.* 2017. 22. P. 11–19.

72. Chen W., Chen G., Hussain S., Zhu B., Wu L. Role of xylo-oligosaccharides in protection against salinity-induced adversities in chinese cabbage. *Environ Sci Pollut R.* 2016. 23. P. 1254–1264.

73. Saddam H., Fahad K., Hussain H. A., Nie L. Physiological and biochemical mechanisms of seed priming-induced chilling tolerance in rice varieties. *Front Plant Sci.* 2016. 7. P. 1-14.

74. Khan M. N., Zhang J., Luo T., Liu J., Rizwan M., Fahad S., Xu Z., Hu L. Seed priming with melatonin coping drought stress in rapeseed by regulating reactive oxygen species detoxification: Antioxidant defense system, osmotic adjustment, stomatal traits and chloroplast ultrastructure perseveration. *Ind Crop Prod.* 2019. 140. P. 1-11.

75. Kuźniak E., Skłodowska M. Ascorbate, glutathione and related enzymes in chloroplasts of tomato leaves infected by *Botrytis Cinerea*. *Plant Sci.* 2001. 160. P. 723–731.

76. Vaidyanathan H., Sivakumar P., Chakrabarty R., Thomas G. Scavenging of reactive oxygen species in NaCl-stressed rice (*Oryza Sativa* L.) – differential response in salt-tolerant and sensitive varieties. *Plant Sci.* 2003. 165. P. 1411–1418.

77. Schonhof I., Kläring H.-P., Krumbein A., Claußen W., Schreiner M. Effect of temperature increase under low radiation conditions on phytochemicals and ascorbic acid in greenhouse grown broccoli. *Agriculture, ecosystems & environment.* 2007. 119. P. 103–111.

78. Wang B., Xu M., Shi Q., Cao J. Effects of high temperature stress on antioxidant systems, chlorophyll and chlorophyll fluorescence parameters in early cauliflower leaves. *Zhongguo nongye kexue.* 2004. 37. P. 1245–1250.

79. Bernstein L. Osmotic adjustment of plants to saline media. I. Steady state. *American Journal of Botany.* 1961. 48. P. 909–918.

80. Blum A. Crop responses to drought and the interpretation of adaptation. In Drought tolerance in higher plants: Genetical, physiological and molecular biological analysis. *Springer.* 1996. P. 57–70.

81. Rathinasabapathi B. Metabolic engineering for stress tolerance: Installing osmoprotectant synthesis pathways. *Ann Bot-London.* 2000. *86*. P. 709–716.

82. Parihar P., Singh, S., Singh R., Singh V. P., Prasad S. M. Effect of salinity stress on plants and its tolerance strategies: A review. *Environ Sci Pollut R.* 2015. *22*. P. 4056–4075.

83. Wang D., Li G., Su D. Effect of drought stress on osmotic adjustment substances and activity of protective enzymes in two species of apocynum. *Journal of Arid Land Resources and Environment.* 2012. 26. P. 177–181.

84. Li J. L., Wan R. G., Yao M., Yue L. W., Shi W. Physiological and biochemical mechanism of spermidine improving drought resistance in maize

seedlings under drought stress. *The journal of applied ecology*. 2018. 29. P. 554-564.

85. Rensburg L. V., Krüger G., Krüger H. Proline accumulation as drought-tolerance selection criterion: Its relationship to membrane integrity and chloroplast ultrastructure in *Nicotiana Tabacum* L. *J Plant Physiol.* 1993. 141. P. 188–194.

86. Mansour M., Salama K., Ali F., Abou Hadid A. Cell and plant responses to NaCl in *Zea Mays* L. Varieties differing in salt tolerance. *Gen. Appl. Plant Physiol.* 2005. 31. P. 29–41.

87. Iqbal N., Umar S., Khan N. A. Nitrogen availability regulates proline and ethylene production and alleviates salinity stress in mustard (*Brassica Juncea*). *J Plant Physiol.* 2015, 178, P. 84–91.

88. Ren D., Zhao S. Effects of water stress on protein metabolism of flag leaves of spring wheat growing in semi-arid region. *Zuo wu xue bao.*1 997. 23. P. 468–473.

89. Amini F., Ehsanpour A. A. Soluble proteins, proline, carbohydrates and na+/k+ changes in two tomato (*Lycopersicon Esculentum* mill.) varieties under in vitro salt stress. *American Journal of Biochemistry and Biotechnology.* 2005. 1. P. 212–216.

90. Verma V., Ravindran P., Kumar P. P. Plant hormone-mediated regulation of stress responses. *Bmc Plant Biol.* 2016. 16. P. 86.

91. Seki M., Umezawa T., Urano K., Shinozaki K. Regulatory metabolic networks in drought stress responses. *Current opinion in plant biology.* 2007. 10.

P. 296–302.

92. Yoshida T., Fujita Y., Sayama H., Kidokoro S., Maruyama K., Mizoi J., Shinozaki K., Yamaguchi-Shinozaki K. Areb1, Areb2, and Abf3 are master transcription factors that cooperatively regulate ABA - dependent ABA signaling involved in drought stress tolerance and require aba for full activation. *The Plant Journal.* 2010. 61. P. 672–685.

93. Finkelstein R. R., Gampala S. S., Rock C. D. Abscisic acid signaling in seeds and seedlings. *The Plant Cell.* 2002. 14. P. S15–S45.

94. Sreenivasulu N., Harshavardhan V. T., Govind G., Seiler C., Kohli A. Contrapuntal role of aba: Does it mediate stress tolerance or plant growth retardation under long-term drought stress? *Gene.* 2012. 506. P. 265–273.

95. Bray E. A. Drought-and aba-induced changes in polypeptide and mrna accumulation in tomato leaves. *Plant Physiology.* 1988. 88. P. 1210–1214.

96. Verslues P. E., Agarwal M., Katiyar-Agarwal S., Zhu J., Zhu J. K. Methods and concepts in quantifying resistance to drought, salt and freezing, abiotic stresses that affect plant water status. *The Plant Journal.* 2006. 45. P. 523–539.

97. Kishor P. K., Sangam S., Amrutha R.. Laxmi P. S., Naidu K., Rao K., Rao S., Reddy K., Theriappan P., Sreenivasulu N. Regulation of proline biosynthesis, degradation, uptake and transport in higher plants: Its implications in plant growth and abiotic stress tolerance. *Curr Sci.* 2005. 88. P. 424–438.

98. Sharp R. E., Poroyko V., Hejlek L. G., Spollen W. G., Springer G. K., Bohnert H. J., Nguyen H. T. Root growth maintenance during water deficits:

Physiology to functional genomics. *J Exp Bot.* 2004. 55. P. 2343–2351.

99. Zhao Y. D. Auxin biosynthesis and its role in plant development. *Annual Review of Plant Biology.* 2010. 61. P. 49–64.

100. Kohli A., Sreenivasulu N., Lakshmanan P., Kumar P. The phytohormone crosstalk paradigm takes center stage in understanding how plants respond to abiotic stresses. *Plant Cell Rep.* 2013. 32. P. 945–957.

101. Huang G., Zhang D. The plasticity of root systems in response to external phosphate. *International journal of Molecular Sciences*. 2020. 21(17). P. 5955.

102. Hooks T., Niu G., Ganjegunte G. Seedling emergence and seedling growth of mustard and rapeseed genotypes under salt stress. *Agrosystems, Geosciences & Environment.* 2019. 2. P. 1–8.

103. Melnik A. V., Zherdetska S. V., Ali S., Romanko Y. O., Makarchuk A.V., Akuaku J. State and prospects for growing oil crops in Ukraine under the conditions of climate change. *Science and World.* 2015. 1(10). P. 113–116.

104. Shekhawat K., Rathore S., Premi O., Kandpal B., Chauhan J. Advances in agronomic management of indian mustard (*Brassica Juncea* (L.) czernj. *Cosson*): an overview. *International journal of Agronomy.* 2012. P. 1-14.

105. Buttar G. S., Aulakh C. S. Effect of sowing date, nitrogen and row spacing on growth, yield attributes and yield of indian mustard (*Brassica Juncea*). *Indian Journal of Agronomy.* 1999. 4. P. 813–815.

106. Li Y. Cultivation techniques of mustard in autumn and winter. *Fujian Agricultural Science and Technology.* 2015. P. 41-42.

107. Wang L., Liu Q., Dong X., Liu Y., Lu J. Herbicide and nitrogen rate effects on weed suppression, n uptake, use efficiency and yield in winter oilseed rape (*Brassica Napus* L.). *Global Ecology and Conservation.* 2019. 17. P. 1-10.

108. Ma N., Zhang C. L., Li J., Li G. M. Regulation of planting density on source-sink relationship and yield at seed-set stage of rapeseed (*Brassica Napus* L.). *Chinese Journal of Oil Crop Sciences.* 2009. P.180-184.

109. Lei H. X., Chen A., Zhang C., Luo K., Chen X. Effect of symbiosis period and seeding amount on growth and yield of rape-seed undersowing rice. *Acta Agronomica Sinica.* 2011. 37(8). P.1449-1456.

110. Li Y., Yu C., Hu X., Xie L., Zhang S., Che Z., Liao X., Liao X. Effects of planting density on agronomic characters and yield of direct seeding rape. *Hunan Agricultural Sciences.* 2012. 15. P. 22–25.

111. Duan Q. Y., Liao F. Q., Liu S. S., Xiao-Bin P. U., Niu Y. Z., Yong-Cheng W. U., University S. A. Effects of plant density and row spacing on agronomic traits,yield and seed quality in directly-sown rapeseed (*Brassica Napus* L.). *Journal of Sichuan Agricultural University.* 2017. P. 167-171.

112. Li X. Y., Zhou M., Wang T., Zhang L., Kuai J. Effects of planting density on the mechanical harvesting features of semi-winter rapeseed. *Acta agronomica sinica.*2018. 44. P. 78–287.

113. Lewis C. E., Knight C. W. Yield response of rapeseed to row spacing and rates of seeding and n-fertilization in interior alaska. *Canadian journal of plant science = Revue canadienne de phytotechnie.* 1987. *67*. P. 53–57.

114. Christensen J. V., Drabble J. C. Effect of row spacing and seeding rate

on rape seed yield in northwest alberta. *Revue Canadienne De Phytotechnie.* 1984. 64. P. 1011–1013.

115. Kumari N., Rai P. K., Bara B. M., Singh I. Effect of halo priming and hormonal priming on seed germination and seedling vigour in maize (*Zea Mays* L.) seeds. *Journal of Pharmacognosy and Phytochemistry.* 2017. 6. P. 27–30.

116. Chen K., Fessehaie A., Arora R. Dehydrin metabolism is altered during seed osmopriming and subsequent germination under chilling and desiccation in *Spinacia Oleracea* L. Cv. *Bloomsdale*: Possible role in stress tolerance. *Plant Sci.* 2012. 183. P. 27–36.

117. Abid M., Hakeem A., Shao Y., Liu Y., Zahoor R., Fan Y., Suyu J., Ata-Ul-Karim S. T., Tian Z., Jiang D. Seed osmopriming invokes stress memory against post-germinative drought stress in wheat (*Triticum Aestivum* L.). *Environ Exp Bot.* 2018. 145. P. 12–20.

118. Kahn N. A., Samiuilah Aziz O. Response of mustard to seed treatment with pyridioxine and basal and foliar application of nitrogen and phosphorus. *Journal of plant nutrition.* 1993 16. P. 1651–1659.

119. Lot D., Danial G. Effect of rapeseed seed priming with salicylic acid on induction of antixenotic resistance to cabbage aphid in field conditions. Conference: 23rd Iranian Plant Protection Congress, 27-30 Aug. 2018, GUASNR, Gorgan, IRAN 2018. P. 231-247.

120. Khan M. J., Khattak R. A., Khan M. A. Influence of sowing methods on the performance of canola grown in saline field. *Pakistan Journal of Biological Sciences.* 2000. 3. P. 687–691.

121. Miller P. R., Mcdonald C. L., Derksen D. A. Waddington J. The adaptation of seven broadleaf cropsto the dry semiarid prairie. *Can J, Plant Sci.* 2001. 81. P. 29–43.

122. Mandal K., Sinha A. Nutrient management effects on light interception, photosynthesis, growth, dry - matter production and yield of indian mustard (*Brassica Juncea*). *J Agron Crop Sci.* 2004. 190. P. 119–129.

123. Evans J. R. Nitrogen and photosynthesis in the flag leaf of wheat (*Triticum Aestivum* L.). *Plant Physiology.* 1983. 72. P. 297–302.

124. Evans J. R. Photosynthesis and nitrogen relationships in leaves of c 3 plants. *Oecologia.* 1989. 78. P. 9–19.

125. Muller O., Oguchi R., Hirose T., Werger M., Hikosaka K. The leaf anatomy of a broad-leaved evergreen allows an increase in leaf nitrogen content in winter. *Physiol Plantarum.* 2010. 136. P. 299–309.

126. Aulakh M., Pasricha N., Sahota N. Yield, nutrient concentration and quality of mustard crops as influenced by nitrogen and sulphur fertilizers. *The Journal of Agricultural Science.* 1980. 94. P. 545–549.

127. Srensen J. N. Use of the nmin-method for optimization of vegetable nitrogen nutrition. *Workshop on Ecological Aspects of Vegetable Fertilization in Integrated Crop Production in the Field*. 1993. 179-192.

128. Ragothama K. G. Phosphate acquisition. *Annu Rev Plant Physiol Plant Mol Biol.* 2005. 274. P. 37–49.

129. Lickfett T., Matthäus B., Velasco L., Möllers C. Seed yield, oil and phytate concentration in the seeds of two oilseed rape varieties as affected by

different phosphorus supply. *Eur J Agron.* 1999. 11. P. 293–299.

130. Shahid M. Q., Saleem M. F., Khan H. Z., Anjum S.A. Performance of soybean (*Glycine Max* L.) under different phosphorus levels and inoculation. *Pak J Agr Sci.* 2009. 46. P. 237–241.

131. Sha X. Q., Wang X. Z., Wei X. Y., Shi E. G., Peng Z. P. Effects of phosphorus on plant growth and p conversion in root rhizosphere of different maize seedlings. *Journal of Agricultural University of Hebei.* 2011. P. 13-17.

132. Malhi S., Gan Y., Raney J. Yield, seed quality, and sulfur uptake of brassica oilseed crops in response to sulfur fertilization. *Agron J.* 2007. 99. P. 570–577.

133. Ahmad G., Jan A., Arif M., Jan M.T., Shah H. Effect of nitrogen and sulfur fertilization on yield components, seed and oil yields of canola. *Journal of plant nutrition.* 2011. 34. P. 2069–2082.

134. Zhao F., Evans E. J., Bilsborrow P. E., Syers J. K. Influence of sulphur and nitrogen on seed yield and quality of low glucosinolate oilseed rape (*Brassica Napus* L.. *J Sci Food Agr.* 1993. 63. P. 29–37.

135. Fismes J., Vong P., Guckert A., Frossard E. Influence of sulfur on apparent n-use efficiency, yield and quality of oilseed rape (*Brassica Napus* L.) grown on a calcareous soil. *Eur J Agron.* 2000. 12. P. 127–141.

136. Hao H., Zhang P., Liu F., Bai J., Li J. Effects of foliar spray zinc fertilizer on cadmium uptake by rape. *Environment and Development.* 2017. P. 207-209.

137. Shorrocks V. M. The occurrence and correction of boron deficiency.

Plant & Soil. 1997. 193. P. 121–148.

138. Gupta U., Solanki H. Impact of boron deficiency on plant growth. *International Journal of Bioassays.* 2013. 2. P. 1048–1050.

139. Melnyk A. V., Zherdetska S. V. Vplyv doz mineralnykh dobryv na vrozhaynist hirchytsi yaroyi syzoyi v umovakh pivnichno-skhidnoho Lisostepu Ukrayiny (The effect of rates of mineral fertilizers on the yield capacity of spring gray mustard in terms of the northeastern Forest-Steppe of Ukraine). *Naukovyy Visnyk natsionalnoho universytetu bioresursiv i pryrodokorystuvannya Ukrayiny.* Kyiv, 2017. № 269. P. 177–185. (in Ukrainian)

140. Zhuykov O. H. Ahrobiolohichne obhruntuvannya kompleksu tekhnolohichnykh pryyomiv vyroshchuvannya vydiv hirchytsi v umovakh Pivdennoho Lisostepu (Agrobiological substantiation of the complex of technological methods of growing mustard species in the conditions of the southern Forest-Steppe). Avtoref. dys. na zdobuttya nauk. stupenya d-ra s.-h. nauk: 06.01.09. Kherson, 2015. 43 p. (in Ukrainian)

141. Jardin P.d. Plant biostimulants: Definition, concept, main categories and regulation. *Sci Hortic-Amsterdam.* 2015. 196. P. 3–14.

142. Xiong S., Chen S. Application of biostimulant in green development of agriculture and its market prospect. *Chemical Fertilizer Industry.* 2018. 45(6). P. 1-6.

143. Setia R., Setia N., Ahuja K., Malik C. Effect of ‘mixtalol’on growth, yield and yield components of indian mustard (*Brassica Juncea*). *Plant Growth Regul.* 1989. 8. P. 185–192.

144. Silva-Matos R., Cavalcante I., Júnior G.S., Albano F., Cunha M., Beckmann-Cavalcante M. Foliar spray of humic substances on seedling production of watermelon cv. Crimson sweet. *Journal of Agronomy.* 2012. 11. P. 60–64.

145. Li L., Gu W., Qian Z., Zhao D., He Z., Yang D., Shi W., Hao W., University N. A. Effects of exogenous spermidine on leaf physiologic and root feature parameter of maize seedling under drought stress. *Chinese Journal of Pesticide Science.* 2015. 17(3). P. 291-299.

146. Shabbir G. The performance of oilseeds of the *Brassicaceae* family depending on the application of fertilizers under the conditions of the northeastern Forest Steppe of Ukraine. Thesis for a Candidate Degree in Agricultural Sciences (PhD): Specialty 06.01.09 “Crop Production”. Sumy National Agrarian University, Ministry of Education and Science of Ukraine. Sumy, 2021. 23 p.

147. Billard V., Etienne P., Jannin L., Garnica M., Cruz F., Garcia-Mina J.-M., Yvin J.-C., Ourry A. Two biostimulants derived from algae or humic acid induce similar responses in the mineral content and gene expression of winter oilseed rape (*Brassica Napus* L.). *J Plant Growth Regul.* 2014. 33. P. 305–316.

148. Prabha V. V., Senthil A., Sritharan N., Boominathan P. Effect of foliar application of plant growth regulators and nutrients on physiological traits of finger millet (*Eleusine Coracana*). *Research on Crops.* 2016. 17. P. 483.

149. Zheng D. F., Zhao L. M., Feng N. J. Effects of plant growth regulators (PGRs) on endogenous hormone contents and activities of protective enzymes in soybean leaves. *Acta Agronomica Sinica* .2008. 34(7). P.1233-1239.

150. Ullah F., Bano A., Nosheen A. Effects of plant growth regulators on

growth and oil quality of canola (*Brassica Napus* L.) under drought stress. *Pak. J. Bot.* 2012. 44. P. 1873–1880.

151. Shi Y., Zhang Y., Han W., Feng R., Hu Y., Guo J., Gong H. Silicon enhances water stress tolerance by improving root hydraulic conductance in *Solanum Lycopersicum* L. *Front Plant Sci.* 2016. 7. P. 196.

152. Yang J., Kloepper J. W., Ryu, C.-M. Rhizosphere bacteria help plants tolerate abiotic stress. *Trends in plant science.* 2009. 14. P. 1–4.

153. Jia P., Melnyk A., Zhang Z. Effects of different plant growth regulators in a vegetative chamber on seedling morphology parameters of yellow mustard (*Brassica Juncea* L.). *AgroLife Scientific Journal*. 2020. 9(1). P. 180–185.

154. Jia P., Melnyk A., Zhang Z., Butenko S., Kolosok V. Effects of seed pre-treatment with plant growth compound regulators on seedling growth under drought stress. *Agraarteadus*. 2021. 32(2). P. 251–256.

155. Ijaz M., Honermeier B. Effect of triazole and strobilurin fungicides on seed yield formation and grain quality of winter rapeseed (*Brassica Napus* L.). *Field Crop Res.* 2012. 130. P. 80–86.

156. Singh R. K., Singh R. P., Singh M. Weed management in rapeseed-mustard - a review. *Agricultural Reviews.* 2013. 34. P. 36–49.

157. Singh K. P., Kumari P., Rai P. K. Current status of the disease-resistant gene(s)/QTLs, and strategies for improvement in Brassica Juncea. *Front Plant Sci.* 2021. 12. P. 61.

158. Willis C. E., Foster S. P., Zimmer C. T., Elias J., Davies T. Investigating the status of pyrethroid resistance in uk populations of the cabbage

stem flea beetle (*Psylliodes Chrysocephala*). *Crop Protection.* 2020. P. 1-6.

159. Mazur V. O., Protsiv P. B., Hamaliy S. M., Popovych Yu. V. *Hirchytsya* (Mustard). Ivano-Frankivsk: Symfoniya-forte, 2009. 88 p. (in Ukrainian)

160. Lys N. M., Bodnar O. Y., Tkachuk N. L., Moysey S. I., Ivanyuk R. S. Vplyv mikrobiolohichnykh preparativ na produktyvnist hirchytsi (The influence of microbiological preparations on the productivity of mustard: collection of sciences). *Zbirnyk nauk. prats NNTS Instytut zemlerobstva NAAN.* 2015. Vyp. 2. P. 143–151. (in Ukrainian)

161. Mekonnen T.W., Wakjira A., Genet T. Correlation and path coefficient analysis among yield component traits of ethiopian mustard (*Brassica Carinata* A. *Brun*) at Adet, Northwestern, Ethiopia. *Journal of Plant Sciences.* 2014. 2(2). P. 89-96.

162. Gupta P., Chaudhary H. B., Lal S. K. Heterosis and combining ability analysis for yield and its components in indian mustard (*Brassica Junceal*. Czern & coss). *Frontiers of Agriculture in China.* 2010. 4. P. 299–307.

163. Li X., Li J., Liu L.x., Wang F., Hao R., Wang T., Zhang C., Ma N. Comprehensive analysis on yield and quality parameters of direct-seeding rapeseed in different environments. *Chinese Journal of Oil Crop Sciences.* 2021. 43. P. 251–259.

164. Hamayunova V. V., Khonenko L. H., Kovalenko O. A., Hyrlya L. M. Urozhaynist hirchytsi zalezhno vid pohodnykh umov ta normy vysivu na chornozemakh pivdennykh (Yield capacity of mustard depending on weather

conditions and sowing rate on southern black soil). *Tavriyskyy naukovyy visnyk.* Kherson: Aylant, 2014. Vyp. 88. P. 50–56. (in Ukrainian)

165. Guan C. L. G. Effect of seeding date on yield features of different rapeseed (*Brassica Napus*) genotypes. *Chinese Journal of Applied Ecology.* 2001.12(6). P.853-858

166. Diepenbrock W. Yield analysis of winter oilseed rape (*Brassica Napus* L.): A review. *Field Crop Res* .2000. 67. P. 35–49.

167. Zajac T., Kulig B., Oleksy A., Stoklosa A., Pyziak K., Styrc N. Development and yield of morphologically different groups of winter oilseed rape canopy ii. The harvest index value depending on the cutting height. *Acta Scientiarum Polonorum Agricultura.* 2013. 15. P. 57–64.

168. Bailey J. Oilseed rape harvesting losses can be high. *Arable Farming.* 1980. P. 212-231.

SECTION 2

OBJECT, SUBJECT, AND METHODOLOGY OF THE RESEARCH

This research consisted of two parts. One was the response of growth and yield components of two mustard varieties to plant growth regulators under agro-ecological conditions in the northeastern Forest-Steppe of Ukraine. The second was on the morphological and physiological response of mustard to stress and the effect of plant growth regulators on seedlings.

The field research was conducted in the research field of ERPC (educational, research, and production complex) of the Sumy National Agrarian University, Ukraine, in 2019-2021. The experimental plots of Sumy NAU are located within the city of Sumy (latitude 50°52.742N, 34°46.159E Longitude, and 137.7 m above sea level) and belong to the northeastern part of the Forest-Steppe. Research work was performed according to the thematic plans and within the framework of state scientific topics of the Sumy National Agrarian University “Optimization of the elements of mustard cultivation technology in terms of the northeastern Forest-Steppe of Ukraine”, state registration number 0115U001051 and “The development of modern methods of identification of the stress of crops and forest plantation and ways to reduce it”, state registration number 0121U113642.

Responses of Mustard seedlings to stress under hydroponic conditions and the effects of growth regulators were performed at Henan Institute of Science and Technology, Xinxiang, China. This research was supported by the Program for Innovative Research Team (in Science and Technology) at the University of Henan

Province (21IRTSTHN023), China.

2.1. Soil and climatic conditions of the research

Field experiments were carried out on black soil features for the coarse-medium loam. Soil samples were taken before the start of the experiments to determine the soil type. Composite soil samples were collected from 0-30 and 30-60 cm. They were air-dried, crushed, and tested for physical and chemical properties. Chemical tests resulted in 120 $mgkg^{-1}$ N, 202 $mgkg^{-1}$ P_2O_5, and 85 $mgkg^{-1}$ K_2O with pH of 6.0–6.2 and an organic matter (humus) of 4.1–4.5 %.

In April and June, the amount of precipitation was lower than the long-term average by 4.8and 11.9 mm, respectively (Figure 2.1). The largest deficit of moisture was observed in August, and precipitation was less by 24.2 mm. During the whole growth period, the temperature showed a trend of gradual increase. From May to August, temperatures were 0.3 to 3.4° c higher than the long-term index, with the highest temperature in August.

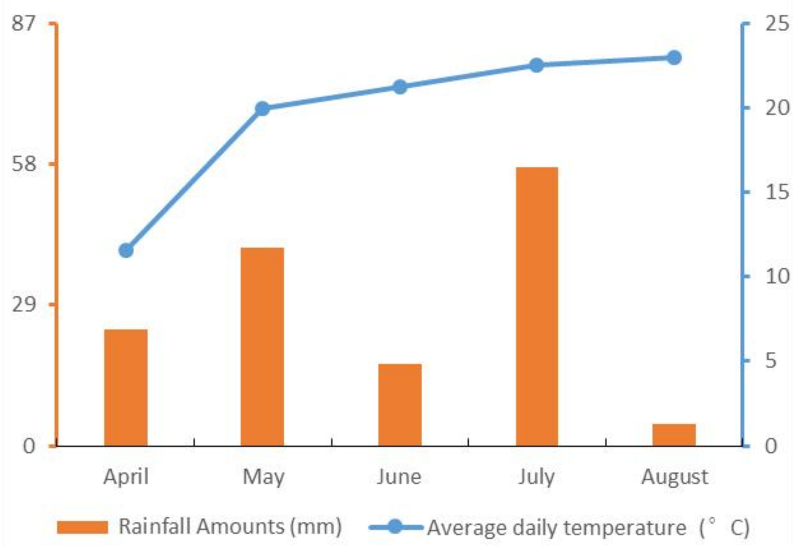


Figure 2.1. Diagram of temperatures and precipitation (2019 year)

During the vegetation period (April-August), the total active temperatures were 2,917.6°C and the precipitation was 143.3 mm. Thus, the northeastern Forest-Steppe of Ukraine is characterized by the following adverse climatic phenomena: droughts, dry winds, gusts of wind, ice, and more. The most dangerous phenomenon is drought. Great damage is caused by frost in spring – morning and evening drops in the air temperature are below 0°C at positive temperatures during the day. Therefore, the year 2019 was characterized by high temperatures and insufficient rainfall for all months; according to the hydrothermal coefficient of the growing season, the conditions are very arid (HTC = 0.49).

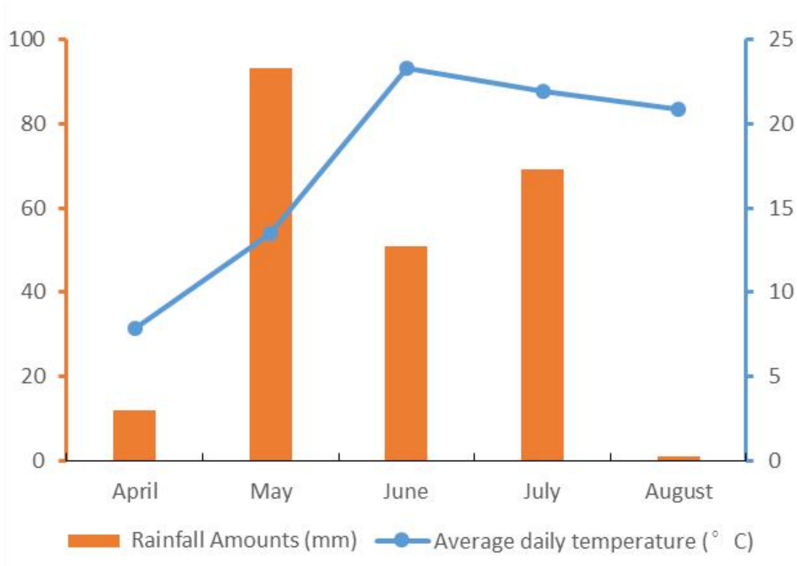


Figure 2.2. Diagram of temperatures and precipitation (2020 year)

During the vegetative growth period in 2020, the total precipitation in May, June, and July was 93.2 mm, 50.9 mm, and 69.1 mm, respectively, which were 48.0 mm, 5.7 mm, and 23.9 mm higher than the average precipitation (45.2 mm), respectively (Figure 2.2.). The lowest rainfall was observed in April and August, at 12 mm and 0.9 mm, respectively, below the average for the growing season. The air temperature in April and May was lower than the average long-term values by 9.6°C and 4.0°C. In all other months of the vegetation period, the temperature was higher than the average values (17.5 ° C). The total active temperature was 2,682.9°C and the precipitation was 226.1 mm. Analysis of weather conditions, and hydrothermal coefficient (HTC) revealed that the vegetative period of 2020 was a moderately dry year (HTC= 0.84).

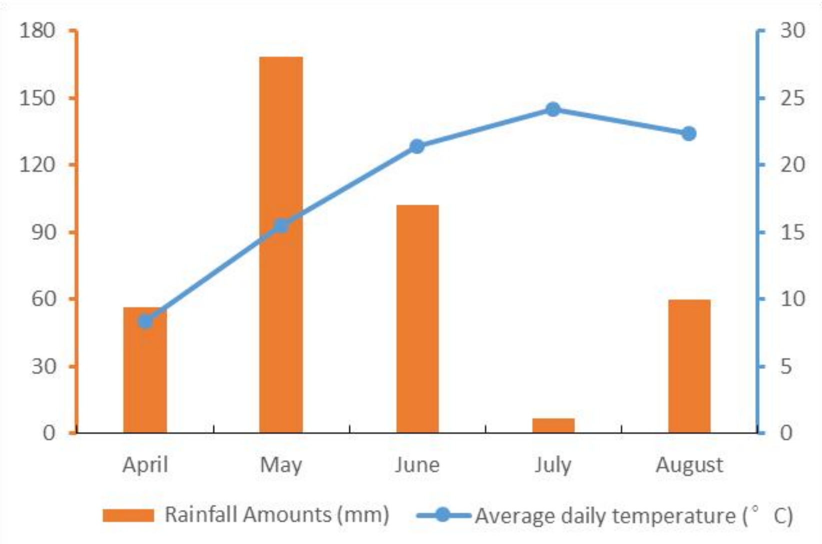


Figure 2.3. Diagram of temperatures and precipitation (2021 year)

According to the weather conditions of the growing season in 2021, the precipitation is mainly in May and June, which are 168.3 mm and 101.9 mm, respectively, higher than the average precipitation of 89.6 mm and 23.2 mm (Figure 2. 3.). The rainfall in April and August was 56.5 mm and 59.7 mm, with the lowest in July at 7.0 mm. During the vegetation period (April-August), the total active temperature was 2,816.9°C and the precipitation was 393.4 mm. Therefore, 2021 was described as normal moisture based on the hydrothermal coefficient (HTC= 1.39).

The hydroponic experiment on mustard was done as follows: the seedlings were grown in an artificial climate chamber at the Henan Institute of Science and Technology, Xinxiang, China. The temperature was set to 28/23°C and a light cycle of 14/10 h (day/night) with a relative humidity of 40 to 50%. All seedlings were hydroponically cultured with Hoagland's solution. The composition of the nutrient solution is 2.5 mmol·L^{-1} $Ca(NO_3)_2$, 1 mmol·L^{-1} $MgSO_4$, 0.5 mmol·L^{-1} $(NH_4)H_2PO_4$, 2.5 mmol•L^{-1} KCl, 2 mmol•L^{-1}NaCl, 2×10^{-4} mmol·L^{-1} $CuSO_4$, 1×10^{-3} mmol·L^{-1} $ZnSO_4$, 0.1mmol·L^{-1} EDTAFeNa, 2×10^{-2} mmol·L^{-1} H_3BO_3, 5×10^{-6} mmol·L^{-1} $(NH4)_6Mo_7O_{24}$, and 1×10^{-3}mmol·L^{-1} $MnSO_4$.

2.2. Object, scheme, and methods of the research

The object of the research was to evaluate the adaptation of mustard roots and shoots to salt and drought stress and the effects of growth regulators in an artificial climate chamber. The response of mustard depends on varietal features, growth tissue, growth regulators, and weather conditions.

The subject of the study is *Brassica Juncea* L. varieties (Prima and Felicia), methods of application, types of plant growth regulators, abiotic stress (salinity and drought), weather conditions, yield composition, and cultivation technique elements, as well as economic and energy efficiency of the use of plant growth regulators for the cultivation of *Brassica Juncea* L. in terms of the Left-Bank Forest-Steppe of Ukraine.

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 *Brassica Juncea* L. seedlings.

Scheme of experiment 1. The level of exposed salt stress *Brassica Juncea* L. seedlings (Hoagland's solutions): control (CK, water), low salt stress (50 mM NaCl), moderate salt stress (100 mM NaCl), and severe salt stress (200 mM NaCl).

Experiment parameters 1: la = 4; n=8.The *Brassica Juncea* L. seeds were surface sterilized and germinated for five days. Eight seedlings were transplanted into each plastic pot that was filled with 5 L Hoagland's solution. These seedlings were cultured in an artificial climate chamber at 28 ± 2℃, 14-h light/ 10-h night photoperiod, and 45% relative humidity. Hoagland's solutions that contained up to 50, 100, and 200 mM NaCl were regarded as subjecting the plants to low, moderate, and severe salt stress, accordingly. All the nutrient solutions were changed twice weekly to prevent fungal contamination. Morphological and physiological indices were measured on days 3, 7, and 10 after treatment (DAT).

Morphological parameters include total root length, total lateral root length, root surface area, main root length, lateral root number, leaf area, stem length, etc. Biomass is dry and fresh weight. Physiological indicators are chlorophyll content, enzyme activity (SOD, POD, CAT, APX), malondialdehyde, and protein content.

Experiment 2. Effects of drought and rehydration on the growth and physiological features of *Brassica Juncea* L. seedlings.

Scheme of experiment 2. The level of exposed drought stress and rehydration *Brassica Juncea* L. seedlings: control (CK-Hoagland's solution); mild drought (10 % PEG + Hoagland's solution); moderate stress (15 % PEG + Hoagland's solution); severe stress (20 % PEG + Hoagland's solution).

Experiment parameters 2: la = 4; n=5. The *Brassica Juncea* L**.** seedlings were grown in a plastic container (40×28×14 cm) with 5 L Hoagland's solution in an artificial climate chamber at the Henan Institute of Science and Technology, Xinxiang, China. The temperature was set to 28/23 °C and a light cycle of 14/10 h (day/night) with a relative humidity of 40 to 50 %. After 9 days, all the drought treatments were transferred into Hoagland's solution and cultured for 6 days after they were rehydrated to the CK treatment level. Samples were measured 3, 6, and 9 days after drought treatments and 6 days after rehydration. The roots and shoots of five plants in each treatment were measured manually. The morphological parameters include root length, stem length, and biomass. Physiological indicators: chlorophyll content and chlorophyll fluorescence, enzyme activity (SOD, POD, CAT, APX), malondialdehyde, and protein content.

Experiment 3. Effect of seed pre-treatment with plant growth compound regulators on *Brassica Juncea* L. seedling growth under drought stress.

Scheme of experiment 3. Factor A – varieties of *Brassica Juncea* L. (Prima, Felicia); factor B – plant growth regulators: control, Albit, Vermistim D, Antistress, Agrinos, Regoplan, Bioforge, Stimulate, and Fast Start.

Experiment parameters 3: la = 2, lb = 9; n=6, the same size, healthy *Brassica Juncea* L. seeds were selected and coated with eight kinds of PGRs to cultivate in germination bags. Each bag was added with 110 ml distilled water or 10% PEG-6000 (Sigma Chemicals Co., USA) solutions to simulate drought stress.

All experiments were conducted in the growth chamber (day/night temperature at 28/20 °C) with the provision of 14 h light (350 μmol /(m^2•s)), as well as 10 h dark. Each treatment contained six germinate bags, which were considered six replicates. The germination rate was counted after 2 days of culture, and the growth parameters of root and shoot of 15 seedlings were calculated after 6 days of treatment. The fresh weight of five plants was weighed for one repetition and divided into three replicates. Growth parameters: total root length, total lateral root length, root surface area, main root length, lateral root number, leaf area, stem length, etc.

Experiment 4. Varietal features of the formation of *Brassica Juncea* L. performance depend on growth regulators in the conditions of the forest-steppe of Ukraine.

Scheme of experiment 4. Factor A – varieties of *Brassica Juncea* L. (Prima, Felicia); factor B – methods of application of plant growth regulators: seed treatment ($BBCH_{00}$); leaf application ($BBCH_{14–18}$); seed treatment ($BBCH_{00}$) and leaf application ($BBCH_{14–18}$); factor C – plant growth regulators: control, Albit, Antistress, Agrinos, Bioforge, Fast Start, Regoplan, Stimulate, and Vermistim D.

Experiment parameters 4: la = 2, lb = 3; lc = 9; n=4, the area of the accounting plot is 15 m^2. The plots are placed by the method of organized repetitions. Agronomic traits: plant height, primary branches per plant, number of pods per plant, seed weight per plant, length of pods, seed yield per plot, the area of the leaf surface and chlorophyll content, and seed quality; oil and protein content. The main ingredients and rates of growth regulators are shown in Table

2.1. For seed dressing, the seeds were mixed with water and eight growth regulators, and then the treated seeds were dried at room temperature before sowing. Foliar sprays growth regulators are applied sequentially twice at recommended rates [1].

The plots are arranged by the method of organized repetitions in four tiers [2, 3]. Sowing was completed from 10 to 20 April and the crop was harvested around the middle of August of the investigated years. The site was cleared mechanically, ploughed, and disked before marking and demarcating the experimental plots. In the course of the research, mustard cultivation technologies were generally accepted for the research area, except for the elements studied. For three years, automatic seed drills (Klen 1,5 s, Ukraine) were used for sowing seeds at a standard density of 1.5 million plants ha^{-1}, 15 cm in the row spacing, and 15 to 20 mm in depth. At maturity, whole plots were harvested with a combine-harvester (Massey Ferguson, 307). The recommended nitrogen (N) fertilizer was used at the rate of 240 kg ha^{-1} in the form of urea (N, 46%). Half of the N fertilizer was applied at sowing and the remaining half was applied before the tassel stage. A total of 150 kg phosphorus (P_2O_5) ha^{-1} as calcium superphosphate (P_2O_5 12%) and 150 kg potassium (K_2O) ha^{-1} as potassium sulfate (K_2O 45%) were applied during seedbed preparation. The crop was solely dependent on natural precipitation during growing seasons. All other field management and cultural practices such as weeding, hoeing, irrigation, and pesticide application were implemented according to the local demand and production technology [4-5].

Table 2.1

Nutrient compositions of regulator application

Regulators	Application rate	Composition (main)
Albit	30 ml/t	Poly-beta-hydroxamic acid-6.2 g / kg; potassium nitric acid-91.2 g / kg; potassium phosphoric acid (ortho) -91.1 g / kg; carbamide 181.5 g / kg; magnesium sulfate-29.8 g / kg
Antistress	0.68 l/t	Endophyte L1-11.77 g / kg; sodium humate-1.1 g / kg; sodium humate-2.2 g / kg; glycerin-34.68 g / kg; polyethylene oxide 1500-190.59 g / kg; Potassium dihydrophosphate-588.24 g / kg; dimethyl sulfoxide-20.03 g / kg
Agrinos	0.15 l/t	Free amino acids: L-tryptophan, L-aspartic acid, L-glutamic acid, L-serine, L-histidine, L-glycine, L-threonine, L-alanine, L-proline, L-tyrosine, L-agrinine, L -one, L-methonine, L-isoleucine, L-leucine, L-phenylalanine, L-lysine-10%; Chitin; Chitosan, Glucosamine-6%
Bioforge	1.5–2.5 l/t	Diformyl urea (The product of the reaction of two natural substances: urea and formic acid) N-2%; K_2O%
Fast Start	2.0–2.5 l/t	Zn-8%; S-3%; Free Amino Acids-1.6%; Organic acids-0.5%; Fulvic acids-0.1%
Regoplan	0.25 l/t	Growth regulator "Joy", containing active substances of the plant growth regulator Emistim C-0.3 g / L; potassium salt of alpha-naphthylacetic acid-1.0 mg / L; complex of biogenic microelements B^{3+}, Cu^{2+}, Mn^{2+}, Zn^{2+}, Co^{2+}, Fe^{2+}, J-, Mo^{6+} - total concentration 1.75 g / L; Medicinal product "Diamond Green" - 0.01 g /L; Avertsectin C - a natural complex consisting of 8 individual avermectins - 0.01 g / L
Stimulate	0.5–1.5 l/t	Cytokinin (kinetin) -0.009%; Auxin-0.005%; Gibberellic acid-0.005%
Vermistim D	6-8 l/t	Phytohormones, humic and fulvic acids, vitamins, amino acids, microorganisms: lactic acid bacteria Lactobacillus plantarum-not less than 1.0 x 10^5, Lactobacillus casei-not less than 1.0 x10^4, phototrophic bacteria Rhodopseudomonas palustris-not less than 1.0 x10^4; yeast; Saccharomyces cerevisiae not less than 1,0 x 10^4

Research methods. Field experiment: data on the following agronomic traits were collected from ten randomly selected plants in each plot at flowering and maturity of mustard and the average was considered per plant basis.

Plant height: the height of plants was measured in centimeters from the ground to the highest point of the main stem when vegetative growth ceased. Primary branches per plant: the lateral branches growing from the main stem were considered primary branches, and the average number of primary branches of all plants was calculated. The number of pods per plant: the average number of pods for ten plants. Seed weight per plant: the average seed weight of ten plants. Length of pods (cm): the average length of 25 pods in each plot. Seed yield per plot: seed yield capacity per plot was measured in grams after the moisture of the seed is adjusted to 7 %. The area of the leaf surface was determined by the method of “carving”. The content of chlorophyll in the leaves was determined by preparing the solution in an alcohol extract with further determination by a spectrophotometer ULAB 102 [6]. The oil content of the seeds was determined on the SupNir 2750 infrared analyzer [7, 8].

Morphological and physiological indexes of hydroponic seedlings.

The leaves and roots of five plants from each treatment were separated. An Epson Perfection V800 Photo scanner (Epson America, lnc., Long Beach, CA, USA) was used to scan the roots and shoots of seedlings, and WinRHIZO 2007 (Regent Instruments. Inc., Quebec, Canada) was used to analyze the scanning results, including the total root length, total surface area, and the projected area of leaves among others. The number of first-order lateral roots was counted manually.

The fresh weights were directly determined, and the plants were dried at 80 °C for 48 h to determine their dry weight.

The first-order lateral root density (cm^{-1}) $=\frac{\text{Number of first-order lateral roots}}{\text{Lateral root zone}}$.

Root: shoot ratio (dry weight) (%)$=\frac{\text{Root dry weight}}{\text{Shoot dry weight}} \times 100$.

Dry weight/Fresh weight ratio of the shoot (root) (%) $=\frac{\text{Shoot (root) dry weight}}{\text{Shoot (root) fresh weight}} \times 100$.

Chlorophyll concentration: the relative chlorophyll content of five expanded leaves from each treatment was measured using a Dualex Scientific (Force-A, Orsay, France).

Chlorophyll fluorescence: a portable fluorometer (PEA, Hansatech Instruments Ltd, King's Lynn, UK) was used to determine the maximal photochemical efficiency (F_v/F_m) and performance index (PI_{ABS}). Five leaves were selected from each treatment as replicates, and all the treated leaves were placed in the dark for half an hour before measurement.

Enzyme assays and protein determination: to avoid potential differences in the content of antioxidant enzymes in different plant positions, all the leaves were excised from the third or fourth fully expanded leaves at the bottom of the plant, and the roots were collected from the taproot tips. One-half gram each of lyophilized leaves and roots were homogenized with 5 mL of 100 mM potassium phosphate buffer (pH 7.5) that contained 1 mM EDTA and 1 % polyvinylpyrrolidone (PVPP). The homogenate was centrifuged at 12,000 g for 20 min at 4 ℃, and the crude extract was collected to assay the protein, enzyme activities, and lipid peroxidation.

The content of soluble protein was measured using Coomassie brilliant blue G250 staining [9]. A total of 30 μl supernatant and 170 μl of Coomassie brilliant blue G250 were mixed, and the absorbance was read at 595 nm using bovine serum albumin as a standard. The activity of superoxide dismutase (SOD) was assayed as described by Beauchamp [10] at 560 nm. The activity of peroxidase (POD) was determined using guaiacol as the substrate [11]. The absorbance of the mixture was determined at 470 nm within 3 min. The activity of catalase (CAT) was determined as described by Neto [12] with modifications. The activity of CAT was calculated based on the rate of disappearance of H_2O_2 in 240 nm of ascorbate. The activity of ascorbate peroxidase (APX) was determined as described by Nakano and Asada[13], and the absorbance of the mixture was measured at 290 nm.

Lipid peroxidation (MDA): the content of MDA was determined using TBA [14]. 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.

Statistical analysis was conducted with SPSS 22 (IBM, Armonk, NY, USA). Different lowercase letters differ significantly based on Duncan’s multiple range test, and $P<0.05$ was used as the significance level. Pearson’s correlation coefficient (r) was used to test the significant correlation between physiological features [15].

The economic evaluation of the studied factors was carried out according to the method of determining the economic efficiency in agricultural production at the prices in Ukraine as of October 2021. The costs per 1 ha, the cost of 1 ton of seeds, the net profit, and the level of profitability were determined [16]. The energy assessment was carried out according to the methods of A. K. Medvedovsky and P. I. Ivanenko, and others [17].

Conclusions to section 2

1. The research concluded that in recent years there has been an insufficient amount of precipitation and increased air temperature, drought, and heat. Therefore, there is an increase in the influence of abiotic stress factors during the cultivation of *Brassica Juncea* L. under the field conditions of the Left-Bank Forest-Steppe of Ukraine.

2. The research program envisages a comprehensive approach to the tasks, in particular, conducting laboratory research in a controlled environment (climatic chamber), as well as a sufficient number of records and observations in the field. The conducted four experiments will enable us to deeply and comprehensively reveal the essence of the action of the studied factors. The obtained results will optimize the technology of growing brown mustard (*Brassica Juncea* L.) in terms of the Left-Bank Forest-Steppe of Ukraine.

References to section 2

1. State register of pesticides and agrochemicals approved for use in Ukraine in 2019. URL: https://mepr.gov.ua/content/derzhavniy-reestr-pesticidiv-i-agrohimikativ-dozvolenih-do-vikoristannya-v-ukraini (Last accessed: 02.08.2022).

2. Metodyka derzhavnogo sortovyprobuvannja sil'skogospodarskyh kultur / red. V. V. Volkodav; Derzh. Komisija Ukrainy po vyprobuvannju ta ohoroni sortiv roslyn. Kyiv : Alefa, 2000. Vyp. 1. 100 p.

3. Osoblyvosti provedennya doslidzhen z khrestotsvitymy oliynymy kulturamy (Peculiarities of conducting research with cruciferous oil crops) / Sayko V. F., Kaminskyy V. F., Vyshnivskyy P. S. ta in.; za red. P. S. Vyshnivskoho. Kyiv. 2011. 76 p. (in Ukrainian)

4. Naukovo obgruntovana systema vedennya silskoho hospodarstva Sumskoyi oblasti (Scientifically substantiated agricultural management system of the Sumy region). Sumy: Kozatskyy val, 2004. 662 p. (in Ukrainian)

5. Naukovi osnovy ahropromyslovoho vyrobnytstva v zoni Lisostepu Ukrayiny (Scientific basis of agro-industrial production in the forest-steppe zone of Ukrain) / [V. M. Zubets ta in.]; za red. V. M. Zubtsya. K. : Lohos, 2004. 776 p. (in Ukrainian)

6. Ermakov A., Arasimovich V., Smirnova-Ikonnikova M., Yarosh N., Lukovnikova G. Methods for the biochemical analysis of plants. *Methods for the biochemical analysis of plants.* 1972. (Ed. 2)

7. Hrytsayenko Z., Hrytsayenko A., Karpenko V. *Methods of*

biological and agronomic research of plants and soils. Kyiv: ZAT “Nichlava”. 2003. 320 p.

8. Nasinnya silskohospodarskykh kultur. Metody vyznachennya yakosti (Seeds of agricultural crops. Quality determination methods): DSTU 4138–2002 [Chynnyy vid 01.01.2004]. Kyiv : Derzhstandart Ukrayiny, 2003. 173 p. (National Standard of Ukraine). (in Ukrainian)

9. Bradford M. M. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical biochemistry.* 1976. 72. P. 248-254.

10. Beauchamp C. Superoxide dismutase: Improved assays and an assay applicable to acrylamide gels. *Analytical biochemistry.* 1971. *44*. P. 276-287.

11. Kochba J., Lavee S., Spiegel-Roy P. Differences in peroxidase activity and isoenzymes in embryogenic ane non-embryogenic “shamouti” orange ovular callus lines. *Plant & Cell Physiology.* 1977. 18(2). P. 463-467

12. Neto A., Prisco J. T., Enéas-Filho J., Abreu C. B., Gomes-Filho E. Effect of salt stress on antioxidative enzymes and lipid peroxidation in leaves and roots of salt-tolerant and salt-sensitive maize genotypes. *Environmental & Experimental Botany*. 2006. 56. P. 87-94.

13. Nakano Y., Asada K. Hydrogen peroxide is scavenged by ascorbate-specific peroxidase in spinach chloroplasts. *Plant Cell Physiol.* 1981. 22. P. 867-880.

14. Madhava Rao K.V., Sresty TV. Antioxidative parameters in the seedlings of pigeonpea (*Cajanus Cajan* (L.) *Millspaugh*) in response to Zn and Ni stresses. *Plant Sci.* 2000. 157. P. 113-128.

15. Ermantraut E. R., Prysjazhnjuk O. I., Shevchenko I. L. *Statystychnyj analiz agronomichnyh doslidnyh danyh v paketi Statistica – 6.* Metodychni vkazivky. Kyiv, 2007. 55 p.

16. Kovalchuk M. I. *Ekonomichnyy analiz u silskomu hospodarstvi* (Economic analysis in agriculture): navch.-metod. posibnyk dlya samost. vyvch. dysts. Kyiv: KNEU, 2002. 282 p. (in Ukrainian)

17. Medvedovskyy O. K., Ivanenko P. I. *Enerhetychnyy analiz intensyvnykh tekhnolohiy v silskohospodarskomu vyrobnytstvi* (Energy analysis of intensive technologies in agricultural production). Kyiv: Urozhay, 1988. 208 p. (in Ukrainian)

SECTION 3

MORPHOLOGICAL AND PHYSIOLOGICAL VARIETAL RESPONSES OF MUSTARD (*BRASSICA JUNCEA* L.) TO STRESS AND EFFECTS OF PLANT GROWTH REGULATORS ON SEEDLINGS

Salt and drought are frequent abiotic stresses during plant growth and development. They restrict plant growth in many ways. Salt stress reduces the plant height, leaf area, and relative water content and affects the thickness of the whole leaf and biomass [1, 2]. Plants have established a sophisticated mechanism to adapt to stress conditions. However, differences in crop responses to stress vary with tissue, environment, and variety.

3.1. Effects of salt stress on the growth and physiological features of mustard (*Brassica Juncea* L.) seedlings

Salinity is an increasingly serious global agricultural issue, which inhibits the growth of plants and reduces the performance of crops [3, 4]. Twenty percent of the 230 million hectares of irrigated croplands are affected by salts, and this proportion increases dramatically each year owing to unsuitable irrigation practices [5]. It is estimated that 50 % of the world's arable land will be salinized by 2050 [6]. Therefore, it is urgent to improve the tolerance of crops to salt. One way to help to ensure higher agricultural production is to explore novel salt-tolerant germplasms.

Salt stress increases the concentration of sodium and chloride ions, thus, leading to nutritional imbalance and even plant death [7]. Salt stress reduces the plant height, leaf area, and relative water content, as well as affects the thickness of the whole leaf and biomass [1, 2]. Salinity accelerates the degradation of chloroplasts and then inhibits the synthesis of chlorophyll [8]. Leaf chlorophyll is involved in the capture, absorption, and transfer of light energy in photosynthesis, and the decrease in the content of chlorophyll correlates negatively with the plant yield capacity [9].

Plant roots are closely associated with nutrients and water uptake and are the first contact tissue that responds to stress signals. Multiple Figures determine the root system architecture (RSA), particularly, salinity [10, 11]. Plants have established a sophisticated mechanism to adapt to salt stress conditions, such as regulating the plant RSA [11]. A study in *Arabidopsisthaliana* reported that salt stress markedly promotes the elongation of lateral roots [12]. In *Brassica napus*, stress stimulates changes in root morphology, including the growth and development of root hairs on lateral roots, which leads to an additional increase in the root surface area compared with plants that are not stressed. To some extent, the increase in root surface area indicates that plants can absorb more water and nutrients from the surrounding rhizosphere, and this change induced by stress in root morphology serves as an adaptation strategy [13]. The natural variation of RSA enables its use as a modern breeding strategy to improve the efficiency of uptake of water and nutrients, and further increase crop yields [14, 15].

ROS accumulates under stress conditions. To keep the ROS in balance and not harm the plant, the plant activates its antioxidant system to eliminate the deleterious ROS [16]. It has been documented that the antioxidant enzyme activity was positively related to salt resistance in rice (*Oryzae sativa*) [17], chickpea (*Cicer arietinum*) [18], and maize *(Zea may)* [19]. ROS are necessary for cellular proliferation and differentiation, even though excessive amounts of ROS inhibit the synthesis of proteins and chlorophyll, resulting in wilting or death under severe stress [20]. A recent study in *Brassica napus* revealed that in addition to hormones, ROS can also regulate the growth and development of roots [21].

In recent years, abiotic stresses (limited moisture supply, high transpiration, and continuous high temperature) have intensified the salinization of soil and further inhibited the growth of mustard in Ukraine. Most previous studies on *Brassica* have focused on assessing the differences in morphology, physiology, and gene expression between different varieties in response to salt stress [22-24], while few studies have been conducted on the morphological and physiological mechanisms of the adaptation of different tissues of mustard when subjected to salt stress. Therefore, our goal was to investigate the effects of antioxidant enzymes and mechanisms of morphological adaptation in the roots and shoots of mustard seedlings subjected to salinity. Different adaptations of tissues contribute to an understanding of the mechanism of tolerance to salinity and will provide a better understanding for future cultivation programs to better enable plants to respond to stress.

The phenotype of mustard. NaCl induced a prominent reduction in the traits of the shoots of mustard as shown in Table 3.1. The reduction in leaf area was greater when subjected to severe salt stress and reached 33.2 %, 71.1 %, and 92.8 % on 3, 7, and 10 DAT, accordingly. A low concentration of salt slightly increased the leaf area compared with the control by 7.2 % only on 3 DAT. Salt stress reduced the stem length compared with plants that were not subjected to salt stress, and the stem length was significantly reduced by 22.4 % and 50.4 % with moderate and severe salt stress on 10 DAT, accordingly.

Salt stress also affected the RSA of seedlings (Table 3.2, Figure 3.1). The plants were stressed for 3 days, and severe salt stress reduced the root growth and development. However, the low concentration of salt increased the growth of mustard. Compared with plants that were not subjected to salt stress, the total root length, number, and density of the first-order lateral roots that were treated with 50 mM NaCl markedly increased by 21.2 %, 36.3 %, and 23.7 % on 3 DAT, accordingly. Other traits of RSA also increased, but they did not differ significantly. Despite the dramatic inhibition of the growth of seedling roots after 10 days of salt exposure, the number and density of first-order lateral roots following treatment with 200 mM NaCl were higher than those under normal conditions by 28.7 % and 58.5 %, accordingly. These results clearly showed that salt stress modulates RSA in mustard.

Fresh and dry weights of mustard seedlings. The fresh and dry weights of plants gradually decreased for both shoots and roots as the treatment and level of stress were prolonged (Table 3. 1). These data showed that the dry weights of roots decreased by 24.3 %, 43.5 %, and 80.3 %, and the dry weights of shoots decreased by 12.1 %, 38.7 %, and 84.1 % when the plants were exposed to three levels of salt for 10 days. We observed the same results on the fresh weight of the roots and shoots, which indicated that the biomass gradually decreased for both shoots and roots when treated with the three salt concentrations. However, during the early stages of salt stress, low salt stress promoted the growth of seedlings, and the fresh and dry weights of the shoots increased by 10.1 % and 8.7 %, and those of the roots by 33.3 % and 23.1 %, accordingly. Therefore, the response of plants to salt stress depends on concentration and time. The dry-fresh ratio of shoots subjected to severe salt stress was higher than those subjected to low and moderate stress. Moreover, the root-shoot ratio of severe salt stress significantly increased by 26.1 % compared with the control during the later stages of salt treatment. Moreover, the root-shoot ratio did not change when subjected to low and moderate levels of stress.

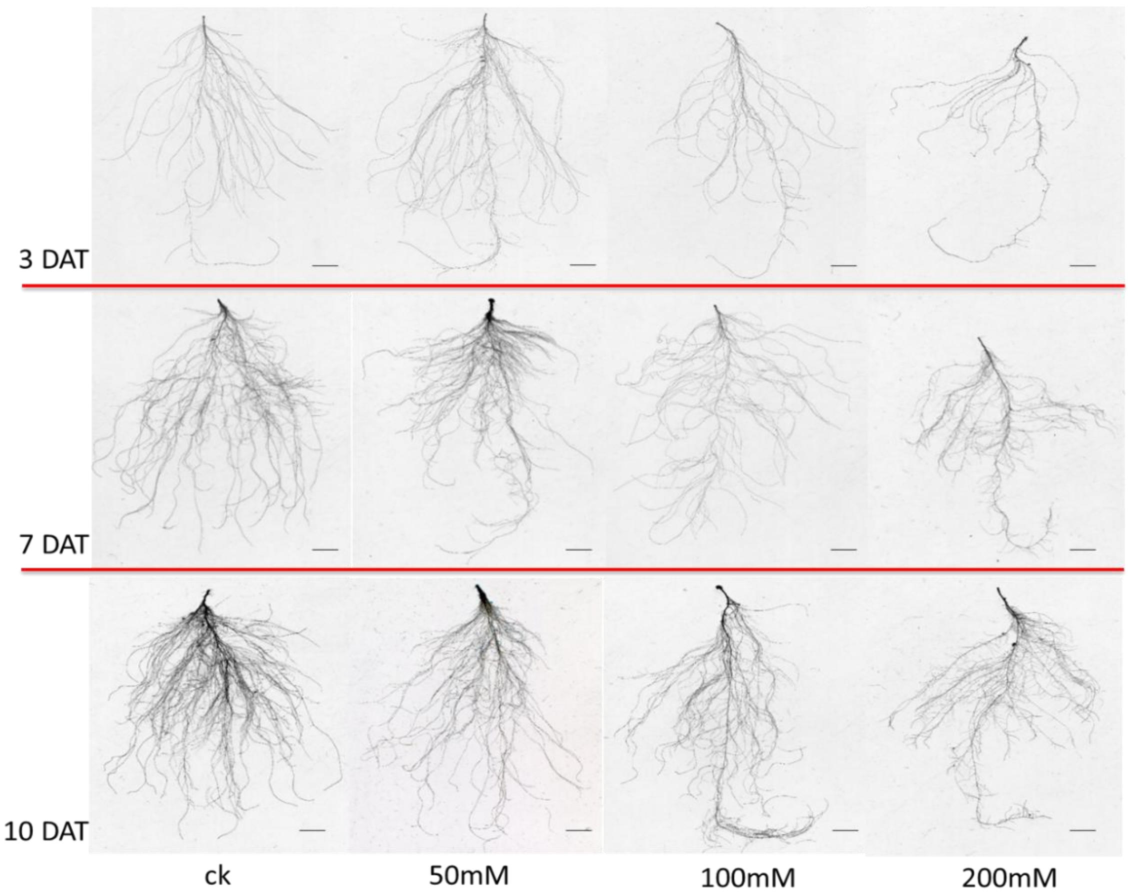


Figure 3.1. Effects of salt stress on the RSA of mustard seedlings.

DAT: days after treatment. RSA: root system architecture.

Table 3.1

Effects of NaCl treatment on the biomass and growth of *Brassica Juncea* L. seedlings

DATA (d)	NaCl	Shoot					Root			Root:shoot ratio(DW)(%)
		Leaf area(cm²)	Stem length(cm)	Fresh weight (mg)	Dry weight (mg)	DW/FW ratio(%)	Fresh weight (mg)	Dry weight(mg)	DW/FW ratio(%)	
	Control	24.68±7.56a	8.97±1.18a	907.80±275.79ab	68.67±6.43a	8.33±0.02a	303.40±89.54a	17.33±1.53b	6.8±0.04a	25.47±0.04ab
	Low salt stress	26.46±5.21a	7.16±1.02b	999.80±176.04a	74.67±6.51a	7.7±0.02a	404.40±106.06a	21.33±2.08a	5.38±0.02a	28.77±0.04a
3	Moderate salt stress	16.88±2.71b	6.88±0.64b	692.80±144.37b	45.40±2.62b	6.96±0.01a	297.60±86.14a	13.63±1.82c	5.01±0.01a	29.94±0.02a
	Severe salt stress	8.97±1.26c	7.12±1.67b	404.80±67.32c	37.13±2.42b	10.11±0.03a	107.20±32.43b	7.20±0.60d	7.03±0.03a	19.43±0.02b
	Control	64.54±14.73a	13.10±1.54a	2633.67±761.02a	287.67±19.86a	11.63±0.04a	815.67±187.01a	58.17±2.47a	7.38±0.02ab	20.24±0.01c
7	Low salt stress	54.91±7.88a	8.06±1.25b	2571±310.60a	250.33±12.50b	10.1±0.01a	761.50±137.34a	48.33±2.52b	6.73±0.01b	19.31±0c
	Moderate salt stress	23.80±1.8b	8.02±1.29b	1405.50±182.32b	137.83±19.36c	10.17±0.02a	463±57.01b	42.33±3.06c	10.32±0.02a	33.91±0.01a
	Severe salt stress	10.43±1.86c	7.81±1.05b	534.80±53.77c	55.07±4.50d	10.24±0a	194±35.93c	13.83±0.65d	7.08±0.01ab	25.21±0.02b
	Control	105.16±37.54a	14.20±1.88a	3977±1620.73a	367.67±15.95a	11.75±0.02a	1524.75±490.47a	85±10.54a	6.6±0a	23.08±0.02b
	Low salt stress	70.29±22.92b	14.89±2.75a	4069±1845.56a	323±23.64b	7.09±0.03b	1061.80±271.65b	64.33±6.11b	5.83±0.01a	20.02±0.03b
10	Moderate salt stress	30.36±5.9c	11.02±1.51b	2422.80±397.70a	225.70±7.88c	10.06±0.01ab	834.20±197.39b	48.07±1.66c	5.72±0.01a	21.3±0b
	Severe salt stress	7.57±2.57c	7.04±1.49c	574.20±141.92b	58.33±4.73d	12.35±0.02a	283.60±30.55c	16.67±0.78d	5.85±0a	28.71±0.03a

Note: Means ± SD, n = 5. Values in a column followed by different lowercase letters are significantly different at $P<0.05$ according to Duncan′s multiple range test.CK: control; DW: dry weight; FW: fresh weight. DAT: days after treatment.

Table 3.2

Effects of NaCl treatment on the root system architecture of *Brassica Juncea* L. seedlings

DATA (d)	NaCl	Total root length (cm)	Total root surface area (cm^2)	Total root diameter (mm)	Total root volume (cm^3)	Number of first-order lateral roots	Length of primary root (cm)	First-order lateral root district(cm)	First-orderlateral root density (cm^{-1})	Total of lateral root length (cm)
	Control	577.41±101.01b	40.78±11.94a	0.22±0.01a	0.23±0.08a	63.4±6.77b	9.96±1.84a	7.82±1.66a	8.34±1.65b	567.45±148.19a
3	Low salt stress	699.69±87.43a	48.17±7.09a	0.22±0.01a	0.26±0.06a	86.4±11.72a	10.54±2.37a	8.54±1.62a	10.32±1.78a	689.15±186.5a
	Moderate salt stress	529.44±95.07b	37.17±10.28a	0.22±0.01a	0.21±0.06a	68.8±5.72b	9.62±0.91a	7.11±0.59a	9.71±0.86ab	519.86±153.14a
	Severe salt stress	249.69±71.6c	18.02±5.53b	0.23±0.02a	0.1±0.04b	39.2±6.8c	10.19±0.71a	7.98±0.93a	5.1±0.51c	240.96±74.1b
	Control	1267.04±167.82a	101.34±18.44a	0.25±0.01a	0.64±0.15a	82.25±3.2b	15.54±1.64a	12.65±2.19a	6.53±0.94b	1269.06±226.89a
7	Low salt stress	1161.26±203.6a	93.53±21.5a	0.26±0.02a	0.6±0.11a	94.5±14.53ab	10.15±1.72b	8.39±1.78b	11.47±2.02a	1179.81±377.33a
	Moderate salt stress	933.61±102.8b	64.95±10.93b	0.22±0.01b	0.36±0.08b	101.5±7.59a	10.62±2.16b	8.24±2.17b	12.76±2.4a	934.27±115.9a
	Severe salt stress	563.48±67.6c	37.44±5.02c	0.21±0.01b	0.2±0.03c	92.25±5.19ab	9.37±0.89b	8.49±0.81b	11.1±0.62a	554.11±66.92b
	Control	1826.31±194.1a	172.35±39.53a	0.3±0.03a	1.31±0.43a	79.25±5.74c	11.9±3.81a	9.8±1.45a	7.93±0.76b	1826.11±373.31a
10	Low salt stress	1601.87±291.18ab	117.2±45.26b	0.26±0.03b	0.74±0.22b	84.25±9.43bc	8.89±1.21b	7.35±1.18b	11.53±2.77ab	1472.98±716.97ab
	Moderate salt stress	1485.51±135.7b	106.3±22.09b	0.23±0.01c	0.61±0.13bc	97.25±7.18ab	8.87±1.14b	7.84±1.15b	12.52±1.4a	1451.47±342.57ab
	Severe salt stress	808.99±105.8c	53.09±7.21c	0.21±0.01c	0.28±0.05c	102±15.98a	9.26±0.93ab	8.48±1.18ab	12.57±3.79a	799.73±105.22b

Note: Means ±SD, n = 5. Values in a column followed by different lowercase letters are significantly different at $P<0.05$ according to Duncan′s multiple range test.DAT: days after treatment.

Chlorophyll content. All the salt treatments resulted in a decrease in the content of chlorophyll, which positively correlated with the concentration of salt. Besides, the chlorophyll content of moderate and severe salt stress decreased with the extension of the time of stress, from 10.8% and 12.3% on 3 DAT to 15.6% and 29.8% on 10 DAT, accordingly. Low salt stress did not significantly affect the content of chlorophyll (Figure 3.2).

Chlorophyll fluorescence. The maximal photochemistry of PSII (F_v/F_m) and performance index (PI_{ABS}) serve as important parameters of chlorophyll fluorescence. Mustard leaves grown with and without stress exhibited an insignificant change in the F_v/F_m, and the value was distributed at approximately 0.8 (Figure 3.3 A). However, the PI_{ABS} decreased significantly as the concentration of NaCl increased compared with that of the control plants (Figure 3.3B). Moreover, PI_{ABS} reached its minimum under severe stress.

MDA content. The content of MDA in the leaves and roots indicated the degree of peroxidation of plants (Figure 3.4). The concentration of MDA in the roots increased with the duration of low and moderate stress compared with the control plant, and the accumulation of MDA reached its highest levels during the later stage of stress. Notably, the content of MDA decreased when the plants were subjected to severe salt stress, and the lowest value appeared on day 10 of this stress. The content of MDA in salt-stressed leaves increased on 3 DAT, but the difference was not significant. The content of MDA decreased or was not affected at low and moderate salt stress on 7 and 10 DAT, while the content of MDA was higher than that of the control when the plants were subjected to severe salt stress and reached their maximum value of 199.5% on 10 DAT.

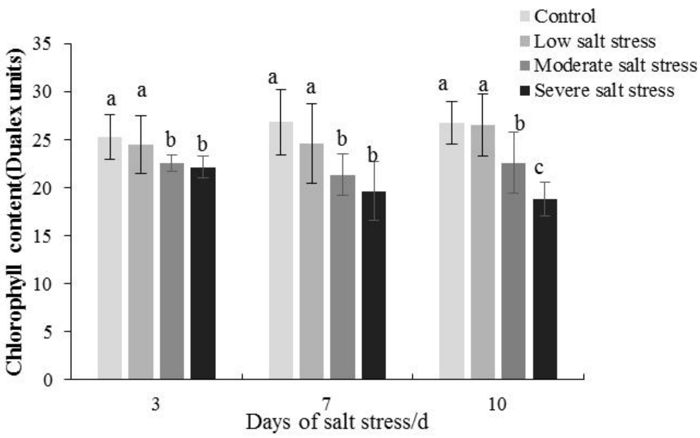


Figure 3.2. Changes in chlorophyll content under salt stress (0, 50, 100, and 200 mM NaCl for 3, 7, and 10 d). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 5.

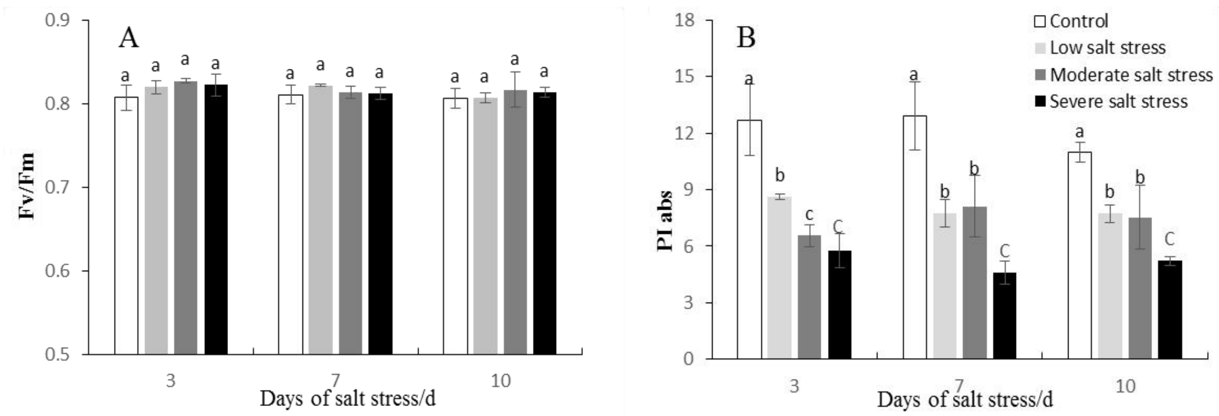


Figure 3.3. Changes in the parameters of chlorophyll fluorescence of seedlings under salt stress (0, 50, 100, and 200 mM NaCl for 3, 7, and 10 d), A: Fv/Fm; B: PI_{ABS}. Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 5.

Enzyme activity. The change in the activities of antioxidant enzymes (SOD, POX, APX, and CAT) are shown in Figure 3.5. The activity of SOD induced by salt stress differed significantly in the roots and leaves of mustard seedlings. The activity of SOD in all of the treatments in roots was higher than that of the plants that were not subjected to salt stress.

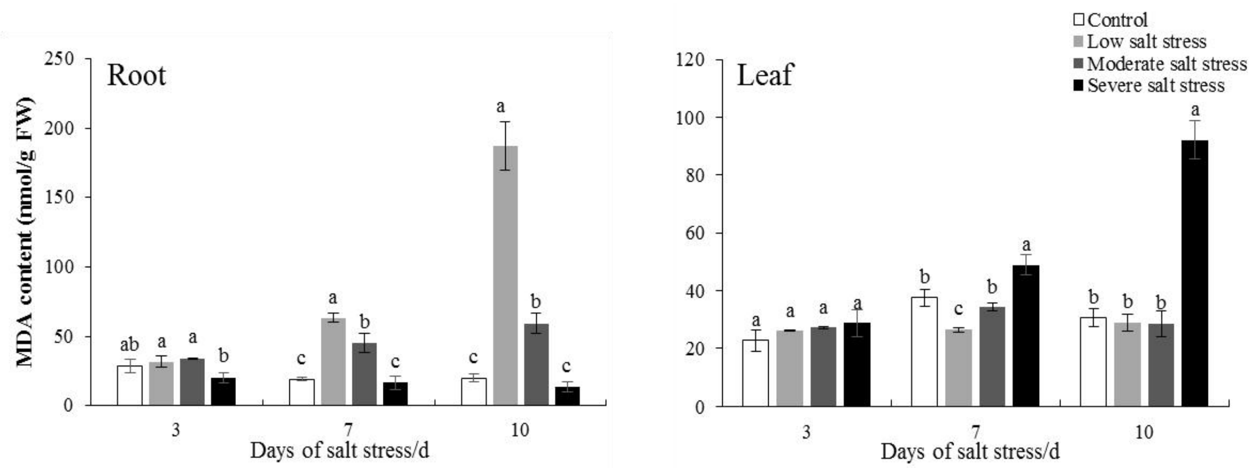


Figure 3.4. Changes in the content of MDA of seedlings under salt stress (0, 50, 100, and 200 mM NaCl for 3, 7, and 10 d). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 3.

The specific activity of SOD dramatically increased with the levels of salt by 61.4%, 61.4%, and 114.3%, and reached its maximum value on 3 DAT. With the extension of time of stress, the activities of SOD in the roots subjected to low and severe salt stress were 33.0% and 34.4% greater on 10 DAT, accordingly. Among the groups of leaves treated with NaCl, the activity of SOD activity was 23.9%, 23.1%, and 58.1% on 7 DAT than in the controls, while it remained almost unchanged on both 3 and 10 DAT. The other treatments decreased by 18.4% with low salt stress on 3 DAT and by 40.0% at severe salt stress on 10 DAT, accordingly.

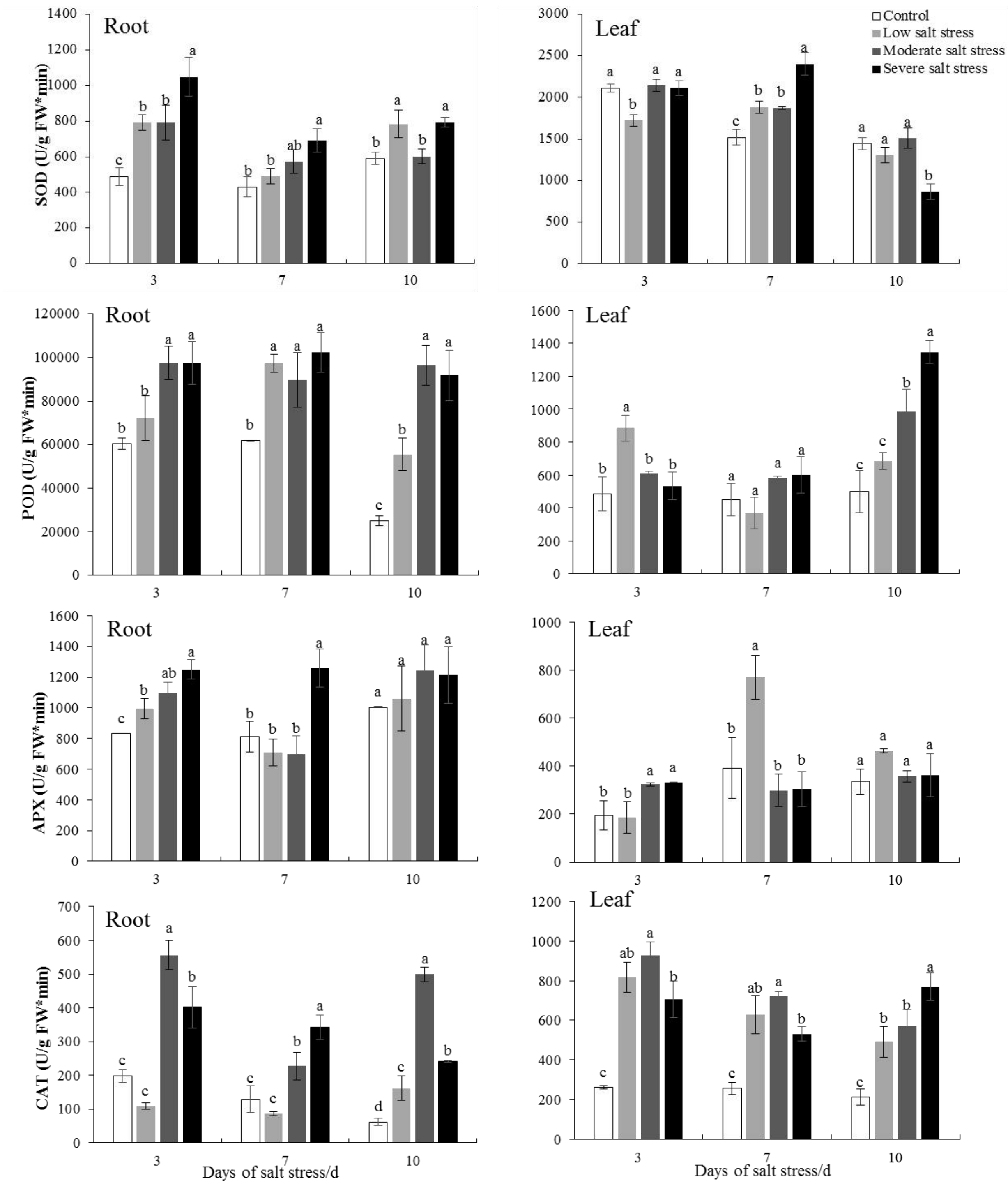


Figure 3.5. Changes in the activities of SOD, POD, APX, and CAT in the leaves and roots of seedlings (0, 50, 100, and 200 mM NaCl for 3, 7, and 10 d). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 3.

The activity of POD in stressed leaves and roots differed significantly during the experimental period. Salt induced a rapid increase in the activity of POD in the roots and maintained a high level throughout the treatment period. The activity of POD of the root treatment group increased by 122.5%, 286.1%, and 267.7% at 10 DAT compared with the control treatment group, accordingly. The activity of POD in leaves increased by 36.9%, 97.0%, and 169.5% with the NaCl treatments after 10 days, accordingly, and there was no significant difference compared with the control at both 3 and 7 DAT, except for the group treated with low salt stress on 3 DAT. Besides, the activity of POD in roots increased markedly compared with that in the leaves.

The levels of root APX activity increased with the increments of NaCl on 3 DAT by 19.4%, 31.8%, and 50.2%, accordingly, and the maximum activity increased by 54.7% with severe salt stress on 7 DAT. The APX activity in the roots changed slightly on 10 DAT but did not differ significantly compared with the control plants. A similar result was observed for the activity of APX in leaves. The concentrations of salt (100 and 200 mM NaCl) rapidly induced the activity of APX on 3 DAT by 67.1% and 71.7%, accordingly. The activity of APX did not differ significantly under all the treatments on both 7 and 10 DAT, except for a rapid increase in the treatment of a low concentration on 7 DAT.

Moderate and severe salt stress rapidly increased the activity of CAT in the roots during all the treatment days and peaked by 713.2% and 293.1% on 10 DAT, accordingly. However, the activity of CAT in the roots of low salt treatment did not increase significantly until 10 DAT. NaCl induced a surge of increase in the activity of CAT in leaves compared with the treatment without salt stress during the experimental period. The activity of CAT of the leaves was the highest at 212.4 % and 255.2 % on 3 DAT following treatment with low and moderate salt, accordingly. Salt-induced CAT maintained a high level in both the roots and leaves throughout the stress period.

Soluble protein: The content of protein in all the salt treatments differed significantly (Figure 3.6).

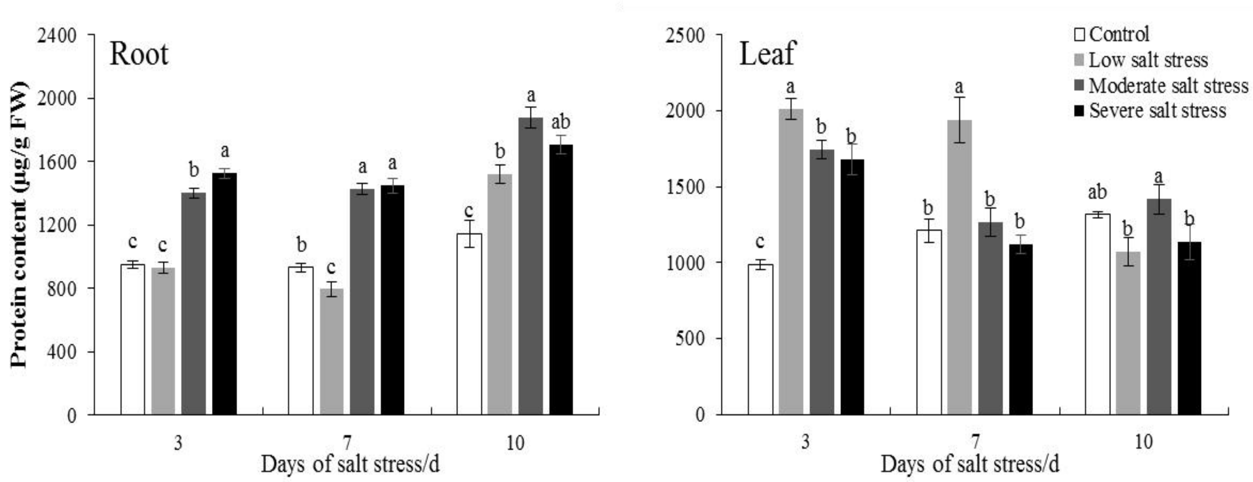


Figure 3.6. Changes in the content of seedling protein subjected to salt stress (0, 50, 100, and 200 mM NaCl for 3, 7, and 10 d). Means followed by different lowercase letters differ significantly according to Duncan's multiple range test, P<0.05, n = 3.

Except for low salt stress, in which the content of protein decreased or did not change significantly on 3 and 7 DAT, the treatment with moderate and severe salt stress caused an increase in the concentration of protein in the roots. Moreover, the content of protein increased with the stress time, which was 32.5 %, 64.2 %, and 49.1 % compared with the treatment on 10 DAT that lacked salt, accordingly. In contrast, the highest content of protein in the leaves was noted under salt-treated conditions on 3 DAT, which were 103.9 %, 76.9 %, and 70.1 % over the control, accordingly. The change in the content of protein in the leaves decreased during the experiment.

Correlation analysis of the shoot physiological features under stress indicated that the dry and fresh weight of shoots as determined by the leaf area and stem length, and the content of chlorophyll correlated positively with the leaf area and protein. The activity of SOD was regulated positively by the content of chlorophyll and the dry and fresh weights of the shoot. However, the activity of POD correlated negatively with the leaf area and shoot biomass (Table 3.3).

The increase in the total lateral length of roots increased the total root length. SOD and the root biomass were correlated positively. MDA correlated negatively with the density and number of first-order lateral roots. The protein correlated positively with CAT and MDA (Table 3.4).

Table 3.3

Pearson's correlation coefficient (r) for the relationships among the physiological features of shoot under NaCl treatments in mustard

ITEM	SFW	LA	SDW	SL	Chl	PI	APX	CAT	SOD	POD	MDA
LA	0.85**										
SDW	0.43	0.27									
SL	0.75**	0.59**	0.48*								
Chl	0.37	0.48*	-0.04	0.19							
PI	-0.31	-0.55	-0.27	-0.20	-0.35						
APX	0.42	0.32	0.56	0.28	-0.54	-0.14					
CAT	-0.71	-0.22	-0.48	-0.67	0.46	-0.47	-0.27				
SOD	0.81*	0.56	0.86**	0.62	-0.24	0.00	0.60	-0.76*			
POD	-0.82*	-0.77*	-0.93**	-0.66	0.21	0.05	-0.75*	0.54	-0.85**		
MDA	-0.70	-0.51	-0.87**	-0.48	0.04	-0.24	-0.46	0.75*	-0.92**	0.81*	
Protein	-0.14	0.29	0.31	-0.32	0.91**	-0.07	-0.28	0.36	-0.10	-0.02	-0.15

Note: LA, leaf area; SDW, shoot dry weight; SFW: shoot fresh weight; SL: stem length; Chl: chlorophyll; PI_{ABS}: performance index; APX: ascorbate peroxidase; POD, peroxidase; SOD, superoxide dismutase; CAT, catalase; MDA, malondialdehyde.*P < 0.05. **P < 0.01.

Table 3.4

Pearson's correlation coefficient (r) for the relationships among the physiological features of root under NaCl treatments in mustard.

ITEM	RFW	TRL	DW	TLRL	PRL	NLR	DLR	APX	POD	SOD	CAT
TRL	0.23										
RDW	0.34	-0.03									
TLRL	0.41	0.60**	0.13								
PRL	-0.20	-0.39	0.14	-0.25							
NLR	-0.06	0.01	-0.28	-0.04	0.29						
DLR	-0.19	0.31	-0.52*	0.28	0.07	0.73**					
APX	0.19	0.36	0.39	-0.15	-0.19	0.12	-0.01				
POD	-0.65	0.17	-0.69	-0.07	-0.29	0.14	0.17	-0.20			
SOD	0.72*	0.08	0.88**	0.09	0.11	-0.51	-0.55	0.16	-0.84**		
CAT	0.15	-0.36	0.15	-0.28	-0.41	-0.80*	-0.71*	-0.05	0.02	0.29	
MDA	0.01	-0.27	0.07	-0.39	-0.48	-0.91**	-0.85**	-0.10	0.06	0.24	0.91**

Note: RDW, root dry weight; RFW: root fresh weight; TRL, total root length; TLRL: total lateral root length;PRL, primary root length; NLR: number of first-order lateral root;DLR: density of first-order lateral root; APX: ascorbate peroxidase; POD, peroxidase; SOD, superoxide dismutase; CAT, catalase; MDA, malondialdehyde. *$P < 0.05$. **$P < 0.01$.

Discussion. Salinity is the major adversity factor. It impacts the global environment and economy negatively [25]. The adaptability of mustard to salt stress is a comprehensive reflection of many factors. Plant morphology, leaf features, photosynthesis, RSA, antioxidant enzyme activity, and biomass allocation are important indicators that reveal differences in the tolerance of plants to salt and are also crucial indicators that reflect the tolerance of plants to salt.

Changes in biomass are a comprehensive reflection of the plant response to salt stress and a direct plant indicator of salt tolerance [26]. Previous studies suggested that a 50% decrease in biomass was a critical survival threshold [27]. Our results indicated that the reduction in seedling dry weight was 14.3 %, 40.7 %, and 83.6 % under 50, 100, and 200 mM NaCl, accordingly. Thus, 100 mM NaCl was a survival threshold for mustard seedlings. The distribution of biomass in different tissues and organs reflects the response of plants to stress. In this study, the plant biomass was inhibited by salt stress on 10 DAT, while the root-shoot ratio increased significantly by 26.1 % following treatment with severe stress, indicating that more dry matter accumulates in the roots under severe stress (Table 3.1). Increasing the root-shoot ratio is a strategy, by which plants respond to salt stress. Previous studies on elevated root-shoot ratios under stress have been reported in maize (*Zea mays*) [28] and pepper (*Capsicum annuum*) [29], suggesting that plants preferentially transport photosynthetic products to roots under severe stress, which helps to maintain root growth and increase the total surface area of root absorption.

Photosynthesis is undoubtedly the most important physiological process that affects plant growth and biomass. Chloroplasts are one of the sites in which ROS are primarily formed. The reasons for the decrease in photosynthesis by the accumulation of ROS include the destruction of chlorophyll structure, a decrease in the content of chlorophyll, and the inhibition of PSII. Our results indicated that NaCl stress affected the content of chlorophyll and PI_{ABS}. Besides, the reduction of leaf area caused by salt stress correlated positively with the content of chlorophyll (Table 3.3). Therefore, we hypothesized that salt stress inhibited photosynthesis and then reduced the shoot growth and biomass. PI_{ABS} and F_v/F_m can reflect the reaction center activity of PS II, and the change in their values can reflect the inhibition of active centers by stress [30]. However, our results showed that F_v/F_m did not change under salt stress. These results were consistent with previous research on rapeseed (*Brassica napus*) [22] and wheat (*Triticum sp.*) [31]. As previously reported, PI_{ABS} was suggested to be a more effective photosynthetic parameter than F_v/F_m under stress [32,33]. Thus, PI_{ABS} can be useful markers to screen mustard genotypes and identify salt-tolerant genotypes. The decrease of leaf area under salt stress is closely related to the chlorophyll content.

Plant roots are the primary part of the stress response, and the modification of RSA has been identified as an adaptive mechanism [34]. *Brassica* is composed of the main root (support and fixed) and lateral roots (absorption moisture and nutrients) [13]. Stress conditions can have both negative and positive effects on the development of lateral roots [35]. In this research, salinity reduced the growth and development of mustard seedling roots, particularly, at severe salt stress but increased the number and density of first-order lateral roots by 28.7% and 58.5% on 10 DAT, accordingly (Table 3.2). These results are consistent with those of quinoa (*Chenopodium quinoa*) [36], which suggested that the expansions of plant cells and lateral buds occurred because osmotic stress inhibited the uptake of water by the plant roots. The number and density of the first-order lateral roots increased the root surface area to some extent. Considering the function of lateral roots, the increase in root surface area further improved the ability of plants to absorb water and nutrients, which, in turn, can be considered a strategy for plants to adapt to stress [13]. This result was also demonstrated by a significant increase in the root-shoot ratio when the plants were subjected to severe salt stress, which indicated that the increase in the number and density of first-order lateral roots influenced positively the accumulation of dry matter by the root.

As a product of membrane lipid peroxidation, the content of MDA correlated positively with membrane lipid damage [37]. In our experiment, the content of MDA in the roots did not change and increased in leaves with severe salt stress compared with those that were not subjected to treatment with salt (Figure 3.4). The specific changes in the content of MDA demonstrated that the leaves and roots had different mechanisms of adaptation to salt stress. There are two possible explanations for the result that the levels of MDA did not change when the plants were under severe salt stress. Wang et al. [38] and Pan et al. [39] suggested that the content of MDA only increased during the early hours of a high-concentration treatment and then dropped to a level close to that of the plants that were not subjected to stress. Another reason was that the highly effective antioxidant enzymes removed the toxicity of ROS and reduced the damage to membrane lipids. Combined with the fact that the root-shoot ratio significantly increased under severe salt stress, this suggested that effective activities were owing to the latter hypothesis.

Salt tolerance is related to the efficient anti-oxidative system that includes antioxidant compounds and several antioxidative enzymes [19]. SOD is considered to be a key ROS scavenger owing to its conversion of superoxide anion ($O_2^{\cdot -}$) to H_2O_2 and acts as the first line of defense against ROS. In contrast, other enzymes, such as POD, APX, and CAT, have the main functions to detoxify H_2O_2 and can be induced by H_2O_2 to increase their activity [40]. The activity of SOD of roots maintained a higher level than the control and reached its peak on day 3 under saline conditions. The activities of CAT, APX, and POD also increased rapidly. In contrast, different trends of variation were observed in the leaves. The activity of SOD in leaves only significantly increased on 7 DAT, while the activity of POD increased on 10 DAT (Figure 3.5). The synergistic effect of antioxidant enzymes in roots slowed down the production of ROS and improved the adaptability of roots to salt. Similar results were observed in rice [41] and sesame (*Sesamum indicum*) [42].

Moreover, the activity of CAT tended to increase in both the roots and leaves treated with salt, and the activity of POD maintained a relatively high level in the roots throughout the experiment. It could be assumed that CAT and POD play an important role in scavenging ROS. Similar results showed that two varieties of sesame that are strongly tolerant to stress have higher activities of POD and CAT [42]. Alternatively, efficient ROS detoxification in plants may suggest that maintaining a certain level of ROS may be necessary for cell proliferation and differentiation [20]. A hydroponics study proved that zinc stress stimulated an increase in the lateral roots in *B. Juncea* and *B. napus* [43]. Altogether, this research suggested that the antioxidant system increased the number and density of lateral roots, which in turn enhanced the tolerance of roots to higher levels of salt.

3.2. Effects of drought and rehydration on the growth and physiological features of mustard (*Brassica Juncea* L.) seedlings

In the current scenario of global climate change, drought stress has become a challenging problem and is threatening sustainable agricultural performance worldwide. Water deficit disturbs various physiological and biochemical traits and adversely affects the growth and performance of crop plants [44, 45]. Under natural conditions, plants are often exposed to an environment in which they are subjected to alternating drought and rehydration. Plant adaptability includes not only drought tolerance but also a process of recovery after rehydration that improves growth and physiological metabolism [46]. Therefore, studying the dynamic growth and physiological responses of plants under drought and rehydration conditions can facilitate a better understanding of the adaptive mechanism of plants.

Although drought restricts plant growth and development, plants exhibit growth compensation or overcompensation after some level of drought stress and rehydration [46-49]. The plant compensation effect usually makes up for the loss caused by stress. A PS II study of maize leaves found that the rehydration compensation effect reached its maximum on the 6th day after drought treatment [50]. Studies of soybean [46] and *Brassica carinata* [51] showed that plants can exhibit compensation on the root length, leaf area, and the number of leaves after some level of drought stress and rehydration. An increase in the number of tillers after rehydration is necessary for the adaptation of rice to drought-prone environments [52]. In sorghum, the chlorophyll content, water potential, and osmotic potential recovered to or even exceeded the level of control after rehydration [53]. Antioxidant enzymes play a crucial role in scavenging the reactive oxygen species (ROS) generated by stress conditions. The synthesis and increase of antioxidant enzymes can reduce the damage to plant cells from ROS, and enable the plants to quickly recover after rehydration [54, 55]. In *Artemisia halodendron*, the chlorophyll content, membrane permeability, activities of superoxide dismutase (SOD) and catalase (CAT), and the contents of the three osmoregulatory substances began to recover under moderate drought stress and rehydration [56]. As a product of membrane lipid peroxidation, the content of malondialdehyde (MDA) can reflect the degree of damage to the cell membrane. The decrease in hydrogen peroxide (H_2O_2) and content of MDA during the post-drought recovery of tea seedlings indicated that rehydration reduced the negative effects of drought stress [57].

Previous studies primarily focused on assessing the effects of drought stress on the growth and physiology of *Brassica* [58, 59]. However, few studies have been dedicated to the physiological responses that occur after rehydration. This study was designed to examine the effects of drought stress and rehydration on the growth, photosynthesis, and antioxidant system of mustard. These results should provide a better theoretical basis for the ability of mustard to adapt to drought stress.

The effect of drought stress and rehydration on mustard growth. The growth parameters of mustard seedlings treated with different levels and durations of drought stress were investigated. Table 3.5 shows that drought stress inhibited seedling growth in terms of length and fresh weight. Moreover, the inhibitory effect significantly increased with an increase in the level and duration of drought. Compared with the control plants, all the drought treatments for 9 days significantly reduced the root length by 16.18 %, 22.55 %, and 28.67 %, and the shoot length by 6.93 %, 10.39 %, and 18.48 %, accordingly. The relative growth rate of root and shoot lengths decreased significantly after 9 days of drought treatment, particularly, under severe drought conditions. After 6 days of rehydration, the stressed plants partially recovered. For the growth rate of root length, the compensation effect under mild (2.46 %) and moderate (11.77 %) stress was greater than that of control (0.25 %). However, the compensation effect in shoot lengths was not apparent after rehydration.

Drought stress significantly affected the fresh weight (FM) of roots and shoots compared with the control (Table 3.5). In all of the treated plants, 9 days of drought stress decreased the root fresh weight by 51.19 %, 82.29 %, and 85.31 %, and the fresh weight of shoots by 60.18 %, 86.09 %, and 88.73 %, accordingly. The relative growth rate of fresh weight of root and shoot decreased rapidly under moderate and severe stress. After 6 days of rehydration, growth rates of fresh weight in roots and shoots were higher than before rehydration. Under normal growth conditions, the relative growth rates of root and shoot fresh weight were only 36.5 % and 3.82 %, but there was an overcompensation of roots (82.93 % and 191.19 %) and shoots (172.55 % and 347.58 %) under moderate and severe stress, accordingly.

Table 3.5

Effects of drought stress and rehydration on the growth and fresh weight of mustard seedlings

Growth parameters	Treatment	D0 Mean±SD	D3 Mean±SD	D6 Mean±SD	D9 Mean±SD	R6 Mean±SD	Growth rate% (D9 VS D0)	Growth rate% (D9 VS R6)
Root length(cm)	CK	37.67±3.06	38.75±3.5a	50.67±3.75a	51±2.65a	51.13±4.8a	35.40	0.25
	10%		39.13±9.82a	44.25±11.09ab	42.75±6.3a	43.8±2.08ab	13.50	2.46
	15%		38.88±3.47a	41.5±3.42ab	39.5±8.96a	44.15±6.11ab	4.87	11.77
	20%		37.38±7.18a	36.13±5.04b	36.38±5.94a	36.53±5.93b	-3.42	0.41
Shoot length(cm)	CK	3.46±0.50	3.43±0.83a	3.17±0.29b	4.33±0.67a	4.43±0.82a	24.90	2.31
	10%		3.75±0.5a	3.98±0.21a	4.03±0.53ab	4.1±0.47a	16.25	1.74
	15%		3.45±0.58a	3.88±0.63a	3.88±0.22b	3.95±0.91a	11.92	1.8
	20%		3.25±0.65a	2.45±0.42c	3.53±0.29b	3.55±0.46a	1.83	0.57
Root fresh weight(g)	CK	0.85±0.06	2.11±0.36a	4.27±0.18a	4.63±0.35a	6.32±0.81a	441.94	36.5
	10%		0.86±0.08b	1.95±0.76b	2.26±0.31b	2.42±0.57b	164.53	7.08
	15%		0.86±0.2b	1.21±0.39b	0.82±0.04c	1.5±0.52b	-4.02	82.93
	20%		1.1±0.13b	1.41±0.32b	0.68±0.1c	1.98±0.62b	-20.41	191.18
Shoot fresh weight(g)	CK	2.42±0.33	3.89±1.22a	5.84±1.04a	11±0.9a	11.42±1.29a	391.95	3.82
	10%		2.76±0.3ab	4.06±0.64b	4.38±0.43b	6.2±1.09b	95.89	41.55
	15%		2.84±0.51ab	3.2±0.22b	1.53±0.23c	4.17±0.87c	-31.57	172.55
	20%		2.15±0.49b	3.65±0.5b	1.24±0.44c	5.55±0.42bc	-44.54	347.58

Mustard seedlings were measured on the 0, 3, 6, and 9th days of drought stress (D0, D3, D6, and D9), and the 6th day after rehydration (R6). Means ± SD, n = 5. Values in a column followed by different lowercase letters are significantly different at P<0.05 according to Duncan's multiple range test.

Changes in chlorophyll content and chlorophyll fluorescence. The chlorophyll content could reflect the level of photosynthesis to some extent and could further affect plant growth. The chlorophyll content changed in varying manners under different stress levels and stress times (Figure 3.7). Exposure to drought stress for 3 days increased chlorophyll content, particularly under mild and moderate stress by 25.74 % and 11.87 %, accordingly. After 9 days of drought stress, the chlorophyll content decreased significantly by 12.84 % and 21.95 % under moderate and severe stress, accordingly. Though, it was 14.69 % higher than the control under mild stress. After 6 days of rehydration, the chlorophyll content of moderate and severe stress did not return to the control level. The leaf chlorophyll content after subjection to mild stress was lower than that before rehydration and did not differ from the control level.

Drought stress decreased the F_v/F_m and PI_{ABS} (Figure 3.8), and there was no significant difference between the drought-treated groups on day 3. With the extension of the stress to 9 days, the F_v/F_m and PI_{ABS} of the stressed plants were still lower than those of the control plants. Rehydration led to an increase in the PI_{ABS}, particularly, under mild and moderate stress and it comprised 52.17 % and 98.47 %, accordingly. However, the F_v/F_m did not return to control levels.

Changes in contents of soluble protein and malondialdehyde content. The results shown in Figure 3.9 indicate that 9 days of drought stress increased the soluble protein content in the roots and leaves. After rehydration, the soluble proteins in roots and shoots changed in different manners. The protein content of all treatments in the roots was significantly higher than that of the control by

42.68 %, 70.89 %, and 35.62 %, while the protein content of mild and moderate stress in the leaves was 35.07 % and 13.30 % lower than that of the control.

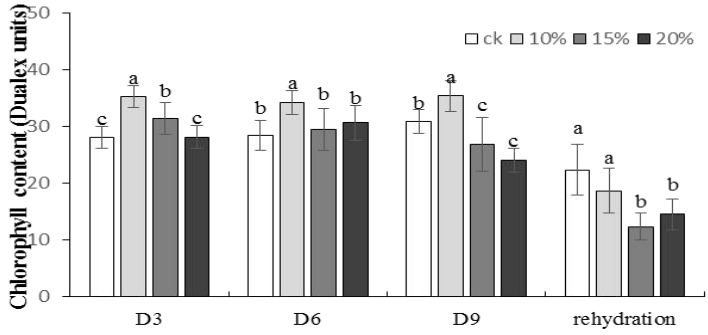


Figure 3.7. Effect of drought stress and rehydration on the leaf chlorophyll content. Values are means ± SD (n = 5). Means followed by different lowercase letters are significantly different at P<0.05 according to Duncan's multiple range test

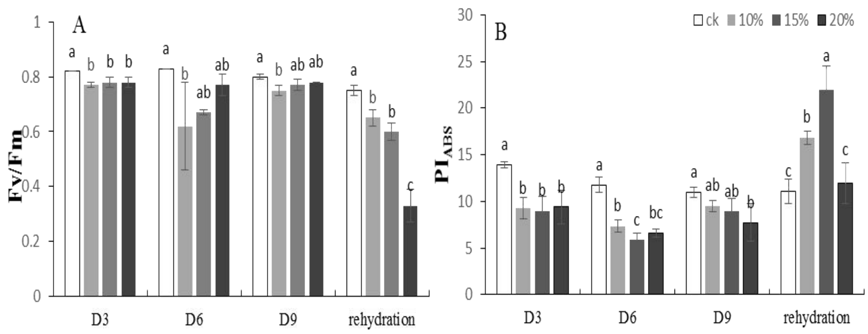


Figure 3.8. Effects of drought stress and rehydration on A: F_v/F_m, the maximal photochemistry of PSII; B: PI_{ABS}, performance index on absorption basis. Values are means ± SD (n = 5). Means followed by different lowercase letters are significantly different at P<0.05 according to Duncan's multiple range test.

In response to drought stress for 3 days, the content of MDA in treated leaves rapidly increased by 124.61 %, 197.37 %, and 303.29 % compared with the control (Figure 3.10).

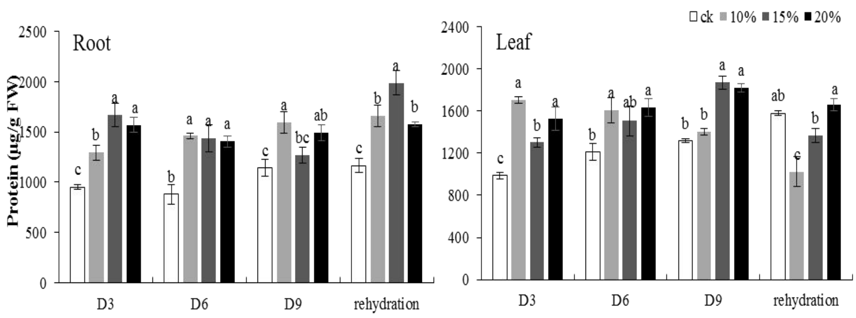


Figure 3.9. Effects of drought stress and rehydration on the protein content of mustard seedlings. Means ±SD, n = 3. Values in a column followed by different lowercase letters are significantly different at P<0.05 according to Duncan's multiple range test.

With the prolongation of the stress period, the MDA content of all the stressed leaves decreased slightly, but it was still significantly higher (71.57 %, 94.11 %, and 131.68 %) than the control level on the 9th day of stress. After rehydration, the content of MDA under moderate and severe stress was higher than that of the control by 92.07 % and 73.38 %, accordingly, and the content of MDA returned to the control level under mild stress. The change in the content of MDA in the roots was completely different from that in the leaves. Compared with the plants under normal conditions, the content of MDA in the roots that had been subjected to drought decreased by 34.68 %, 76 %, and 71.79 % after 3 days.

There was no significant change in the content of MDA in roots after 9 days of drought treatment. However, rehydration caused a significant increase in the content

of MDA in roots compared with untreated plants. The effect was particularly strong in the plants under severe stress, increasing as high as 731.99 %.

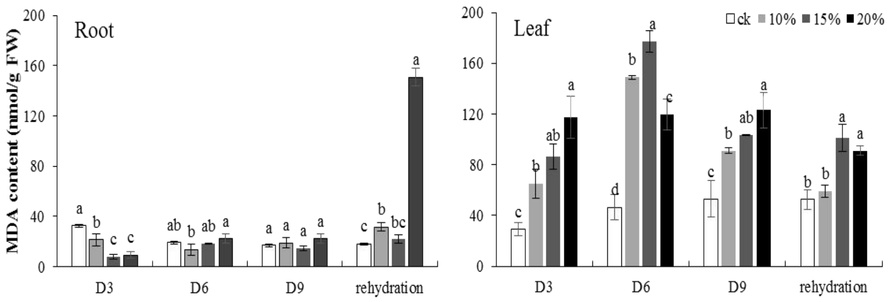


Figure 3.10. Effects of drought stress and rehydration on MDA content of mustard seedlings. Means ±SD, n = 3. Values in a column followed by different lowercase letters are significantly different at $P<0.05$ according to Duncan's multiple range tests.

Changes in antioxidant enzyme activities. As shown in Figure 3. 11, the activity of SOD in the roots increased significantly by 20.41 %, 29.77 %, and 35.21 % during the initial 3 days of drought stress, respectively. With the increase in duration and intensity of drought, the activity of SOD in the roots under moderate and severe drought was both dramatically higher (143.26 % and 152.90 %) than in the control on the 6th day of drought. On the 9th day, the SOD activity under severe drought was significantly higher than that in the control and other stress treatments. After rehydration, the SOD activity of the three drought treatments was higher than that of the control. The change in the activity of SOD in leaves occurred later than that in the roots. The activity of SOD in leaves under moderate and severe stress did not significantly increase until the 6^{th} day after the drought. Among the treated, the activity of SOD was greater in the treated leaves than in controls by 36.10 %, 47.93 %, and 8.84 % on the 9th day. After rehydration, the SOD of the severe stress treatment was 19.76 % higher than that of the control, and the activities of other treatments recovered to the control level.

The drought-induced changes in the activity of POD in the roots and leaves are shown in Figure 3.11. The activity of POD in roots increased remarkably and maintained a high level of activity under moderate and severe drought throughout the treatment period. The activity of POD increased dramatically by 209.35 %, 203.97 %, and 251.55 % with the extension of stress time, and reached its maximum value on the 9^{th} day of drought stress. The activity of POD in all treatments was lower than that before rehydration, and the activity of POD in severe drought was higher than that of the control and other treatments. After 3 and 6 days of drought treatment, the activity of leaf POD under moderate and severe stress was higher than that under the control and mild stress. After 9 days of leaf stress, the activity of POD increased significantly from 65.99 % to 135.92 % under moderate stress, and there was no difference between the other treatments and the control. After rehydration, the activity of POD returned to the control level under mild stress, while the activity of POD was higher than that under the control by 35.36 % and 250.47 % under moderate and severe stress, accordingly.

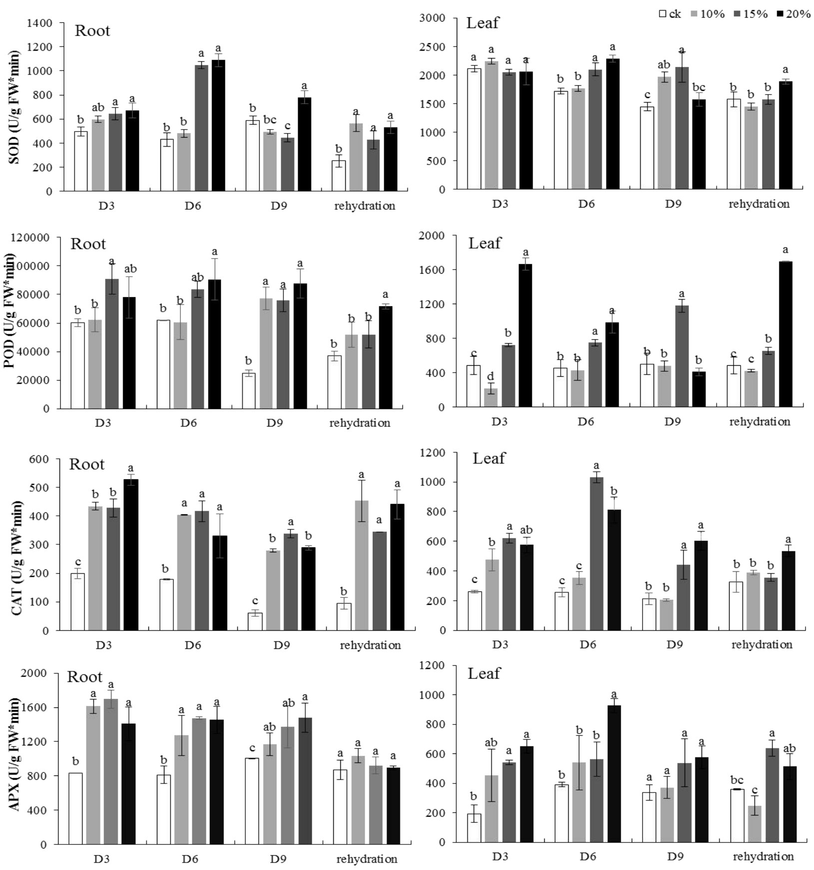


Figure 3.11. Effects of drought stress and rehydration on enzyme activities in mustard seedlings. Means ±SD, n = 3. Values in a column followed by different lowercase letters are significantly different at P<0.05 according to Duncan's multiple range tests

The figure 3.11. illustrates different effects of stress levels and times on the activity of CAT in roots and leaves. Drought stress induced a rapid increase in the activity of CAT in roots during all treatment days and reached its maximum on the 9th day by 354.26 %, 451.68 %, and 368.88 %. After rehydration, the activities of CAT in roots under all drought treatments were still higher than that of the control by 382.06 %, 266.94 %, and 368.88 %. The activity of CAT increased dramatically in the leaves compared with the treatment without drought stress on the third day.

The activity of CAT in the leaves under moderate and severe stress was notably higher than that of the control, and the activity reached its maximum on the 6th day by 303.09 % and 217.04 %, accordingly. After rehydration, the activity of CAT did not differ from that of the control under mild and moderate stress, but the activity under severe stress was 63% higher than that of the control.

The drought-induced APX maintained a high level in the roots during the experimental period (Figure 3.11). The activity of APX in all the drought-treated roots on the 9th day was lower than that on the third day and decreased gradually. After rehydration, the activity of APX of all the treatments recovered to the control level. The APX activity in leaves increased substantially after 3 and 6 days of stress and reached the maximum value of 134.07 %, 178.86 %, and 236.01 % on the third day. On the 9th day of drought stress, there was no difference between all the treatments compared with the control. After rehydration, the activity of APX decreased by 30.58 % under mild stress and increased by 77.62 % and 43.26 % under moderate and severe stress, accordingly.

Discussion. Drought is a major limiting abiotic stress factor during the growth and development of crop plants [60]. Changes in growth, photosynthesis, and physiology after drought and rehydration can affect the growth status and stress tolerance in plants to some extent. Therefore, the assessment of mustard stress resistance and the ability to recover from water deficit is an important task of modern crop production.

The growth rate is an important index of the plant growth status. Drought stress inhibited plant growth and reduced the growth rate. However, timely rehydration after drought stress can induce the drought-resistant ability of plants and result in a compensation effect. Compensation is an important self-regulatory mechanism adapted by plants to defend against environmental stresses or injuries [46]. Previous studies have suggested a growth compensation effect after drought stress and rehydration in terms of the root length, shoot length, leaf area, and the number of leaves [46, 51, 61]. The results of this study showed that the growth rate of root length decreased by 61.86 %, 85.76 %, and 109.66 % compared with the control under drought stress. After rehydration, the root length grew rapidly, and the growth rate of mild and moderate stress (2.46 % and 11.77 %, accordingly) was greater than that of control (0.25 %), indicating that there was growth compensation in the root length. However, there was no compensating effect for shoot length. The results suggested that the growth compensation of root and shoot lengths differed after drought stress and rehydration.

The accumulation of plant biomass was reduced by abiotic stress and preferentially supplies to the root system, which led to an increase in the root-shoot ratio [28, 29]. In this study, the root-shoot ratio of plants under three drought levels increased by 56.70%, 99.65%, and 48.05% compared with controls after 9 days of drought stress. After rehydration, the fresh weight of seedlings recovered rapidly. The growth rates of root fresh weights under moderate and severe stress were 82.93 % and 191.19 %, accordingly, and the shoot fresh weights were 172.55 % and 347.58 %, accordingly. However, under normal conditions, the fresh weight of the root and shoot was only 36.5 % and 3.82 %, accordingly. These results indicated that the fresh weight of roots and shoots had a compensating effect after rehydration. Besides, the shoot allocated more assimilates after rehydration, which resulted in a decrease in the root-shoot ratio of stressed plants. Compensation growth effects after drought and rehydration were observed in the studies of Guan et al. [62], who concluded that explosive growth was an effective strategy to compensate for the carbon deficit. The compensation effect was related to the degree and duration of stress periods. In a study of soybeans, mild and short-term stress can lead to more compensation [46]. *Artemisia halodendron* was able to tolerate a longer period under moderate drought and recover to pre-drought levels after rehydration [56]. The results of this study indicated that under moderate and severe drought stress, the fresh weight of the plant benefitted from more compensation. These results may indicate variations in the resistance to drought stress among plants.

Chlorophyll is the main photosynthetic pigment, and its content positively correlates with photosynthetic carbon fixation and drought resistance [51]. Previous studies of *Brassica* species and varieties had reported that the chlorophyll content decreased under drought stress [63, 64], which is different from the results of this study. In the early stage of drought, the chlorophyll content was significantly higher than that of the control by 12 % and 15 % under mild and moderate drought, accordingly. In the late stage of stress treatment, the chlorophyll content under mild stress was 12 % higher than that of the control, but the chlorophyll content decreased by 12 % and 13 % under moderate and severe stress, accordingly. These results suggested that mustard can more effectively adapt to mild and short drought by maintaining a high chlorophyll content. Moreover, the decrease in leaf water content with drought increased the chlorophyll concentration per unit area to some extent, which led to the increase in chlorophyll content. The excessive accumulation of ROS under severe stress accelerated the degradation of chloroplasts and then inhibited chlorophyll synthesis [65]. After rehydration, under moderate and severe stress, the chlorophyll content was still significantly lower than that under normal conditions, indicating that the damage of chloroplasts under moderate and severe stress could not be recovered and it may cause yellowing of the leaves.

Chlorophyll fluorescence is a useful tool to quantify the effect of abiotic stress on photosynthesis [66]. PI_{ABS} and F_v/F_m can reflect the reaction center activity of PS II , particularly since PI_{ABS} has been suggested to be a better parameter for reflecting the effect of stress on photosynthetic apparatus compared with F_v/F_m [32, 33]. PI_{ABS} and F_v/F_m decreased significantly in the drought-treated plants compared with plants without stress, indicating that the reaction center of PS II was inactivated, and the performance of PSII decreased. After rehydration, the PI_{ABS} recovered or was higher than the control level, which indicated a recovery in PS II performance and a compensatory effect. However, F_v/F_m failed to recover even after the release of the stress by the added water. One of the reasons for this difference could be the fact that PI_{ABS} was more sensitive to stress than F_v/F_m.

Abiotic stress tolerance in crop plants depends on the enhancement of the antioxidative defense system, which includes antioxidant compounds and several antioxidative enzymes [67]. In this study, drought stress induced a notable increase in the activities of SOD, POD, APX, and CAT in roots and leaves compared with the well-watered control plants, which indicated the activation of the antioxidant system. SOD is one of the ubiquitous enzymes in aerobic organisms and is considered to be a key ROS scavenger by converting $O_2^{\cdot -}$ to H_2O_2, while other enzymes, such as POD, APX, and CAT, have the main function of detoxifying H_2O_2 [40]. Thus, SOD constitutes the first line of defense against the superoxide-derived oxidative stress in the plant cells. In the stressed leaves, although the activities of POD, CAT, and APX significantly increased, the activity of SOD was not different from that of the non-stressed leaves, which further led to the accumulation of ROS and the peroxidation of membrane lipid. This hypothesis can be proven by the increase in the content of MDA in stressed leaves. In the root, the increase in SOD activity accompanied by the increase in the activities of POD, APX, and CAT can decrease the excessive accumulation of ROS, which was consistent with the low content of MDA in roots. The synergistic effect of antioxidant enzymes is a good indication of plant tolerance. The same result was obtained in drought-tolerant cotton [68] and sesame [69]. After rehydration, the activities of CAT, POD, and SOD in the stressed roots were higher than those in the control plants. The activities of SOD, POD, CAT, and APX in the leaves under severe stress were significantly higher. Previous studies have shown that after drought and rehydration, the antioxidant enzymes in wheat [70] and glycyrrhiza [71] remain highly active, which was consistent with the results of this study. The reason for the high level of enzyme activity after rehydration could be maintaining the balance of ROS and mitigating the damage to membranes.

3.3. Effect of seed pre-treatment with plant growth compound regulators on mustard (*Brassica Juncea* L.) seedling growth under drought stress

As the climate changes, drought is the most important natural factor, which influences plant growth and production. Drought stress caused changes in plant morphology, physiology, and gene expression [72, 73]. Available literature suggested that polyethylene glycol (PEG) can be used to simulate drought conditions and study the effects of drought stress on plants [74-76]. PEG is an inert long-chain polymer with high molecular weight, which has little effect on cells. Moreover, PEG osmotic stress method has the advantages of being simple, easy to control, good repeatability, and short test cycle.

Plant growth regulator (PGR) shows prominent effects on plant metabolism, resistance, growth, and performance [77, 78]. Most of the previous studies focused on the effects of a single endogenous hormone or nutrient on plants under drought stress [79-81]. However, there are few studies on the effects of compound growth regulators on the morphology of mustard. The objective of the study was to evaluate the effectiveness of PGRs on the root and shoot morphology of mustard during the seedling stage under simulated drought conditions, which would provide a theoretical basis for the practice of compound growth regulators in mustard and simplify cultivation and management.

The effects of PGRs on germination rate under drought stress. As shown in Figure 3.12, the germination rate of the two varieties changed under different treatments.

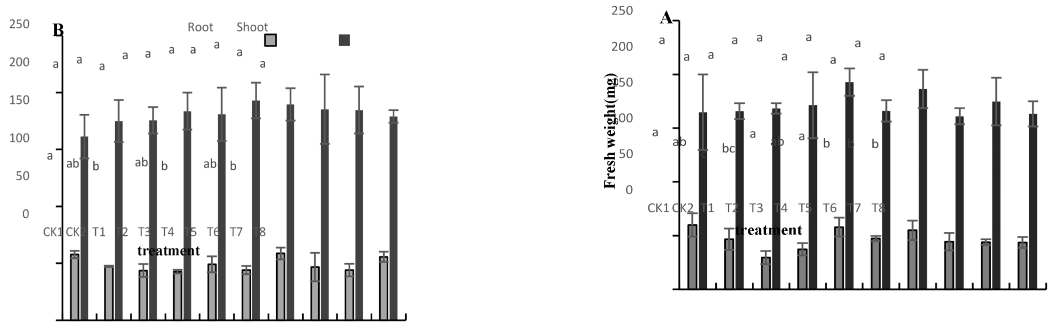


Figure 3.12. The seed germination rate of mustard under different treatments. A: Felicia, B: Prima. CK1: distilled water; CK2: 10% PEG-6000; T1: 10% PEG-6000 + Albit; T2: 10% PEG -6000 + Vermistimd; T3: 10% PEG -6000 + Antistress; T4: 10% PEG -6000 + Agrinos; T5: 10% PEG -6000 + Regoplan; T6: 10% PEG -6000 + Bioforge; T7: 10% PEG -6000 + Stimulate; T8: 10% PEG -6000 + Fast Start

In Felicia, the germination rate under T1 reached the minimum value (81 %) compared to the CK1 (89 %), CK2 (87 %), and other treatments. The germination rate reached the maximum with T7 and T8, both by 90 %, and was higher than in normal growing conditions (89 %) (Fig.1-A). For Prima, the germination rate of T1 (89 %), T2 (88 %), and T3 (87 %) were slightly higher than that of CK1 (83 %) and CK2 (85 %) (Figure 1-B). Besides, there was a difference between the two varieties in terms of germination rate. The germination rate of Felicia was higher (89 %) than that of Prima (83 %) under normal conditions. Although the sensitivity of Prima and Felicia to PGRs was different, the difference was not significant.

The effects of PGRs on fresh weight of mustard under drought stress. The results indicated that drought stress reduced the root fresh weight of Felicia and Prima by 22.22 % and 17.93 % compared with the CK1 (Figure 3.13).

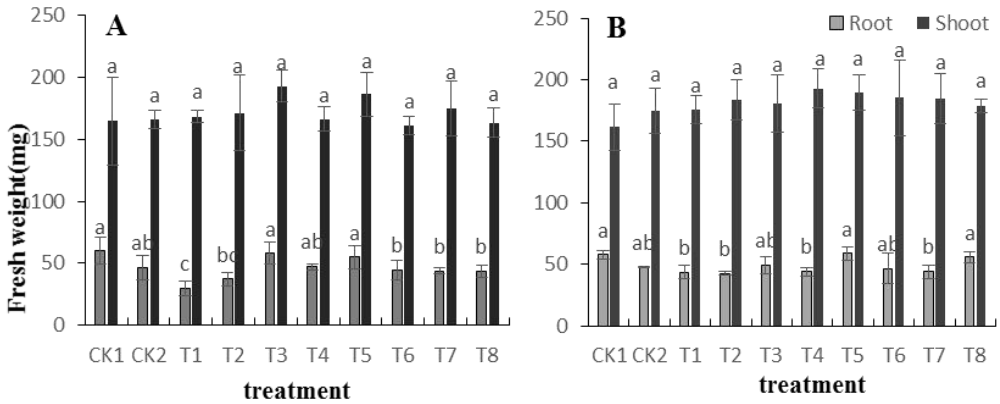


Figure 3.13. Fresh weight of *Brassica Juncea* L. under different treatments. A: Felicia, B: Prima. CK1: distilled water; CK2: 10% PEG-6000; T1: 10% PEG-6000 + Albit; T2: 10% PEG-6000 + Vermistimd; T3: 10% PEG-6000 + Antistress; T4: 10% PEG-6000 + Agrinos; T5: 10% PEG-6000 + Regoplan; T6: 10% PEG-6000 + Bioforge; T7: 10% PEG-6000 + Stimulate; T8: 10% PEG-6000 + Fast Start

The root fresh weight in Felicia increased after the application of T3 and T5 by 24.28 % and 17.85 %. However, the application of T1 and T2 significantly reduced the root fresh weight of Felicia by 36.43 % and 20 %, and the root fresh weight of T4 was not different compared with CK2. For the root fresh weight of Prima, the application of T5 and T8 was 23.96 % and 17.62 % higher than CK2. Moreover, there was no significant difference between all treatments regarding the shoot fresh weight of Felicia and Prima. Compared with the CK1, the effect of drought stress on root fresh weight was greater than shoot, indicating that root was very sensitive to drought stress.

The effect of PGRs on root growth of mustard under simulated drought stress. An extensive root system is advantageous for supporting plant growth during the early crop growth stage and absorbs more water from the rhizosphere. Mustard is a straight root system, and its total root length consists of lateral roots and a primary root (Figure 3.14).

The root system architecture (RSA) was determined by multiple environmental factors. In Felicia and Prima, drought stress (CK2) reduced TRL (total root length) by 12 % and 15 % compared to normal conditions (CK1) (Table 3.6), although there was no significant difference. For other root parameters, the effects of drought on the two varieties showed opposite results. Drought significantly reduced lateral root number and primary root length in Prima but not in Felicia. Drought significantly reduced average root diameter and total root volume in Felicia but these indexes were not affected in Prima.

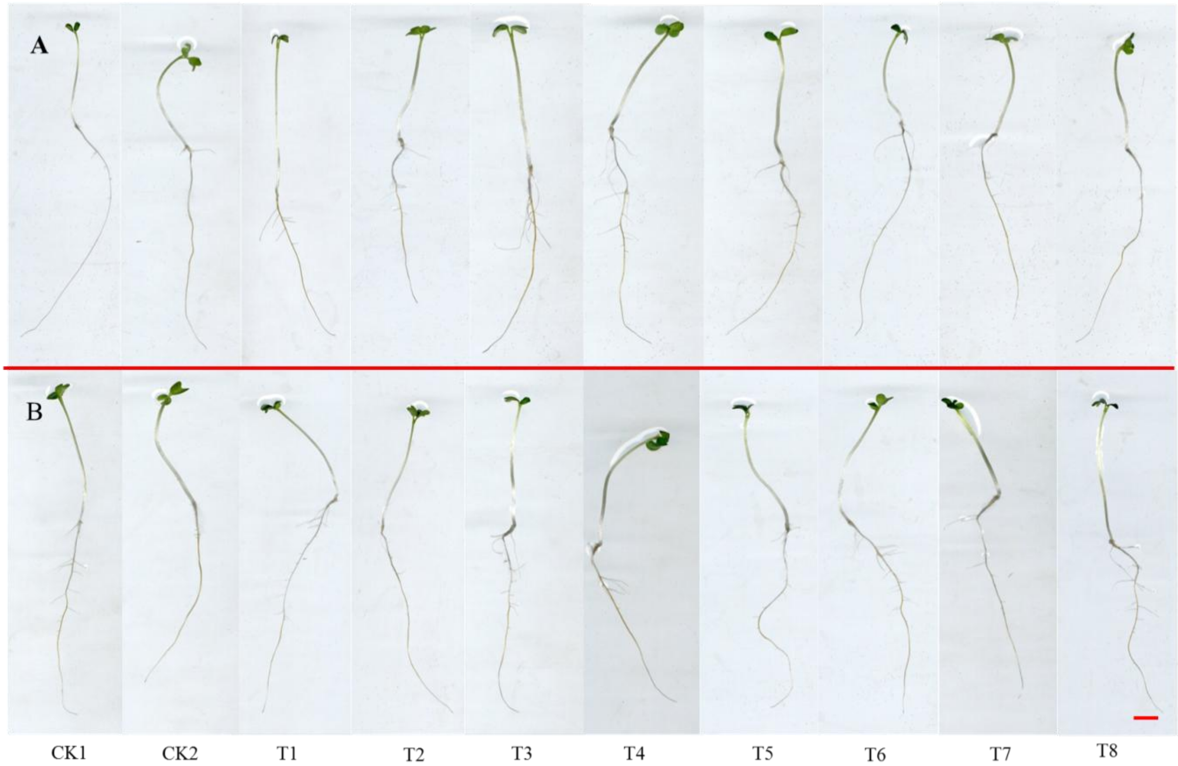


Figure 3.14. The appearance of the root system under the use of growth regulators: A-Felicia, B-Prima.

The responses of the two varieties to PGRs were different under drought conditions. In Felicia, the application of T3 and T4 significantly increased the total root length by 3.3 % and 8.2 %, while other treatments were lower than CK2. Moreover, the number of lateral roots reached the maximum under T4 and T5 treatment compared with that of CK2, which were 135.55% and 121.20 %, accordingly. For Prima, the PGRs increased the root length and the surface area under drought stress, except for T4 and T7. For lateral root number and primary root length, all regulators showed positive effects, and T8 treatment had the most prominent effect. Notably, the application of T8 had a remarkable effect on the root growth by increasing the root length (18.12 %), surface area (28.57 %), the average diameter (6.06 %), root volume (37.76 %), lateral root number (211.20 %), and primary root length (53.75 %).

Table 3.6

Root growth parameters in different experimental setups

Varieties	Treatments	Total root length (cm)	Total root surface area (cm^2)	Average root diameter (mm)	Total root volume (cm^3)	Number of first-order lateral roots	Length of primary root (cm)
Felicia	CK1	9.18±1.37ab	1.07±0.07a	0.38±0.04a	10.00±1.00a	3.33±0.58e	8.81±0.17a
	CK2	9.01±2.82abc	0.96±0.25ab	0.34±0.03bc	8.20±2.04b	4.67±0.58de	8.42±0.50ab
	T1	7.19±1.35c	0.78±0.14c	0.35±0.03bc	6.67±1.45c	5.33±0.58cd	6.48±0.20e
	T2	7.87±2.34abc	0.84±0.23bc	0.34±0.03bc	7.20±2.27bc	6.33±1.15bcd	7.34±0.36cd
	T3	9.31±2.51ab	0.96±0.22ab	0.33±0.04bc	8.00±2.00bc	7.75±0.96b	7.12±0.54cde
	T4	9.75±2.81a	0.98±0.18ab	0.33±0.04c	7.87±1.13bc	11.00±1.73a	6.94±0.21cde
	T5	8.09±2.30abc	0.90±0.20bc	0.36±0.04ab	7.93±1.71bc	10.33±1.15a	5.68±0.38f
	T6	7.99±2.79abc	0.87±0.24bc	0.35±0.03abc	7.60±1.88bc	5.33±0.58cd	7.72±0.36bc
	T7	7.49±1.61bc	0.88±0.16bc	0.38±0.04a	8.27±1.83b	5.67±0.58cd	7.04±0.65cde
	T8	8.41±2.06abc	0.88±0.16bc	0.34±0.03bc	7.47±0.99bc	6.75±0.96bc	6.61±0.64de
Prima	CK1	10.48±2.26a	1.04±0.23ab	0.32±0.03ab	8.33±2.44b	6.00±1.00f	9.47±1.29a
	CK2	8.94±1.89ab	0.91±0.16bc	0.33±0.04ab	7.60±1.80b	3.75±0.96h	5.73±0.23c
	T1	9.13±1.94ab	0.97±0.15bc	0.34±0.05ab	8.33±1.80b	8.75±0.96cd	7.96±0.27b
	T2	9.10±1.57ab	0.91±0.15bc	0.32±0.04ab	7.33±1.72b	7.50±0.55de	6.19±0.39c
	T3	9.91±3.12ab	0.96±0.24bc	0.32±0.04b	7.60±1.59b	10.33±0.58ab	6.36±0.47c
	T4	8.47±2.65b	0.83±0.23c	0.32±0.05b	6.73±2.22b	10.67±0.58ab	5.58±0.50c
	T5	9.11±1.74ab	0.95±0.15bc	0.34±0.05ab	8.07±2.09b	7.80±1.10de	7.53±0.08b
	T6	9.18±3.05ab	0.94±0.24bc	0.33±0.04ab	7.80±1.74b	7.00±1.00ef	7.46±0.27b
	T7	8.39±1.95b	0.85±0.15c	0.33±0.04ab	6.93±1.33b	9.33±0.58bc	6.37±0.47c
	T8	10.56±1.92a	1.17±0.19a	0.35±0.03a	10.47±2.17a	11.67±1.53a	8.81±0.51a

Means ± SD, followed by different lowercase letters are significantly different according to Duncan's multiple range test, $P<0.05$, n = 3.

The effects of PGRs on the shoot growth of mustard under drought stress. For Felicia, the PGRs promoted the growth of the shoot under the drought condition, except for the T6 treatment group (Table 3.7).

Table 3.7

Shoot growth parameters in different experimental setups

Varieties	Treatments	Leaf Area(cm^2)	Stem Length(cm)	Stem Diam(mm)	Stem Volume(mm^3)
Felicia	CK1	0.94 ± 0.18 bc	3.62 ± 0.67 bc	0.82 ±0.05 a	19.40 ± 4.32 ab
	CK2	0.89 ± 0.15 c	3.56 ± 0.67 c	0.80 ± 0.07 a	17.73 ± 3.13 b
	T1	1.03 ± 0.15 abc	4.02 ± 0.47 abc	0.81 ±0.08a	21.07 ± 4.62 ab
	T2	1.03 ±0.20 abc	4.21 ± 0.92 ab	0.79 ± 0.07 a	20.33 ± 4.47 ab
	T3	1.11 ± 0.17 a	4.25 ± 0.68 a	0.83 ± 0.06 a	23.20 ±4.02 a
	T4	0.97 ± 0.14 abc	3.96 ±0.58 abc	0.78 ± 0.04a	19.07 ± 2.94 b
	T5	1.06 ± 0.18 ab	4.22 ± 0.81 ab	0.80 ± 0.07a	21.07 ± 3.86 ab
	T6	0.88 ± 0.13 c	3.54 ± 0.53 c	0.80 ± 0.08 a	17.67 ± 3.54 b
	T7	1.05 ± 0.24 ab	4.14 ± 0.98 abc	0.81 ± 0.06a	21.27 ± 5.20 ab
	T8	0.98 ± 0.27 abc	3.78 ±0.80 abc	0.82 ± 0.09a	20.40 ± 8.45 ab
Prima	CK1	1.00 ± 0.13 b	4.03 ±0.48 ab	0.79 ± 0.05 a	19.93 ± 3.28 b
	CK2	1.07 ± 0.14 ab	4.23 ±0.47 ab	0.81 ± 0.08 a	22.07 ± 4.67 ab
	T1	1.05 ± 0.19 ab	4.06 ±0.57 ab	0.82 ± 0.08 a	21.93 ± 5.92 ab
	T2	1.04 ± 0.19 ab	4.16 ±0.74 ab	0.80 ± 0.08 a	20.93 ± 4.70 b
	T3	1.03 ±0.14 b	4.15 ±0.61 ab	0.79 ± 0.06 a	20.33 ± 3.35 b
	T4	1.01 ± 0.33 b	3.91 ±1.15 b	0.80 ± 0.12 a	21.00 ± 7.37 b
	T5	1.15 ± 0.16 ab	4.64 ±0.80 a	0.79 ± 0.05a	22.93 ± 3.10 ab
	T6	1.13 ± 0.13 ab	4.55 ±0.61 a	0.79 ± 0.07 a	22.27 ± 3.45 ab
	T7	1.14 ± 0.32 ab	4.53 ±1.00 a	0.80 ± 0.10 a	23.20 ± 9.55 ab
	T8	1.24 ± 0.49 a	4.51 ±0.64 ab	0.86 ± 0.23 a	29.20 ± 24.13 a

Means ± SD, followed by different lowercase letters are significantly different according to Duncan's multiple range test, $P<0.05$.

Leaf area, stem length, and stem volume after the application of T3 increased significantly compared with CK2 by 24.7 %, 19.4%, and 30.9 %, accordingly. For the shoot growth of Prima, the application of T8 significantly increased the leaf area and stem volume by 15.9 % and 32.3 %, while there was no significant difference between other regulators and CK2.

Discussion. Drought stress is one of the most common abiotic stresses in agricultural production. Climate change makes it more frequent and severe in the world [82]. The application of plant growth regulators is considered an effective strategy to improve plant stress resistance in agricultural production [83, 84]. This study used PEG 6000 to simulate drought stress in mustard seedlings, and different types of PGRs were applied to evaluate the changes in germination rate and growth indicators of root and shoot.

Seed germination is the first stage for plants to endure environmental stress. Growth regulators are used in the pre-sowing seed treatment and play an important role in regulating germination and vigour [85, 86]. Previous reports suggested that seed germination and seedling vigour depend on the priming method and the concentration used [87]. In this study, it has been determined that compound regulator has little effect on the germination rate of Felicia and Prima. This is different from previous reports, which hypothesized that it may be due to differences in PGRs. On the other hand, mustard is considered a well-adapted crop, and its germination may be related to the genotype and the ability to transform nutrients in the endosperm. To some extent, the germination rate is not a good indicator to screen the effects of the regulator on mustard under drought conditions.

Roots are the first organ to sense and respond to environmental factors. In response to stress, root system changes include not only the elongation of primary roots but also the occurrence and elongation of lateral roots [88]. In the present results, although drought did not significantly reduce the total root length of the two varieties, it did significantly reduce the lateral root number and lateral root number of Prima (Table 3.6). Furthermore, variety Felicia presented no significant response to 10% PEG stress regarding lateral root formation and primary root elongation, but its root diameter and total root volume were significantly reduced by the mimicked drought stress, indicating root thickening was retarded. The results suggest that Prima is more sensitive to drought than Felicia. The PGRs significantly promoted the root growth of cultivated Prima under drought conditions. Unlike for Prima, T1-T8 treatments did not improve those root parameters for Felicia. These results suggested that PGRs had a positive role against drought on drought-sensitive variety; on the contrary, for drought non-sensitive variety, the PGRs exhibited relatively poor effects against drought. These results indicated the response of mustard to PGRs under simulated drought in the climate chamber, and the evaluation of regulators in field experiments under natural conditions needs to be further verified.

Conclusions to section 3

For experiment 1.

1. The results indicated that the reduction in seedling dry weight was 14.3 %, 40.7 %, and 83.6 % under 50, 100, and 200 mM NaCl, accordingly. Thus, 100 mM NaCl was a survival threshold for mustard seedlings.

2. The results indicated that NaCl stress negatively affected the content of chlorophyll and PI_{ABS}. Besides, the reduction of leaf area caused by salt stress correlated positively with the content of chlorophyll. The salt stress inhibited photosynthesis and then reduced the shoot growth and biomass. PI_{ABS} and F_v/F_m can reflect the reaction center activity of PSII, and the change in their values can reflect the inhibition of active centers by stress.

3. Salinity reduced the growth and development of mustard seedling roots, particularly, at severe salt stress but increased the number and density of first-order lateral roots by 28.7 % and 58.5 % on 10 DAT, accordingly. This result was also demonstrated by a significant increase in the root-shoot ratio when the plants were subjected to severe salt stress, which indicated that the increase in the number and density of first-order lateral roots influenced positively the accumulation of dry matter by the root.

For experiment 2.

4. Compared with the control plants, all the drought treatments for 9 days significantly reduced the root length by 16.18 %, 22.55 %, and 28.67 %, and the shoot length by 6.93 %, 10.39 %, and 18.48 %, accordingly. For the growth rate of

root length, the compensation effect under mild (2.46 %) and moderate (11.77 %) stress was greater than that of control (0.25 %). However, the compensation effect in shoot lengths was not apparent after rehydration.

5. The drought stress decreased the root fresh weight by 51.19 %, 82.29 %, and 85.31 %, and the fresh weight of shoots by 60.18 %, 86.09 %, and 88.73 %, accordingly. Under normal growth conditions, the relative growth rates of root and shoot fresh weight were only 36.5 % and 3.82 % but there was an overcompensation of roots (82.93 % and 191.19 %) and shoots (172.55 % and 347.58 %) under moderate and severe stress, accordingly.

6. The exposure to drought stress for 3 days resulted in an increase in chlorophyll content, particularly, under mild and moderate stress by 25.74 % and 11.87 %, accordingly. After 9 days of drought stress, the chlorophyll content decreased significantly by 12.84 % and 21.95 % under moderate and severe stress, accordingly. Though, it was 14.69 % higher than the control under mild stress. The protein content of all treatments in the roots was significantly higher than that of the control by 42.68 %, 70.89 %, and 35.62 %, while the protein content of mild and moderate stress in the leaves was 35.07 % and 13.30 % lower than that of the control.

7. The activity of POD in roots increased remarkably and maintained a high level of activity under moderate and severe drought throughout the treatment period. The activity of POD increased dramatically by 209.35 %, 203.97 %, and 251.55 % with the extension of stress time, and reached its maximum value on the 9th day of drought stress. The leaf stress of the activity of POD increased

significantly from 65.99 % to 135.92 % under moderate stress, and there was no difference between the other treatments and the control. After rehydration, the activity of POD returned to the control level under mild stress, while the activity of POD was higher than that under the control by 35.36 % and 250.47 % under moderate and severe stress, accordingly.

8. Drought stress induced a rapid increase in the activity of CAT in roots during all treatment days and reached its maximum on the 9^{th} day by 354.26 %, 451.68 %, and 368.88 %. The activity of CAT in the leaves under moderate and severe stress was notably higher than that of the control, and the activity reached its maximum on the 6^{th} day by 303.09 % and 217.04 %, accordingly.

9. The activity of APX in all the drought-treated roots on the 9^{th} day was lower than that on the third day and it decreased gradually. The APX activity in leaves increased substantially after 3 and 6 days of stress and reached the maximum value of 134.07 %, 178.86 %, and 236.01 % on the third day.

For experiment 3.

10. The application of growth regulators promoted the growth of seedlings under drought stress but had no obvious effect on the germination rate of the two varieties. The root fresh weight, total root length, leaf area, stem length, and stem volume in Felicia significantly increased with ANTISTRESS treatment by 24.28, 3.30, 24.70, 19.40, and 30.90 %.

11. The number of lateral roots reached the maximum with AGRINOS and REGOPLAN treatment compared with plants without regulators under drought conditions, which were 135.55 and 121.20 %, accordingly. For Prima, the

application of FAST START had a remarkable effect on root fresh weight, total root length, lateral root number, primary root length, root surface area, leaf area, and stem volume by 17.62, 18.12, 211.20, 53.75, 28.57, 15.90, and 32.30 %, accordingly.

12. The leaf area, stem length, and stem volume after the application of ANTISTRESS increased significantly compared with CK2 by 24.7 %, 19.4 %, and 30.9 %, accordingly. For the shoot growth of Prima, the application of FAST START significantly increased the leaf area and stem volume by 15.9 % and 32.3 %, while there was no significant difference between other regulators and CK2.

References to section 3

1. Uddin M., Islam M. T., Karim M. Salinity tolerance of three mustard/rapeseed cuitivars. *Journal of the Bangladesh Agricultural University.* 2005. *3*. P. 203-208.

2. Purty R. S., Kumar G., Singla-Pareek S. L., Pareek A. Towards salinity tolerance in brassica: An overview. *Physiology & Molecular Biology of Plants.* 2008. 14. P. 39-49.

3. Jia P., Melnyk A., Zhang Z. Differential adaptation of root and shoot to salt stress correlates with antioxidant capacity in mustard. *Pakistan journal of botany.* 2022. № 54 (6). P. 2001-2011. DOI: http://dx.doi.org/10.30848/PJB2022-6(32)

4. Melnyk A. V., Jia P., Butenko S. O. The role of melatonin in salt stress on mustard. *Матеріали міжнародної науково-практичної конференції «Гончарівські читання».* (Суми, 25-26 травня 2020). Суми, 2020. С. 99.

5. Deinlein U., Stephan A. B., Horie T., Luo W., Xu G., Schroeder J. I. Plant salt-tolerance mechanisms. *Trends in plant science.* 2014. 19. P. 371-379.

6. Jamil A., Riaz S., Ashraf M., Foolad M. R. Gene expression profiling of plants under salt stress. *Critical Reviews in Plant Sciences.* 2011. 30. P. 435-458.

7. Zahedi A. M., Fazeli I., Zavareh M., Dorry H., Gerayeli N. Evaluation of the sensitive components in seedling growth of common bean (*Phaseolus Vulgaris* L.) affected by salinity. *Asian Journal of Crop Science.* 2012. 4. P. 159-164.

8. Ma Q., Yue L.-J., Zhang J.-L., Wu G.-Q., Bao A.-K., Wang S.-M. Sodium chloride improves photosynthesis and water status in the succulent xerophyte zygophyllum xanthoxylum. *Tree Physiol.* 2012. 32. P. 4-13.

9. Feng Z. T., Deng Y. Q., Fan H., Sun Q. J., Sui, N., Wang B. S. Effects of NaCl stress on the growth and photosynthetic features of *Ulmus Pumila* L. Seedlings in sand culture. *Photosynthetica.* 2014. 52. P. 313-320.

10. Osmont K. S., Sibout R., Hardtke C. S. Hidden branches: Developments in root system architecture. *Annual review of plant biology.* 2007. 58. P. 93-113.

11. Galvan-Ampudia C. S., Testerink C. Salt stress signals shape the plant root. *Current Opinion in Plant Biology.* 2011. 14. P. 296-302.

12. Wang Y., Li K., Li X. Auxin redistribution modulates plastic development of root system architecture under salt stress in *Arabidopsis Thaliana*. *J Plant Physiol.* 2009. 166. P. 1637-1645.

13. Arif M. R., Islam M. T., Robin A. H. K. Salinity stress alters root morphology and root hair traits in *Brassica Napus*. *Plants.* 2019. 8. P. 192.

14. White P. J., George T. S., Gregory P. J., Bengough A. G., Mckenzie B. M. Matching roots to their environment. *Ann Bot-London.* 2013. 112. P. 207-222.

15. He Y., Hu D., You J., Wu D., Cui Y., Dong H., Li J., Qian W. Genome-wide association study and protein network analysis for understanding candidate genes involved in root development at the rapeseed seedling stage. *Plant Physiol Bioch.* 2019. 137. P. 42-52.

16. Jia P., Li R. Different responses of morphology, chlorophyll fluorescence and antioxidant enzyme activity to salt stress of mustard (*Brassica Juncea* L.) Seedling. *Proceedings of the international scientific and practical conference "Scientific principles of increasing the efficiency of agricultural production".* (Kharkiv, November 26-27, 2020). Kharkiv, 2020. P. 35.

17. Khan M., Singha K. L., Panda S. Changes in antioxidant levels in *Oryza Sativa* L. Roots subjected to NaCl-salinity stress. *Acta Physiol Plant.* 2002. 24. P. 145-148.

18. Rasool S., Ahmad A., Siddiqi T. O., Ahmad P. Changes in growth, lipid peroxidation and some key antioxidant enzymes in chickpea genotypes under salt stress. *Acta Physiol Plant.* 2013. 35. P. 1039-1050.

19. Neto A., Prisco J. T., Enéas-Filho J., Abreu C. B., Gomes-Filho E. Effect of salt stress on antioxidative enzymes and lipid peroxidation in leaves and roots of salt-tolerant and salt-sensitive maize genotypes. *Environmental & Experimental Botany.* 2006. 56. P. 87-94.

20. Mittler R. Ros are good. *Trends in plant science.* 2017. 22. P. 11-19.

21. Feigl G., Molnár A., Szőllősi R., Ördög A., Törőcsik K., Oláh D., Bodor A., Perei K., Kolbert Z. Zinc-induced root architectural changes of rhizotron-grown *B. Napus* correlate with a differential nitro-oxidative response. *Nitric Oxide.* 2019. 90. P. 55-65.

22. Hooks T., Niu G., Ganjegunte G. Seedling emergence and seedling growth of mustard and rapeseed genotypes under salt stress. *Agrosystems, Geosciences & Environment.* 2019. 2. P. 1-8.

23. Uddin M., Islam M. T., Karim M. Salinity tolerance of three mustard/rapeseed cuitivars. *Journal of the Bangladesh Agricultural University.* 2005. 3. P. 203-208.

24. Singh J., Singh V., Vineeth T. V., Kumar P., Kumar N., Sharma P.C. Differential response of indian mustard (*Brassica Juncea* L., czern and coss) under salinity: Photosynthetic traits and gene expression. *Physiol Mol Biol Pla.* 2019. 25. P. 71-83.

25. Munns R. Genes and salt tolerance: Bringing them together. *New Phytol.* 2005. 167. P. 645-663.

26. Levitt, J. Responses of plants to environmental stresses. Volume II. Water, radiation, salt, and other stresses (No. Ed. 2). *Academic Press.* 1980..

27. Alshammary S. F., Qian Y. L., Wallner S. J. Growth response of four turfgrass species to salinity. *Agr Water Manage.* 2004. *66*. P. 97-111.

28. Ren Y., Liu J., Li Z.X., Li Q. Root morphology and dry matter accumulation of maize seedlings in response to low iron stress. *Crops.* 2020. 6. P, 69-79.

29. Tang R., Wang C., Wang H., Wu H., Han Y., Lin Q., Lei K. Effects of low phosphorus stress on growth and physiological features of pepper at seedling stage. *Southwest China Journal of Agricultural Sciences.* 2020. *33*. P. 1933-1942.

30. Strasser R. J., Srivastava A., Tsimilli-Michael M. The fluorescence transient as a tool to characterize and screen photosynthetic samples. *Probing photosynthesis: mechanisms, regulation and adaptation.* 2000. P. 445-483.

31. Mehta P., Jajoo A., Mathur S., Bharti S. Chlorophyll a fluorescence

study revealing effects of high salt stress on photosystem II in wheat leaves. *Plant Physiol Bioch.* 2010. 48. P. 16-20.

32. Appenroth K. J., Stöckel J., Srivastava A., Strasser R. Multiple effects of chromate on the photosynthetic apparatus of S*pirodela Polyrhiza* as probed by ojip chlorophyll a fluorescence measurements. *Environmental Pollution.* 2001. 115. P. 49-64.

33. Heerden P., Tsimilli‒Michael M., Krüger G. H., Strasser R. J. Dark chilling effects on soybean genotypes during vegetative development: Parallel studies of co2 assimilation, chlorophyll a fluorescence kinetics o ‐ j ‐ i ‐ p and nitrogen fixation. *Physiol Plantarum.* 2003. 117. P. 476-491.

34. Dorairaj D., Suradi M. F., Mansor N. S., Osman N. Root architecture, rooting profiles and physiological responses of potential slope plants grown on acidic soil. *Peerj.* 2020. 8. P. 93-95.

35. Sun C.-H., Yu J.-Q., Hu D.-G. Nitrate: A crucial signal during lateral roots development. *Front Plant Sci.* 2017. 8. P. 485.

36. Panuccio M., Jacobsen S.E., Akhtar S. S., Muscolo A. Effect of saline water on seed germination and early seedling growth of the halophyte quinoa. *AoB plants.*2014. 6. P. 1-18.

37. Chen Q., Zhang M., Shen S. Effect of salt on malondialdehyde and antioxidant enzymes in seedling roots of jerusalem artichoke (*Helianthus Tuberosus* L.). *Acta Physiol Plant.* 2011. 33. P. 273-278.

38. Wang H. M., Xiao X. R., Yang M. Y., Gao Z. L., Zang J., Fu X. M., Chen Y. H. Effects of salt stress on antioxidant defense system in the root of

kandelia candel. *Botanical Studies.* 2014. 55(1). P. 1-7.

39. Pan Y., Wu L. J., Yu Z. L. Effect of salt and drought stress on antioxidant enzymes activities and sod isoenzymes of liquorice (*Glycyrrhiza Uralensis* Fisch). *Plant Growth Regul.* 2006. 49. P. 157-165.

40. Mittova V., Guy M., Tal M., Volokita M. Salinity up - regulates the antioxidative system in root mitochondria and peroxisomes of the wild salt - tolerant tomato species *Lycopersicon Pennellii. J Exp Bot.* 2004. 55. P. 1105-1113.

41. Nounjan N., Nghia P. T., Theerakulpisut P. Exogenous proline and trehalose promote recovery of rice seedlings from salt-stress and differentially modulate antioxidant enzymes and expression of related genes. *J Plant Physiol.* 2012. 169. P. 596-604.

42. Koca H., Bor M., Zdemir F., Türkan S. The effect of salt stress on lipid peroxidation, antioxidative enzymes and proline content of sesame varieties. *Environ Exp Bot.* 2007. 60. P. 344-351.

43. Feigl G., Kolbert Z., Lehotai N., Molnár Á., Ördög A., Bordé Á., Laskay G., Erdei L. Different zinc sensitivity of brassica organs is accompanied by distinct responses in protein nitration level and pattern. *Ecotox Environ Safe.* 2016. 125. P. 141-152.

44. Maevskaya S., Nikolaeva M. Response of antioxidant and osmoprotective systems of wheat seedlings to drought and rehydration. *Russ J Plant Physl.* 2013. 60. P. 343-350.

45. Furlan A. L., Bianucci E., del Carmen Tordable M., Castro S., Dietz K. J. Antioxidant enzyme activities and gene expression patterns in peanut nodules

during a drought and rehydration cycle. *Funct Plant Biol.* 2014. 41. P. 704-713.

46. Dong S., Jiang Y., Dong Y., Wang L., Wang W., Ma Z., Yan C., Ma C., Liu L. A study on soybean responses to drought stress and rehydration. *Saudi J Biol Sci.* 2019. 26. P. 2006-2017.

47. Iovieno P., Punzo P., Guida G., Mistretta C., Van Oosten M. J., Nurcato R., Bostan H., Colantuono C., Costa A., Bagnaresi P. Transcriptomic changes drive physiological responses to progressive drought stress and rehydration in tomato. *Front Plant Sci.* 2016. *7*. P. 371.

48. Bu L.D., Zhang R., Han M., Xue J., Chang Y. The physiological mechanism of compensation effect in maize leaf by re-watering after draught stress. *Acta Agriculturae Boreali-Occidentalis Sinica.* 2009. 18. P. 88-92.

49. Jin R., Shi H., Han C., Zhong B., Wang Q., Chan Z. Physiological changes of purslane (*Portulaca Oleracea* L.) after progressive drought stress and rehydration. *Sci Hortic-Amsterdam.* 2015. 194. P, 215-221.

50. Gao J., Li Q. F., Xue J. Q., Zhang R. H. Physiological compensation mechanism of photosystem ii in maize leaves induced by drought stress and re-watering condition. *Plant Physiology Journal.* 2016. 52. P. 1413–1420.

51. Husen A., Iqbal M., Aref I. M. Growth, water status, and leaf features of brassica carinata under drought and rehydration conditions. *Brazilian Journal of Botany.* 2014. 37. P. 217-227.

52. Okami M., Kato Y., Kobayashi N., Yamagishi J. Morphological traits associated with vegetative growth of rice (*Oryza Sativa* L.) during the recovery phase after early-season drought. *Eur J Agron.* 2015. 64. P. 58-66.

53. Liu T., Chen D., Wang S., Yin L., Deng X. Physio-ecological responses to drought and subsequent re-watering in sorghum seedlings. *Acta Prataculturae Sinica.* 2018. 27. P. 100-110.

54. Men Y., Wang D., Li B., Su Y., Chen G. Effects of drought stress on the antioxidant system, osmolytes and secondary metabolites of saposhnikovia divaricata seedlings. *Acta Physiol Plant.* 2018. 40. P. 1-14.

55. Jia P., Melnyk A., Li L., Kong X., Dai H., Zhang Z., Butenko S. Effects of drought and rehydration on the growth and physiological features of mustard seedlings. *Journal of Central EuropeanAgriculture*. 2021. 22 (4). P. 836-847. DOI:https://doi.org/10.5513/JCEA01/22.4.3246.

56. Chen J., Zhao X., Zhang Y., Li Y., Cong A. Effects of drought and rehydration on the physiological responses of *artemisia halodendron*. *Water.* 2019. 11. P. 793.

57. Upadhyaya H., Panda S. K. Responses of camellia sinensis to drought and rehydration. *Biol Plantarum.* 2004. 48. P. 597-600.

58. Alam M. M., Hasanuzzaman M., Nahar K., Fujita M. Exogenous salicylic acid ameliorates short-term drought stress in mustard (*Brassica Juncea* L.) seedlings by up-regulating the antioxidant defense and glyoxalase system. *Australian Journal of Crop Science.* 2013. 7. P. 1053.

59. Hossain M. A., Fujita M. Hydrogen peroxide priming stimulates drought tolerance in mustard (*brassica Juncea* L.) seedlings. *Plant Gene and Trait.* 2013. 4. P. 109-123.

60. Melnyk A., Jia P., Growth and physiological compensation of mustard

seedling after drought stress and rehydration. *International scientific and practical conference* “*Ideas and innovation in natural sciences*”. (Lublin, the Republic of Poland, March 12–13, 2021). Lublin, 2021. P. 11–13. DOI https://doi.org/10.30525/978-9934-26-047-6-2.

61. Chen X. Y., Gao Z. H., Luo Y. P. Compensatory effect of drought-wet changing environment on winter wheat growth. *Journal of Inner Mongolia Agricultural University (natural Science Edition)*. 2001. 22(2), 62-66.

62. Guan J., Gu L., Liu J. Effects of drought and rehydration on the growth and photosynthetic physiological features of *Salix Matsudana*. *Forest By-Product and Speciality in China.* 2019. 6. P. 13-20.

63. Kauser R., Athar H.-U.-R., Ashraf M. Chlorophyll fluorescence: A potential indicator for rapid assessment of water stress tolerance in canola (*Brassica Napus* L.). *Pak J Bot.* 2006. 38. P. 1501-1509.

64. Lada R. Water-stress and n-nutrition effects on photosynthesis and growth of brassica carinata. *Photosynthetica.* 2012. 49. P. 309-315.

65. Anjum F., Yaseen M., Rasul E., Wahid A., Anjum S. Water stress in barley (*Hordeum Vulgare* l.). Ii. Effect on chemical composition and chlorophyll contents. *Pakistan Journal of Agricultural Sciences (Pakistan)*. 2003. 40. P. 45-49.

66. Husen A., Iqbal M., Aref I. M. Growth, water status, and leaf features of brassica carinata under drought and rehydration conditions. *Brazilian Journal of Botany*. 2014. 37. P. 217-227.

67. Neto A. D. d. A., Prisco J. T., Enéas-Filho J., Abreu C. E. B. D., Gomes-Filho E. Effect of salt stress on antioxidative enzymes and lipid

peroxidation in leaves and roots of salt-tolerant and salt-sensitive maize genotypes. *Environmental & Experimental Botany.* 2006. 56. P. 87-94.

68. Gossett D. R., Millhollon E. P., Lucas M. C. Antioxidant response to NaCl stress in salt‐tolerant and salt‐sensitive varieties of cotton. *Crop Sci.* 1994. 34. P. 706-714.

69. Koca H., Bor M., Özdemir F., Türkan İ. The effect of salt stress on lipid peroxidation, antioxidative enzymes and proline content of sesame varieties. *Environ Exp Bot.* 2007. 60. P. 344-351.

70. Zhang F., Guo J.-K., Yang Y.-L., He W.-L., Zhang L.-X. Changes in the pattern of antioxidant enzymes in wheat exposed to water deficit and rewatering. *Acta Physiol Plant.* 2004. 26. P. 345-352.

71. Zhou X., Wang G., Liang Z., Han R. Effects of drought stress and rehydration on physiological features and glycyrrhizin accumulation of *Glycyrrhiza Uralensis* Fisch. Seedling. *Acta Agriculturae Boreali-occidentalis Sinica.* 2011. 20. P. 64-70.

72. Hamidi H., Safarnejad A. Effect of drought stress on alfalfa varieties (*Medicago Sativa* L.) in germination stage. *American-Eurasian Journal of Agricultural & Environmental Sciences.* 2010. 8. P. 705-709.

73. Khan M. N., Zhang J., Luo T., Liu J., Rizwan M., Fahad S., Xu Z., Hu L. Seed priming with melatonin coping drought stress in rapeseed by regulating reactive oxygen species detoxification: Antioxidant defense system, osmotic adjustment, stomatal traits and chloroplast ultrastructure perseveration. *Ind Crop Prod.* 2019. 140. P. 111597.

74. Bressan R., Hasegawa P., Handa A. K. Resistance of cultured higher plant cells to polyethylene glycol-induced water stress. *Plant Science Letters.*1981. 21. P. 23-30.

75. Berg L. V. d., Zeng Y. J. Response of south african indigenous grass species to drought stress induced by polyethylene glycol (PEG) 6000. *S Afr J Bot.* 2006. 72. P. 284-286.

76. Jia P., Melnyk A., Zhang Z. Effects of different plant growth regulators in a vegetative chamber on seedling morphology parameters of yellow mustard (*Brassica Juncea* L.). *AgroLife Scientific Journal*. 2020. № 9(1). P. 180–185.

77. Cao, F. B., Shan, S. L., Gao, W., Zhi-Bin, L. I., Zou, Y. B., Zhang, H. D., et al. (2017). Effects of xinqing attapulgite microbial compound fertilizer and conditioning agent on growth and cadmium content in rice. *Tillage and Cultivation.* 2017. 04. P. 4-6.

78. Rademacher W. Plant growth regulators: Backgrounds and uses in plant production. *J Plant Growth Regul.* 2015. 34. P. 845-872.

79. Arnao M. B., Hernández-Ruiz J. Melatonin: A new plant hormone and/or a plant master regulator? *Trends in Plant Science.* 2019. 24. P. 38-48.

80. Yavas I., Unay A. Effects of zinc and salicylic acid on wheat under drought stress. *Journal of Animal and Plant Sciences.* 2016. 26. P. 1012-1101.

81. Gill S. S., Tuteja N. Polyamines and abiotic stress tolerance in plants. *Plant signaling & behavior.* 2010. 5. P. 26-33.

82. Jia P., Melnyk A., Zhang Z., Butenko S., Kolosok V. Effects of seed pre-treatment with plant growth compound regulators on seedling growth under

drought stress. *Agraarteadus*. 2021. 32(2). P. 251-256. DOI: https://doi.org/10.15159/jas.21.35.

83. Ma Q.-Q., Wang W., Li Y.-H., Li D.-Q., Zou Q. Alleviation of photoinhibition in drought-stressed wheat (*Triticum Aestivum*) by foliar-applied glycinebetaine. *J Plant Physiol.* 2006. 163. P. 165-175.

84. Sharma A., Kumar V., Singh R., Thukral A.K., Bhardwaj R. Effect of seed pre-soaking with 24-epibrassinolide on growth and photosynthetic parameters of *Brassica Juncea* L. In imidacloprid soil. *Ecotox Environ Safe.* 2016. 133. P. 195-201.

85. Basra A. S., Dhillon R., Malik C. Influence of seed pre-treatments with plant growth regulators on metabolic alterations of germinating maize embryos under stressing temperature regimes. *Ann Bot-London.* 1989. 64. P. 37-41.

86. Melnyk A., Jia P., Butenko S. Effect of Seed treatment with Plant Growth regulators under Stress conditions in Mustard. *Матеріали Міжнародній науково-практичній конференції «Розвиток аграрної галузі на впровадження наукових розробок у виробництво»* (Миколаїв, 18 листопада 2021 р.). Миколаїв: МНАУ, 2021. С. 80-81.

87. Kumari N., Rai P. K., Bara B. M., Singh I. Effect of halo priming and hormonal priming on seed germination and seedling vigour in maize (*Zea Mays* L.) seeds. *Journal of Pharmacognosy and Phytochemistry.* 2017. 6. P. 27-30.

88. Tvs K., Marconi M., Vega A., O'Brien J., Benková E. Modulation of plant root growth by nitrogen source defined regulation of polar auxin transport. *The EMBO Journal.* 2021. 40(3). P. e106862.

SECTION 4

VARIETAL RESPONSES OF MUSTARD (*BRASSICA JUNCEA* L.) GROWTH AND PERFORMANCE ACCORDING TO GROWTH REGULATORS

Mustard is one of the world's major sources of vegetable oil and protein. Mustard oil is widely used in food processing, such as canning and baking, as well as in the production of candy and margarine [1, 2]. Moreover, mustard oil has been explored as a potential biofuel, which is favored by the majority of researchers because of its ability to minimize air pollution and the emission of greenhouse gases [3]. Mustard has more vigorous seedling growth, faster ground covering ability along better resistance to adversity [4]. It is a more adaptable oilseed crop than *Brassica napus* in stressful environments associated with low rainfall, high temperature, and late sowing [5]. Changes in Ukraine's climate over the past decades have led to an increase in annual mean temperature, changes in snow formation conditions and duration, a gradual increase in heat supply during the growing season, and an increase in the number and intensity of adverse meteorological phenomena (drought, heavy rains, etc.) [6]. To a certain extent, changes in Ukraine's climate contributed to the expansion of mustard cultivation.

Plant growth regulators are related substances or products that induce crops to develop stress-resistant mechanisms and improve the utilization of active ingredients of fertilizers, pesticides, and herbicides. They also significantly improve crop yield capacity and quality without harming the environment [7-11]. A study on maize showed that plant growth regulators increased dry matter and yield capacity by increasing leaf area, 100-kernel weight, and kernels per row [12]. The finger millet treated with the compound of nutrients and plant growth regulators showed a prominent increase in total chlorophyll content, indicating that major and micro-nutrients and special plant regulators are beneficial to chlorophyll synthesis and prevent its degradation [13]. Spraying Mixtalol on the leaf surface of mustard increased the number of second and third branches, as well as starch, protein, and oil content [14]. Exogenous melatonin has been reported to improve growth and stress tolerance effectively in rape seeds [15]. Currently, a wide variety of plant growth regulators are used in production, and their effects vary according to the crop, mode of application, and environment [16]. To optimize mustard production, it is necessary to understand the application method of plant regulators and their response to mustard. Although there have been reports on mustard production, little information is available on the effects of growth regulators on mustard yield capacity and yield composition in the northeastern Forest-Steppe of Ukraine [17]. Therefore, it is of great practical significance to study the application method and effect of plant growth regulators to improve the yield capacity and quality of mustard.

4.1. Effects of growth regulators on morphological parameters and photosynthetic activity of mustard (*Brassica Juncea* L.)

Plant Height (cm). Among the two varieties investigated, Prima created a significantly taller average plant (145.7 cm) (Table 4.1). However, there were no differences between the three application methods. Except for Albit (139.7 cm), all other applications produced a significantly bigger plant height than the control (141.0 cm) in Prima. Average plant height increased by 1.8-6.7 %, among which the growth regulators of Agrinos, Fast Start, and Regoplan had the most obvious effect. The average plant height of Felicia increased by 4.3-6.0 %, but there was no significant difference with the application of Albit and Vermistim D. The interaction showed no significant difference.

The number of branches per plant^{-1}. For genotypes, Felicia had a significantly higher number of branches than Prima (Table 4.2). The three application methods did not affect on Prima but had a significant difference on Felicia. Moreover, the combination of seed dressing and foliar spraying significantly increased the number of branches in Felicia. The effects of different growth regulators vary in a variety. All growth regulators increased the number of branches in Prima and reached a maximum of 7.4 % with Regoplan. A similar effect was observed in Felicia. All interactions did not differ except between genotype and application method. **Leaf area.** The leaf area growth determines light interception and is a major parameter of plant performance. For genotypes, Felicia had a larger leaf area than Prima (Table 4.3). All the application methods had the same trend for both varieties, among which the combination of seed dressing and foliar spraying reached the maximum leaf area, and the seed dressing effect was the worst. The mean leaf area of Prima and Felicia increased by 9.0%-17 % and 6.5%-15.4 %, accordingly, compared with those without the growth regulators. Regoplan had the most excellent effect on the average leaf area of both varieties.

Table 4.1

Effects of different growth regulators on plant height of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	foliar	seeds+foliar	Average	seeds	foliar	seeds+foliar	Average
Control	141.0bc	141.0c	141.0cd	141.0de	136.0bc	136.0c	136.0c	136.0b
Albit	139.0c	140.0c	140.1d	139.7e	135.2c	135.2c	137.9bc	136.1b
Antistress	149.5a	146.4abc	148.6ab	148.2ab	143.0ab	141.4abc	146.6a	143.7a
Agrinos	150.7a	151.0a	147.4abc	149.7a	142.2abc	140.6abc	144.1ab	142.3a
Bioforge	142.7bc	143.7bc	146.4abcd	144.3cd	143.1ab	140.6abc	143.4abc	142.3a
Fast Start	146.9ab	152.8a	149.1ab	149.6a	142.7ab	144.2ab	142.9abc	143.3a
Regoplan	149.9a	148.4ab	152.9a	150.4a	144.3a	145.1a	143.0abc	144.1a
Stimulate	147.3ab	141.2c	147.5abc	145.3bc	142.8ab	140.2abc	142.3abc	141.8a
Vermistim D	144.0abc	141.7c	144.7bcd	143.5cd	136.9abc	137.4bc	136.4c	136.9b
Average	145.7a	145.1a	146.4a		140.7a	140.1a	141.4a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	1023.03	1023.03	*				
Factor B	2	45.11	22.56	NS				
Factor C	8	1827.1	228.39	*				
A×B	2	0.02	0.01	NS				
A×C	8	113.87	14.23	NS				
B×C	16	158.15	9.88	NS				
A×B×C	16	151.6	9.47	NS				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, $*p < 0.05$.

Table 4.2

Effects of different growth regulators on branching number of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	**foliar**	**seeds+foliar**	**mean**	**seeds**	**foliar**	**seeds+foliar**	**mean**
Control	4.2a	4.2a	4.2a	4.2c	4.5ab	4.5a	4.5c	4.54c
Albit	4.1a	4.3a	4.2a	4.23bc	4.4b	4.7a	4.7bc	4.58c
Antistress	4.4a	4.4a	4.3a	4.37abc	4.8ab	4.8a	5.1ab	4.91ab
Agrinos	4.5a	4.4a	4.2a	4.38abc	4.7ab	4.7a	5.1a	4.86ab
Bioforge	4.4a	4.4a	4.4a	4.41abc	4.5ab	4.6a	4.9abc	4.67bc
Fast Start	4.4a	4.5a	4.5a	4.49ab	4.6ab	4.7a	4.9abc	4.72abc
Regoplan	4.6a	4.4a	4.6a	4.51a	4.9a	5a	5abc	4.94a
Stimulate	4.3a	4.3a	4.2a	4.26abc	4.6ab	4.7a	4.8abc	4.7abc
Vermistim D	4.3a	4.2a	4.3a	4.3abc	4.5ab	4.6a	4.6c	4.58c
Average treatment	4.4a	4.3a	4.3a		4.6b	4.7ab	4.8a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	5.7	5.7	*				
Factor B	2	0.23	0.11	NS				
Factor C	8	2.01	0.25	*				
A×B	2	0.44	0.22	*				
A×C	8	0.42	0.05	NS				
B×C	16	0.3	0.02	NS				
A×B×C	16	0.53	0.03	NS				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, *$p < 0.05$.

Table 4.3

Effects of different growth regulators on leaf area of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	**foliar**	**seeds+foliar**	**mean**	**seeds**	**foliar**	**seeds+foliar**	**mean**
Control	34.3d	34.3c	34.3e	34.35e	38.7e	38.7d	38.7e	38.73e
Albit	37.1ab	36.9b	38.4d	37.45d	39.1e	41.9c	42.9cd	41.26d
Antistress	38.2ab	39ab	39.8cd	38.98abc	43.2ab	44.1ab	46.0a	44.43ab
Agrinos	38.9a	38.1ab	39.6cd	38.86bc	41.8bcd	43.5ab	46.4a	43.92ab
Bioforge	34.9cd	38.3ab	41.5abc	38.26bcd	41.8bcd	44.0ab	45.2ab	43.64b
Fast Start	37.6ab	38.5ab	42.1ab	39.37ab	42.3abc	44.5a	45.1ab	43.98ab
Regoplan	38.1ab	40.1a	42.4a	40.2a	43.7a	44.7a	45.6ab	44.68a
Stimulate	37.6ab	40a	40.0bcd	39.22ab	41.1cd	42.8bc	44.1bc	42.66c
Vermistim D	36.5bc	37b	39.8cd	37.76cd	40.8d	41.9c	42.5d	41.74d
Average treatment	37.02c	38.02b	39.80a		41.4c	42.91b	44.04a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	820.13	820.13	*				
Factor B	2	197.07	98.53	*				
Factor C	8	457.24	57.15	*				
A×B	2	2.62	1.31	NS				
A×C	8	17.35	2.17	NS				
B×C	16	47.23	2.95	*				
A×B×C	16	42.38	2.65	NS				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan’s multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, *$p < 0.05$.

Chlorophyll contents (mg/g). The leaf chlorophyll content is an important physiological index reflecting leaf photosynthetic intensity and plant senescence. Prima showed significantly higher chlorophyll content (1.17 mg/gram) than Felicia (1.07 mg/gram) (Table 4.4). Likewise, the combination of seed dressing and foliar had the largest influence on chlorophyll content in both varieties, while seed dressing alone had the worst effect. For Prima, all growth regulators increased average chlorophyll content compared to control, except Vermistim D. In Felicia, the growth regulators had, on average, a 6.3 % to 18.8 % increase in chlorophyll content compared to those without the growth regulators. Regoplan increased the chlorophyll content of Prima and Felicia by 10.7 % and 18.8 %, accordingly, compared with the control.

The number of pods per plant^{-1} (pcs). The data given in Table 4.5 revealed that genotypes had a significant effect on the number of pods, among which Felicia (131 pcs) had a significantly higher pod number than Prima (113 pcs). Compared with the other two treatments, the combination of seed dressing and foliar application significantly increased the number of pods of the two varieties, followed by foliar application, and the seed dressing effect was the worst. The Regoplan significantly increased the number of pods in Prima by 12 pcs with the combined treatment of seed dressing and foliar application, Antistress and Regoplan increased the number of pods in Felicia by 19 pcs and 17 pcs, accordingly. Average pod increases ranged from 2 to 9 pcs for Prima and from 4 to 14 pcs for Felicia.

Table 4.4

Effects of different growth regulators on Chlorophyll content of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	**foliar**	**seeds+foliar**	**mean**	**seeds**	**foliar**	**seeds+foliar**	**mean**
Control	1.12e	1.12d	1.12d	1.12f	0.96c	0.96e	0.96e	0.96d
Albit	1.15cde	1.14d	1.19c	1.16de	1.03ab	1.05cd	1.03d	1.04c
Antistress	1.17bcd	1.18bc	1.21bc	1.19bc	1.05ab	1.06cd	1.15abc	1.09b
Agrinos	1.19ab	1.19b	1.24ab	1.21b	1.07ab	1.07cd	1.1c	1.08b
Bioforge	1.19abc	1.2ab	1.23ab	1.21b	1.07ab	1.15ab	1.17a	1.13a
Fast Start	1.16bcde	1.18bc	1.2bc	1.18cd	1.04ab	1.14ab	1.16ab	1.11ab
Regoplan	1.22a	1.24a	1.27a	1.24a	1.08a	1.19a	1.13abc	1.14a
Stimulate	1.13de	1.15cd	1.18c	1.15e	1.01bc	1.1bc	1.13abc	1.08b
Vermistim D	1.06f	1.08e	1.10d	1.08g	0.95c	1.01de	1.1bc	1.02c
Average treatment	1.15b	1.16b	1.19a		1.03c	1.08b	1.10a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	0.4	0.4	*				
Factor B	2	0.09	0.05	*				
Factor C	8	0.36	0.04	*				
A×B	2	0.01	0.01	*				
A×C	8	0.04	0	*				
B×C	16	0.04	0	*				
A×B×C	16	0.03	0	*				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, $*p < 0.05$.

Table 4.5

Effects of different growth regulators on pod number per plant of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	foliar	seeds+foliar	mean	seeds	foliar	seeds+foliar	mean
Control	109b	109cd	109d	109d	121de	121e	121e	121f
Albit	109b	113bc	111cd	111cd	120e	130cd	129d	126e
Antistress	113ab	116ab	114bcd	114b	129abc	137ab	144a	137ab
Agrinos	117a	113bc	114bcd	115b	128bc	133bcd	143ab	135bc
Bioforge	110b	113bc	116b	113bc	127bc	135abc	139bc	134c
Fast Start	113ab	117ab	117b	116b	131ab	139a	139bc	136abc
Regoplan	116a	120a	122a	119a	133a	138ab	142ab	138a
Stimulate	112ab	113bc	115bc	113bc	125cd	130cd	137c	131d
Vermistim D	109b	106d	113bcd	110d	124cde	129d	126d	126e
Average treatment	112b	113ab	115a		126c	132b	136a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	13302.62	13302.62	*				
Factor B	2	964.53	482.27	*				
Factor C	8	2717.68	339.71	*				
A×B	2	318.9	159.45	*				
A×C	8	375.38	46.92	*				
B×C	16	344.58	21.54	*				
A×B×C	16	342.43	21.4	*				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, *$p < 0.05$.

Average seed weight of the plant^{-1} (g). As shown in Table 4.6, the average seed weight per plant of Felicia (1.27 g) was significantly higher than that of Prima (1.19 g). The combination of seed dressing and foliar spraying was significantly higher than that of seed dressing or foliar spraying alone in both varieties. In the combination of seed dressing and foliar application of Prima, Regoplan and Fast Start significantly increased seed weight per plant by 10.4 % and 8.7 %, and for Felicia, Antistress, Agrinos, and Regoplan significantly increased seed weight by 15.3 %, 14.4 %, and 12.7 %, accordingly, compared with plants without growth regulators. Different growth regulators increased the average seed weight per plant, and there were significant differences. Among these growth regulators, Regoplan had the most obvious effect on Prima (1.24 g), and Antistress and Regoplan had the greatest effect on Felicia (1.32 g and 1.32 g). **1000-seed weight (g).** The data in Table 4.7 revealed a significant difference in 1000-seed weight between the two varieties. The 1000-seed weight of Prima was higher than that of Felicia. Besides, there were differences among the three treatments, and the combination of seed dressing and foliar application had the greatest influence on the 1000-seed weight of the two varieties. However, the interaction effect between varieties and application methods of growth regulators was not significant. All growth regulators increased the average 1000-grain weight of both varieties, and there were differences. For Prima, the influence of Fast Start and Regoplan on 1000-grain weight reached the maximum value, which was 9.5 %. Except for Albit and Vermistim D, the other growth regulators significantly increased Felicia’s 1000-grain weight from 5.8 % to 11.7 %.

Table 4.6

Effects of different growth regulators on seed weight per plant of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	foliar	seeds+foliar	mean	seeds	foliar	seeds+foliar	mean
Control	1.15de	1.15f	1.15f	1.15g	1.18ef	1.18e	1.18e	1.18f
Albit	1.14e	1.17ef	1.17ef	1.16fg	1.18f	1.24d	1.24d	1.22e
Antistress	1.21ab	1.22abc	1.22cd	1.21bc	1.28ab	1.31ab	1.36a	1.32a
Agrinos	1.23a	1.2bcd	1.19de	1.21cd	1.27b	1.29bc	1.35a	1.31abc
Bioforge	1.15de	1.19cde	1.24bc	1.19de	1.25bcd	1.3ab	1.32bc	1.29c
Fast Start	1.19bc	1.24a	1.25ab	1.23ab	1.26bc	1.32ab	1.31bc	1.3bc
Regoplan	1.22a	1.23ab	1.27a	1.24a	1.31a	1.33a	1.33ab	1.32a
Stimulate	1.18bcd	1.18def	1.21cd	1.19e	1.23cd	1.26cd	1.29c	1.26d
Vermistim D	1.17cde	1.16f	1.19de	1.17f	1.22de	1.23d	1.23d	1.23e
Average treatment	1.18b	1.19b	1.21a		1.24c	1.27b	1.29a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	0.22	0.22	*				
Factor B	2	0.04	0.02	*				
Factor C	8	0.22	0.03	*				
A×B	2	0	0	*				
A×C	8	0.02	0	*				
B×C	16	0.02	0	*				
A×B×C	16	0.02	0	*				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, *$p < 0.05$.

Table 4.7

Effects of different growth regulators on 1000-seed weight of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	**foliar**	**seeds+foliar**	**mean**	**seeds**	**foliar**	**seeds+foliar**	**mean**
Control	3.38de	3.38d	3.38e	3.38d	3.09cd	3.09e	3.09e	3.09d
Albit	3.31e	3.46cd	3.47de	3.41d	3.06d	3.22d	3.23cd	3.17c
Antistress	3.53bc	3.57bc	3.59cd	3.57b	3.42a	3.4b	3.54a	3.45a
Agrinos	3.73a	3.49cd	3.52d	3.58b	3.30b	3.35bc	3.51a	3.39a
Bioforge	3.37de	3.54c	3.67bc	3.53b	3.27b	3.46ab	3.42ab	3.39a
Fast Start	3.53bc	3.81a	3.76ab	3.7a	3.28b	3.53a	3.43ab	3.41a
Regoplan	3.62ab	3.68b	3.81a	3.7a	3.43a	3.46ab	3.45ab	3.45a
Stimulate	3.51bc	3.47cd	3.57cd	3.52bc	3.21b	3.28cd	3.34bc	3.27b
Vermistim D	3.47cd	3.40d	3.49de	3.45cd	3.19bc	3.19de	3.19de	3.19c
Average treatment	3.50b	3.53b	3.59a		3.25b	3.33a	3.36a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	2.07	2.07	*				
Factor B	2	0.26	0.13	*				
Factor C	8	2.09	0.26	*				
A×B	2	0.01	0.01	NS				
A×C	8	0.14	0.02	*				
B×C	16	0.37	0.02	*				
A×B×C	16	0.21	0.01	*				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, *$p < 0.05$.

Table 4.8

Effects of different growth regulators on seed yield of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	**foliar**	**seeds+foliar**	**mean**	**seeds**	**foliar**	**seeds+foliar**	**mean**
Control	1.61de	1.61e	1.61f	1.61f	1.66fg	1.66e	1.66e	1.66f
Albit	1.6e	1.63de	1.64ef	1.62ef	1.65g	1.74d	1.74d	1.71e
Antistress	1.69ab	1.7ab	1.71bc	1.7b	1.8ab	1.83ab	1.91a	1.84ab
Agrinos	1.72a	1.68abc	1.67cde	1.69bc	1.78bc	1.81bc	1.89a	1.83abc
Bioforge	1.62de	1.67bcd	1.73ab	1.67cd	1.75cde	1.82ab	1.84bc	1.8c
Fast Start	1.66bc	1.73a	1.76a	1.72ab	1.77bcd	1.85ab	1.83bc	1.82bc
Regoplan	1.71a	1.72a	1.77a	1.74a	1.84a	1.87a	1.86ab	1.85a
Stimulate	1.65bcd	1.65cde	1.69cd	1.66d	1.73de	1.77cd	1.8c	1.76d
Vermistim D	1.64cde	1.62e	1.66de	1.64e	1.7ef	1.72d	1.72d	1.71e
Average treatment	1.66b	1.67b	1.69a		1.74c	1.78b	1.81a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	0.44	0.44	*				
Factor B	2	0.07	0.04	*				
Factor C	8	0.44	0.05	*				
A×B	2	0.01	0	*				
A×C	8	0.03	0	*				
B×C	16	0.04	0	*				
A×B×C	16	0.03	0	*				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, $*p < 0.05$.

4.2. Effects of growth regulators on the yield capacity and quality of mustard (*Brassica Juncea* L.) seeds

Seed yield capacity (t/ha). According to the data, the seed yield capacity of Felicia (1.78 t/ha) was significantly higher than that of Prima (1.67 t/ha) (Table 4.8). In both varieties, the combination of seed dressing and foliar application produced higher yields than either method of biostimulant applied alone. All growth regulators increased the average seed yield. The maximum yield for Prima was a combination of variants using Fast start – 1,72 t/ha and Regoplan – 1,72 t/ha. For Felicia, Agrinoss – 1,89t/ha, Antistress – 1,89 t/ha). There were significant differences in the interactions between varieties, application methods, and biostimulants.

Oil content (%). The greatest average oil content was created with the combination of seed dressing and foliar application in Prima (39.04%) and this was significantly greater than the other two treatments (Table 4.9). The application of growth regulators increased the average oil content by 5.61 % to 1.18 %. Among these regulators, Agrinos, Fast Start, and Regoplan have a significant effect on the oil content of Prima. However, there was no significant difference in the average oil content of Felicia between the regulator and the application method.

Protein content (%). There was no difference in protein content between the two varieties (Table 4.10). Similarly, the application and method of external regulators had little effect on average protein content.

Table 4.9

Effects of different growth regulators on oil content of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	**foliar**	**seeds+foliar**	**mean**	**seeds**	**foliar**	**seeds+foliar**	**mean**
Control	39.1a	34.73d	37.88bc	37.24d	37.67a	37.6a	41.98a	39.08a
Albit	37.51a	38.1abc	37.43c	37.68d	38.08a	38a	37.67b	37.92a
Antistress	37.78a	38.68abc	38.37abc	38.28abcd	39.23a	37.3a	38.32b	38.28a
Agrinos	38.62a	39.4ab	39.95a	39.33a	39.23a	38.57a	39.13b	38.98a
Bioforge	37.13a	37.87abc	39.47ab	38.16bcd	38.47a	38.22a	38.87b	38.52a
Fast Start	38.33a	39.67a	39.69ab	39.23ab	39.09a	38.8a	38.33b	38.74a
Regoplan	38.64a	38.34abc	40.3a	39.1abc	38.47a	38.8a	39.13b	38.8a
Stimulate	37.3a	37.56bc	39.2abc	38.02cd	39.6a	39.17a	38.67b	39.15a
Vermistim D	37.93a	37.29c	39.02abc	38.08cd	37.57a	37.93a	37.03b	37.51a
Average treatment	38.04b	37.96b	39.04a		38.6a	38.27a	38.79a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	1.75	1.75	NS				
Factor B	2	18.65	9.33	*				
Factor C	8	36.41	4.55	*				
A×B	2	4.56	2.28	NS				
A×C	8	23.59	2.95	NS				
B×C	16	41.4	2.59	NS				
A×B×C	16	49.54	3.1	*				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan’s multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, *$p < 0.05$.

Table 4.10

Effects of different growth regulators on protein content of *Brassica Juncea* L. (2019-2021）

Regulators	Prima				Felicia			
	seeds	**foliar**	**seeds+foliar**	**mean**	**seeds**	**foliar**	**seeds+foliar**	**mean**
Control	23.39a	25.43a	23.62abc	24.14a	24.61a	24.84a	22.32b	23.92a
Albit	24.18a	23.55b	24.23ab	23.99ab	24.19ab	23.84ab	23.97a	24a
Antistress	24.37a	23.89b	23.75abc	24ab	23.66ab	24.64ab	24.77a	24.35a
Agrinos	24.23a	23.53b	23.09c	23.62ab	23.83ab	23.63ab	24.35a	23.94a
Bioforge	24.18a	24.09b	23.63abc	23.96ab	23.67ab	24.11ab	24.18a	23.99a
Fast Start	23.72a	23.61b	23.85abc	23.73ab	23.45ab	23.64ab	23.97a	23.69a
Regoplan	23.9a	23.97b	24.5a	24.12a	24.53ab	24.03ab	24.08a	24.21a
Stimulate	24.23a	24.02b	23.39bc	23.88ab	23.24b	23.41b	24.2a	23.62a
Vermistim D	23.88a	23.23b	23.45bc	23.52b	24.01ab	23.87ab	24.21a	24.03a
Average treatment	24.01a	23.93a	23.72a		23.91a	24a	24a	
Significance	ds	SS	MS	F 0.05				
Factor A	1	0.31	0.31	NS				
Factor B	2	0.34	0.17	NS				
Factor C	8	4.76	0.6	NS				
A×B	2	0.97	0.49	NS				
A×C	8	2.47	0.31	NS				
B×C	16	16.77	1.05	*				
A×B×C	16	13.94	0.87	*				

Values within columns in the same substrate followed by the same letter are not significantly different according to Duncan's multiplerange test at the $p < 0.05$ level. Effects of factors according tothree-way ANOVA: NS – non-significant effect, *$p < 0.05$.

The correlation analysis between agronomic features and the yield capacity. The yield capacity is the result of the internal physiological and biochemical changes and the external environment during plant growth and development [18]. Correlations between agronomic traits and the yield capacity were shown in Figure 4.1.

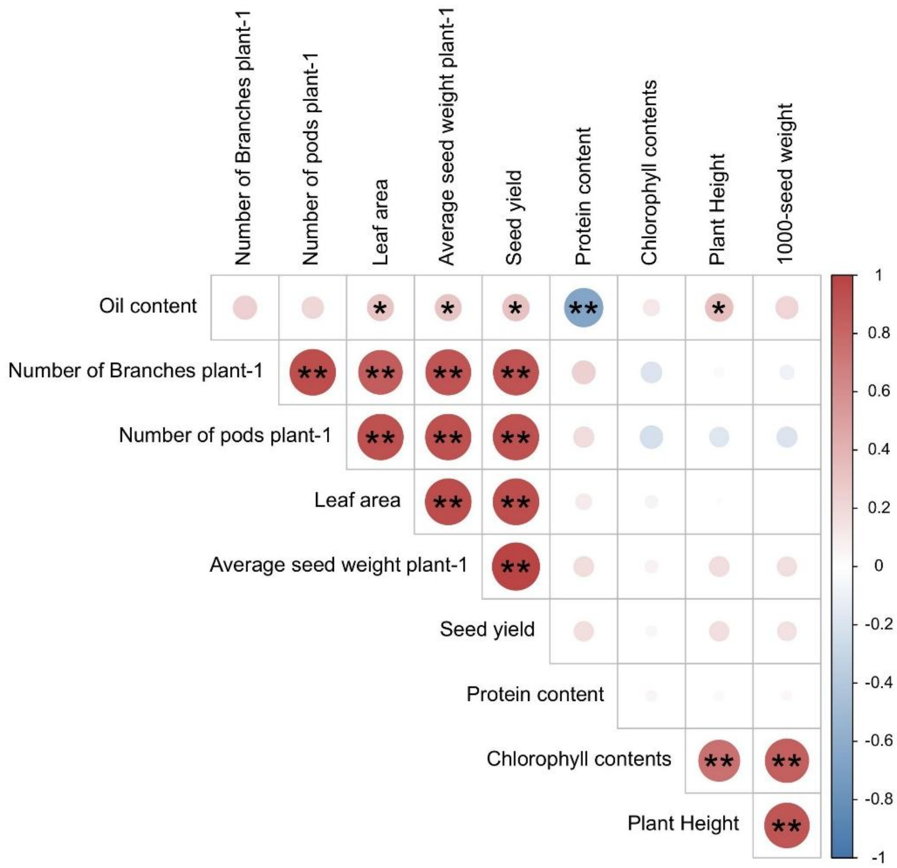


Figure 4.1. The correlation analysis between agronomic features and the yield capacity of *Brassica Juncea* L.

At the phenotypic level, seed yield had positive and highly significant ($p<0.01$) correlations with the number of pods per plant, the number of branches per plant, the leaf area, and the average seed weight per plant. In contrast, seed yield was not significantly correlated with chlorophyll content, plant height, and 1000-seed weight. The 1000-seed weight was a positively highly significant

($p<0.01$) association with chlorophyll content and plant height. These results showed that the number of branches, yield per plant, pod number, and leaf area were the main factors determining the yield capacity in both varieties. Oil content and protein are important parameters to evaluate the quality of mustard. Correlation results showed that oil content correlated negatively with protein.

Discussion. In practice, there are a variety of seed treatments, mainly including seed dressing, soaking, and priming [19-21]. Seed priming and soaking require precise processing time and often create problems for seeding. Seed dressing has the advantages of simple operation and low cost. Moreover, seed dressing can reduce the dose applied by concentrating the active ingredients on the seeds and roots of the plant. Therefore, it is used as a common processing method in production. Many previous studies have shown that seed dressing can improve germination rate, promote plant growth, elevate resistance to stress, delay plant senescence, and prevent diseases, insects, and pests [19-21].

Another common application of growth regulators on crops is foliar spraying. Foliar spray of nutrients and plant growth regulators is the fastest way to boost crop growth because the nutrients are available to plants at the initial and critical stages [13]. Foliar application of plant growth regulators could increase leaf area index, dry matter accumulation, delay root senescence and increase crop yield [24-25]. In both varieties, seed dressing combined with foliar application increased leaf area by 7.5 % and 6.4 % (Table 4.3), chlorophyll content by 3.5 % and 6.8 % (Table 4.4), pod number by 2.7 % and 7.9 % (Table 4.5), average seed weight per plant by 2.5 % and 4.0 % (Table 4.6), 1000-seed weight by 2.6 % and 3.4 % (Table

4.7), and seed yield by 1.8 % and 4.0 % (Table 4.8), accordingly, compared with seed dressing alone. Seed dressing and foliar application had a successful synergistic effect on the growth and yield capacity of mustard. These results were in line with the report on seed dressing and foliar application of molybdenum fertilizer on soybean [26]. Similarly, seed dressing with humic and foliar spraying of potassium fertilizer improved wheat quality [27]. The result may be attributed to the fact that seed dressing before sowing was beneficial to the seedling's root growth and nutrient absorption, and foliar spraying at flowering was conducive to increasing leaf area and grain filling, which ultimately led to an increase in the seed yield capacity. Moreover, the active components of the regulator have high internal absorbability in plants. After pre-treatment by seed dressing, the active substances of the regulator can be quickly absorbed by roots or budding seedlings, migrate to cotyledons and leaves, and finally stimulate the growth of crop seedlings [21].

Growth regulators are involved in controlling plant development and improving yield and quality [25-33]. We observed a positive effect of growth regulators on seed yield, 1000-seed weight, the number of branches per plant, the number of pods per plant, the leaf area, and the plant height of both varieties. But significant variation was found between different growth regulators. Overall, Regoplan and Fast Start had a remarkable effect on mustard growth and yield capacity. The differences may be attributed to the composition and concentration of growth regulators.

Seed yield is the result of many interdependent characters. Generally, the seed yield capacity was positively correlated with 1000-seed weight, plant height, and chlorophyll content, but there was no significant correlation between them in our study. This implies that increasing these features does not improve the seed yield capacity. Conversely, increasing the number of pods per plant, branches per plant, the leaf area, and average yield per plant were beneficial to increasing the seed yield capacity.

Conclusions to section 4

1. The variety of Prima created a significantly taller average plant (145.7 cm). An average plant height increased by 1.8%-6.7 %, among which the growth regulators of Agrinos, Fast Start, and Regoplan had the most obvious effect. The average plant height of Felicia increased by 4.3-6.0 %, but there was no significant difference with the application of Albit and Vermistim D. The variety of Felicia had a significantly higher number of branches than Prima. The combination of seed treatment and foliar spraying significantly increased the number of branches in Felicia. All growth regulators increased the number of branches in Prima and reached a maximum of 7.4 % with Regoplan.

2. The mean leaf area of Prima and Felicia increased by 9.0-17 % and 6.5-15.4 %, accordingly, compared with those without the growth regulators. Regoplan had the most excellent effect on the average leaf area of both varieties. The variety of Prima showed significantly higher chlorophyll content (1.17 mg/gram) than Felicia (1.07 mg/gram). Regoplan maximum increased the chlorophyll content of Prima and Felicia by 10.7 % and 18.8 %, accordingly, compared with the control.

3. The genotypes had a significant effect on the number of pods, among which Felicia (131 pcs) had a significantly higher pod number than Prima (113 pcs). The Regoplan significantly increased the number of pods in Prima by 12 pcs with the combined treatment of seed dressing and foliar application. Antistress and Regoplan increased the number of pods in Felicia by 19 pcs and 17 pcs,

accordingly. Different growth regulators increased the average seed weight per plant, and there were significant differences. Among these growth regulators, Regoplan had the most obvious effect on Prima (1.24 g), and Antistress and Regoplan had the greatest effect on Felicia (1.32 g and 1.32 g).

4. The seed yield capacity of Felicia (1.78 t/ha) was significantly higher than that of Prima (1.67 t/ha). The maximum yield capacity for Prima was the combination of variants using Fast start – 1,72 t/ha and Regoplan – 1,72 t/ha. For Felicia, Agrinoss – 1,89 t/ha, Antistress – 1,89 t/ha. All growth regulators increased the average 1000-grain weight of both varieties. For Prima, the influence of Fast Start and Regoplan on 1000-grain weight reached the maximum value, which was 9.5 %. Except for Albit and Vermistim D, the other growth regulators significantly increased Felicia's 1000-grain weight from 5.8 % to 11.7 %.

5. The application of growth regulators increased the average oil content from 1.18 % to 5.61 %. Among these regulators, Agrinos, Fast Start, and Regoplan have a significant effect on the oil content of Prima. However, there was no significant difference in the average oil content of Felicia between the regulator and the application method. There was no difference in protein content between the two varieties and variants using growth regulators.

6. As the result of the correlation analyses, the seed yield capacity had positive and highly significant ($p<0.01$) correlations with the number of pods per plant, the number of branches per plant, the leaf area, and average seed weight per plant. The 1000-seed weight was a positively highly significant ($p<0.01$) association with chlorophyll content and plant height. These results showed that

branch number, yield per plant, the number of pods, and leaf area were the main factors determining yield capacity in both varieties. The oil content correlated negatively with protein.

References to section 4

1. Raymer P. L. Canola: An emerging oilseed crop. *Trends in new crops and new uses.* 2002. 1. P. 122–126.

2. Melnyk A. V., Zherdetska S. V., Shabir H., Jia P. Optymizatsiya systemy zhyvlennya hirchytsi syzoyi v umovakh pivnichno-skhidnoho Lisostepu Ukrayiny (Optimization of the brown mustard nutrition system in terms of the northeastern Forest-Steppe of Ukraine). *Visnyk Sumskoho NAU*, 2018. № 9 (36). P. 60–63. (in Ukrainian).

3. Jham G. N., Moser B. R., Shah S. N., Holser R. A., Dhingra O. D., Vaughn S. F., Berhow M. A., Winkler−Moser J. K.. Isbell T. A., Holloway R. K. Wild brazilian mustard (*Brassica Juncea* L.) seed oil methyl esters as biodiesel fuel. *Journal of the American Oil Chemists' Society.* 2009. 86. P. 917–926.

4. Wright P., Morgan J., Jessop R. Comparative adaptation of canola (*Brassica Napus*) and indian mustard (*B. Juncea*) to soil water deficits: Plant water relations and growth. *Field Crop Res.* 1996. 49. P. 51–64.

5. Gunasekera C., Martin L., Siddique K., Walton G. Genotype by environment interactions of indian mustard (*Brassica Juncea* L.) and canola (b. Napus l.) in mediterranean-type environments: 1. Crop growth and seed yield. *Eur J Agron.* 2006. *25*. P. 1–12.

1. 6. Melnyk A., Zherdetska S., Melnyk T., Shabir G., Shahid A. Agrobiological features of mustard (*Brassica Juncea* L.) in Ukraine under current

climate change conditions. *AgroFor International Jornal*. Vol. 4. Issue No. 1, 2019. P. 93-12.

7. Xiong S., Chen S. Application of biostimulant in green development of agriculture and its market prospect. *Chemical Fertilizer Industry.* 2018. 45(6). P. 1-6.

8. Melnyk A. V., Butenko S. O., Jia P. Perspektyvy vykorystannya rehulyatoriv rostu z antystresovoyu diyeyu dlya oliynykh kultur rodyny Brassicaceae za umov zminy klimatu v livoberezhnomu lisostepu ukrayiny (Prospects of the use of growth regulators with anti-stress effects for oil crop of the Brassicaceae family in terms of climate change in the left-bank forest-steppe of Ukraine). *Naukovo-praktychna konferentsiya «Klimatychni zminy ta silske hospodarstvo».* (Mykolayiv, 1–12 April, 2019). Mykolayiv, 2019. P. 212-213 (in Ukrainian)

9. Melnyk A. V., Jia P., Butenko S. O. Influence of seeds tretment of growth regulators getermination of seeds mustard. *International scientific and practical conference "Goncharivski readings".* (Sumy, May 24-25, 2019). Sumy, 2019. P. 80-81.

10. Shvaykivskyy B. Ya., Lopushnyak V. I., Kyrychuk R. H. Rehulyatory rostu roslyn – efektyvnyy zasib pidvyshchennya produktsiyi silskohospodarskykh kultur (Plant growth regulators as an effective means of increasing production of agricultural crops). *Silskyy hospodar.* 2000. № 5–6. P. 3–4. (in Ukrainian)

11. Anishyn L. A. Rehulyatory rostu roslyn: sumnivy i fakty (Plant growth regulators: doubts and facts). *Propozytsiya*. 2002. № 5. P. 64–65. (in Ukrainian)

12. Han Y., Ying S., Du J., Feng N., Zheng D. Effects of plant growth regulators compound on growth and yield of maize (*Zea Mays* L.). *Journal of Northeast Agricultural Sciences*. 2016. 41(1). P.28-31.

13. Prabha V. V., Senthil A., Sritharan N., Boominathan P. Effect of foliar application of plant growth regulators and nutrients on physiological traits of finger millet (*Eleusine Coracana*). *Research on Crops.* 2016. 17. P. 483.

14. Setia R., Setia N., Ahuja K., Malik C. Effect of 'mixtalol'on growth, yield and yield components of indian mustard (*Brassica Juncea*). *Plant Growth Regul.* 1989. *8.* P. 185–192.

15. Zeng L., Cai J., Li J., Lu G., Li C., Fu G., Zhang X., Liu Q. Zou X., Cheng Y. Exogenous application of a low concentration of melatonin enh,a,nce salt tolerance in rapeseed (*Brassica Napus* L.) seedlings. *Journal of integrative agriculture.* 2018. 17. P. 328–335.

16. Melnyk A., Jia P., Li R., Kubrak T., Shyian M., Bobonych V. Impact of growth regulators on the yield capacity of brown mustard in Ukraine. *VII International Scientific and Practical conference "The world of science and innovation".* (United Kingdom, London, 10–12 February, 2021). London, 2021. P. 114–119.

17. Butenko S. O., Jia P. Vplyv rehulyatoriv rostu roslyn na yakist nasinnya hirchytsi v umovakh pivnichno-skhidnoho Lisostepu Ukrayiny (The influence of plant growth regulators on the quality of mustard seeds in terms of the northeastern Forest-Steppe of Ukraine). *Tavriyskyy naukovyy visnyk.* 2022. № 124. P. 10–18. (in Ukrainian) DOI: https: //doi.org/ 10.32851/ 2226-0099.2022.124.2

18. Shpota V. I. Korrelyatsiya priznakov u yarovogo rapsa (Correlation of traits in spring rapeseed). *Nauch.-tekhn. byul. VNIIMK.* Krasnodar, 1986. Vyp. 11(93). P. 18–20. (in Russian)

19. Khan M. N., Zhang J., Luo T., Liu J., Rizwan M., Fahad S., Xu Z., Hu L. Seed priming with melatonin coping drought stress in rapeseed by regulating reactive oxygen species detoxification: Antioxidant defense system, osmotic adjustment, stomatal traits and chloroplast ultrastructure perseveration. *Ind Crop Prod.* 2019. *140*. P. 111597.

20. Kumari N., Rai P. K., Bara B.M., Singh I. Effect of halo priming and hormonal priming on seed germination and seedling vigour in maize (*Zea Mays* L) seeds. *Journal of Pharmacognosy and Phytochemistry.* 2017. 6. P. 27–30.

21. Duan Q., Jiang X., Bao J., Wang C., Li X., Liu P., Zhang J. Effects of seed dressing with imidacloprid on the seedlings growth and protective enzyme activities of high-yielding summer maize. *Yingyong Shengtai Xuebao.* 2011. 22. P. 2482–2486.

22. Huang L., Zhao C.-l. Huang F., Bai R.-e., Lü Y.-b., Yan F.-m., Hao Z.-p. Effects of imidacloprid and thiamethoxam as seed treatments on the early seedling features and aphid-resistance ,of oilseed rape. *Journal of Integ,rative Agriculture.* 2015. 14. P. 2581–2589.

23. Shao R. X., Jian L. I., Zhao Y., Jin-Jin L. I. Effect of kinetin and succinic acid seed dressing on the antioxidant system and the endogenous plant hormones in aging process of maize. *Plant Physiology Journal.* 2012. 48(4). P. 343–349.

24. Yasari E., Vahedi A. Impact of urea as nitrogen source and pix as growth regulator on cotton (*Gossypium Hirsutum*L). *International Journal of Biology*. 2012. 4. P. 140.

25. Nilesh G., Chakrborti P., Rai A., Gupta P. Effect of plant growth regulator on growth response and yield component in wheat (*Triticum Aestivum* L.) crop. *Research Journal of Agricultural Sciences*. 2012. 3. P. 204–208.

26. Zhu W. C., Cheng-Ye L. I., Xiao-Feng W. U., Tao W., Zhou Q. ,Min X. U., Xie Y. Z., Tang L. Z. Effects of different molybdenum fertilizer application ways on agronomic characters and yield of spring soybean “wuyuehuang”. *Hunan Agricultural Sciences*. 2019. 8. P. 46-49.

27. Knapowski T., Szczepanek M., Wilczewski E., Pobereżny J. Response of wheat to seed dressing with humus and foliar potassium fertilization. *Journal of Agricultural Science & Technology*. 2015. 17. P. 1559–1569.

28. Freeha, A., Abdul, W., Farrukh, J., & Muhammad, A. (2008). Influence of foliar applied thiourea on flag leaf gas exchange and yield parameters of bread wheat (*Triticum Aestivum*) cultivars under salinity and heat stresses. *International Journal of agriculture and Biology*. 2008. 10(6), 619-626.

29. Butenko S. O., Jia P. Vplyv rehulyatoriv rostu roslyn na yakist nasinnya hirchytsi v umovakh pivnichno-skhidnoho Lisostepu Ukrayiny (The influence of plant growth regulators on the quality of mustard seeds in terms of the northeastern Forest-Steppe of Ukraine). *Tavriyskyy naukovyy visnyk*. 2022. 124. P. 10–18. (in Ukrainian)

30. Butenko S. O., Jia P., Kolosok V. H. Osoblyvosti vykorystannya

fotosytnetychno aktyvnoyi radiatsiyi roslynamy hirchytsi yaroyi v umovakh Livoberezhnoho Lisostepu Ukrayiny (Peculiarities of the use of photosynthetically active radiation by spring mustard plants in the conditions of the Left-Bank Forest-Steppe of Ukraine). *Materialy mizhnarodnoyi naukovo-praktychnoyi konferentsiyi «Honcharivski chytannya».* Sumy, 2021. P. 78–79. (in Ukrainian)

31. Melnyk A. V., Jia P., Kolosok V. Response of growth and yield components of two varieties of oilseed mustard (*Brassica Juncea* L.) To growth regulators under the agro-ecological conditions of north-eastern forest-steppe of ukraine. *Material of the International Scientific and Practical conference "Honcharivski readings" dedicated to the 93th anniversary of Doctor of Agricultural Sciences professor Mykola Demyanovych Honcharov.* (Sumy, 25 May, 2022). Sumy, 2022. P. 83–84.

32. Polyakov O., Zhuravel V. Perspektyvy vyroshchuvannya hirchytsi (Prospects of mustard cultivation). *Propozytsiya.* 2009. № 2. P. 54–56. (in Ukrainian)

33. Hamayunova V. V., Khonenko L. H., Kovalenko O. A., Hyrlya L. M. Urozhaynist hirchytsi zalezhno vid pohodnykh umov ta normy vysivu na chornozemakh pivdennykh (Mustard yield capacity depending on weather conditions and sowing rates on southern black soil). *Tavriyskyy naukovyy visnyk.* Kherson : Aylant, 2014. Vyp. 88. P. 50–56. (in Ukrainian)

SECTION 5

ECONOMIC AND ENERGY EFFICIENCY OF MUSTARD (*BRASSICA JUNCEA* L.) CULTIVATION ACCORDING TO THE VARIETY, METHOD OF TREATMENT, AND GROWTH REGULATORS

5.1. Economic efficiency of cultivating mustard according to the variety, method of treatment, and growth regulators

Currently, the economic profitability of new technological operations in the system of cultivating crops becomes an important issue in the process of their implementation, as prices for fuel and lubricants, fertilizers, seeds, as well as wages are cultivating every year. This causes high production costs, which in the case of insufficient efficiency of a certain technological method can lead to losses. Thus, in economic terms, the basis of modern management is to minimize the cost of unit production [1].

The main indicators of production efficiency are unit cost and profitability. To increase profitability and reduce production costs, it is necessary to create conditions for obtaining the highest yield by fulfilling the potential of agricultural varieties, optimizing cultivation technology, prudent use of fertilizers and growth regulators to reduce costs at all stages of production [2].

Most components of profitability indicators will be used to evaluate the efficiency of new technological methods. Mass of profit can be considered the key indicator of economic effect, as it helps to form an idea of the profitability of cultivating a particular crop in the economy, as well as the economic effect as a whole. To consider the fact that the repeated use of unreasonable methods in cultivation technology has led to higher prices and, as a consequence, – losses [3].

Economic efficiency was calculated at prices of 2021. The costs of cultivating finished products were calculated according to standard technological maps [4]. The yield is taken as the average for three years of research (2019-2021). Extended tables with the calculation of the economic efficiency of cultivating brown mustard varieties of Prima and Felicia at different methods of treatment with growth regulators are presented in Annexes.

The main indicators of economic efficiency of brown mustard variety Prima at different methods of treatment with growth regulators are presented in Table 5.1.

The table indicates that all options for the methods of treatment and growth regulators are cost-efficient.

According to economic efficiency indicators, it is more profitable to grow Prima brown mustard at seed treatment with Agrinos growth regulator, as the profit per hectare is UAH 20,630, which gave the highest level of profitability of 133% at the lowest cost (UAH 9,005.7). At the foliar application of growth regulators in the cultivation of a brown mustard variety of Prima, the use of Regoplan was the most cost-efficient, its profitability was 132% and the profit was 20,530 UAH per hectare.

At the seed treatment + foliar application of growth regulators, the maximum values of profitability (137%) and the profit of UAH 21,509 / ha were achieved with the use of Regoplan. It is worth noting that this growth regulator provided the maximum yield for Prima brown mustard, which provided a reduction in cost and an increase in profitability.

Table 5.1

Economic efficiency of cultivating a yellow mustard variety of Prima according to the methods of treatment with growth regulators (average for 2019-2021)

Method of treatment	Growth regulators	Economic indicators			
		Yield capacity, t/ha	Self-costUAH / t	Profit, UAH / t	Profitability, %
Seed treatment	Control	1,61	9 526,4	18 473	120
	Albit	1,60	9 577,7	18 276	119
	Antistress	1,69	9 143,9	20 037	130
	Agrinos	1,72	9 005,7	20 630	133
	Bioforge	1,62	9 484,6	18 655	121
	Fast start	1,66	9 286,8	19 444	126
	Regoplan	1,71	9 050,8	20 433	132
	Stimulate	1,65	9 333,8	19 249	125
	Vermistim D	1,64	9 383,6	19 051	124
Foliar application	Albit	1,63	9 510,3	18 728	121
	Antistress	1,70	10 856,9	17 243	93
	Agrinos	1,68	9 225,4	19 781	128
	Bioforge	1,67	10 412,1	17 682	102
	Fast start	1,73	9 708,2	19 535	116
	Regoplan	1,72	9 063,7	20 530	132
	Stimulate	1,65	10 072,9	18 030	108
	Vermistim D	1,62	10 540,8	16 944	99
Seedt reatment + foliar application	Albit	1,64	9 461,0	18 924	122
	Antistress	1,71	10 805,1	17 433	94
	Agrinos	1,67	9 273,7	19 583	126
	Bioforge	1,73	10 106,4	18 846	108
	Fast start	1,76	9 571,9	20 114	119
	Regoplan	1,77	8 847,8	21 509	137

	Stimulate	1,69	9 871,9	18 806	113
	Vermistim D	1,66	10 326,2	17 719	103

Therefore, in economic terms, growing Prima yellow mustard is the most profitable with the use of seed treatment + foliar application of Regoplan growth regulator.

To analyze the economic efficiency of cultivating the yellow mustard variety of Felicia according to the methods of treatment with growth regulators, we use the indicators of yield, cost, profit, and profitability presented in Table 5.2.

The table indicates that, in economic terms, absolutely all options for the Felicia variety of brown mustard are economically viable, because absolutely all options have positive profitability.

At the seed treatment with growth regulators, the maximum value of profitability (147 %) was calculated for Regoplan. Since this chemical increased yield capacity. As the self-cost decreased, it led to increased profitability.

At the foliar application of growth regulators, the maximum value of profitability of 149 % was provided by Regoplan. Its self-cost was 8,446.3 UAH / t, and the profit was 23,475 UAH per hectare. When treating seeds + foliar application with growth regulators, Regoplan chemical provided the highest economic effect. The level of profitability was 147 % and the profit per hectare was 23,276 UAH.

Thus, the cultivation of the mustard variety of Felicia is economically viable. The maximum value of profitability for all methods of treatment was provided by the growth regulators of Regoplan and Argrinos, as its application increased yield capacity, which in turn led to a reduction in unit costs and increased profits per hectare. The most profitable method of treatment was foliar application and treating seeds + foliar application. The profit per hectare was more then 23,000 UAH.

Table 5.2

Economic efficiency of cultivating a yellow mustard variety of Felicia according to the methods of treatment with growth regulators (average for 2019-2021)

Method of treatment	Growth regulators	Economic indicators			
		Yield capacity, t/ha	Self-cost UAH / t	Profit, UAH / t	Profitability, %
Seed treatment	Control	1,66	9 280,6	19 454	126
	Albit	1,65	9 328,9	19 257	125
	Antistress	1,80	8 668,6	22 197	142
	Agrinos	1,78	8 748,2	21 808	140
	Bioforge	1,75	8 881,5	21 207	136
	Fast start	1,77	8 794,6	21 604	139
	Regoplan	1,84	8 507,8	22 986	147
	Stimulate	1,73	8 965,4	20 820	134
	Vermistim D	1,70	9 100,6	20 229	131
Foliar application	Albit	1,74	8 995,5	20 888	133
	Antistress	1,83	10 182,7	19 796	106
	Agrinos	1,81	8 661,0	22 334	142
	Bioforge	1,82	9 666,6	20 627	117
	Fast start	1,85	9 167,1	21 891	129
	Regoplan	1,87	8 446,3	23 475	149
	Stimulate	1,77	9 482,6	20 386	121
	Vermistim D	1,72	10 007,4	18 907	110
Seed treatment + foliar application	Albit	1,74	8 995,8	20 877	133
	Antistress	1,91	9 816,8	21 360	114
	Agrinos	1,89	8 353,3	23 902	151
	Bioforge	1,84	9 583,9	21 006	119
	Fast start	1,83	9 258,0	21 488	127
	Regoplan	1,86	8 485,8	23 276	147
	Stimulate	1,80	9 352,2	20 966	125

	Vermistim D	1,72	10 013,6	18 897	110

Having conducted an economic evaluation of the cultivation of brown mustard according to the variety, method of treatment, and growth regulators, we found that all variants of the experiment, including controls, are advantageous, because profitability ranged from 94 to 151 %. It was found that the growth regulators of Regoplan and Agrinos had the maximum values of profitability. Regarding the method of treatment, the most profitable for the Prima variety was seed treatment + foliar application, and for the Felicia variety – foliar application. The maximum profit was obtained by cultivating the Felicia mustard variety.

5.2. Energy efficiency of yellow mustard cultivation according to the variety, method of treatment, and growth regulators

Due to the aggravation of the energy crisis in Ukraine and other countries, the issue of energy conservation in agricultural production is quite acute. To solve this problem, the introduction of new technological methods of cultivating crops in terms of energy efficiency should be analyzed.

The analysis of energy efficiency includes the determination of energy consumption for the use of a separate technological method and the comparison of the general level of various technologies and machine complexes for their implementation, regardless of the pricing policy. Therefore, for current economic conditions, the universality of this method of evaluating the efficiency of recommended agricultural practices is very important [4].

Energy efficiency helps to describe the element of cultivation technology, as it shows the degree of energy use per unit of the final product produced. Energy efficiency is assessed not only by quantitative indicators, such as the amount of energy used per unit of final product but also by qualitative – low, high [5].

To determine the energy efficiency of gray mustard cultivation depending on the variety, the method of treatment with growth regulators took into account the energy costs for cultivation, determined the energy yield of the crop, and calculated the energy efficiency ratio Appendices.

The coefficient of energy efficiency is the main indicator in the energy analysis of the introduction of certain technological methods in crop cultivation and is defined as the ratio of aggregate to metabolic energy [5].

In terms of energy evaluation, when the crop's energy efficiency coefficient is more than 1, it is considered that such a crop is profitable and efficient [2].

The graphic representation of the levels of the energy efficiency coefficient of cultivating a brown mustard variety of Prima at the seed treatment with growth regulators is shown in Figure. 5.1.

Figure 5.1. indicated that the use of Agrinos growth regulator for the seed treatment was energy efficient. The energy efficiency coefficient for this chemical was 2.60. This is because the chemical increased yield capacity and, as a result, the energy output indicator increased with the yield (28,294 mJ). Even at maximum cost (10,903 mJ), the maximum level of energy efficiency war guaranteed.

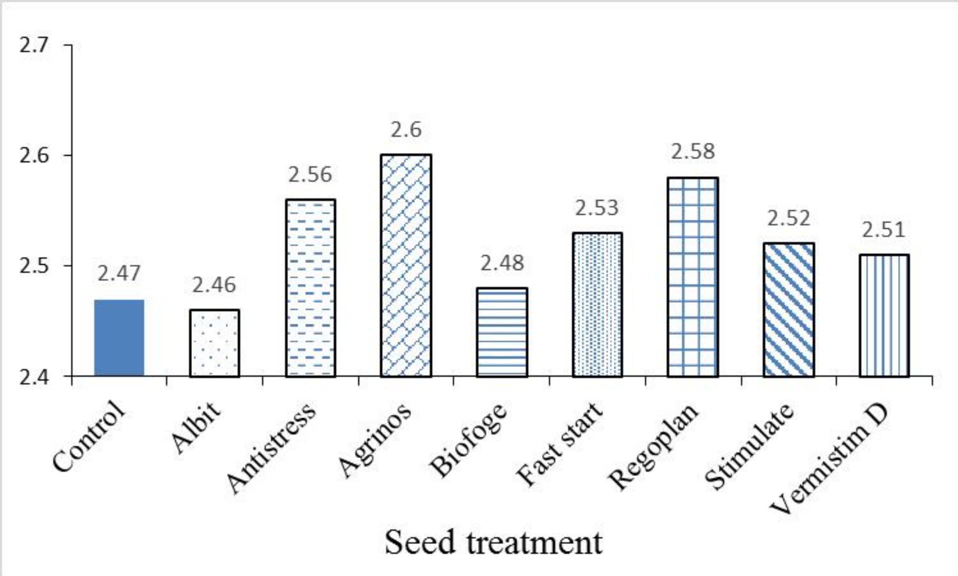


Figure. 5.1. Energy evaluation of the efficiency (K_{ee}) of cultivating a yellow mustard variety of Prima for the seed treatment with growth regulators (average for 2019-2021)

To evaluate the energy efficiency of cultivating a brown mustard variety of Prima with the foliar application of growth regulators, a graphical representation of the levels of energy efficiency coefficients in Figure. 5.2 is used.

It is most effective to cultivate a brown mustard variety of Prima at the foliar application of Regoplan growth regulator. This is evidenced by the highest energy efficiency coefficient– 2.62. The highest level of energy output with the yield of 28,459 mJ is calculated for this chemical, while the total energy cost is 10,799 mJ.

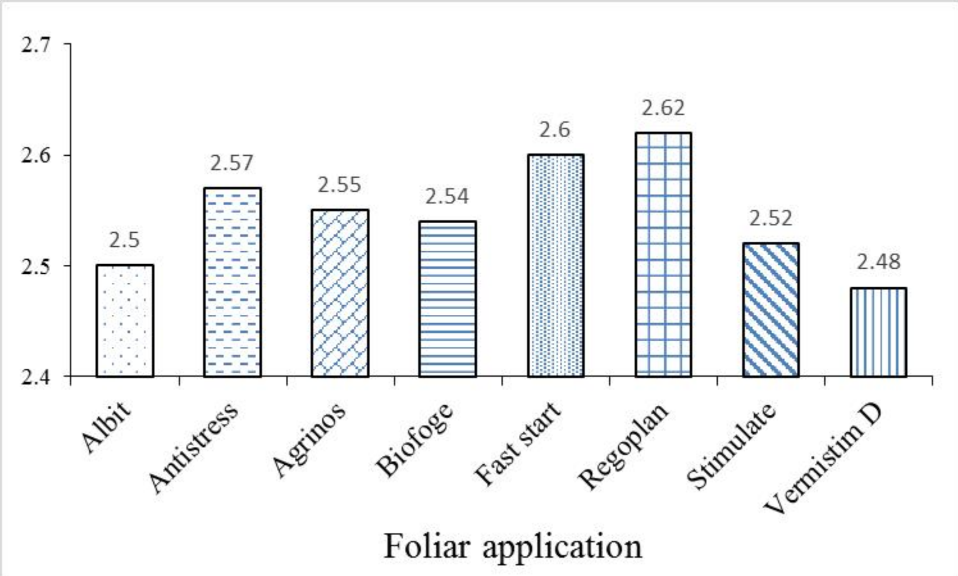


Figure. 5.2. Energy evaluation of the efficiency (K_{ee}) of cultivating a yellow mustard variety of Prima for the foliar application of growth regulators (average for 2019-2021)

The analysis of energy efficiency of cultivating a brown mustard variety of Prima for the seed treatment + foliar application of growth regulators is shown in Figure. 5.3.

The highest level of energy output with the yield was obtained when cultivating a brown mustard variety of Primafor the seed treatment + foliar application of growth regulator Regoplan. It was 29,117 mJ, which at a total energy cost of 11,002 mJ, led to the maximum energy efficiency coefficient of 2.65.

Thus, the analysis of energy efficiency of cultivating a brown mustard variety of Prima according to the methods of treatment and growth regulators shows that absolutely all variants of the experiment, including the control are energy efficient, as energy efficiency coefficients were higher than 1. The maximum level of energy efficiency was recorded for the seed treatment + foliar application of the Regoplangrowth regulator. K_{ee}=2.65, the energy output with a yield was 29,117 mJ. It is worth noting that for the variants with the foliar application of growth regulators, Regoplan was also the best chemical.

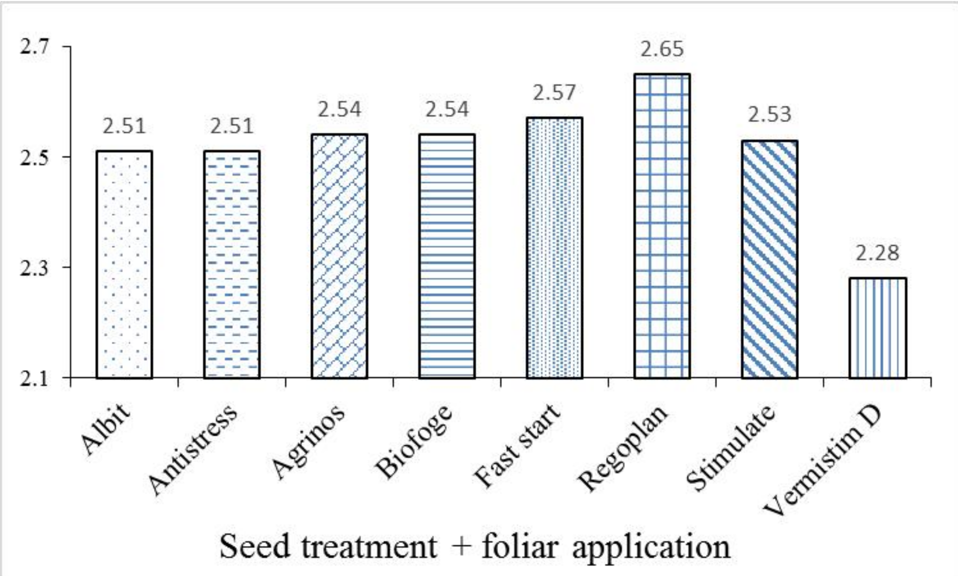


Figure. 5.3. Energy evaluation of the efficiency (K_{ee}) of cultivating a yellow mustard variety of Prima for the seed treatment + foliar application of growth regulators (average for 2019-2021)

Indicators of energy efficiency of cultivating a brown mustard variety of Felicia for the seed treatment with growth regulators are presented in Figure. 5.4.

The figure shows that in the seed treatment with growth regulators, the maximum value of the energy efficiency coefficient of 2.72 was calculated for the Regoplan chemical. This is because the use of this growth regulator increased yield capacity and, as a result, the energy output with the yield was 30,268 mJ, as well as the total cost of cultivation was 11,117 mJ. However, we can state that the cultivation cost is quite justified.

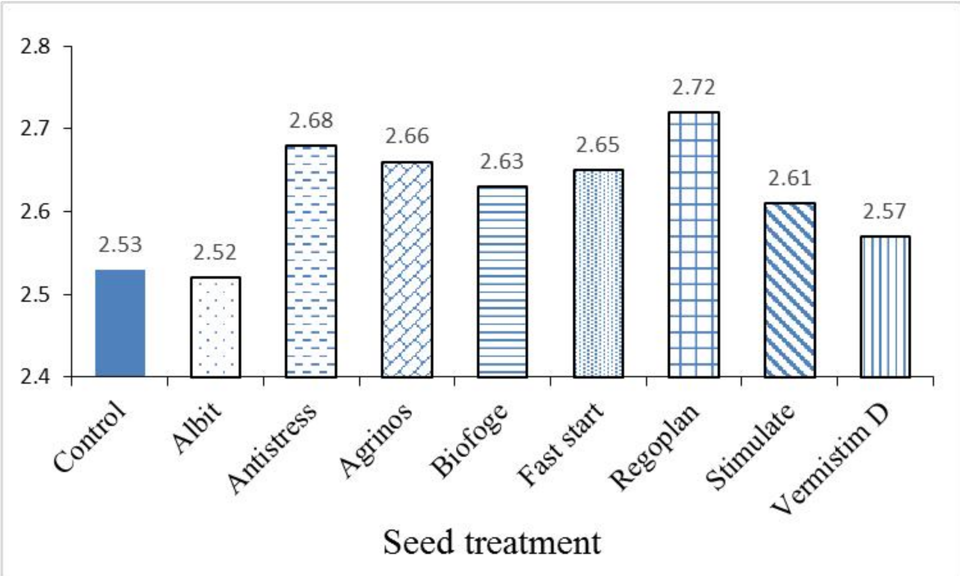


Figure. 5.4. Energy evaluation of the efficiency (K_{ee}) of cultivating a yellow mustard variety of Felicia for the seed treatment with growth regulators (average for 2019-2021)

In terms of energy efficiency, to analyze the cultivation of the Felicia brown mustard variety with the foliar application of growth regulators, the diagram of indicators of the energy efficiency coefficient presented in Figure. 5.5 is used.

Having analyzed the results of calculations of energy efficiency of cultivating a brown mustard variety of Felicia with the foliar application of growth regulators, it was determined that the maximum energy output with a yield of 30,762 mJ was obtained for Regoplan, which, at a total energy consumption of 11,170 mJ, led to a maximum the level of the energy efficiency coefficient is 2.75. This is because the growth regulator Regoplan increased yield capacity to 1.87 t / ha.

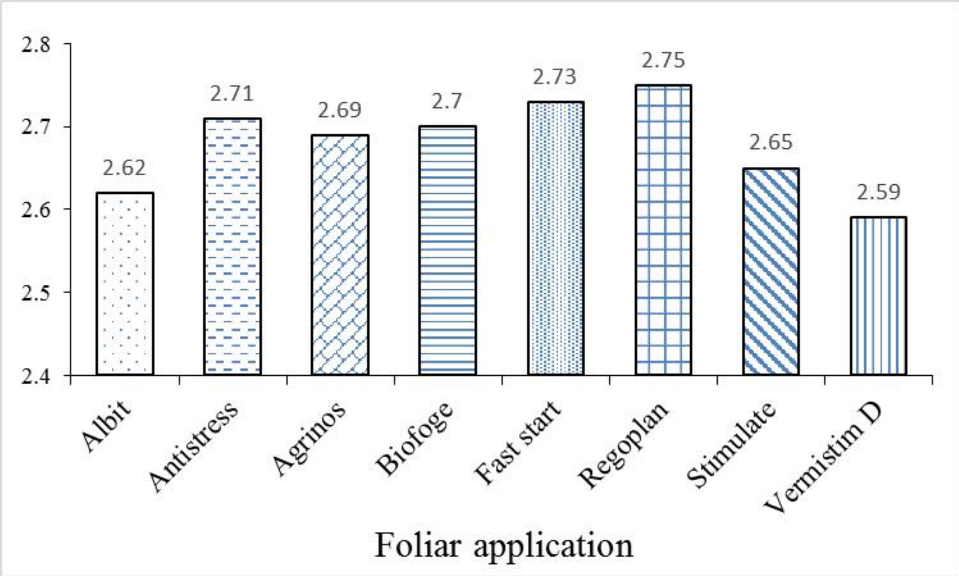


Figure. 5.5. Energy evaluation of the efficiency (K_{ee}) of cultivating a yellow mustard variety of Felicia for the foliar application of growth regulators (average for 2019-2021)

The graphical presentation of energy efficiency coefficients in Figure. 5.6 allows evaluating the energy efficiency of cultivating a brown mustard variety of Felicia for the seed treatment + foliar application of growth regulators.

As the figure indicates, the maximum value of the energy efficiency coefficient (2.65) was recorded for the growth regulator of Regoplan for the seed treatment + foliar application. The energy output with the yield was 27,801 mJ, while the total energy cost was 10,999 mJ.

In general, the cultivation of a brown mustard variety of Felicia is energy efficient, as the energy efficiency factor for all variants and controls was more than 1.

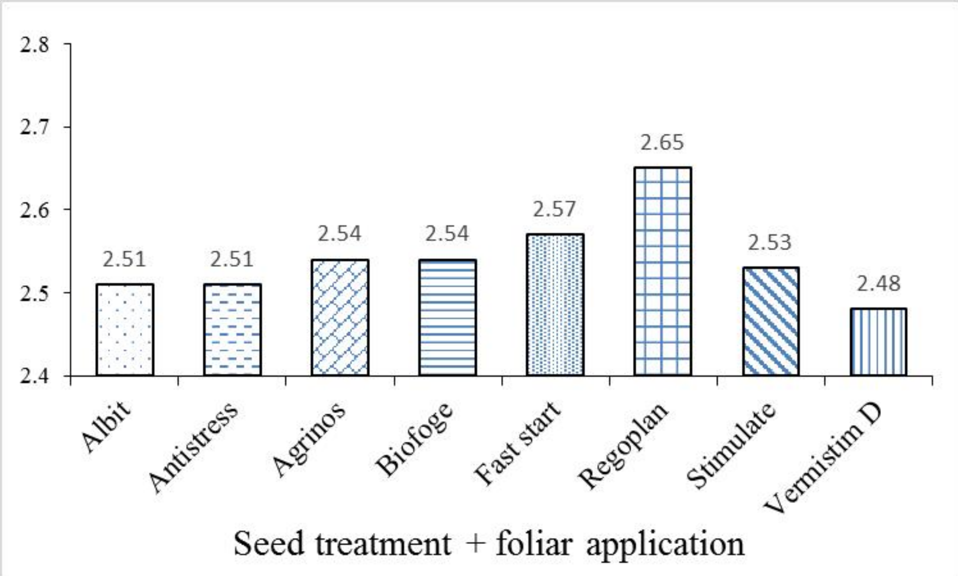


Figure. 5.6. Energy evaluation of the efficiency (K_{ee}) of cultivating a yellow mustard variety of Felicia for the seed treatment + foliar application of growth regulators (average for 2019-2021)

It is most profitable to grow the Felicia mustard according to the treatment variant – foliar application of growth regulators, as it has the highest energy efficiency – 2.75. As for the growth regulator, Regoplan had the most positive effect on all methods of treatment.

Having conducted the energy assessment of mustard cultivation efficiency according to the variety, methods of treatment, and growth regulators, we can state the energy efficiency, as none of the coefficients was less than 1. In general, the trend towards K_{ee} has been determined, indicating that for almost all varieties and treatment methods, the maximum values belonged to the Regoplan and Agrinos growth regulators. Regarding the method of treatment, the highest values of energy efficiency coefficients for the Prima variety were calculated for the seed treatment + foliar application and the Felicia variety – the foliar application and the seed treatment + foliar application. Felicia turned out to be the most profitable variety.

Conclusions to section 5

Having evaluated the economic and energy efficiency of cultivating yellow mustard according to the variety, method of treatment, and growth regulators, we can conclude the following:

1. Cultivating yellow in the northeastern Forest-Steppe of Ukraine is economically and energy profitable. This is confirmed by the calculated profits, profitability levels, and indicators of energy efficiency coefficients (K_{ee}).

2. For yellow mustard, the maximum level of profitability (142-151 %) and the highest profit (about 23 thousands UAH) were obtained for the cultivation of the variety of Felicia and the foliar application and seed treatment + foliar application of the Regoplan and Agrinos growth regulators.

3. Structured costs for growing yellow mustard are as follows: labor costs average ≈ 5-7%; seeds up to 2% (domestic); means of protection ≈ 16-27%; fuel ≈ 23-29%; other costs ≈ 20%.

5. The maximum value of the energy efficiency coefficient (2.74-2.77) and the highest energy output with a yield capacity (about 30 thousands mJ) was calculated for the cultivation of the yellow mustard variety of Felicia with the foliar application of Regoplan and Agrinos growth regulators.

References to section 5

1. Matsybora V. I. *Ekonomika silskoho hospodarstva: pidruchnyk* (Agricultural Economics: a textbook). K.: Vyshcha shkola, 1994. p. 415.

2. Yashchenko O. I., Romanyuk O. P. *Ekonomichni ta sotsialni aspekty otsinky efektyvnosti* (Economic and social aspects of performance evaluation). Naukovyy visnyk NLTU Ukrayiny. 2008. Vyp. 18.6. P. 237–238.

3. *Ekonomika silskoho hospodarstva:* navch. posibnyk (Economics of agriculture: textbook). Zbarskyy V. K., Matsybora V. I. ta in.; za red. V. K. Zbars′kohoi V. I. Matsybory. K.: TOV «Ahrar Media Hrup», 2013. p. 316.

4. Medvedovskyy O. K., Ivanenko P. I. *Enerhetychnyy analiz intensyvnykh tekhnolohiy v silskohospodarskomu vyrobnytstvi* (Energy analysis of intensive technologies in agricultural production). K.: Urozhay, 1988. p. 208.

5. Sabluk P. T., Melnyk Yu. F., Zubets M. V. et al.. *Tsinoutvorennya ta normatyvni vytraty v silskomu hospodarstvi: teoriya, metodolohiya, praktyka. U dvokhtomakh* (Pricing and regulatory costs in agriculture: theory, methodology, practice. In two volumes). T.1. Teoriya tsinoutvorennya ta tekhnolohichni karty vyroshchuvannya silskohospodarskykh kultur. Kyiv: NNTS IAYE, 2008. p. 697.

CONCLUSIONS

1. **For experiment 1.** The PI_{ABS} can be useful markers to screen *Brassica Juncea* L. genotypes and identify salt-tolerant genotypes. The decrease of leaf area under salt stress is closely related to the chlorophyll content.

2. The results indicated that 100 mM NaCl was a survival threshold for seedlings, and PI_{ABS} can be considered a good indicator for screening *Brassica Juncea* L genotypes. Understanding the mechanisms of the adaptation of mustard roots and shoots to salt could be of great importance. It may provide a theoretical basis for further analysis on genotypes of yellow mustard that are tolerant to salt.

3. **For experiment 2.** These results indicated that the fresh weight of roots and shoots had a compensating effect after rehydration. In addition, the shoot allocated more assimilates after rehydration, which resulted in a decrease in the root-shoot ratio of stressed screen *Brassica Juncea* L. plants.

4. These results suggested that screen *Brassica Juncea* L. can more effectively adapt to mild and short drought by maintaining a high chlorophyll content. Moreover, the decrease in leaf water content with drought increased the chlorophyll concentration per unit area to some extent, which led to the increase in chlorophyll content.

5. PI_{ABS} and F_v/F_m decreased significantly in the drought-treated screen *Brassica Juncea* L. compared with plants without stress, indicating that the reaction center of PSII was inactivated, and the performance of PSII decreased. After rehydration, the PI_{ABS} recovered or was higher than the control level, which

indicated a recovery in PS II performance and a compensatory effect. However, F_v/F_m failed to recover even after the release of the stress by the added water. One of the reasons for this difference could be the fact that PI_{ABS} was more sensitive to stress than F_v/F_m.

6. The drought stress induced a notable increase in the activities of SOD, POD, APX, and CAT in roots and leaves compared with the well-watered control plants, which indicated the activation of the antioxidant system. The activities of SOD, POD, CAT, and APX in the leaves under severe stress were significantly higher.

7. **For experiment 3.** Drought reduced root fresh weight in both varieties screen *Brassica Juncea* L. but did not affect shoot fresh weight and germination rate. There were differences in the inhibition degree of root growth between 'Felicia' and 'Prima' under drought stress.

8. Drought significantly reduced average root diameter and total root volume in 'Felicia', as well as the lateral root number and primary root length of 'Prima'. According to the morphological parameters of roots, 'Prima' was more sensitive to drought than 'Felicia'.

9. The PGRs mitigated the effects of drought on seedlings to some extent, but there were differences between the two varieties screen *Brassica Juncea* L. For drought-sensitive 'Prima', PGRs had a positive role against drought; on the contrary, for drought non-sensitive 'Felicia' the PGRs exhibited relatively poor effects against drought.

10. **For experiment 4.** The field reach results indicated that application with

growth regulators had a more beneficial effect on seed yield, 1000-seed weight, number of branches per plant, number of pods per plant, leaf area, and plant height of both varieties. The present study has demonstrated that the combination of seed dressing and foliar spraying effectively promoted screen *Brassica Juncea* L. growth compared to single seed dressing or foliar spraying.

11. The seed yield of Felicia (1.78 t/ha) was significantly higher than that of Prima (1.67 t/ha). The maximum yield for Prima was combination variants using Fast start - 1,76 t/ha and Regoplan - 1.77 t/ha. For Felicia: Agrinoss - 1.89 t/ha; Antistress - 1.91 t/ha).

12. All growth regulators increased the average 1000-grain weight of both varieties. For Prima, the influence of Fast Start and Regoplan on 1000-grain weight reached the maximum value, which was 9.5%. Except for Albit and Vermistim D, the other growth regulators significantly increased Felicia's 1000-grain weight by 5.8% to 11.7%.

13. The application of growth regulators increased the average oil content from 1.18% to 5.61%. Among these regulators, Agrinos, Fast Start, and Regoplan have a significant effect on the oil content of Prima. However, there was no significant difference in the average oil content of Felicia between the regulator and the application method. There was no difference in protein content between the two varieties and variants that use growth regulators.

14. As the result of correlation analyses, seed yield had positive and highly significant ($p<0.01$) correlations with the number of pods per plant, number of branches per plant, leaf area, and average seed weight per plant. The 1000-seed

weight had a positively highly significant ($p<0.01$) association with chlorophyll content and plant height. These results showed that branch number, yield per plant, pod number, and leaf area were the main factors determining yield in both varieties. The oil content was negatively correlated with protein.

15. Cultivating *Brassica Juncea* L. in the north-eastern Forest-Steppe of Ukraine is economically and energy profitable. For yellow mustard, the maximum level of profitability (142-151%) and the highest profit (about 23 thousands UAH) were obtained for the cultivation of the variety of Felicia and the foliar application and seed treatment + foliar application of the Regoplan and Agrinos growth regulators.

RECOMMENDATION

For the laboratory research:

1. The PI_{ABS} can be considered a good indicator for screening *Brassica Juncea* L genotypes. Understanding the mechanisms of the adaptation of mustard roots and shoots to salt could be of great importance. It may provide a theoretical basis for further analysis on genotypes of mustard that are tolerant to salt.

2. Drought stress significantly affected the growth of *Brassica Juncea* L. seedlings, inhibited photosynthetic activity, and activated the antioxidant enzyme system. After rehydration, seedling growth and PI_{ABS} recovered quickly and had a compensating effect. The contents of chlorophyll and MDA did not recover to the control level under moderate and severe stress. Drought stress and rehydration increased the activity of antioxidant enzymes, but the changes in antioxidant enzymes in roots and leaves differed. The results suggest that there are specific enzymes in roots and leaves that removed excess ROS.

3. Polyethylene glycol (PEG) can be used to simulate drought conditions and study the effect of plant growth regulators (PGRs). For drought-sensitive *Brassica Juncea* L variety Prima, PGRs had a positive role against drought; on the contrary, for drought non-sensitive Felicia the PGRs exhibited relatively poor effects against drought.

For the field research

4. For high performance, economic and bioenergetic efficiency of the cultivation of *Brassica Juncea* L. in the conditions of the forest-steppe of Ukraine,

the technology should provide for the use of the Felicia variety of foliar application or seed treatment + foliar application: Regoplan (0.25 l/t + 0.05 l/ha) or Agrinos (0.15 l/t + 25 ml/ha). The term for foliar application in micro stages $BBCH_{14–18}$.

APPENDICE

APPENDICES A.1

Meteorological data for 2019 year

	April		May		June		July		August	
Day	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm
1	6.3		22	2.2	13.7	4.0	20.5		23.7	
2	4.7		24.3		19	6.3	15.2		25	
3	2.5		23.2		16.7		16.7		25	
4	6.3		24.2	2.0	22.5		20		25	
5	9.5		24.5		19.3		19.3		27	
6	11.3		21.2		14.7		24.7	1.6	25.3	
7	10.3		21.9		14.8		24		23.7	
8	9.3		22.8	20.9	19.8		21	1.5	21.3	2.1
9	13		22.9	9.0	21.3		22	0.4	21	
10	12.7		17.4		17.8	2.2	24.3		22	2.4
11	10.3		14.2		21		23		22.7	
12	5.5		16.8	1.4	20.3		24.7		22.3	
13	10	2.2	13.6		23		23	6.2	22.7	
14	10		14.8		24		21.7		24.3	
15	14.7		18		24.3		23		24.6	
16	17	20.1	21.7		19		21.7	37.6	23.9	
17	15.7		22.5		24		18.7	4.6	22.8	
18	14		17.5		23		20	0.6	23.8	
19	11		17.3		24.7		24		24.4	
20	12		16.2		24.3		23.3		22.1	
21	16		13		24.2		22.3		23.4	
22	12.7		18.7	1.8	27.2		23.3		17.5	
23	8		20.2		25		21.7		16.8	
24	10.3		22.3	2.6	15		23.3		21	
25	13		22.2	0.8	19		22.3		22	
26	19		18.3		20.3	4.3	23		24	
27	10.7	1.6	19		24		25		22.8	
28	13.6		23.5		25		26.7			
29	16.5		19.5		24.3		25			
30	19.8		22.5		24.5		27.3			
31			22.2				27	4.9		
∑ . з а М.	345.7	23.9	618.4	40.7	635.7	16.8	697.7	57.4	620.1	4.5
С е р .за М.	22.3	12.0	38.7	9.0	41.0	6.7	43.6	12.8	44.3	3.0

APPENDICES A.2

Meteorological data for 2020 year

	April		May		June		July		August	
	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm	average daily temperature, C	average daily precipitation, mm
1	-0.6		16.7	0.5	12.4	8.7	22		16.3	
2	2		17.3		14	6.0	25		19	
3	8.3		18.7	18.1	16.6		25		19.7	
4	8.5		13.3		14.2	15.8	27		21.8	
5	6.7		17.3		15.4	5.7	26		24	
6	6.3		14	2.9	21.4	1.7	26.3		24.7	
7	7.8		12.3	1.7	24		28.7		26	
8	13.3		10	14.0	25.4		16.3	6.3	23.7	
9	9		11.7	1.2	26.7		15.3		21.7	
10	9.3		16		27.7		19.8		21.7	
11	6.7		17.7		28.2		25.7		21.3	0.9
12	5		16.7	1.4	28.4		25.7		17	
13	9.3		9.7		24.2		18.3		16.5	
14	8.2	3.6	12	0.7	24.6		14.7	39.8	15.7	
15	2.7	5.6	11.7	0.4	25		15	23.0	17	
16	4		12.3	0.5	26		20		21	
17	6.7		15.3		26.7		22.3		21	
18	9		12.3	4.6	26.8		22.7		25.7	
19	5.3		11		27		22.3		25	
20	6		13.7	6.3	25.3	1.0	24		21.7	
21	7.3		10	1.2	25.7		25		20.7	
22	8.7		6.7		24		20		19	
23	10		9	5.6	21.3		16.7		21	
24	9		11.7		24		18.7		18.3	
25	7.3		14.3		22.3		20.3		24.3	
26	6	2.8	13	3.7	24.7		21		20	
27	9.3		14	0.7	26.7		24		18	
28	12.3		12.7	14.3	27.3		25.7		18	
29	15.7		18.5	0.4	20.7	1.6	24.3		20	
30	17		15	13.5	23.3	10.4	23		24	
31			14.3	1.5			20		23.3	
∑.за М.	236.1	12.0	418.9	93.2	700.0	50.9	680.8	69.1	647.1	0.9
Сер.за М.	15.2	6.0	26.2	8.9	45.2	11.3	42.6	34.6	40.4	0.9

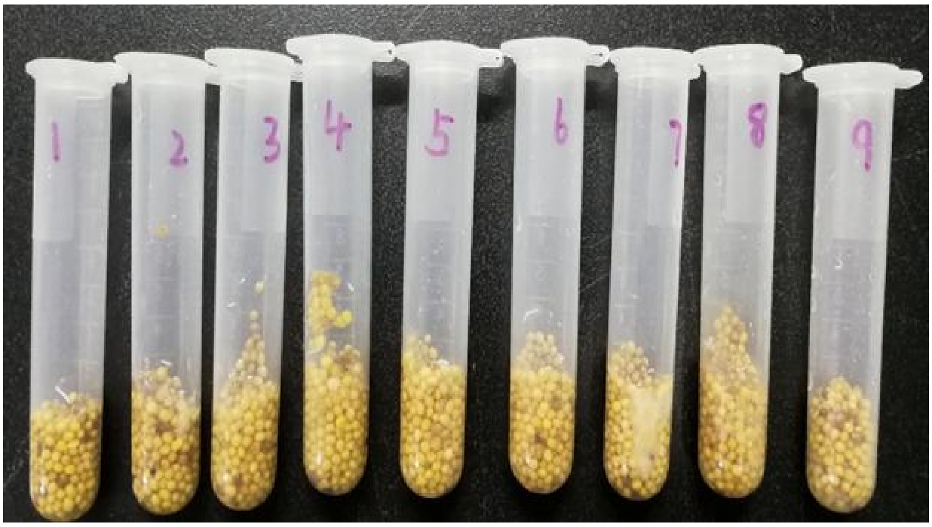
APPENDICES A.3

Meteorological data for 2021 year

	April		May		June		July		August	
Day	Average daily temperature, C	Average daily precipitation, mm	Average daily temperature, C	Average daily precipitation, mm	Average daily temperature, C	Average daily precipitation, mm	Average daily temperature, C	Average daily precipitation, mm	Average daily temperature, C	Average daily precipitation, mm
1	9.0		17.0	56.5	10.3		24.3		28.0	
2	9.0		16.3	2.6	13.7		24.0		25.7	14.8
3	4.0	5.7	14.3	2.3	17.0		23.3	4.4	20.7	
4	6.7	4.0	9.0	2.0	17.3		24.3		22.7	
5	5.3		15.0		17.7		25.0	2.6	21.3	
6	8.0		13.3		16.7	1.3	22.0		21.3	2.5
7	6.3		13.7	1.8	16.7	7.2	24.0		23.3	2.8
8	3.3	2.8	12.0	2.0	17.3		24.3		23.3	
9	5.3		8.0	19.4	19.7	5.2	25.3		24.7	
10	8.3		6.7		17.7	12.4	25.0		25.3	
11	11.3		14.3	30.1	18.3	33.2	26.3		24.7	0.6
12	14.3		11.0		19.3		26.7		24.0	
13	13.0		11.5	1.1	19.0	6.3	26.3		23.3	
14	13.0		18.3	4.6	21.0	0.9	27.0		22.0	
15	11.0	2.1	19.0		24.3		28.0		23.3	
16	9.0	4.8	18.8		21.0		26.0		24.8	
17	9.0	0.4	24.0		20.7	5.7	27.7		26.0	
18	5.0	10.3	17.7		23.0		28.0		24.3	3.3
19	8.0	0.5	15.7	7.5	24.3		26.7		21.2	6.7
20	8.0	2.1	14.3	7.2	24.3		26.7		20.5	0.8
21	6.4	3.5	13.0	20.9	27.0		21.3		18.3	
22	12.2		17.7		26.7		20.3		18.3	
23	10.5		19.0		27.3		22.0		18.8	
24	5.7	9.6	13.3		29.7		24.0		20.0	
25	6.7		18.0	7.1	30.0		23.6		20.7	
26	3.3	8.6	22.7		29.0		23.3		20.7	3.2
27	3.7	2.1	20.7		26.0	9.6	27.5		19.2	4.6
28	7.7		21.7		22.3	13.6	24.0		20.7	
29	12.5		20.0	3.2	21.7	6.5	26.7		22.0	
30	15.3		15.0		24.3		25.8		24.3	
31			10.0						19.0	20.4
∑.за М.	250.8	56.5	481.0	168.3	643.3	101.9	749.4	7.0	692.4	59.7
Сер.за М.	16.2	8.1	30.1	21.0	41.5	17.0	48.3	4.7	43.3	10.9

Appendices B.1

A

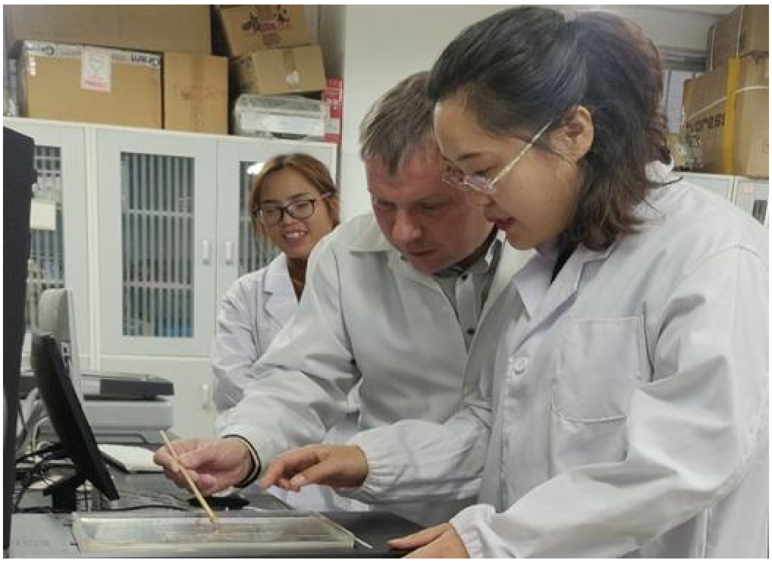


B

The photo of laboratory research (experiment 1-3) at Henan Institute of Science and Technology, Xinxiang, China: A – effects of stress on the growth of mustard under hydroponic conditions; B – pre-treatment of seeds with growth regulators

Appendices B.2

A



B

The photo of laboratory research (experiment 1-3) at Henan Institute of Science and Technology, Xinxiang, China: A – hydroponic seedling sampling; B – scan of mustard seedling morphology parameters

Appendices C.1

A

B

The photo of field research (experiment 4), Sumy National Agrarian University (latitude 50o52.742N, 34o46.159E Longitude, and 137.7 m above sea level):
A – measuring soil temperature before sowing; B – sowing plots of mustard seeds

Appendices C.2

A

B

The photo of field research (experiment 4), Sumy National Agrarian University (2019) (latitude 50°52.742N, 34°46.159E Longitude, and 137.7 m above sea level):
A – foliar spray growth regulators; B – plots of mustard in the stage of the beginning of flowering

Appendices D.1

Effects of salt stress on the growth and physiological features of *Brassica Juncea* L. seedlings.

(Experimental 1)

Effects of salt stress on the chlorophyll content (Dualex units)

Treatment	3 days	7 days	10 days
Control	27.203	28.944	26.728
	27.246	26.066	28.149
	26.308	23.363	30.019
	26.463	22.897	27.506
	22.036	33.131	22.458
	20.235	31.135	23.71
	25.793	28.367	27.5
	26.613	25.181	27.458
	25.353	25.163	28.375
	25.977	24.194	26.295
Low salt stress	28.598	32.034	21.824
	29.48	30.301	23.633
	26.532	22.138	29.485
	26.202	19.295	30.332
	23.832	22.071	26.063
	22.269	22.225	24.385
	22.907	28.1	26.848
	21.608	23.501	23.153
	22.891	22.238	28.796
	20.91	24.203	30.892
Moderate salt stress	22.063	19.382	19.458
	21.003	18.884	18.404

	21.976	20.277	19.728
	22.769	23.222	19.299
	23.486	18.862	26.529
	22.759	19.928	23.13
	22.711	24.555	23.253
	21.855	23.958	25.882
	23.657	22.711	24.633
	23.417	21.855	25.967
Severe salt stress	22.623	21.579	21.018
	23.822	20.195	19.3
	23.417	14.035	21.528
	22.676	14.447	18.082
	20.041	21.32	15.804
	21.911	22.786	18.644
	22.339	19.955	18.435
	22.529	21.512	19.99
	22.08	22.036	16.822
	20.429	18.749	18.75

	Treatment	3 days	7 days	10 days
Mean	Control	25.3227	26.8441	26.8198
	Low salt stress	24.5229	24.6106	26.5411
	Moderate salt stress	22.5696	21.3634	22.6283
	Severe salt stress	22.1867	19.6614	18.8373
Std. Deviation	Control	2.32	3.43	2.23
	Low salt stress	2.99	4.13	3.24
	Moderate salt stress	0.84	2.16	3.14
	Severe salt stress	1.18	3.08	1.75

Appendices D.2

Changes of Fv/Fm and PI $_{abs}$ under salt stress

	Fv/Fm				PI abs		
Treatment	3 days	7 days	10 days		3 days	7 days	10 days
Control	0.797	0.801	0.769		10.529	13.949	10.381
	0.825	0.808	0.787		14.082	14.025	11.227
	0.801	0.823	0.774		13.517	10.847	11.32
Low salt stress	0.82	0.821	0.798		8.626	8.177	8.204
	0.828	0.822	0.812		8.465	6.88	7.729
	0.812	0.823	0.813		8.767	8.203	7.235
Moderate salt stress	0.827	0.82	0.805		6.668	7.629	6.175
	0.825	0.816	0.801		5.947	6.777	9.428
	0.83	0.806	0.836		7.056	9.979	6.981
Severe salt stress	0.829	0.814	0.817		5.39	4.838	5.477
	0.831	0.805	0.814		6.787	3.912	5.02
	0.807	0.819	0.812		5.124	5.046	5.202

Fv/Fm	Treatment	3 days	7 days	10 days
Mean	Control	0.807666667	0.810666667	0.806666667
	Low salt stress	0.82	0.822	0.806666667
	Moderate salt stress	0.827333333	0.814	0.816666667
	Severe salt stress	0.822333333	0.812666667	0.813333333
Std. Deviation	Control	0.015143756	0.01123981	0.011547005
	Low salt stress	0.008	0.001	0.005773503
	Moderate salt stress	0.002516611	0.007211103	0.02081666
	Severe salt stress	0.013316656	0.007094599	0.005773503

PI abs	Treatment	3 days	7 days	10 days
Mean	Control	12.70933333	12.94033333	10.97666667
	Low salt stress	8.619333333	7.753333333	7.723333333

	Moderate salt stress	6.557	8.128333333	7.53
	Severe salt stress	5.767	4.598666667	5.233333333
Std. Deviation	Control	1.909239727	1.813278063	0.518684233
	Low salt stress	0.151110335	0.756440568	0.480034721
	Moderate salt stress	0.562770824	1.658373098	1.693369422
	Severe salt stress	0.8933023	0.603696392	0.231804515

Appendices D.3

Changes of SOD in roots under salt stress

3 DAYS

	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Control	489.1754	50.50738	35.71411	35.3846	942.9663	453.46	524.89
Low salt stress	789.9071	42.78139	30.25101	405.5316	1174.2826	759.66	820.16
Moderate salt stress	789.9088	97.27129	68.78119	-84.0391	1663.8567	721.13	858.69
Severe salt stress	1048.1250	108.80907	76.93963	70.5142	2025.7357	971.19	1125.06
Total	779.2791	220.06841	77.80593	595.2973	963.2609	453.46	1125.06

7 DAYS

	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Control	430.7050	57.69831	40.79886	-87.6938	949.1037	389.91	471.50
Low salt stress	489.8812	42.75467	30.23211	105.7458	874.0167	459.65	520.11
Moderate salt stress	571.3936	66.48348	47.01092	-25.9368	1168.7240	524.38	618.40
Severe salt stress	689.8505	65.93955	46.62630	97.4071	1282.2938	643.22	736.48
Total	545.4576	113.06312	39.97385	450.9344	639.9807	389.91	736.48

10 DAYS

	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
Control	589.5333	34.40514	24.32811	280.4154	898.6512	565.21	613.86
Low salt stress	784.0920	76.61174	54.17268	95.7628	1472.4212	729.92	838.26
Moderate salt stress	601.8416	41.93109	29.64976	225.1057	978.5775	572.19	631.49
Severe salt stress	792.1734	26.68959	18.87239	552.3769	1031.9698	773.30	811.05
Total	691.9101	109.42104	38.68618	600.4318	783.3883	565.21	838.26

Appendices E.1

RESULTS OF STATICTICAL ANALYSES (ANOVA)

Effects of growth regulators on morphological and performance parameters of mustard (*Brassica Juncea* L.) seeds

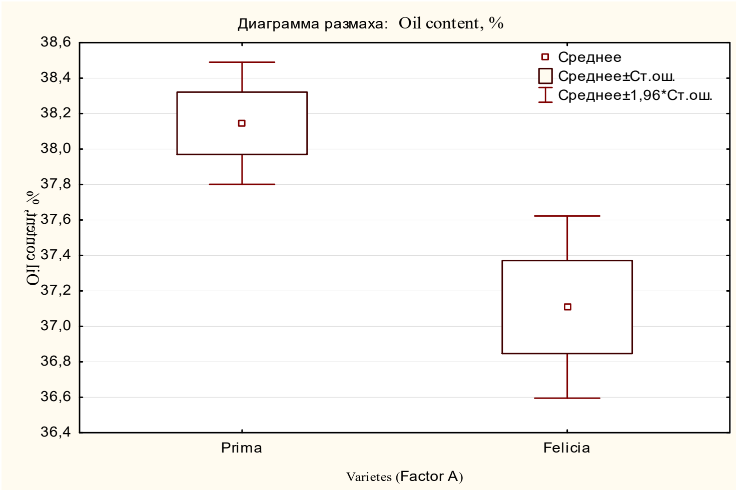
(Experimental 4)

Parameters	ANOVA (Duncan test)		
Plant height, cm	21.7591641	22.9039532	23.6346936
Number of branches in one plant	0.536101383	0.56430665	0.582310601
Number of pods	36.4550978	38.3730667	39.5973422
The content of chlorophylls “a” and “c” in the plant material in the fresh weight, mg/g	0.42563806	0.44803165	0.4623259
n-tester			
Average length, cm	0.325221898	0.342332412	0.353254374
Seed weight 25 pcs, g	0.459817359	0.484009184	0.499451281
Number of seeds in one pod	5.8203632	6.12658307	6.32204897
Weight of 1 pod, g	0.3215525	0.33846996	0.349268693
Yield capacity, t/ha	0.71889546	0.7725014	0.8671908
Weight of 1000 seeds, g	1.13210607	1.19166822	1.22968787
Oil content, %	1.38450793	1.4573494	1.50384548

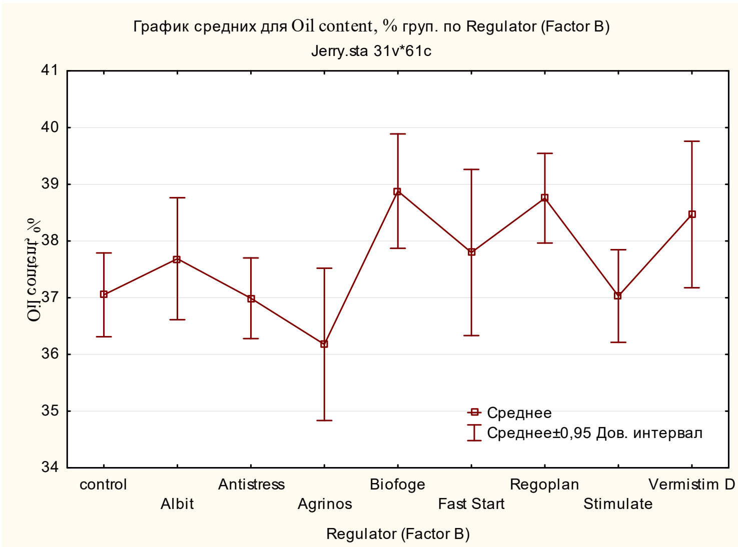
Appendices E.2

GRAPHS OF STATICTICAL ANALYSES (ANOVA)

Effects of growth regulators on the quality of mustard seeds (Experimental 4)



A



B

Graphs effects of growth regulators on the oil content of mustard seeds:

A – oil content (factor A); B – growth regulators (factor B)

Appendices F.1

Economic efficiency of growing brown mustard (Prima)												
№	Yield capacity t/ha	Wages, UAH	Seeds	Fertilizers	Meaans of protection	Fuel	Other options	Total costs	GDP, UAH	Self-cost 1 c, UAH	Profit, UAH/ha	Profitability, %
	Seed treatment											
Control	16,1	968,2	186	4318	2470	4328	3067	15337	33810	952,64	18473	120
Albit	16	965,6	186	4318	2470	4319	3065	15324	33600	957,77	18276	119
Antistress	16,9	989,3	186	4318	2475	4394	3091	15453	35490	914,39	20037	130
Agrinos	17,2	997,2	186	4318	2472	4419	3098	15490	36120	900,57	20630	133
Bioforge	16,2	970,8	186	4318	2481	4336	3073	15365	34020	948,46	18655	121
Fast start	16,6	981,4	186	4318	2478	4369	3083	15416	34860	928,68	19444	126
Regoplan	17,1	994,6	186	4318	2472	4411	3095	15477	35910	905,08	20433	132
Stimulate	16,5	978,8	186	4318	2477	4361	3080	15401	34650	933,38	19249	125
Vermistim D	16,4	976,1	186	4318	2479	4353	3078	15389	34440	938,36	19051	124
	Foliar application											
Albit	16,3	973,5	186	4318	2580	4344	3100	15502	34230	951,03	18728	121
Antistress	17	992,0	186	4318	4867	4402	3691	18457	35700	1085,69	17243	93
Agrinos	16,8	986,7	186	4318	2523	4386	3100	15499	35280	922,54	19781	128
Bioforge	16,7	984,0	186	4318	4045	4378	3478	17388	35070	1041,21	17682	102
Fast start	17,3	999,9	186	4318	3505	4427	3359	16795	36330	970,82	19535	116
Regoplan	17,2	997,2	186	4318	2552	4419	3118	15590	36120	906,37	20530	132
Stimulate	16,5	978,8	186	4318	3453	4361	3324	16620	34650	1007,29	18030	108
Vermistim D	16,2	970,8	186	4318	3850	4336	3415	17076	34020	1054,08	16944	99

	Appendices F.1											
	Seed treatment + foliar application											
Albit	16,4	976,1	186	4318	2580	4353	3103	15516	34440	946,10	18924	122
Antistress	17,1	994,6	186	4318	4872	4411	3695	18477	35910	1080,51	17433	94
Agrinos	16,7	984,0	186	4318	2524	4378	3097	15487	35070	927,37	19583	126
Bioforge	17,3	999,9	186	4318	4056	4427	3497	17484	36330	1010,64	18846	108
Fast start	17,6	1007,8	186	4318	3513	4452	3369	16846	36960	957,19	20114	119
Regoplan	17,7	1010,4	186	4318	2554	4460	3132	15661	37170	884,78	21509	137
Stimulate	16,9	989,3	186	4318	3459	4394	3337	16684	35490	987,19	18806	113
Vermistim D	16,6	981,4	186	4318	3859	4369	3428	17141	34860	1032,62	17719	103

Appendices F.2

Economic efficiency of growing brown mustard (Felicia)												
№	Yield capacity t/ha	Wages, UAH	Seeds	Fertilizers	Meaans of protection	Fuel	Other options	Total costs	GDP, UAH	Self-cost 1 c, UAH	Profit, UAH/ha	Profitability, %
	Seed treatment											
Control	16,6	981,4	186	4318	2470	4369	3081	15406	34860	928,06	19454	126
Albit	16,5	978,8	186	4318	2470	4361	3079	15393	34650	932,89	19257	125
Antistress	18	1018,3	186	4318	2475	4485	3121	15603	37800	866,86	22197	142
Agrinos	17,8	1013,1	186	4318	2472	4469	3114	15572	37380	874,82	21808	140
Bioforge	17,5	1005,1	186	4318	2481	4444	3109	15543	36750	888,15	21207	136
Fast start	17,7	1010,4	186	4318	2478	4460	3113	15566	37170	879,46	21604	139
Regoplan	18,4	1028,9	186	4318	2472	4519	3131	15654	38640	850,78	22986	147
Stimulate	17,3	999,9	186	4318	2477	4427	3102	15510	36330	896,54	20820	134
Vermistim D	17	992,0	186	4318	2479	4402	3094	15471	35700	910,06	20229	131
	Foliar application											
Albit	17,4	1002,5	186	4318	2580	4436	3130	15652	36540	899,55	20888	133
Antistress	18,3	1026,3	186	4318	4867	4510	3727	18634	38430	1018,27	19796	106
Agrinos	18,1	1021,0	186	4318	2523	4494	3135	15676	38010	866,10	22334	142
Bioforge	18,2	1023,6	186	4318	4045	4502	3519	17593	38220	966,66	20627	117
Fast start	18,5	1031,5	186	4318	3505	4527	3392	16959	38850	916,71	21891	129
Regoplan	18,7	1036,8	186	4318	2552	4543	3159	15795	39270	844,63	23475	149
Stimulate	17,7	1010,4	186	4318	3453	4460	3357	16784	37170	948,26	20386	121
Vermistim D	17,2	997,2	186	4318	3850	4419	3443	17213	36120	1000,74	18907	110

Appendices F.2

	Seed treatment + foliar application											
Albit	17,4	976,1	186	4318	2580	4353	3103	15516	34440	946,10	20877	133
Antistress	19,1	994,6	186	4318	4872	4411	3695	18477	35910	1080,51	21360	114
Agrinos	18,9	984,0	186	4318	2524	4378	3097	15487	35070	927,37	23902	151
Bioforge	18,4	999,9	186	4318	4056	4427	3497	17484	36330	1010,64	21006	119
Fast start	18,3	1007,8	186	4318	3513	4452	3369	16846	36960	957,19	21488	127
Regoplan	18,6	1010,4	186	4318	2554	4460	3132	15661	37170	884,78	23276	147
Stimulate	18,0	989,3	186	4318	3459	4394	3337	16684	35490	987,19	20966	125
Vermistim D	17,2	981,4	186	4318	3859	4369	3428	17141	34860	1032,62	18897	110

Appendices F.3

	Cost structure, %, of brown mustard (Prima)							Energy, brown mustard (Prima)									
	Wages, UAH.	Seeds	Fertilizers	Means of protection	Fuel	Other costs.	Total costs	Tractors and machines	Fertilizers	Pesticides	Fuel	Seeds	Labour costs	Total costs	Energy yield with crop, Mj	Costs for 1 c	Kee
	Seed treatment							Seed treatment									
Control	6,31	1,21	28,15	16,10	28,22	20,00	100,00	1282	5147	1090	2055	87	1047	10706	26485	665	2,47
Albit	6,30	1,21	28,18	16,12	28,19	20,00	100,00	1274	5147	1090	2051	87	1040	10689	26320	668	2,46
Antistress	6,40	1,20	27,94	16,02	28,44	20,00	100,00	1345	5147	1091	2082	87	1099	10850	27801	642	2,56
Agrinos	6,44	1,20	27,88	15,96	28,53	20,00	100,00	1369	5147	1090	2092	87	1118	10903	28294	634	2,60
Bioforge	6,32	1,21	28,10	16,15	28,22	20,00	100,00	1290	5147	1092	2058	87	1053	10726	26649	662	2,48
Fast start	6,37	1,21	28,01	16,08	28,34	20,00	100,00	1321	5147	1092	2071	87	1079	10798	27307	650	2,53
Regoplan	6,43	1,20	27,90	15,97	28,50	20,00	100,00	1361	5147	1090	2088	87	1112	10885	28130	637	2,58
Stimulate	6,36	1,21	28,04	16,08	28,32	20,00	100,00	1313	5147	1091	2068	87	1073	10779	27143	653	2,52
Vermistim D	6,34	1,21	28,06	16,11	28,28	20,00	100,00	1305	5147	1097	2065	87	1066	10767	26978	657	2,51
	Foliar application							Foliar application									
Albit	6,28	1,20	27,85	16,64	28,02	20,00	100,00	1297	5147	1090	2061	87	1060	10742	26814	659	2,50
Antistress	5,37	1,01	23,40	26,37	23,85	20,00	100,00	1353	5147	1091	2085	87	1105	10868	27965	639	2,57
Agrinos	6,37	1,20	27,86	16,28	28,30	20,00	100,00	1337	5147	1090	2078	87	1092	10831	27636	645	2,55
Bioforge	5,66	1,07	24,83	23,26	25,18	20,00	100,00	1329	5147	1092	2075	87	1086	10815	27472	648	2,54
Fast start	5,95	1,11	25,71	20,87	26,36	20,00	100,00	1377	5147	1092	2095	87	1125	10922	28397	631	2,60
Regoplan	6,40	1,19	27,70	16,37	28,35	20,00	100,00	1369	5147	1090	2092	87	1118	10799	28294	634	2,62
Stimulate	5,89	1,12	25,98	20,77	26,24	20,00	100,00	1313	5147	1091	2068	87	1073	10779	27143	653	2,52
Vermistim D	5,69	1,09	25,29	22,55	25,39	20,00	100,00	1290	5147	1097	2058	87	1053	10732	26649	662	2,48

Appendices F.3

	Seed treatment + foliar application							Seed treatment + foliar application									
Albit	6,29	1,20	27,83	16,63	28,05	20,00	100,00	1305	5147	1098	2065	87	1066	10768	26978	657	2,51
Antistress	5,38	1,01	23,37	26,37	23,87	20,00	100,00	1361	5147	1427	2088	87	1112	11222	28130	656	2,51
Agrinos	6,35	1,20	27,88	16,30	28,27	20,00	100,00	1329	5147	1095	2075	87	1086	10818	27472	648	2,54
Bioforge	5,72	1,06	24,70	23,20	25,32	20,00	100,00	1377	5147	1389	2095	87	1125	11219	28459	649	2,54
Fast start	5,98	1,10	25,63	20,85	26,43	20,00	100,00	1401	5147	1389	2105	87	1144	11273	28952	641	2,57
Regoplan	6,45	1,19	27,57	16,31	28,48	20,00	100,00	1409	5147	1100	2108	87	1151	11002	29117	622	2,65
Stimulate	5,93	1,11	25,88	20,74	26,34	20,00	100,00	1345	5147	1240	2082	87	1099	10999	27801	651	2,53
Vermistim D	5,73	1,09	25,19	22,51	25,49	20,00	100,00	1321	5147	2285	2071	87	1079	11991	27307	722	2,28

Appendices F.4

	Cost structure, %, of brown mustard (Felicia)							Energy, brown mustard (Felicia)									
	Wages, UAH.	Seeds	Fertilizers	Means of protection	Fuel	Other costs.	Total costs	Tractors and machines	Fertilizers	Pesticides	Fuel	Seeds	Labour costs	Total costs	Energy yield with crop, Mj	Costs for 1 c	Kee
	Seed treatment							Seed treatment									
Control	6,37	1,21	28,03	16,03	28,36	20,00	100,00	1321	5147	1090	2071	87	1079	10795	27307	650	2,53
Albit	6,36	1,21	28,05	16,05	28,33	20,00	100,00	1313	5147	1090	2068	87	1073	10778	27143	653	2,52
Antistress	6,53	1,19	27,67	15,86	28,75	20,00	100,00	1433	5147	1091	2119	87	1170	11046	29610	614	2,68
Agrinos	6,51	1,19	27,73	15,87	28,70	20,00	100,00	1417	5147	1090	2112	87	1157	11010	29281	619	2,66
Bioforge	6,47	1,20	27,78	15,96	28,59	20,00	100,00	1393	5147	1092	2102	87	1138	10958	28788	626	2,63
Fast start	6,49	1,19	27,74	15,92	28,65	20,00	100,00	1409	5147	1092	2108	87	1151	10994	29117	621	2,65
Regoplan	6,57	1,19	27,58	15,79	28,86	20,00	100,00	1465	5147	1090	2132	87	1196	11117	30268	604	2,72
Stimulate	6,45	1,20	27,84	15,97	28,54	20,00	100,00	1377	5147	1091	2095	87	1125	10921	28459	631	2,61
Vermistim D	6,41	1,20	27,91	16,02	28,46	20,00	100,00	1353	5147	1097	2085	87	1105	10874	27965	640	2,57
	Foliar application							Foliar application									
Albit	6,40	1,19	27,59	16,48	28,34	20,00	100,00	1385	5147	1090	2098	87	1131	10938	28623	629	2,62
Antistress	5,51	1,00	23,17	26,12	24,20	20,00	100,00	1457	5147	1091	2129	87	1190	11099	30104	607	2,71
Agrinos	6,51	1,19	27,54	16,09	28,66	20,00	100,00	1441	5147	1090	2122	87	1177	11063	29775	611	2,69
Bioforge	5,82	1,06	24,54	22,99	25,59	20,00	100,00	1449	5147	1092	2125	87	1183	11083	29939	609	2,70
Fast start	6,08	1,10	25,46	20,67	26,69	20,00	100,00	1473	5147	1092	2135	87	1203	11136	30433	602	2,73
Regoplan	6,56	1,18	27,34	16,15	28,77	20,00	100,00	1489	5147	1090	2142	87	1216	11170	30762	597	2,75
Stimulate	6,02	1,11	25,73	20,57	26,58	20,00	100,00	1409	5147	1091	2108	87	1151	10993	29117	621	2,65
Vermistim D	5,79	1,08	25,09	22,37	25,67	20,00	100,00	1369	5147	1097	2092	87	1118	10910	28294	634	2,59

Appendices F.4

	Seed treatment + foliar application							Seed treatment + foliar application									
Albit	6,29	1,20	27,83	16,63	28,05	20,00	100,00	1305	5147	1098	2065	87	1066	10768	26978	657	2,61
Antistress	5,38	1,01	23,37	26,37	23,87	20,00	100,00	1361	5147	1427	2088	87	1112	11222	28130	656	2,71
Agrinos	6,35	1,20	27,88	16,30	28,27	20,00	100,00	1329	5147	1095	2075	87	1086	10818	27472	648	2,77
Bioforge	5,72	1,06	24,70	23,20	25,32	20,00	100,00	1377	5147	1389	2095	87	1125	11219	28459	649	2,65
Fast start	5,98	1,10	25,63	20,85	26,43	20,00	100,00	1401	5147	1389	2105	87	1144	11273	28952	641	2,64
Regoplan	6,45	1,19	27,57	16,31	28,48	20,00	100,00	1409	5147	1100	2108	87	1151	11002	29117	622	2,74
Stimulate	5,93	1,11	25,88	20,74	26,34	20,00	100,00	1345	5147	1240	2082	87	1099	10999	27801	651	2,65
Vermistim D	5,73	1,09	25,19	22,51	25,49	20,00	100,00	1321	5147	1097	2071	87	1079	11002	27307	663	2,88

Appendices G.1

Узгоджено	**Затверджую**
	Директор
Проректор з наукової роботи	ФГ «Еліта»
д. е. н., професор Данько Ю. І.	Заєць О. С.
„__” „__” ”20__ р.	„15” „__” ”20__ р.

Акт впровадження

Результатів науково-дослідних і технологічних розробок

Замовник: *Фермерське господарство «Еліта», Сумська область,Буринський район, с. Слобода, вул. Комарова 14*

Керівник організації (директор): *Заєць Олена Степанівна*

Цим актом підтверджується, що результати роботи: *Ефективність позакореневого підживлення гірчиці сизої сорту Пріма*

яка виконана *аспіранткою Цзя Пей Пей та студентками кафедри рослинництва Сумського національного аграрного університету Кубрак Тетяною Михайлівною та Шиян Мариною Олександрівною*

впровадженні на землях *Фермерського господарства «Еліта», Сумська область, Буринський район, с. Слобода, вул. Комарова 14*

1. Вид впровадження результатів: *Встановлювали вплив препарату Регопландля обробки насіння на врожайність та економічну ефективність вирощування гірчиці сизої сорту Пріма.*

Отримано врожайність для сорту Пріма на варіанті за використання - 1,77 т/га.

2. Характеристика масштабу впровадження*20 га.*

3. Новизна науково-дослідних робіт: *вперше в умовах Лісостепу України встановлено ефективний вплив обробки насіння препарату Регоплан для гірчиці сизої сорту Пріма.*

4. Впроваджені: у сільськогосподарське виробництво *Фермерського господарства «Еліта», Сумська область, Буринський район, с. Слобода, вул. Комарова 14*

Appendices G.1

5. Очікуваний прибуток – *від обробки насіння Регоплан в порівнянні з контролем – 750,0 грн./га.*

фактичний прибуток- *від обробки насіння Регоплан в порівнянні з контролем – 1345,0 грн./га.(з 20 га 26,9 тис. грн.)*

6. Питома економічна ефективність впровадження: *рівень рентабельності за обробки насіння Реглоном–59,5 %.*

7. Соціально-науковий ефект: *забезпечення олійною сировиною (гірчичний порошок, цільні зерна гірчиці) для кондитерської промисловості, створення робочих місць на переробних підприємствах, підвищення достатку населення*

Примітка:

Цей акт завіряється гербовими печатками з боку Замовника і Виконавця

Від ВНЗ:	**Від підприємства:**
Завідувач науково дослідною частиною, д. е .н.,професор	*Головний бухгалтер*
Пасько О. В.	*Іванов Г П.*
Виконавці:	
Цзя Пей Пей	*Відповідальний за впровадження*
Кубрак Т.М.	*Заєць О. С.*
Шиян М. О.	

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

Appendices G.2

Узгоджено	**Затверджую**
Проректор з наукової роботи	Директор ФГ «Родина-2017»,
д. е. н., професор Данько Ю.І.	Білокінь В.О.
________________	________________
„___”, „ 09 ” 2021р.	„ 17 ”, „ 09 ” 2021 р.

Акт впровадження

Результатів науково-дослідних і технологічних розробок

Замовник: *Фермерське господарство «Родина-2017», Полтавська область, Кобеляцький р-н, село Канави, вулиця Центральна, будинок 1*

Керівник організації (директор): *Білокінь Віталій Олегович*

Цим актом підтверджується, що результати роботи: *Ефективність застосування регуляторів росту рослин за вирощування гірчиці сизої сорту Феліція*

яка виконана *аспіранткою Сумського НАУ, Цзя Пей Пей*

впровадженні на землях *Фермерське господарство «Родина-2017», Полтавська область, Кобеляцький р-н, село Канави*

1. Вид впровадження результатів: *Досліджували ефективність застосування регуляторів росту для гірчиці сизої (Альбіт, Антистрес, Агрінос, Біофордж, Регоплан, Фаст старт, Вермистим Д). Встановлено, що найбільш доцільно (прибуток з одиниці площі 23 тис. грн.), вирощувати гірчицю сизу сорту Феліція за позакореневового внесення та комплексного застосування «насіння+позакоренево» регуляторів росту Агрінос та Регоплан. Рівні рентабельності були 131-135 % відповідно.*

2. Характеристика масштабу впровадження *30 га.*

3. Новизна науково-дослідних робіт: *Вперше в умовах Лісостепу України встановлено економічну доцільність застосування регуляторів росту рослин Агрінос та Регоплан.*

4. Впроваджені: у сільськогосподарське виробництво *Фермерське господарство «Родина-2017», Полтавська область, село Канави.*

5. Річний економічний ефект *(додатковий прибуток в порівнянні з контролем - де отримали 18050 грн/га):*

очікуваний - *140 тис. грн. з площі 30 га*

фактичний – *130,5 тис. грн. з площі 30 га (за застосування отримали прибутку 22400 грн/га).*

6. Питома економічна ефективність впровадження: *чистий прибуток на 1 гектар посіву - 4350 грн.; розрахунковий рівень рентабельності – 133 %.*

7. Соціально-науковий ефект: *збільшення робочих місць та об'єму сировини для переробної промисловості.*

Цей акт завіряється гербовими печатками з боку Замовника і Виконавця

Від ВНЗ:	**Від підприємства:**
Завідувач науково-дослідною частиною Сумського НАУ, к. е .н., доцент	*Головний бухгалтер*
______________ *Пасько О. В.*	______________ *Смирнова В. В.*
Виконавець, аспірант	*Відповідальний за впровадження, агроном*
______________ *Цзя Пей Пей.*	______________ *Білокінь В.О.*

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