The Influence of Plant Growth Regulators on Morphological Indexes and Performance of *Brassica juncea* L. in the Forest-Steppe of Ukraine

Andrii Melnyk[1], Peipei Jia[2], Tetiana Melnyk[1](✉), Andrii Butenko[1], Volodymyr Kolosok[1], and Sergey Butenko[1]

[1] Sumy National Agrarian University, Herasyma Kondratyeva St. 160, Sumy 40021, Ukraine
melnyk_ua@yahoo.com

[2] Henan Institute of Science and Technology, Hualan St. 90, 453003 Xinxiang, People's Republic of China

Abstract. Plant growth regulators have a great impact on agricultural production, but an application of the conventional application mode has certain restrictions on the growth and yield improvement. The subject of the study is *Brassica juncea* L. varieties (Prima and Felicia), methods of application and types of plant growth regulators, weather conditions, yield, and quality seeds for the cultivation in terms of the Left-Bank Forest-Steppe of Ukraine. The seed yield capacity of Felicia (1.78 t/ha) was significantly higher than that of Prima (1.67 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%. The application of growth regulators increased the average oil content from 1.18% to 5.61%. As the result of correlation analyses, seed yield had positive and highly significant ($p < 0.01$) correlations with the number of pods per plant, the number of branches per plant, leaf area, and the average seed weight per plant. The 1000-seed weight was a positive highly significant ($p < 0.01$) association with the chlorophyll content and the plant height. These results showed that the branch number, yield per plant, pod number, and leaf area were the main factors determining yield capacity in both varieties. The oil content was negatively correlated with protein.

Keywords: plant growth regulators · morphological and photosynthesis indexes · the performance of *Brassica juncea* L

1 Introduction

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. Mustard is an important cash crop. 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.

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Among the oilseed crops, mustard and rape seed is in the second position after soybean. 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 [1, 2]. Isocyanates, enriched in mustard seeds, have been shown to play an essential role in preventing cancer and bacteria [3, 4]. Besides, mustard oil is widely used in food processing, such as canning and baking, as well as in the production of candy and margarine [5].

High-quality low erucic acid oil obtained by genetic engineering plays an important role in increasing the performance and area of mustard [6]. 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 [7].

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. 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 [2, 7].

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 [8]. 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 [9].

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 [10].

2 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.

The Hydrothermal Coefficient (HTC) was calculated using the formula: $HTC = \Sigma p \times 10/\Sigma t$. Among them, Σp and Σt are the total precipitation (mm) and the total temperature (°C) when the daily average temperature is above 10 °C, respectively. The lower the HTC indicator, the drier the area. If HTC < 0.4 - very severe drought; from 0.4 to 0.5 - severe drought; from 0.5 to 0.6 - medium drought; from 0.7 to 0.9 - mild drought; from 1.0 to 1.5 - sufficiently moist and the HTC > 1.6 – excessively wet [11].

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 [12]. The oil content of the seeds was determined on the SupNir 2750 infrared analyzer [11].

3 Results and Discussion

The changes climate in world and Ukraine's 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.) [13]. 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 [14–18].

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 [19]. 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 [20]. Spraying Mixtalol on the leaf surface of mustard increased the number of second and third branches, as well as starch, protein, and oil content [21]. Exogenous melatonin has been reported to improve growth and stress tolerance effectively in rape seeds [22]. 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 [23]. 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 [24]. 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.

3.1 Plant Height (cm)

As the result among the two varieties investigated, Prima created a significantly taller average plant (145.7 cm) (Table 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.

3.2 Leaf Area and Chlorophyll Contents

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. 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 leaf chlorophyll content is an important physiological index reflecting leaf photosynthetic intensity and plant senescence. Prima showed significantly higher chlorophyll content (1.17 mg/g) than Felicia (1.07 mg/g).

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.

3.3 Productivity and Seed Yield

The data 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 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. 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%.

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 2).

In both varieties, the combination of seed dressing and foliar application produced higher yields than either method of biostimulant applied alone. All growth regulators

Table 1. Effects of different growth regulators on plant height of *Brassica juncea* L.

Varieties	Growth regulators	Methods of application			
		seeds	foliar	seeds + foliar	Average
Prima	Control	141.0bc	141.0c	141.0cd	141.0de
	Albit	139.0c	140.0c	140.1d	139.7e
	Antistress	149.5a	146.4abc	148.6ab	148.2ab
	Agrinos	150.7a	151.0a	147.4abc	149.7a
	Bioforge	142.7bc	143.7bc	146.4abcd	144.3cd
	Fast Start	146.9ab	152.8a	149.1ab	149.6a
	Regoplan	149.9a	148.4ab	152.9a	150.4a
	Stimulate	147.3ab	141.2c	147.5abc	145.3bc
	Vermistim D	144.0abc	141.7c	144.7bcd	143.5cd
	Average	145.7a	145.1a	146.4a	
Felicia	Control	136.0bc	136.0c	136.0c	136.0b
	Albit	135.2c	135.2c	137.9bc	136.1b
	Antistress	143.0ab	141.4abc	146.6a	143.7a
	Agrinos	142.2abc	140.6abc	144.1ab	142.3a
	Bioforge	143.1ab	140.6abc	143.4abc	142.3a
	Fast Start	142.7ab	144.2ab	142.9abc	143.3a
	Regoplan	144.3a	145.1a	143.0abc	144.1a
	Stimulate	142.8ab	140.2abc	142.3abc	141.8a
	Vermistim D	136.9abc	137.4bc	136.4c	136.9b
	Average	140.7a	140.1a	141.4a	

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 – 1,89 t/ha, Antistress – 1,89 t/ha). There were significant differences in the interactions between varieties, application methods, and biostimulants.

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 [20]. Foliar application of plant growth regulators could increase leaf area index, dry matter accumulation, delay root senescence and increase crop yield [25, 26].

3.4 Correlation Between Productivity Features and Seed Yield

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

Table 2. Effects of different growth regulators on seed yield of *Brassica juncea* L.

Varieties	Growth regulators	Methods of application			
		seeds	foliar	seeds + foliar	Average
Prima	Control	1.61de	1.61e	1.61f	1.61f
	Albit	1.6e	1.63de	1.64ef	1.62ef
	Antistress	1.69ab	1.7ab	1.71bc	1.7b
	Agrinos	1.72a	1.68abc	1.67cde	1.69bc
	Bioforge	1.62de	1.67bcd	1.73ab	1.67cd
	Fast Start	1.66bc	1.73a	1.76a	1.72ab
	Regoplan	1.71a	1.72a	1.77a	1.74a
	Stimulate	1.65bcd	1.65cde	1.69cd	1.66d
	Vermistim D	1.64cde	1.62e	1.66de	1.64e
	Average	1.66b	1.67b	1.69a	
Felicia	Control	1.66fg	1.66e	1.66e	1.66f
	Albit	1.65g	1.74d	1.74d	1.71e
	Antistress	1.8ab	1.83ab	1.91a	1.84ab
	Agrinos	1.78bc	1.81bc	1.89a	1.83abc
	Bioforge	1.75cde	1.82ab	1.84bc	1.8c
	Fast Start	1.77bcd	1.85ab	1.83bc	1.82bc
	Regoplan	1.84a	1.87a	1.86ab	1.85a
	Stimulate	1.73de	1.77cd	1.8c	1.76d
	Vermistim D	1.7ef	1.72d	1.72d	1.71e
	Average	1.74c	1.78b	1.81a	

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 (Fig. 1).

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.

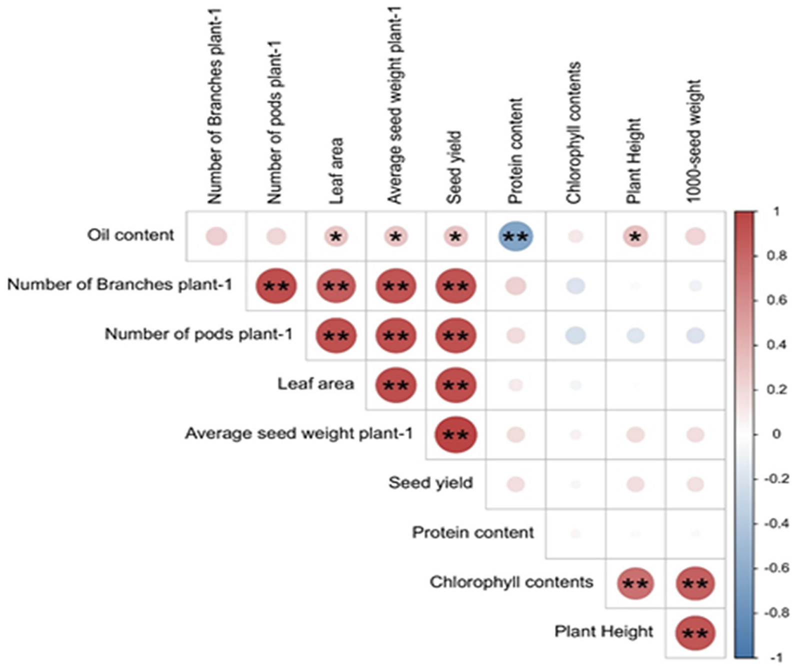

Fig. 1. Correlation between productivity features and seed yield of *Brassica juncea* L.

4 Conclusion

The seed yield of Felicia (1.78 t/ha) was significantly higher than 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).

All growth regulators increased the average 1000-grain weight of both cultivars. 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%.

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

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