# EFFECT OF MANNITOL AND GIBBERELLIC ACID ON YIELD AND YIELD ATTRIBUTING CHARACTERISTICS OF MUSTARD

**A THESIS**

**BY**

**NAHIDA PARVIN**
**Student ID: 1701216**
**Semester: 2022-2023**
**Session: January-June 2024**

**MASTER OF SCIENCE (M.S.)**
**IN**
**AGRONOMY**

**DEPARTMENT OF AGRONOMY**

**HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY**
**DINAJPUR-5200**

**JUNE 2024**

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**Submitted to the**
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**Approved as to style and content by**

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**JUNE, 2024**

**Dedicated To**

***My Beloved Parents***

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*June 2024* *The Author*

**ABSTRACT**

A field experiment was carried out at the research field of the Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200 during the period from November 2022 to March 2023 to evaluate the effect of mannitol and gibberellic acid on yield and yield attributing characteristics of mustard. The experiment comprised of two factors namely, Factor A: Different doses of mannitol viz. $M_1$ = 0 ppm (control), $M_2$ = 50 ppm, $M_3$ = 100 ppm, and $M_4$ = 150 ppm and Factor B: Three levels of gibberellic acid viz. $G_1$ = 0 ppm (control), $G_2$ =50 ppm and $G_3$ = 100 ppm. It consisted of twelve different treatment combinations. The experiment was laid out by randomized complete block design (RCBD) with three replications. The maximum growth parameters of mustard were found statistically significant. Considering the application of different doses of mannitol the maximum siliqua plant$^{-1}$ (57.24), seeds siliqua$^{-1}$ (34.22), 1000-seed weight (3.39 g), seed yield (1.45 t ha$^{-1}$), stover yield (2.86 t ha$^{-1}$), biological yield (4.31 t ha$^{-1}$) and harvest index (33.74 %) were observed in $M_4$ (150 ppm) whereas the minimum number of siliqua plant$^{-1}$ (41.97), seeds siliqua$^{-1}$ (28.53), 1000-seed weight (2.93 g), seed yield (1.04 t ha$^{-1}$), stover yield (2.53 t ha$^{-1}$), biological yield (3.58 t ha$^{-1}$) and harvest index (29.20 %) were observed in $M_1$ (0 ppm that is control). In case of different doses of $GA_3$ the maximum siliqua plant$^{-1}$ (52.63), seeds siliqua$^{-1}$ (32.91), 1000-seed weight (3.37 g), seed yield (1.32 t ha$^{-1}$), stover yield (2.76 t ha$^{-1}$), biological yield (4.09 t ha$^{-1}$) and harvest index (32.33 %) were recorded in $G_3$ (100 ppm*)* treatment while the minimum number of siliqua plant$^{-1}$ (48.25), seeds siliqua$^{-1}$ (29.93), 1000-seed weight (3.13 g), seed yield (1.16 t ha$^{-1}$), stover yield (2.64 t ha$^{-1}$), biological yield (3.81 t ha$^{-1}$) and harvest index (30.51 %) were observed in $G_1$ (control). In case of interaction effect of mannitol and gibberellic acid the maximum number of siliqua plant$^{-1}$ (58.06), seeds siliqua$^{-1}$ (35.33), 1000-seed weight (3.51 g), seed yield (1.53 t ha$^{-1}$), stover yield (2.90 t ha$^{-1}$), biological yield (4.43 t ha$^{-1}$) and harvest index (34.57 %) were recorded in $M_4G_3$ treatment combination. The minimum number of siliqua plant$^{-1}$ (38.33), seeds siliqua$^{-1}$ (27.13), 1000-seed weight (2.76 g), seed yield (0.96 t ha$^{-1}$), stover yield (2.38 t ha$^{-1}$), biological yield (3.35 t ha$^{-1}$) and harvest index (28.74 %) were observed in $M_1G_1$ treatment combination respectively. So, it may be suggested that Mannitol (150 ppm) combined with Gibberellic acid (100 ppm) showed better results for the growth and yield of mustard.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AEZ | = Agro-ecological Zone |
| ANOVA | = Analysis of variance |
| BARI | = Bangladesh Agricultural Research Institute |
| BBS | = Bangladesh Bureau of Statistics |
| BINA | = Bangladesh Institute of Nuclear Agriculture |
| cm | = Centimeter |
| CV | = Co-efficient of Variation |
| DAS | = Days After Sowing |
| DMRT | = Duncan's Multiple Range Test |
| GA3 | = Gibberellic Acid |
| M | = Mannitol |
| *et al.* | = And other |
| FAO | = Food and Agriculture Organization |
| $ha^{-1}$ | = Per hactare |
| HI | = Harvest Index |
| LSD | = Least Significant Difference |
| NS | = Non-significant |
| RCBD | = Randomized Complete Block Design |
| SRDI | = Soil Resource Development Institute |
| t | = Ton |
| UNDP | = United Nations Development Programme |
| µg | = Micro-gram |
| @ | = At the rate of |
| RCBD | = Randomized complete Block Design |
| No. | = Number |
| NAA | = Naphthalene Acetic Acid |
| DAE | = Department of Agricultural Extension |
| USD | = United States Dollar |
| USDA | = United States Department of Agriculture |
| SPAD | = Soil Plant Analysis Development |
| ROS | = Reactive Oxygen species |
| mM | = Milimeter |
| PEG | = Polyethylene Glycol |
| ppm | = Parts per million |
| PGRs | = Plant Growth Regulators |
| TSP | = Triple Supper Phosphate |

# CHAPTER I

# INTRODUCTION

Mustard (*Brassica juncea* L.) is a major oil seed crop that belongs to the Brassicaceae family and the genus *Brassica.* There are about 100 species of *Brassica*, of which *Brassica campestries, B. juncea, B. napus, B. nigra and B. alba* are commercially important (Saha *et al.*, 2021). In Bangladesh, about 66.44 % is covered by rapeseed and mustard, less than 7 % by till, 6.28 % by groundnut, 11.62 % by soybean, 7.29 % by coconut, 0.32 % by sunflower and 1.05 % by linseed (BBS, 2023). It is one of the most important oilseed crops for its remarkable edible oil demand in Bangladesh (Sampa *et al.,* 2020). The seeds contain 40-44% oil, 25% protein and 6.4% nitrogen (FAO, 2012). Mustard contains a lot of protein, fiber, vitamin C, and B-complex vitamins. It is an important source of cooking oil in Bangladesh, accounting for one-third of the country's edible oil requirements. Through its extension activities, DAE is promoting the expansion of rapeseed and mustard production and almost 20 different types of mustard have been released by BARI and BINA (USDA, 2022). In terms of area and production, mustard ranks first among the oilseed crops planted in Bangladesh. Total production of rapeseed and mustard was 547 thousand M tons from 947 thousand acres of land in the fiscal year of 2022- 2023 (BBS, 2024)**,** which is very low as compared to that of advanced countries in the world. Bangladesh is a country of about 170 million people and annually consumes about 3.0 million tons of oils and with the increase in population, the demand for edible oil and oilseeds is in increasing trend (Alam, 2020). Bangladesh required 0.30 million tons of oil equivalent to 0.85 million tons of oil seeds to nourish the existing population. At present oilseed production is about 0.32 million tons which covers 30% domestic needs (Khan *et al.,* 2022). Under rice-based cultivation system in Bangladesh, where three forth of total cultivation land was engaged in rice production in 2015-16 (BBS, 2019). So, Bangladesh has to import a noticeable amount of edible oil and oilseeds to meet up the existing accelerating demand. Bangladesh is facing a huge deficit of edible oil. In view of the importance of this crop, attention has to be given to improvement of its production in order to meet the huge shortage of cooking oil in the country. If we can increase the yield of mustard it will mitigate the oil deficiency of our country. To meet domestic demand and diversify the rice-based cropping system, mustard production is receiving more attention. The plant growth regulators (PGR) have a significant role in directing plant developments, enhancing seed yield and quality traits. It has long been ascertained that plant hormones including auxins, gibberellic acid, cytokinin, abscisic acid and ethylene are involved in controlling developmental event.

Plant growth regulators are crucial to the development of plants, increasing yield and improving seed quality. Due to its phytohormonic properties, gibberellic acid, a PGR, enhances seed germination, growth, stem elongation, photosynthesis, flowering, and cell expansion (Yuan and Xu, 2011). Gibberellic acid has the power to enhance mustard flowering, photosynthesis, nutrient transport, pollen development, pollen tube growth, and yield (Khan *et al.,* 2005). A low concentration of $GA_3$ breaks seed dormancy and increases plant growth and overall productivity (Pawar and Laware, 2018). The hydrolytic enzymes are coded by mRNA of gibberellic acid accumulated in dry matter, minerals and carbohydrates. Gibberellins (GAs) constitute a group of tetracyclic diterpenes that are mostly recognized for their effects on plant morphology, flower and fruit development, stem elongation, and leaf expansion (Yamaguchi, 2008; Chauhan *et al.,* 2010). The impact of $GA_3$ was most conspicuous and resulted in a higher growth, efficient translocation and utilization of nutrients. $GA_3$ increased partitioning of biomass to the leaves and stem.

On the other hand, external use of mannitol acts as an Osmo protectant under stress conditions, preserving membrane structure and acting as free radical scavengers, preventing lipid peroxidation, or as a regulator of $K^+$ and $Na^+$ channels in stomata. It helps osmotic adjustment and acts as an antioxidant to scavenge hydroxyl radicals (OH) (Srivastava *et al.,* 2010). Major functions in physiology of plants that include storage of carbon and the defense mechanism against environmental factors are carried about by mannitol (Patel and Willamson, 2016). Mannitol certainly has the ability to performs its role as compound, which is compatible with cellular mechanism act as osmo protectant protect from heat and avoid oxidation. It also stated that mannitol has central importance in decreasing the osmotic stress and the stress caused by the salts in majority of plant species (Bhauso *et al.,* 2014). It has been observed that plant under photosynthetic pigments and biomass level increases by the foliar application of mannitol (Kaya *et al.,* 2013). Though mannitol plays an important role in osmotic adjustment, it acts as an antioxidant to scavenge of hydroxyl radicals (OH). Mannitol is considered essential for photosynthates activity which contributes 60-80% in many plants, it produces photosynthates in leaves that are translocated in phloem. Mannitol synthesis is normal in the cytosol of source leaves with a hexose phosphate pool with sucrose synthesis. Overall plant growth regulators have a positive impact in enhancing qualitative characters in plants. Based on this background a study was initiated to yield performance of mustard following the application of $GA_3$ and mannitol.

Therefore, it is suggested that mannitol and gibberellic acid improve morphology, development and yield of mustard. Keeping in view of above facts, the present study was undertaken with the following specific objectives:

- To know the optimum doses of mannitol for maximizing the yield and yield attributing characters of mustard.
- To find out the suitable doses of gibberellic acid for maximizing the yield and yield attributing characters of mustard.
- To find out the interaction effect of mannitol and gibberellic acid for enhancing yield and yield attributing characters of mustard.

# CHAPTER II

# REVIEW OF LITERATURE

Mustard is one of the most popular oilseed crop of the world as well as Bangladesh. The crop received much attention to the researcher of different countries including Bangladesh. But a few investigations have been taken on the effect of plant growth regulators on mustard production. $GA_3$ and Mannitol are the important plant growth regulators that have been used to modify the growth, yield and yield attributing characters of mustard. The literature and research results related to the present study are reviewed in this chapter.

## 2.1. Effect of mannitol on yield and yield contributing characters of mustard

### 2.1.1 Plant height (cm)

A field study was carried out by Saleh and Hamzah (2021) to know the effect of mannitol and phenylalanine spray on the growth, yield and production of some active compounds of (*Brassica napus* L.) at the experimental farm, College of Agricultural Engineering Sciences-University of Baghdad, Al-Jadiriyah during 2018-2019. The aim was to study the effect of spraying mannitol (0, 1500, 3000) mg $L^{-1}$ and phenylalanine (0, 15, 30) mg $L^{-1}$ on growth, yield and production of Secondary metabolites for two genotypes of rapeseed (Pactol and serw 4). The results showed that the Bactol was significantly superior to the serw4 in terms of plant height, number of branches, number of capsules plant$^{-1}$, number of seeds plant$^{-1}$ and total seed yield, while serw 4 had the highest chlorophyll content in the leaves and the highest weight of 1000 seeds. Spraying of mannitol at 3000 mg $L^{-1}$ and phenylalanine at 30 mg $L^{-1}$ also excelled in the effect on most of the growth and yield characteristics. The interaction treatment of mannitol at 3000 mg $L^{-1}$ and phenylalanine at 15 mg $L^{-1}$ gave high content of glucosinolates (11.50 and 18.50) mmol $g^{-1}$, respectively, for both genotypes, and interaction of mannitol at 3000 mg $L^{-1}$ and phenylalanine at 30 mg $L^{-1}$ gave high content of sinapine (69.12 and 11.90) mmol $g^{-1}$ for both genotypes.

Zaidi *et al.* (2024) conducted an investigation during Rabi season, 2022-23 and 2023-24 at the student instructional farm (SIF) of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya- 224229 (U.P.). The treatment was comprised of control distilled water spray, Mannitol 25, 50, 100 ppm and Nano urea 25, 50, 100 ppm respectively, which was foliar sprayed at 30 DAS. The observations have been studied on the growth, bio-chemical, yield and yield attributes of wheat. Observations were recorded at 60, 90 DAS and at maturity stages for timely sowing (15 November) and late sowing (15 December). However, yield and yield parameters were taken at the time of harvesting of the crop. Foliar spray of mannitol and nano urea were performed well at 60, 90 DAS and at maturity parameters. Foliar application of nano urea with 25 ppm was recorded superior on plant height (cm), dry weight plant$^{-1}$ (g), chlorophyll content in leaves (SPAD value), Catalase activity (mg g$^{-1}$ fresh weight min$^{-1}$), Peroxidase activity (mg g$^{-1}$ fresh weight min$^{-1}$), Super oxide dismutase activity (mg g$^{-1}$ fresh weight min$^{-1}$). However, yield and yield attributes viz length of spike, number of tillers plant$^{-1}$, number of grains spike$^{-1}$, grain yield plant$^{-1}$ It is concluded from the result that foliar spray of nano urea 25 ppm was found most effective to increasing all characters and yield parameters of wheat.

Akram *et al.* (2011) studied the adverse effect of moisture stress and germination and seedling growth of wheat. Four growth substances viz, ethephone, paclobutrazol, succinic acid, triadimefon with varying concentrations and distilled water were used as seed treatment in a lab experiment. Moisture stress of -0.4 M pa induced with the application of mannitol significantly reduced speed of germination and suppressed root, shoot and coleoptiles elongation. However, due to less adverse effects of water stress on root growth, root-shoot ratio was increased. Thus, the decline in speed of germination, root elongation, shoot growth and coleoptiles length was 51, 5.70, 58 and 2.85 percent respectively. Eventually, maximum speed of germination (23.98), root length (10.00 cm), shoot length (24.57 cm) and coleoptiles (5.09 cm) were found in case of control, whereas values of these parameters were minimum under moisture stress with no treatment.

Achakzai and Bazai (2007) studied the effect of four level of water potential (ψ) viz., 0.00; -4.09; -8.18 and -12.28 bars on the seedling growth of six cultivar of maize (*Zea mays* L.). Mannitol was used as an osmoticum along with half strength Hoagland culture solution. Results depicted that in response to different levels of water stress all mentioned entries of seedling growth (except root dry weight) as well as different cultivars of maize in general responded significantly ($P<0.05$). Results also depicted that as water stress level increased seedling growth decreased. Results also showed there is a total of 72.71 % improvement in seedling growth when compared with the results of the same study using no Hoagland culture media.

Kaya *et al. (*2013) reported that the mechanism of growth amelioration in salt-stressed maize (*Zea mays* L. cv., DK 647 $F_1$) by exogenously applied mannitol (M) and thiourea (T) was investigated in pot experiment. Two levels of M (15 and 30 mM) or T (3.5 and 7.0 mM) were sprayed to the leaves of maize seedlings 10 days after germination. Salinity stress caused considerable reduction in plant dry biomass, chlorophyll content, and relative water content in the maize plants. Foliar-applied M or T increased the contents of K, $Ca_2$, and P, but decreased that of Nain the salt-stressed maize plants with respect to those of the salt-stressed plants not supplied with mannitol or thiourea. Mannitol was found to be more effective than thiourea in improving salinity tolerance of maize plants in terms of growth and physiological attributes measured in the present study.

Nilanthi *et al.* (2015) conducted an experiment where surface sterilized seeds of mung bean variety MI 5 and Harsha were introduced to hormone free Murashige and Skoog (MS) basal medium with different concentrations of mannitol (0 %, 10 %, 20 %, 30 %, 40 % and 50 %). Seedlings heights, length of the roots and number of germinated seeds were recorded after 2nd weeks of culture. Results showed that the highest seed germination (100 %) from Mung bean variety MI 5 and Harsha in all mannitol concentrations. Reduction of seedling height and increasing the root length was observed while increasing the mannitol concentration in both varieties.

The study was focused by Bousba *et al.* (2021) at examination of the biochemical and germination parameters effected by low water potential which was generated by polyethylene glycol (PEG) 6000 and mannitol, (0, 5, 10, 15 and 20 % of PEG 6000 and mannitol), related to drought stress and growth of durum wheat genotype. The results showed that both PEG -6000 and mannitol reduced germination. Therefore, a rapid increase was observed in the rate of germination both for the control plants and the plants subjected to a concentration of 5 g $L^{-1}$ and 10 g $L^{-1}$ and changes in proportion to the time. For the concentration of 15g $L^{-1}$ and 20 g $L^{-1}$, this phase is very short, which explains the reduced germination rate due to the inhibitory effect of the two osmoticums on germination.

An experiment was carried out by Rahman (2015) under laboratory conditions and the whole experiment was divided into three experiments. In the first experiment, BARI Mung-3 and BARI Mung-6 were primed in 3, 6, 9, 12, 15, and 18 hours under 2 %, 4 %, 6 %, and 8 % mannitol solution and distilled water, respectively. 9 hours priming time showed the best result for its lowest EC value. In the second experiment, two mung bean varieties were surface sterilized with 75 % alcohol solution, soaked in water and mannitol (2 %, 4 %, 6 %, and 8 %) for 9 hours and dry seed used as control. The highest total germination percentage (98.38 %), germination index (87.78), vigor index (186.9), relative water content (65.64 %), water retention capacity (21.22) and lowest water saturation deficit (34.36 %) were obtained from seeds primed in 2 % mannitol for BARI Mung-3 compare to total germination percentage (93.09 %), germination index (85.41), energy of emergence (97.31 %), vigor index (136.5), relative water content (77.22%), water retention capacity (15.94) and lowest water saturation deficit (22.78%) were obtained from seeds primed in 6 % mannitol for BARI Mung-6. In the final experiment, seeds were primed with distilled water and 2 % mannitol for BARI Mung-3 and 6 % mannitol for BARI Mung-6 by 9 hours; dry seed used as control and were exposed to 0 %, 5 %, 10 %, 15 %, and 20 %. From the results of the study, it was observed that seeds primed with 2 % mannitol for BARI Mung-3 and 6 % mannitol for BARI Mung-6 by 9 hours showed the best result in comparison to water primed seed and dry seed.

### 2.1.2 Number of siliqua plant$^{-1}$

Shakoor *et al.* (2024) was laid down research to understand the effect of exogenously applied mannitol on terminal heat stressed mungbean. The experiment was performed under greenhouse conditions. Heat stress was applied at flower initiation and pod formation stages and different levels (0 mg L$^{-1}$, 100 mg L$^{-}$, 200 mg L$^{-1}$ and 300 mg L$^{-1}$) of mannitol were foliar applied. Morphological, physiological, and yield traits were focused. Heat reduced all the parameters significantly and interaction of mannitol with heat improved all the morphological parameters (shoot and root length (cm), shoot fresh weight (g plant$^{-1}$), root fresh and dry weight (g plant$^{-1}$) significantly as the dose of mannitol was increased. All the biochemical parameters (chlorophyll a and chlorophyll b contents) were increased under heat stress. Mannitol worked as a compatible solute and as an antioxidant that help the plant to overcome the ROS species and showed significant interaction with heat at 300 mg L$^{-1}$. All yield parameters (number of seeds pods$^{-1}$, number of pods plant$^{-1}$, pod length (cm), 1000 seed weight (g) and seed yield (g plant$^{-1}$) were also significantly improved due to interactive effect of mannitol and heat.

Al-Hadithy *et al.* (2022) conducted an experiment to know the effect of spraying boron and mannitol sugar on the growth and yield of cauliflower at the Agricultural Research Station of the College of Agriculture, University of Anbar, in the district of Ramadi Al-Bu Aithah, during the winter season of 2021. The circumference of curd was 77.85 cm, the weight of curd was 2.671 kg plant$^{-1}$, the fresh curd weighed 64.09 mcg ha$^{-1}$, the dry weight of curd was 159.1 g plant$^{-1}$.

### 2.1.3 Number of seed siliqua$^{-1}$

Rashid and Molesh (2022) carried out an experiment at the Research Station of the Department of Horticulture and Landscaping-College of Agriculture-University of Diyala, during the autumn season 2021-2022 to study the effect of foliar spraying with sugar alcohol (mannitol) with Two concentrations in addition to the control treatment of 0, 10, and 15 g liter$^{-1}$, and boron with three concentrations in addition to the control treatment of 0, 50, 100, and 150 mg. liter$^{-1}$ on the growth and yield of pea plants. The results showed that spraying with mannitol 15 g L$^{-1}$ gave the highest number of pods, number of seeds in a pod, yield per plant, and total yield, which reached 27.99, 7.851, 178.8 g and 9.564 ton respectively. While spraying with boron at a concentration of 150 gm L$^{-1}$ was superior in recording the highest mean in number of pods, pod length, number of seeds in a pod, yield per plant, and total yield, which reached 103.3 cm, 64.36 %, 33.34, 12.42 cm, 8.454, 208.5 g, and 11.14 ton, respectively.

### 2.1.4 1000 seed weight (g)

An experiment was laid down by Haque, (2018) at Sher-e-Bangla Agricultural University (SAU), Dhaka, Bangladesh during the period from November 2017 to February 2018 to study the seed yield and quality of mungbean as affected by seed priming. The whole experiment was conducted in two different phases: the first at field condition and second in the Laboratory. Two varieties of mungbean viz. $V_1$ (BARI mung-6) and $V_2$ (BARI mung-8) and different priming chemicals including control viz. $T_0$ (control; No priming), $T_1$ (seed priming with water), $T_2$ (seed priming with PEG) and $T_3$ (seed priming with Mannitol) were considered as treatments of the experiment. Regarding, interaction effect of variety and seed priming treatments, the highest number of pods plant$^{-1}$ (26.60), 1000 seed weight (51.12 g), grain weight plant$^{-1}$ (15.30 g) and grain yield ha$^{-1}$ (1572.20 kg) were found from the treatment combination of $V_1T_3$ (seed priming with mannitol).

A field study was conducted by Saleh and Hamzah (2021) to know the effect of mannitol and phenylalanine spray on the growth, yield and production of some active compounds of (*Brassica napus L.*) at the experimental farm, College of Agricultural Engineering Sciences-University of Baghdad, Al-Jadiriyah during 2018-2019. The aim was to study the effect of spraying mannitol (0, 1500, 3000) mg L$^{-1}$ and phenylalanine (0, 15, 30) mg L$^{-1}$ on growth, yield and production of Secondary metabolites for two genotypes of rapeseed (Pactol and serw 4). The results showed that the Bactol was significantly superior to the serw in terms of plant height, number of branches, number of capsules plant$^{-1}$ number of seeds plant$^{-1}$ and total seed yield, while serw 4 had the highest chlorophyll content in the leaves and the highest weight of 1000 seeds.

### 2.1.5 Seed yield (t ha$^{-1}$)

Dawood *et al.* (2022) reported that mannitol treatments at 20 and 30 mM significantly increased plant fresh and dry weight, total photosynthetic pigments, seed number and weight plant$^{-1}$ seed yield (Kg feddan$^{-1}$), reducing sugar and starch accompanied by significant decreases in total phenolic content, tannins and vicine content. It is worthy to mentioned that mannitol treatments at 0, 10, 20 and 30 mM significantly increased seed yield (Kg feddan$^{-1}$) by 23.73, 31.88 and 40.15 % respectively. Regarding interaction between cultivars and mannitol treatments, it was noted that 30 mM mannitol increased seed yield (Kg feddan$^{-1}$) by 56.37 % in Misr 2 and by 22.21 % in Sakha 3 relative to corresponding controls.

Umair *et al.* (2013) conducted a study for improving yield and biological nitrogen fixation capacity of mung beans through priming techniques. The seeds were invigorated by traditional soaking (hydro priming), osmo conditioning (soaking of seeds in aerated, low-water-potential solutions) with potassium di-hydrogen phosphate ($KH_2PO_4$), mannitol ($C_6H_{14}O_6$), polyethylene glycol ($PEG_{6000}$), sodium molybdate dehydrate ($Na_2MoO_4.2H_2O$) and salicylic acid ($C_7H_6O_3$) while untreated seeds were kept as control. All the priming treatments significantly improved the dry matter yield (4001 to 5262 kg ha$^{-1}$) and seed yield (713 to 948 kg ha$^{-1}$) compared to the control. The highest biological nitrogen fixation (46.39 kg $ha^{-1}$) was observed in phosphorous primed plants compared to the control.

A field experiment was conducted by Lhungdim *et al*. (2018) at College of Agriculture, CAU, Imphal (Manipur) to evaluate the effect of priming methods and sowing depth of desi chickpea variety JG-14 during rabi season of 2014-15 and 2015-16 with two factors viz, priming methods (Distilled water, Mannitol, NaCl and $KNO_3$) and sowing depth (5 cm, 7.5 cm and 10 cm). Hydro-primed seeds of chickpea sown at 10 cm recorded significantly highest growth parameters, yield attributes and seed yield (852.73 kg $ha^{-1}$) while, lowest grain yield was recorded in NaCl primed seeds with 5 cm sowing depth.

### 2.1.6 Stover yield (t $ha^{-1}$)

A study was conducted by Umair *et al.* (2013) for improving yield and biological nitrogen fixation capacity of mung beans through priming techniques. The seeds were invigorated by traditional soaking (hydro priming), osmo conditioning (soaking of seeds in aerated, low-water-potential solutions) with potassium di-hydrogen phosphate ($KH_2PO_4$), mannitol ($C_6H_{14}O_6$), polyethylene glycol ($PEG_{6000}$), sodium molybdate dehydrate ($Na_2MoO_4.2H_2O$) and salicylic acid ($C_7H_6O_3$) while untreated seeds were kept as control. All the priming treatments significantly improved the dry matter yield (4001 to 5262 kg $ha^{-1}$) and seed yield (713 to 948 kg $ha^{-1}$) compared to the control. The highest biological nitrogen fixation (46.39 kg $ha^{-1}$) was observed in phosphorous primed plants compared to the control.

### 2.1.7 Biological yield (t $ha^{-1}$)

A pot experiment was performed by Habiba *et al.* (2019) to examine the role of foliar applied mannitol (0, 50, 100 mg $L^{-1}$) in chromium (0, 5 and 10 mg $kg^{-1}$) stress alleviation in different maize cultivars. Results showed that foliar application of mannitol significantly alleviated the Cr stress and improved growth, biomass, and photosynthetic pigments of maize plants. Mannitol also considerably reduced Cr contents in leaves and roots of both cultivars.

### 2.1.8 Harvest index (%)

An Experiment was conducted by Arshad *et al.* (2022) to know the effect of foliar application of mannitol on growth and yield of maize under different water regimes with various irrigation levels $I_0$: Control, $I_1$: Skip Irrigation at tasseling, $I_2$: Skip Irrigation at dough stage and foliar application of mannitol with given concentration $C_0$: 0 mM, C1: 2 mM, $C_2$: 4 mM, $C_3$: 6 mM on maize variety DS-555. This experiment was conducted at Agronomic Research Area, University of Agriculture, Faisalabad. The plants were uprooted from field at emergence, tasseling, silking, milking and physiological maturity stages and subject to oven dry method to understand the plant biomass partitioning. All parameters of stand establishment, growth and yield related parameters were evaluated in the laboratory. Mannitol individually significantly effects on the harvest index. More harvest index obtained from $C_2$ (41.48) and minimum from $C_0$ (35.93) under mannitol foliar application.

### 2.2 Effect of $GA_3$ on yield and yield contributing characters of mustard

#### 2.2.1 Plant height (cm)

A field experiment was conducted by Sumi *et al.* (2021) to know the effect of Gibberellic Acid (control, 25, 50 and 75 ppm) and Sulphur (control, 20, 40 and 60 kg $ha^{-1}$) on growth and yield of Mustard (*Brassica juncea* L.) during rabi season of 2020-21 at the research farm of Rajasthan College of Agriculture, Udaipur. The significant increase in plant height, dry weight, number of branches $plant^{-1}$, number of siliqua $plant^{-1}$, number of seeds $siliqua^{-1}$, test weight, seed yield and stover yield of mustard was observed with the application of $T_{11}$ (40 kg S $ha^{-1}$ +50 ppm $G_3$), as compared to control.

A plot experiment was conducted by Saha *et al.* (2021) at the Crop Botany Field Laboratory, Department of Crop Botany, Bangladesh Agricultural University during November 2007 to March 2008 to evaluate the effects of Gibberellic Acid ($GA_3$) on morphological and biochemical features of mustard (var. BINAshorisha-6). Four concentrations viz. 0, 25, 50 and 75 ppm of $GA_3$ were sprayed on canopy at 30 days after sowing. The results showed that different levels of $GA_3$ significantly influenced the plant height; number of primary and secondary branches $plant^{-1}$; root, shoot and shell dry weight $plant^{-1}$ total dry matter $plant^{-1}$; total chlorophyll content of leaves and protein and oil content in seeds. The highest plant height (96.57 cm) was produced with the application of 50 ppm $GA_3$.

Rahman *et al.* (2018) showed that application of $GA_3$ @ 100 ppm produced better performance on morpho-physiological characters namely, plant height (56.59), number of leaves plant$^{-1}$ (10.75), branches plant$^{-1}$ (4.75), length of root (24.7cm) and total dry matter (12.67g) which were recorded from the variety BARI Mung-6 with the foliar application of $GA_3$ 100 ppm.

Laboni *et al.* (2024) conducted an experiment to know the effect of different fertilizer combinations and gibberellic acid (GA3) on yield attributing traits of Mustard at the Research Field of the Department Crop Physiology and Ecology of Hajee Mohammad Danesh Science and Technology University, Dinajpur, in accordance with randomized complete block design with three replications. Three mustard varieties viz., BARI Sarisha-14, BARI Sarisha-17 and Bina sarisha-9 were evaluated against four combined fertilizations and $GA_3$. In extent of fertilization, most of the growth parameters showed the highest values in Urea: 250 kg ha$^{-1}$, MoP: 70 kg ha$^{-1}$, TSP: 190 kg ha$^{-1}$, Gypsum: 120 kg ha$^{-1}$, Zinc Sulphate: 4 kg ha$^{-1}$, Boric acid: 10 kg ha$^{-1}$, Poultry litter compost: 10 ton ha$^{-1}$, $GA_3$: Gibberellic Acid 10 % and the lowest values were recorded in Urea: 250 kg ha$^{-1}$, MoP: 70 kg ha$^{-1}$, TSP: 190 kg ha$^{-1}$, Gypsum: 120 kg ha$^{-1}$, Zinc Sulphate: 4 kg ha$^{-1}$, Poultry litter compost: 10 tons ha$^{-1}$. Gibberellic Acid 10 % exhibited the highest performance in the context of fertilization and variety interactions.

Sharma *et al.* (2017) carried an investigation to know the effect of plant growth regulators (PGRs) on growth, biochemical changes and yield of mustard during rabi season, 2013-2014 at the Instructional Farm of Narendra Deva University of Agriculture & Technology, Kumarganj, Faizabad (U.P.), India in randomized block design with ten treatments and three replications. The treatments were comprised of foliar spray of 3 plant growth regulators (PGRs) of different concentrations viz., Salicylic acid (0.1 mM, 0.3 mM and 0.5 mM), $GA_3$ (25 ppm, 50 ppm and 100 ppm) and kinetin (25 ppm, 50 ppm and 100 ppm) along with untreated control (distilled water spray) and spraying was done at 30 DAS. Observations were recorded at 60, 90 DAS and at maturity. All the treatments enhanced the yield and yield contributing characters at all the doses in mustard. On the basis of the above investigation, it may be concluded that foliar spray of PGRs at 30 DAS may be used as a potential tool to improve growth and yield of mustard.

An experiment was carried out by Rahman *et al.* (2015) in pots at Bangladesh Institute of Nuclear Agriculture, Bangladesh to evaluate influence of different concentrations of $GA_3$ (0, 25, 50, 75 and 100 ppm) on biochemical parameters at different growth stages in order to maximize yield of summer tomato var. Binatomato-2. The highest plant height was recorded when 50 ppm of $GA_3$ was applied at the vegetative stage.

An experiment was conducted by Akter *et al.* (2007) in pot house at the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh during November 2003 to February 2004 to evaluate the effects of Gibberellic Acid on growth and yield of mustard var. Bina sarisha-3. Four concentrations viz., 0, 25, 50 and 75 ppm of $GA_3$ were sprayed on canopy at 30 days after sowing. Different concentrations of $GA_3$ had significantly influenced the plant height. Plant height was the highest (95.77 cm) with the application of 50 ppm $GA_3$ which was statistically similar with 75 ppm $GA_3$ and the lowest (77.63 cm) was found in the control.

Islam and Mehraj (2014) stated that foliar application of $GA_3$ ($G_2$= 200 ppm) increased yield and yield traits of wheat. Here, three concentrations of $GA_3$ viz. $G_0$: No $GA_3$ i.e., control condition; $G_1$: 100 ppm $GA_3$ and $G_2$: 200 ppm $GA_3$ were used. They found that maximum plant height (89.9 cm), number of tiller plant$^{-1}$ (5.0), CGR (5.8), RGR (0.04), dry matter content plant$^{-1}$ (26.8 g), number of spikes plant$^{-1}$ (4.1), number of spikelets spike$^{-1}$ (19.0), ear length (17.0 cm), filled grain spike$^{-1}$ (30.4), total grains spike$^{-1}$ (32.6), weight of 1000-grain (45.5 g), grain yield (3.9 t ha$^{-1}$), straw yield (4.6 t ha$^{-1}$), biological yield (8.5 t ha$^{-1}$) and harvest index (46.1 %) were found from $G_2$ (200 ppm) whereas minimum from $G_0$.

### 2.2.2 Number of siliqua plant$^{-1}$

The present study was conducted by Elahi *et al.* (2023) to investigate the potential of $GA_3$ in alleviating drought stress in canola. Three levels of $GA_3$ ($G_0$ = 0 mg L$^{-1}$, $G_1$ = 100 mg L$^{-1}$ and $G_2$ = 150 mg L$^{-1}$) as foliar applications were applied. With the application of $G_2$ = 150 mg L$^{-1}$, the maximum values of no. of siliqua plant$^{-1}$ (15.50), seed siliqua$^{-1}$ (15.55) and siliqua length (5.08 cm) were recorded under drought stress.

A field experiment work was conducted by Dawar *et al*. (2020) at the research field of Pulses Research Unit, Washim Road, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra) during Kharif season of 2018, to study the effect of foliar application of gibberellic acid on growth, yield and economics of blackgram (*Vigna mungo* L.). In blackgram, 11 treatments comprising gibberellic acid management practices (application of 15, 30, 45 ppm $GA_3$ at flower and pod initiation stages and control) were tested. Results indicated that two applications of 30 ppm $GA_3$ at flower and pod initiation stages recorded significantly number of pods cluster$^{-1}$, length of pod (cm), number of grains pod$^{-1}$ number of pods plant$^{-1}$, grain yield plant$^{-1}$ (g), grain yield (kg ha$^{-1}$) and gross monetary returns than no application of the $GA_3$.

### 2.2.3 Number of seeds siliqua$^{-1}$

The investigation entitled the effect of foliar application of $GA_3$ (15 ppm, 30 ppm, 45 ppm, 60 ppm, 75 ppm, 90 ppm, 125 ppm) on yield and quality of Indian mustard [*Brassica Juncea* (L.) Czern. and Coss.] under sodic soil was carried out by (Saini *et al.* 2017) during rabi season, 2016-2017 at the Main Experiment Station (MES) Farm of Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad-224 229 (U.P.) in randomized block design with eight treatments, three replications and variety Narendra rai (NDR-8501). Results indicated that all yield contributing traits like number of silique plant$^{-1}$ (351.46), length of silique (5.65 cm), number of seeds silique$^{-1}$ (15.40), test weight (4.70 g), seed yield plant$^{-1}$ (23.52 g) were found higher with foliar spray of $GA_3$ (125ppm) followed by foliar sprayed of 90 ppm, over rest of treatments including control.

Nizamani *et al.* (2018) reported that gibberellic acid ($GA_3$) is a phytohormone that is required at low concentrations and in tiny amounts to promote the growth and development of plants. Thus, growth regulators can be applied exogenously to a particular crop using $GA_3$ at the appropriate concentration and time to generate favorable conditions. One such plant growth regulator is gibberellic acid, which can be used to control a range of growth and development phenomena in different types of crops. $GA_3$ increases plant growth and promotes stem elongation. Days to maturity and flowering, length of siliqua plant$^{-1}$, number of seeds siliqua$^{-1}$, 1000 seeds, seed yield, and oil content under the concentration of $GA_3$ 10 g ha$^{-1}$, while days to maturity and number of branches plant$^{-1}$ were observed under the concentration of $GA_3$ 5 g ha$^{-1}$. The present results concluded that Rainbow, Dunckled, Con-II, and Oscar under the concentration of 10 g ha$^{-1}$ $GA_3$ found the best concentration for yield and yield attributes of canola.

An experiment was set up by Saini *et al.* (2021) situated at the main Experiment Farm of the university on the Ayodhya to Raibareli road to know the influence of $GA_3$ on Yield and Quality of Indian Mustard. Various concentrations of $GA_3$ (15 ppm, 30 ppm, 45 ppm, 60 ppm, 75 ppm, 90 ppm and 125 ppm) were taken along with untreated control.

The maximum number of seeds silique$^{-1}$ were counted with foliar sprayed of $GA_3$ at 125 ppm (15.40 seeds silique$^{-1}$) followed by foliar sprayed with $GA_3$ at 0 ppm (15.33 seeds silique$^{-1}$) over rest of treatments.

**2.2.4. 1000- seed weight (g)**

A field study was contemplated by Noor *et al.* (2017) to know the effects of gibberellic acid ($GA_3$) on growth and yield parameters of French Bean (*Phaseolus vulgaris* L.) during the Rabi season of 2009-2010 in the research field of Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka. Six levels of $GA_3$, viz. 0, 30, 50, 70, 90 and 110 ppm were sprayed at 18 days after sowing (DAS). $GA_3$ with 30 to 90 ppm significantly increased the number of branches and leaves, leaf area, leaf area index (LAI). The weight of the thousand seeds ranged from 213.50 g to 235.47 g. Significantly maximum 1000 seeds weight was registered for 50 ppm $GA_3$ which was 10.29 % higher compared to the control. It was found that all the $GA_3$ treatments significantly increased 1000 seeds weight, which agrees with the studies of Emongor (2007) for cowpea and Tiwari *et al.* (2011) for rice.

An experiment was conducted by Haifaa and Moses (2022) in paddy variety MR 219, which is the first commercial *indica* rice variety in Malaysia developed MARDI (Malaysia Agriculture Research and Development Institute) in 2001 (MARDI, 2013). This experiment showed the timing of application during different growth stages and mode of application of $GA_3$ on the growth and yield of MR219. Two applications of $GA_3$ at 7 days interval has consistently given higher grain yield than single application. However, there is no significant difference in flag leaf characteristics, one thousand grain weight and milling qualities on different treatments. Our study has clearly illustrated that foliar application of $GA_3$ at weekly interval at 10-30 % panicle heading stage, can increase rice grain yield significantly.

**2.1.5 Seed yield (t ha$^{-1}$)**

The experiment was carried out by Borah *et al.* (2023) during rabi season of 2018-19, 2019-20 and 2020-21 at Experimental unit of Zonal Research Station, Shillongani, Assam. Results revealed that foliar application of 1.0 ppm Auxin + 200 ppm Gibberellic acid resulted in better seed yield (985 kg ha$^{-1}$).

Buriro *et al.* (2022) was studied in 2017-2018 during the rabi season using at the Nuclear Institute of Agriculture, Tandojam to know the effects of foliar application of Gibberellic-Acid on the growth and yield of Canola (*Brassica napus* L.) genotypes. The experiment was performed with four promising Canola genotypes in order to determine the impact of the $GA_3$ foliar application on canola growth and outputs. The effect of the $GA_3$ foliar treatment on canola growth and outputs noted that the development and yield of canola (*Brassica napus* L.) genotypes were affected by the foliar application of cacodylic acid. It was observed that earlier days to maturity (108.39) was recorded in genotype R00-100/6 and maximum siliquae per plant (362.24), siliqua length (7.39 cm), seeds per siliqua (21.49), seed index (4.50 g) and seed yield (1443.08 kg $ha^{-1}$) was observed with the application of $GA_3$ 5g $ha^{-1}$ in SURHRAN-2012 and followed by with the application $GA_3$ @ 6 g $ha^{-1}$ genotype R00- 125/12 and Rainbow (P).

Haifaa and Moses (2022) stated that the timing and mode of application of Gibberellic acid ($GA_3$) in rice cultivation to increase grain yield. It focuses on MR219, a popular Indica rice variety, and two commercial $GA_3$ formulations, ProGibb SG and ProGibb silica Granule. $GA_3$ was applied at late tillering stage and 10-30 % panicle heading stage. The study found that $GA_3$ application during the early reproductive stage, at 10-30 % panicle heading stage, significantly increased grain yield, with over 27 % increase over the untreated control. Two $GA_3$ applications at 7 days interval consistently yielded higher grain yields than a single application. However, no significant difference was found in flag leaf characteristics, grain weight, and milling qualities among different treatments. The study concludes that foliar $GA_3$ application at weekly intervals can significantly increase rice grain yield.

Mazid and Naz (2017) carried out an experiment with an aim to enhance the performance of chickpea by the spray of a small quantity of phosphorus (P) and sulphur (S) with or without the soaking of $GA_3$ treatment (10-6 M GA for 8h) and the $GA_3$ spray treatment (10-6 M GA at 60-70 DAS). P and S each at 2 kg $ha^{-1}$ were sprayed in two equal splits i.e. half at 60 and the remaining half at the 70 DAS alone or in combination with the GA3 treatment. Prior to sowing, total seeds of chickpea were grouped into two; one group of seeds was soaked in 0M $GA_3$ (control) and the other group were soaked in 10-6 M $GA_3$ aqueous solution, each for 8 hours. There was total sixteen treatments with ten combinations of P and S with $GA_3$ are possible viz., FPS, SGA + FP, SGA + FS, SGA + FPS, FGAP, FGAS, FGAPS, SGA + FGAP, SGA + FGAS and SGA+FGAPS. The combined application of P and S with $GA_3$ showed better responses and further improvement in carbonic anhydrase (CA) activity, stomatal conductance (gs), net photosynthetic rate (PN), nitrate reductase activity (NR), and leghemoglobin content (Lb) at two sampling stages (90 and 100 DAS). This treatment also increased pod number per plant, seed yield per plant and harvest index (HI), seed protein and carbohydrate content at harvest. This combination augmented the protein content (21 %), carbohydrate content (11 %), seed yield (86 %) and HI (91.78 %).

An experiment was conducted by Khan *et al.* (2022) at the research field of Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Cumilla during November 2019 to March 2021 to find out the effect of two plant growth regulators (PGR) of IAA and $GA_3$ on yield attributes and yield of mustard (Var. BARI Sarisha-17). There were seven treatments viz. $T_1$= IAA 50 ppm, $T_2$= IAA 75 ppm, $T_3$= IAA 100 ppm, $T_4$= $GA_3$ 50 ppm, $T_5$= $GA_3$ 75 ppm, $T_6$= $GA_3$ 100 ppm, and $T_7$= Control. The highest plant height (115.9 cm), branches plant$^{-1}$ (6.2), siliqua plant$^{-1}$ (79.8), 1000- seed weight (4.1) and seed yield (1788.3 kg ha$^{-1}$) were obtained from $T_5$ ($GA_3$ - 75 ppm) treatment. The lowest seed yield was obtained from the control plants ($T_7$). Foliar application of $GA_3$ and IAA at the rate of 75 ppm could be used at early growth stage for obtaining higher seed yield and economic return.

Keykha *et al.* (2014) conducted a field experiment at Islamic University, Zahedan, Iran to evaluate the effect of salicylic acid and gibberellic acid on some characteristics in mungbean (*Vigna Radiata*) and found that both salicylic acid and gibberellic acid affect the grain yield of mungbean significantly.

Siddiqui *et al*. (2016) conducted research to evaluate the effect of foliar application of nitrogen, phosphorus; gibberellic acid and indole-3-acetic acid with two canola mutants R00-125/14, W97-75/16 with their respective parents Rainbow and Westar were used in this experiment. The application of N, P fertilizers increased 67 % seed yield in brassica. The maximum number of branches plant$^{-1}$, siliqua plant$^{-1}$, 1000 seed weight and seed yield kg ha$^{-1}$ was recorded under the treatment of 90N-45P-10 $GA_3$-10 IAA while minimum number of branches plant$^{-1}$, sliqua plant$^{-1}$ and 1000 seed weight were recorded under the treatment of 90N-45P-15GA3-15 IAA. It was recommended that brassica should be sown under the treatment of 90N-45P-10GA3-10 IAA to achieve best performance to produce more seed yield and quality trait in brassica.

Prasad *et al*. (2021) was carried out an experiment in the field of Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (U.P.) during Rabi season 2020-2021, in order to standardize the suitable pre-sowing seed treatment for Mustard. Different pre-sowing seed treatments with control (Unhardened) were evaluated viz., $T_0$ Control, $T_1$- $Mg(NO_3)_2$ @ 0.1 %, $T_2$- $Mg(NO_3)_2$ @ 0.3 %, $T_3$- $Mg(NO_3)_2$ @ 0.5%, $T_4$-Ca(NO3)2 @ 0.1%, $T_5$-$KNO_3$ @ 0.5%, $T_6$- $Mg(SO_4)_2$ @ 0.1%, $T_7$- $Mg(SO_4)_2$ @ 0.3%, $T_8$- $Mg(SO_4)_2$ @ 0.5%, $T_9$- $GA_3$ @ 25ppm, $T_{10}$- $GA_3$ @ 50ppm, $T_{11}$- $GA_3$ @ 75ppm, $T_{12}$- PEG6000 @ 25ppm. It was found that the all-pre-sowing seed treatments showed significant difference with control. Seed treatment with $KNO_3$ @ 0.5 % was found to be highest in field emergence and yield attributes of Mustard and it was followed by $GA_3$ @ 25ppm and Mg $(NO_3)_2$ @ 0.1 %. Pre-sowing seed treatment with $KNO_3$ @ 0.5 % and $GA_3$ @ 25 ppm showed maximum increase yield of mustard seeds and found to be lowest in control seeds. Pre-sowing seed treatments of the mustard seeds in which $KNO_3$ @ 0.5 % gave the best result to enhanced germinability, seed vigour, seed yield and yielding attributes.

### 2.1.6 Stover yield (t $ha^{-1}$)

An experiment was carried out by Harshitha *et al.* (2021) at student farm, College of Agriculture, Rajendranagar, Hyderabad, Telangana, in sandy loam soils during rabi 2020 to study the effect of hormones on growth and yield of mustard under Southern Telangana Agro-climatic conditions. The result showed the highest stover yield (5468) was observed with the application of RDF + foliar spray of $GA_3$ @ 45 ppm fb humic acid @ 1.5 % with 2 days interval at flowering and pod development ($T_{10}$), which was on par with RDF + foliar spray of $GA_3$ @ 45 ppm fb humic acid @ 1.5 % with 2 days interval at flowering ($T_8$) (5305).

This experiment was designed by Rafique *et al*. (2021) to know the combined effects of Gibberellic Acid and Rhizobium on growth, yield and nutritional status in chickpea (*Cicer arietinum* L.). Exogenous application of $GA_3$ (10-5 M) combined with rhizobium inoculation gave the highest values for number of nodules $plant^{-1}$ (16) and their dry biomass (0.22 g). The most promising results were obtained by the inoculation of Rhizobium accompanied with $GA_3$ (10-5 M). Plant height, grain and stover yield, and chlorophyll contents were enhanced up to 35 %, 39 %, 21 % and 51 %, respectively. A higher increase in stover N, P and K contents by 18 % was attained with the mutual application of Rhizobium and $GA_3$ (10-5 M).

### 2.1.7 Biological yield (t ha$^{-1}$)

Ullah *et al.* (2022) evaluated the role of urease inhibitor [N-(n-butyl) thiophosphorictriamide (NBPT)] and gibberellic acid ($GA_3$) in improving nitrogen uptake and yield of maize under different N levels (120 and 150 kg ha$^{-1}$) along with control. Both N levels alone and in combination with $GA_3$ and NBPT significantly increased yield and yield components of maize over control. In addition, 150 kg N ha$^{-1}$ + NBPT + $GA_3$ produced the highest biological yield, grain, and stover yields, 1000 grain weight, plant height, and N uptake exhibiting 33.15 %, 56.46 %, 27.56 %, 19.56 %, 23.24 %, and 78 % increase over 150 kg N ha$^{-1}$, respectively.

Sumi *et al. (*2021) carried out an experiment to find out the effect of Gibberellic Acid (control, 25, 50 and 75 ppm) and Sulphur (control, 20, 40 and 60 kg ha$^{-1}$) on Growth and Yield of Mustard (*Brassica juncea* L.)" during rabi season of 2020-21 at the research farm of Rajasthan College of Agriculture, Udaipur. The significant increase in plant height, dry weight, number of branches plant$^{-1}$, number of siliqua plant$^{-1}$, number of seeds siliqua$^{-1}$, test weight, seed yield, stover yield and biological yield of mustard was observed with the application of $T_{11}$ (40 kg S ha$^{-1}$ +50 ppm $G_3$) as compared to control.

### 2.1.8 Harvest index (%)

A field experiment was undertaken by Raj *et al*. (2022) at the Crop Research Farm, Department of Agronomy, SHUATS, Allahabad, during the Rabi season (2021-22). PGR1 ($GA_3$ 30 ppm), PGR2 ($GA_3$ 60 ppm), and PGR3 ($GA_3$ 90 ppm) were used as plant growth regulators and zinc ($Zn_1$-5 kg ha$^{-1}$), $Zn_2$-10 kg ha$^{-1}$), and $Zn_3$-15 kg ha$^{-1}$) were used as fertilizers in 3 levels. Foliar sprayed of different concentrations of $GA_3$ increased yield and growth parameters of Toria. Yield and quality contributing characters were shown highest with $GA_3$ application with 90 ppm compared to other treatments. Treatment with application of $GA_3$ 30 ppm + Zn 15 Kg ha$^{-1}$ was recorded maximum harvest index (26.99 %) and minimum with application of $GA_3$ 60 ppm + Zn 15 kg ha$^{-1}$ (22.98 %).

# CHAPTER III

# MATERIALS AND METHODS

The experiment was conducted at the Agronomy field of Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200 during the period from November 2022 to March 2023 to study the effect of mannitol and $GA_3$ on yield and yield attributing characters of mustard. In this chapter the details of materials and methods that were used in conducting the experiment are given below:

## 3.1 Description of the experimental site

### 3.1.1 Location

The study was carried out at the research field of the Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200. The experimental area is located at 25° 38' N latitude and 88° 41' E longitude and it is situated at elevation of 37 meters above the sea level (Appendix I). The land of the experimental site was medium-high. The land belongs to the Agro-ecological Zone AEZ-1 of the Old Himalayan Piedmont Plain (BBS, 2016) (Appendix II).

### 3.1.2 Soil

The soil of the experimental fields belongs to the Old Himalayan Piedmont Plain (Agro-ecological Zone-1). The general soil type of the experimental field was non-calcareous dark gray floodplain. The topsoil was sandy loam in texture. Organic matter content was 1.48 % and soil pH varies from 5.8-6.0. The land is above flood level and well drained (Appendix II).

### 3.1.3 Climate

The climate of the experimental site possesses subtropical, characterized by three distinct seasons, the monsoon runs from November to February and the pre-monsoon period or hot season which runs from March to April and the monsoon period from May to October. The weather data including temperature, rainfall and relative humidity during the period of experimental recorded from the Bangladesh Meteorological station of Bangladesh Wheat and Maize Research Institute (BWMRI). The climate in Dinajpur has been presented in (Appendix III).

### 3.3 Planting materials

BARI Sarisha 14 was used in this experiment. The seeds were collected from Regional Centre of Bangladesh Agricultural Development Corporation, Pulhat, Dinajpur. The seeds were healthy, pulpy, well-matured and free from mixture of other seeds, weed seeds and extraneous materials.

The important characteristics of BARI Sarisha 14 are given below:

- Short duration mustard variety.
- Plant height 75-85 cm.
- Leaves color light green.
- Number of siliqua plant$^{-1}$ 80-102.
- Number of seeds siliqua$^{-1}$ 28-30.
- Flower and seed yellow in color.
- Oil content 44-45 % in seed.
- Yield 1.4-1.6 %

### 3.3 Land preparation

The experimental field which was selected for the experiment was 1st opened by using a power tiller on November 5, 2022. Then it was exposed to the sunshine for 5/6 days pieces followed by each ploughing. All the weeds and stubbles were removed from the experimental field. The plots were spaded one day before planting. Ploughed soil was then brought into desirable fine tilth and leveled by laddering. The final ploughing and land preparation were done on 15 November 2023. According to the fertilizers recommendation by BARI (2014), the whole number of fertilizers were incorporated thoroughly before planting.

### 3.4 Fertilizer application

Urea, TSP, Mop, gypsum, zinc sulphate and boric acid were used as a source of nitrogen, phosphorus, potassium, gypsum, and boron @ 120, 80, 60, 4, 1 kg per hectare, respectively. Half of the urea and all other fertilizers were applied during final land preparation. The remaining 50% urea was top dressed at 30 DAS at the flower initiation stage followed by irrigation. The PGRs were applied thrice at pre-flowering (at 20 DAS), post-flowering stage (at 40 DAS), and at last (at 60 DAS) with a hand sprayer.

### 3.5 Treatments of the experiment

The experiment consisted of two factors as follows:

**Factor A: Mannitol**

$M_1$ = 0 ppm (Control)

$M_2$ = 50 ppm

$M_3$ = 100 ppm

$M_4$ = 150 ppm

**Factor B: Gibberellic acid**

$G_1$ = Control

$G_2$ = 50ppm

$G_3$ = 100ppm

### 3.6 Treatment combination

$M_1G_1$=Mannitol 0 ppm (control) with Gibberellic acid 0 ppm (control)

$M_1G_2$=Mannitol 0 ppm (control) with 50 ppm Gibberellic acid

$M_1G_3$=Mannitol 0 ppm (control) with 100 ppm Gibberellic acid

$M_2G_1$=Mannitol 50 ppm with gibberellic acid 0 ppm (control)

$M_2G_2$=Mannitol 50 ppm with gibberellic acid 50 ppm

$M_2G_3$=Mannitol 50 ppm with gibberellic acid 100 ppm

$M_3G_1$=Mannitol 100 ppm with gibberellic acid 0 ppm (control)

$M_3G_2$=Mannitol 100 ppm with gibberellic acid 50 ppm

$M_3G_3$=Mannitol 100 ppm with gibberellic acid 100 ppm

$M_4G_1$= Mannitol 150 ppm with gibberellic acid 0 ppm (control)

$M_4G_2$=Mannitol 150 ppm with gibberellic acid 50 ppm

$M_4G_3$=Mannitol 150 ppm with gibberellic acid 100 ppm

### 3.7. Experimental design

The experiment was laid out in a Randomized Complete Block Design (Factorial) with three replications. An area of 30m × 6m was divided into 3 equal blocks. The total number of experimental units was 36 (12×3). The unit plot size was 1m × 1m. The space between two blocks and two plots was 0.5 m and 0.25 m, respectively.

### 3.8. Layout of the experiments

The layout of the design of experiments was as follows:

| $R_1$ | $R_2$ | $R_3$ |
|---|---|---|
| **$M_2G_1$** | $M_1G_1$ | $M_4G_3$ |
| **$M_3G_1$** | $M_2G_2$ | $M_2G_1$ |
| **$M_4G_1$** | $M_4G_2$ | $M_3G_1$ |
| **$M_3G_3$** | $M_1G_2$ | $M_4G_1$ |
| **$M_1G_3$** | $M_4G_3$ | $M_3G_3$ |
| **$M_3G_2$** | $M_2G_1$ | $M_1G_3$ |
| **$M_2G_3$** | $M_3G_1$ | $M_3G_2$ |
| **$M_1G_1$** | $M_4G_1$ | $M_2G_3$ |
| **$M_2G_2$** | $M_3G_3$ | $M_1G_1$ |
| **$M_4G_2$** | $M_1G_3$ | $M_2G_2$ |

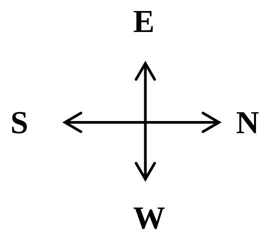


Fig. 1. Field layout of the experiment

### 3.9 Sowing of seeds in the field

Seeds were sown on 25th November, 2022. Sowing seeds were sown as per treatment in broadcasting method at a rate of 8 kg $ha^{-1}$. Row to row and plant to plant distance were 30 cm and 10 cm, respectively. Seeds were placed at about 2-3 cm depth from the soil surface. Several seeds are sown in each plot. The seeds were covered with the soil and slightly pressed by hand. Watering and other cultural practices were done when required.

## 3.10 Intercultural operations

### 3.10.1 Thinning

Emergence of seedling was completed within 10 days after sowing. The optimum plant population was maintained by thinning excess of plants at 15 DAS which was done to remove unhealthy and lineless seedlings. The second thinning was done 10 days after the first thinning.

### 3.10.2 Weeding

In order to maintain weed-free plots and, eventually, improved growth and development, weeding was done. The experimental plots were weeded as needed after the initial 30 DAS weeding.

### 3.10.3 Irrigation and drainage

The irrigation was done as per requirement. Two irrigations were applied at required times. First irrigation was given immediate after top dressing and second irrigation was applied 30 DAS. After irrigation when the plots were in optimum (joe) condition, spading was done uniformly and carefully to conserve the soil moisture for proper growth and development of plants. Stagnant water was effectively drained out at the time of heavy rains.

### 3.10.4 Disease and pest management

As a preventive measure of aphid infestation, Asataf (Acephate 75% SP) @ 1-1.5 gm $L^{-1}$ of water was applied twice at 25 DAS and second at 50 DAS.

### 3.10.5 General observation of the experimental field

In order to minimize losses due to weed competition, insect infestation, and disease infection, the field was regularly checked.

### 3.10.6 Harvesting and threshing

Previous randomly selected ten plants, those were considered for the growth analysis were collected from each plot to analyze the yield and yield contributing characters. The rest of the crops were harvested when 90 % of the siliqua in terminal raceme turned creamy white in color. After collecting sample plants, harvesting was started on 20

February and completed on 10 March, 2023. The harvested crop of each plot was bundled separately, properly tagged and brought to threshing floor. The seeds were separated from the plants by beating bundles with bamboo sticks. Proper care was taken for harvesting, threshing and cleaning of mustard seeds. Fresh weight of grain and siliqua were recorded plot wise. The grains were cleaned and finally the weight was adjusted to a moisture content of 12 %. The Stover was sun dried and the yield of seed and stover plot$^{-1}$ were recorded and converted to t ha$^{-1}$.

### 3.10.7 Drying and weighing

The seeds and stover thus gathered and were dried in the sun for few days. Dried seed and stover of each plot were weighted and subsequently converted into yield t ha$^{-1}$.

### 3.10.8 Sampling and Recording of data

Ten randomly selected plant samples were taken from each plot to obtain the data for the various mustard parameters. Data were recorded at 20 DAS, 40 DAS, and 60 DAS, and they were kept going until the crop's yield-contributing features were finished being recorded after harvest. The following data was recorded during the experiment.

**Crop growth characteristics**

- Plant height (cm)
- Branches plant$^{-1}$ (no.)

**Yield contributing characteristics**

- Siliqua plant $^{-1}$ (no.)
- Seeds siliqua$^{-1}$ (no.)
- 1000 seeds weight (g)

**Yield indices**

- Seed yield (t ha$^{-1}$)
- Stover yield (t ha$^{-1}$)
- Biological yield (t ha$^{-1}$)
- Harvest index (%)

### 3.11 Detailed procedures of recording data

#### 3.11.1 Crop growth character

##### 3.11.1.1 Plant height (cm)

Plant height in cm was measured four times at 20 days intervals such as 20 DAS, 40 DAS, 60 DAS and at harvest. The height of the plant was measured by scale considering the distance from the soil surface to the tip of the randomly 10 selected plants and the mean value was calculated for each treatment.

##### 3.11.1.2 Number of branches plant$^{-1}$

The number of branches per plant was counted from selected plants. The mean value of branches per plant was determined.

#### 3.11.2 Yield contributing characters

##### 3.11.2.1 Siliqua plant$^{-1}$

The number of total siliquae was counted from ten plants of each plot and the mean number was calculated per plant basis.

##### 3.11.2.3 Number of seeds siliqua$^{-1}$

The number of total seeds of ten plants from each plot was counted and the average number was calculated per siliqua basis.

##### 3.11.2.4 Weight of 1000 seeds (g)

One thousand cleaned and dried seeds were counted randomly from each sample and weight by using a digital electric balance and the mean weight was expressed in grams.

##### 3.11.2.5 Seed yield (t ha$^{-1}$)

The plants of the whole plot were harvested for taking seed yield. The seeds were threshed from the plants, cleaned, dried and then weighted. The yield of seed in kg plot$^{-1}$ was adjusted at 12 % moisture content of grain and then it was converted to t ha$^{-1}$.

#### 3.11.2.6 Stover yield (t ha$^{-1}$)

The Stover of the harvested crop in each plot was sun dried to a constant weight. Then the stover yield were weighted and thus the Stover yield plot$^{-1}$ was determined. The yield of Stover in kg plot$^{-1}$ was converted to t ha$^{-1}$.

#### 3.11.2.7 Biological yield (t ha$^{-1}$)

Seed yield and Stover yield together were regarded as biological yield. The biological yield was calculated with the following formula:

Biological yield = Grain yield + Stover yield

#### 3.11.2.8 Harvest index (%)

The harvest index was calculated from the ratio of grain yield to biological yield and expressed in percentage. It was calculated by using the following formula.

Harvest index = Grain yield / Biological yield × 100

### 3.12 Statistical Analysis

The data obtained from the experiment on various parameters were statistically analyzed using the analysis of variance (ANOVA) technique in MSTAT-C computer program (Russell, 1986). The mean values for all the parameters were calculated and the analysis of variance was performed. The treatment means were compared using Duncans Multiple Range Test (DMRT) (Gomez and Gomez, 1984).

# CHAPTER IV

# RESULTS AND DISCUSSION

This chapter comprises presentation and discussion of the results obtained from a study to investigate the influence of different doses of mannitol and $GA_3$ on yield and yield attributing characters of mustard (BARI Sarisha 14). The results of the growth, yield and yield attributing characters of the production of the crop as influenced by different doses of mannitol and $GA_3$ have been presented and discussed in this chapter.

## 4.1 Plant height (cm)

### 4.1.1 Effect of mannitol on plant height of mustard at different day intervals

One of the most important morphological characteristics is plant height that act as a potent indicator of availability of growth resources in its vicinity. Mannitol was significant effect on plant height of mustard. Statistically significant variation (Appendix IV) was observed in terms of plant height at 60 and at harvest with the application of mannitol (Table 1).

At 60 DAS and at harvest the tallest plants (54.35 cm, 60.78 cm) were recorded in $M_4$ (150 ppm) on the other hand the shortest plants (48.48 cm, 55.55 cm) were found in $M_1$ (0 ppm; that is control) which was statistically similar with $M_3$ (100 ppm). The plant height was non-significant at 20 and 40 DAS. From the statistical analysis, plant height was shown significant at 1 % level of probability for 60 DAS and 5 % level of probability at harvest. Habiba *et al.* (2019) showed that foliar application of mannitol significantly alleviated the chromium stress and improved growth, biomass, and photosynthetic pigments of maize plants. Mannitol also considerably reduced chromium contents in leaves and roots of both cultivars.

**Table 1: Effect of mannitol on plant height at different day intervals of mustard**

| Doses of mannitol (ppm) | Plant height (cm) | | | |
|---|---|---|---|---|
| | 20 DAS | 40 DAS | 60 DAS | At harvest |
| $M_1$ | 11.53 | 32.57 | 48.48 b | 55.55 b |
| $M_2$ | 11.40 | 32.83 | 49.97 b | 58.25 ab |
| $M_3$ | 11.66 | 32.75 | 52.66 a | 60.48 a |
| $M_4$ | 11.57 | 32.76 | 54.35 a | 60.78 a |
| $LSD_{(0.05)}$ | 0.2599 | 0.2377 | 1.7604 | 3.2943 |
| CV (%) | 2.30 | 0.74 | 3.51 | 5.73 |
| LS | NS | NS | ** | * |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncans Multiple Range Test

* = Significant at 5% level of significance

** = Significant at 1% level of significance

LS = Level of significance

CV = Co- efficient of variance

LSD = Least Significant Difference

$M_1$ = 0 ppm (control)

$M_2$ = 50 ppm

$M_3$ = 100 ppm

$M_4$ = 150 ppm

**4.1.2 Effect of gibberellic acid on plant height of mustard at different day intervals**

Different doses of $GA_3$ substantially influenced the plant height of mustard (Table 2). Significant variation was recorded on the plant height when Gibberellic acid was exogenously applied. Statistically significant variation was observed in terms of plant height of mustard at 60 DAS and at harvest under the present trial. At 60 DAS, the longest plant height (53.50 cm) was found in $G_3$ (100 ppm) which was statistically equivalent with $G_2$ (50 ppm) and the shortest plant height (48.61 cm) was observed in $G_1$ (that is control). At harvest the highest plant height (62.07 cm) was attained in $G_3$ (100 ppm) which is statistically equivalent with $G_2$ (50 ppm) and the shortest plant height (54.16 cm) was observed in $G_1$ (Control). It was conducted that the plant height of mustard was shown non-significant at 20 and 40 DAS. From the statistical analysis, plant height was shown significant variation at 1 % level of probability for 60 DAS and at harvest. $GA_3$ induced cell division and cell enlargement as well as increase in plant height. The increase in plant height with different levels of $GA_3$ might be due to the fact that cell enlargement was accelerated with the application of $GA_3$. Result indicated that the application of different concentrations of $GA_3$ had increased the plant height over the control. A significant increase in plant height induced by different levels of $GA_3$ was observed in rapes. Sumi *et al.* (2021) was also observed with the application of $GA_3$ significantly increases the plant height of mustard.

**Table 2: Effect of $GA_3$ on plant height, at different day intervals of mustard**

| Doses of $GA_3$ (ppm) | Plant height (cm) | | | |
|---|---|---|---|---|
| | 20 DAS | 40 DAS | 60 DAS | At harvest |
| $G_1$ | 11.45 | 32.72 | 48.61 b | 54.16 b |
| $G_2$ | 11.55 | 32.74 | 51.99 a | 61.07 a |
| $G_3$ | 11.63 | 32.71 | 53.50 a | 62.07 a |
| $LSD_{(0.05)}$ | 0.2251 | 0.2059 | 1.5246 | 2.8529 |
| CV (%) | 2.30 | 0.74 | 3.51 | 5.73 |
| LS | NS | NS | ** | ** |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncan's Multiple Range Test

* = Significant at 5% level of significance
** = Significant at 1% level of significance
LS = Level of significance
CV = Co- efficient of variance
LSD = Least Significant Difference

$M_1$ = 0 ppm (control)
$M_2$ = 50 ppm
$M_3$ = 100 ppm
$M_4$ = 150 ppm

#### 4.1.3. Interaction effect of mannitol and gibberellic on plant height of mustard

Interaction effect of mannitol and gibberellic acid shown significant variation in terms of plant height of mustard at 40 DAS, 60 DAS and at harvest time (Table 3). At 40 DAS, the highest plant height (32.81 cm) was obtained from $M_4G_3$ (Mannitol 150 ppm with gibberellic acid 100 ppm) and the lowest plant height (32.63 cm) was observed from $M_1G_1$ (Mannitol 0 ppm with $GA_3$ 0 ppm, i.e. control) which was statistically non-significant. At 60 DAS the highest plant height (57.33 cm) was observed from $M_4G_3$ (Mannitol 150 ppm with gibberellic acid 50 ppm) and the lowest plant height (47.00 cm) was recorded in $M_1G_1$ (Mannitol 0 ppm with $GA_3$ 0 ppm, i.e. control) which was statistically different from others. At harvest, the highest plant height (64.66 cm) was recorded in $M_4G_3$ (Mannitol 150 ppm with gibberellic acid 50ppm) which is statistically similar with others and the lowest plant height (53.20 cm) was recorded from $M_1G_1$ (Mannitol 50 ppm with $GA_3$ 0 ppm, i.e. control) which was statistically different from others.

**Table 3: Interaction effect of mannitol and $GA_3$ on plant height at different day intervals**

| Interaction of mannitol and $GA_3$ | | Plant height (cm) | | | |
|---|---|---|---|---|---|
| | | 20 DAS | 40 DAS | 60 DAS | At harvest |
| | $G_1$ | 11.60 | 32.63 | 47.00 f | 53.20 d |
| $M_1$ | $G_2$ | 11.43 | 32.48 | 48.70 ef | 55.43 cd |
| | $G_3$ | 11.56 | 32.61 | 49.75 d-f | 57.33 b-d |
| | $G_1$ | 11.13 | 32.91 | 48.00 ef | 53.90 cd |
| $M_2$ | $G_2$ | 11.56 | 32.83 | 49.75 d-f | 59.00 a-c |
| | $G_3$ | 11.51 | 32.73 | 52.18 cd | 62.56 ab |
| | $G_1$ | 11.68 | 32.63 | 49.33 d-f | 54.66 cd |
| $M_3$ | $G_2$ | 11.58 | 32.92 | 53.91 bc | 63.07 a |
| | $G_3$ | 11.72 | 32.69 | 54.75 a-c | 63.71 a |
| | $G_1$ | 11.38 | 32.73 | 50.12 de | 54.90 cd |
| $M_4$ | $G_2$ | 11.63 | 32.75 | 55.60 ab | 62.78 ab |
| | $G_3$ | 11.71 | 32.81 | 57.33 a | 64.66 a |
| $LSD_{(0.05)}$ | | 0.450 | 0.411 | 3.0491 | 5.705 |
| CV (%) | | 2.30 | 0.74 | 3.51 | 5.73 |
| LS | | NS | NS | * | * |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncan's Multiple Range Test

* = Significant at 5% level of significance
** = Significant at 1% level of significance
LS = Level of significance
CV = Co- efficient of variance
LSD = Least Significant Difference

$M_1$ = 0 ppm (control)
$M_2$ = 50 ppm
$M_3$ = 100 ppm
$M_4$ = 150 ppm
$G_1$ = 0 ppm
$G_2$ = 50 ppm
$G_3$ = 100 ppm

#### 4.2. No. of siliqua plant$^{-1}$ (no.)

#### 4.2.1 Effect of mannitol

Siliqua number is a major determining factor in mustard, and it was greatly altered by the application of mannitol. The number of siliqua plant$^{-1}$ was significantly influenced due to the exogenous application of different doses of mannitol during harvest. The $M_4$ (150 ppm) has the highest number of siliqua plant$^{-1}$ (57.24) which was statistically similar with $M_3$ (100 ppm). On the other hand, $M_1$ produced the lowest siliqua number (41.97) (Table 4 and Appendix V). From the statistical analysis the siliqua number was shown significant variation at 1% level of probability. Different doses responded differently for number of seeds siliqua$^{-1}$ to input supply, cultivation method and the prevailing environment during the growing season. The findings proposed that the application of mannitol 150 ppm had positive impact on pod formation. Haque, (2018) also found similar findings on the highest pod number.

**Table 4: Effect of mannitol on number of siliqua plant$^{-1}$ (no.), number of seeds siliqua$^{-1}$ (no.) and 1000-seed weight (g) of mustard**

| Doses of mannitol (ppm) | Number of Siliqua Plant$^{-1}$ (no.) | Number of Seeds Siliqua$^{-1}$ (no.) | 1000-seed weight (g) |
|---|---|---|---|
| $M_1$ | 41.97 c | 28.53 c | 2.93 b |
| $M_2$ | 48.44 b | 30.53 b | 3.27 a |
| $M_3$ | 55.27 a | 33.00 a | 3.37 a |
| $M_4$ | 57.24 a | 34.22 a | 3.39 a |
| LSD $_{(0.05)}$ | 2.7449 | 1.5120 | 0.1487 |
| CV (%) | 5.53 | 4.90 | 4.69 |
| LS | ** | ** | ** |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncan's Multiple Range Test

* = Significant at 5% level of significance
** = Significant at 1% level of significance
LS = Level of significance
CV = Co- efficient of variance
LSD = Least Significant Difference

$M_1$ = 0 ppm (control)
$M_2$ = 50 ppm
$M_3$ = 100 ppm
$M_4$ = 150 ppm

### 4.2.2 Effect of $GA_3$

Different concentration of $GA_3$ treatment significantly changed in terms of siliqua plant$^{-1}$ of mustard. Table-5 showed that the maximum siliqua (52.63) was found from $G_3$ (100 ppm) which was statistically equivalent with $G_2$, while the lowest siliqua plant$^{-1}$ (48.25) was attained from $G_1$ when no treatment was practiced. The total siliqua plant$^{-1}$ was found to have considerable variation at the 1 % probability level. Some experiments manifested that transmission of assimilates to the sex organs due to the presence of $GA_3$ might have improved which can benefit the increase of siliqua per plant. Similar results agreed with Uddin *et al.* (1986) and Soliman (2019).

**Table 5: Effect of $GA_3$ on number of siliqua plant$^{-1}$ (no.), number of seeds siliqua$^{-1}$ (no.) and 1000-seed weight (g) of mustard**

| Doses of $GA_3$ (ppm) | Number of Siliqua Plant $^{-1}$ (no.) | Number of Seeds Siliqua$^{-1}$ (no.) | 1000- seed weight (g) |
|---|---|---|---|
| $G_1$ | 48.25 b | 29.93 b | 3.13 b |
| $G_2$ | 51.32 a | 31.86 a | 3.22 b |
| $G_3$ | 52.63 a | 32.91 a | 3.37 a |
| $LSD_{0.05}$ | 2.3772 | 1.3095 | 0.1288 |
| CV (%) | 5.53 | 4.90 | 4.69 |
| LS | ** | ** | ** |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncans Multiple Range Test

* = Significant at 5% level of significance

** = Significant at 1% level of significance

LS = Level of significance

CV = Co- efficient of variance

LSD = Least Significant Difference

$G_1$ = 0 ppm (control)

$G_2$ = 50 ppm

$G_3$ = 100 ppm

### 4.2.3 Interaction effect of mannitol and $GA_3$

The combined effect of mannitol and gibberellic acid showed significant variation on total siliqua plant$^{-1}$ during harvest (Table 6). The maximum siliqua plant$^{-1}$ (58.06) was observed from $M_4G_3$ (Mannitol 150 ppm with Gibberellic acid 100 ppm) which was statistically equivalent with $M_4G_2$ and the minimum siliqua plant$^{-1}$ (38.33) obtained from $M_1G_1$ (Mannitol control with Gibberellic acid control) combination. It was concluded that total siliqua plant$^{-1}$ showed significant variation at 5 % level of probability.

**Table 6: Interaction effect of mannitol and $GA_3$ on the number of siliqua plant$^{-1}$ (no.), number of seeds plant$^{-1}$ (no) and 1000-seed weight (g) of mustard**

| Interaction of mannitol and $GA_3$ | | Number of Siliqua plant$^{-1}$ (no.) | Number of seeds siliqua$^{-1}$ (no.) | 1000- seed weight (g) |
|---|---|---|---|---|
| | $G_1$ | 38.33g | 27.13 g | 2.76 e |
| $M_1$ | $G_2$ | 42.93 f | 28.80 fg | 2.93 de |
| | $G_3$ | 44.66 ef | 29.66 e-g | 3.10 cd |
| | $G_1$ | 46.66 d-f | 27.93 g | 3.13 cd |
| $M_2$ | $G_2$ | 48.46 c-e | 31.00 d-f | 3.30 abc |
| | $G_3$ | 50.20 cd | 32.66 b-d | 3.40 ab |
| | $G_1$ | 52.33 bc | 31.66 c-e | 3.23 bc |
| $M_3$ | $G_2$ | 55.83 ab | 33.33 a-d | 3.40 ab |
| | $G_3$ | 57.66 a | 34.00 a-c | 3.50 a |
| | $G_1$ | 55.66 ab | 33.00 a-d | 3.23 bc |
| $M_4$ | $G_2$ | 58.00 a | 34.33 ab | 3.43 ab |
| | $G_3$ | 58.06 a | 35.33 a | 3.51 a |
| $LSD_{(0.05)}$ | | 4.7543 | 2.6189 | 0.2575 |
| CV (%) | | 5.53 | 4.90 | 4.69 |
| LS | | * | * | * |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncan's Multiple Range Test

* = Significant at 5% level of significance
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LS = Level of significance
CV = Co- efficient of variance
LSD = Least Significant Difference

$M_1$ = 0 ppm (control)
$M_2$ = 50 ppm
$M_3$ = 100 ppm
$M_4$ = 150 ppm
$G_1$ = 0 ppm
$G_2$ = 50 ppm
$G_3$=100 ppm

### 4.3 Number of seeds siliqua$^{-1}$ (no.)

#### 4.3.1 Effect of mannitol

The number of seeds siliqua$^{-1}$ is one of the most significant yield-attributing characters. A higher number of seeds siliqua$^{-1}$ ultimately leads to greater seed yield. The number of seed siliqua$^{-1}$ of mustard varied significantly due to the exogenous application of mannitol showed in Table 4. It was shown that $M_4$ (Mannitol 150 ppm) produced the highest (34.22) number of seeds siliqua$^{-1}$ and $M_1$ (Mannitol 0 ppm i.e. control) produced the lowest (28.53) number of seeds silique$^{-1}$. It was conducted that the number of seeds siliqua$^{-1}$ of mustard was revealed significant variation at 1 % level of probability (Appendix V). Greater photosynthetic mobilization to individual seeds would therefore counterbalance fewer seeds silique$^{-1}$, which would be a favorable characteristic for sustaining better output. During the growth season, different doses reacted differently to the input supply, cultivation technique, and surrounding environment in terms of the number of seeds silique$^{-1}$. The result indicates that $M_4$ (150 ppm) positively affects the number of seed silique$^{-1}$. This result is highly supported by Haque, (2018).

### 4.3.2 Effect of $GA_3$

Different doses of $GA_3$ showed significant variation in terms of seeds siliqua$^{-1}$ of mustard. The highest seeds siliqua$^{-1}$ (32.91) was obtained from $G_3$ (100 ppm) but the lowest seeds siliqua$^{-1}$ (29.93) was observed from $G_1$ (control, while no treatment is used) Table 5. From the statistical analysis the number of seeds siliqua$^{-1}$ showed significant variation at 1 % level of probability. The plant growth regulators like $GA_3$ might be involved in formation of seeds in the pods and their optimum nourishments have resulted in a smaller number of aborted seeds and thus maximized the survival of fertile seeds siliqua$^{-1}$ in rapes and mustard (Holmberg and German, 1991; Boultior and Morgan, 1992). Different levels of $GA_3$ significantly influenced the number of seeds siliqua$^{-1}$, setting of siliqua plant$^{-1}$ (Saha *et al.*, 2021).

### 4.3.3 Interaction effect of mannitol and $GA_3$

Different concentrations of mannitol and $GA_3$ treatments showed significant differences on seeds siliqua$^{-1}$ due to the interaction effect (Table 6). The highest seeds siliqua$^{-1}$ (35.33) was found from $M_4G_3$ (Mannitol 150 ppm with Gibberellic acid 100 ppm) which was statistically different from others and the lowest seeds siliqua$^{-1}$ (27.13) from $M_1G_1$ (Mannitol control with Gibberellic acid control) which was statistically different from others combination. From the statistical analysis, the number of seeds siliqua$^{-1}$ showed significant variation at 5 % level of probability.

### 4.4 1000-seed weight (g)

#### 4.4.1 Effect of mannitol

There was a statistically significant difference in 1000- seed weight of mustard, as shown in (Table 4). The highest weight of 1000-seed (3.39.8 g) was obtained from $M_4$ (150 ppm) which was statistically similar to $M_3$ while the minimum weight of 1000-seed (2.93 g) was obtained from $M_1$ (control). The result indicates that M4 positively influenced the thousand seed weight of mustard. This is due to the fact that increasing the doses of mannitol increases the 1000-seed weight of mustard by inducing the size of seed. Like this, it was discovered that plants with mannitol accumulation under salinity stress had higher 1000-grain weights than plants without mannitol accumulation under the same stress (El-Yazal *et al.,* 2016).

#### 4.4.2 Effect of $GA_3$

1000-seed weight showed varied significantly for different foliar spray of $GA_3$ treatment shown in (Table 5). The highest 1000-seed weight of mustard found in $G_3$ (3.37 g) and $G_1$ (control) produced the lowest (3.13 g) 1000-seed weight. From the statistical analysis, 1000-seed weight of mustard was shown significant variation at 1% level of probability. It was found that all the $GA_3$ treatments significantly increased 1000 seeds weight, which agrees with the studies of Emongor (2007) for cowpea and Tiwari *et al.* (2011) for rice. This is due to the fact that increasing the doses of $GA_3$ increases the 1000-seed weight of mustard by inducing the size of the seed. The highly significant results for thousand seed weight were also supported by the earlier results of (Zebarjadi *et al.,* 2011).

#### 4.4.3 Interaction effect of mannitol and $GA_3$

Significant variation was observed due to the interaction effect of mannitol and $GA_3$ treatments on weight of 1000-seed (Table 6). The highest weight of 1000-seed (3.51 g) was obtained from $M_4G_3$ (Mannitol 150 ppm with Gibberellic acid 100 ppm) combination which was statistically different from others and the lowest 1000-seed weight (2.76 g) from $M_1G_1$ (control) combination. It was conducted that the 1000-seed weight of mustard was shown significant variation at 5% level of probability.

## 4.5 Seed yield (t ha$^{-1}$)

### 4.5.1 Effect of mannitol

The final expression of the plant's physiological and metabolic processes is the seed yield per hectare. The result of all the elements working together to promote improved growth is seed yield, which in turn raises the yield per plant and, eventually, the yield per hectare. It was observed that significant variation on seed yield of mustard at different doses of mannitol (Fig. 2). It was observed that the highest seed yield (1.45 t ha$^{-1}$) was obtained from $M_4$ (150 ppm) and the lowest seed yield (1.04 t ha$^{-1}$) was observed from $M_1$ (control) (Fig. 3). From the statistical analysis the seed yield of mustard showed significant variation at 1 % level of probability. This result indicates that $M_4$ (150 ppm) had a positive effect on seed yield. This was due to mannitol treatment at this concentration might be influenced the growth and development of seed. Shirinzadeh *et al*. (2013) found a similar result. Dawood *et al.* (2022) reported that the application of mannitol increased seed yield.

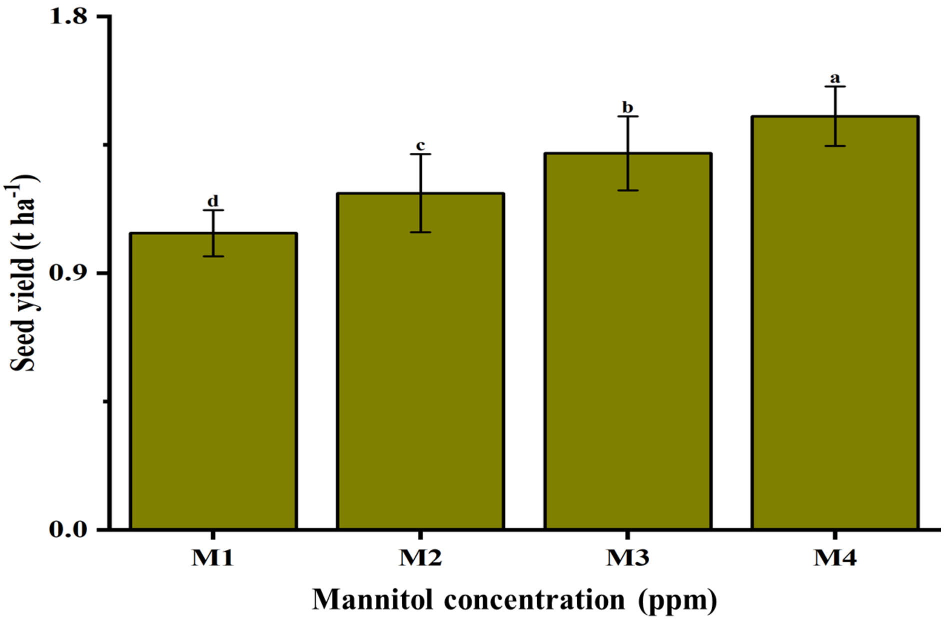



**Fig.2. Effect of mannitol (M) on seed yield (t ha$^{-1}$) of mustard**

$M_1$ = Control (0 ppm)
$M_2$ = 50 ppm
$M_3$ = 100 ppm
$M_4$ = 150 ppm

### 4.5.2 Effect of $GA_3$

Significant variation was observed for seed yield of mustard due to different concentrations of $GA_3$ treatment represented in (Fig. 3). The highest seed yield (1.32 t $ha^{-1}$) was obtained from $G_3$ (100 ppm) which was statistically different from others and the lowest seeds yield (1.16 t $ha^{-1}$) from $G_1$ (Control, when no treatment was used) which was statistically different from others. From the statistical analysis, the number of seeds yield showed significant variation at 1 % level of probability. $GA_3$ application was very effective in increasing seed set rate and grain yield. From the above findings increasing the doses of $GA_3$ significantly increases seed yield. Borah *et al.* (2023) observed that foliar application of $GA_3$ produced better seed yield.

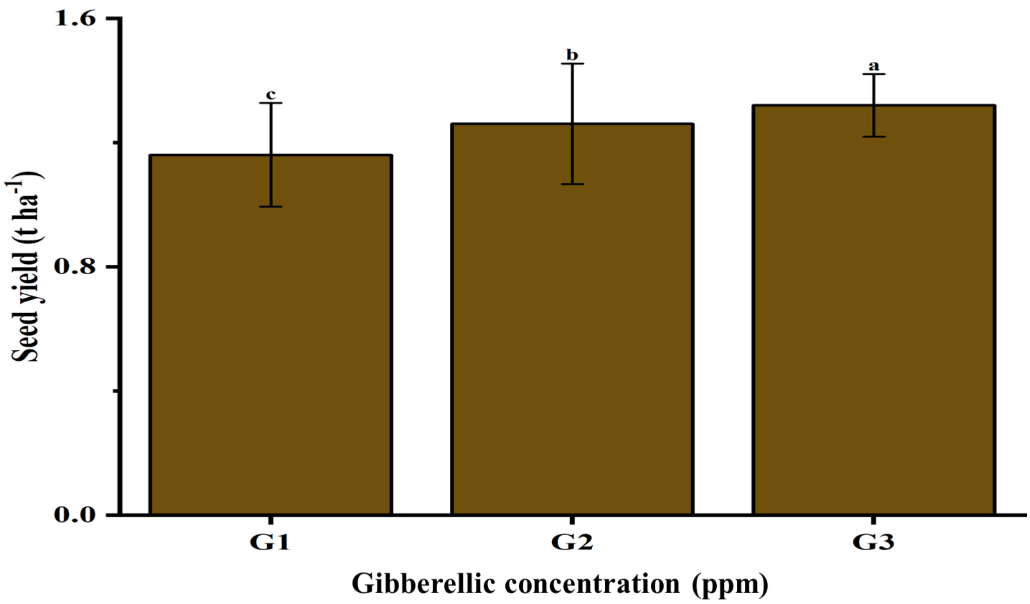



**Fig. 3. Effect of Gibberellic acid ($GA_3$) on seed yield (t $ha^{-1}$) of mustard**

$G_1$ = Control (0 ppm)
$G_2$ = 59 ppm
$G_3$ = 100 ppm

#### 4.5.3 Interaction effect of mannitol and $GA_3$

Different levels of mannitol and $GA_3$ showed significant variation on yield of seed due to interaction effect in (Fig. 4). The highest seed yield (1.53 t $ha^{-1}$) was found from $M_4G_3$ (Mannitol 150 ppm with Gibberellic acid 100 ppm) combination which was statistically different from others and the lowest seed yield (0.96 t $ha^{-1}$) from $M_1G_1$ (Control). It was conducted that the seed yield of mustard showed significant variation at 5 % (Appendix-VI) level of probability.

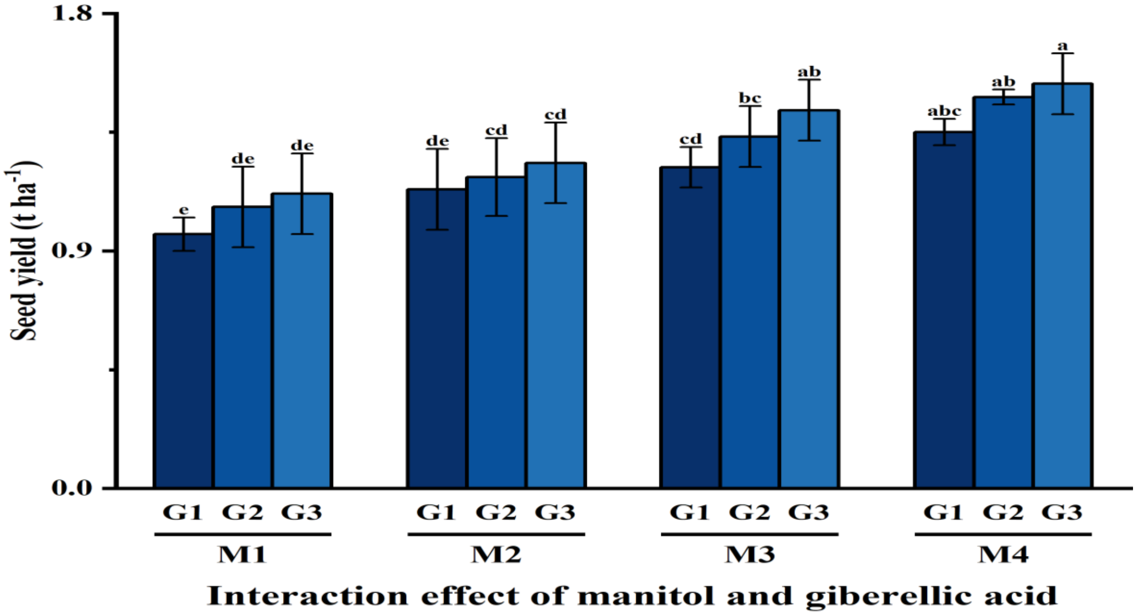



**Fig. 4. Interaction effect of mannitol and $GA_3$ on seed yield (t $ha^{-1}$)**

$M_1$ = 0 ppm (control)
$M_2$ = 50 ppm
$M_3$ = 100 ppm
$M_4$ = 150 ppm
$G_1$ = 0 ppm
$G_2$ = 50 ppm
$G_3$= 100 ppm

#### 4.6.1. Stover yield (t $ha^{-1}$)

#### 4.6.1 Effect of mannitol

Increases in vegetative growth and, to a lesser extent, the reproductive section of the plants are directly linked to increases in stover yield. Stover yield of mustard showed significant variation due to exogenous application of mannitol (Table 7). It was found that $M_4$ (150 ppm) gave the highest (2.86 t $ha^{-1}$) number of stover yield and $M_1$ (0 ppm i.e., control) gave the lowest (2.53 t $ha^{-1}$) number of stover yield. From the statistical analysis, the number of stover yield of mustard showed significant variation at 1 % level of probability.

**Table 7: Effect of mannitol on stover yield (t $ha^{-1}$), biological yield (t $ha^{-1}$) and harvest index (%) of mustard**

| Doses of mannitol (ppm) | Stover Yield (t $ha^{-1}$) | Biological Yield (t $ha^{-1}$) | Harvest Index (%) |
|---|---|---|---|
| $M_1$ | 2.53 c | 3.58 d | 29.20 c |
| $M_2$ | 2.65 bc | 3.84 c | 30.72 bc |
| $M_3$ | 2.77 b | 4.10 b | 32.32 ab |
| $M_4$ | 2.86 a | 4.31 a | 33.74 a |
| $LSD_{(0.05)}$ | 0.1104 | 0.1016 | 1.7987 |
| CV (%) | 4.17 | 2.62 | 5.84 |
| LS | ** | ** | ** |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncan's Multiple Range Test

* = Significant at 5% level of significance — $M_1$ = 0 ppm (control)
** = Significant at 1% level of significance — $M_2$ = 50 ppm
LS = Level of significance — $M_3$ = 100 ppm
CV = Co- efficient of variance — $M_4$ = 150 ppm
LSD = Least Significant Difference

#### 4.6.2 Effect of $GA_3$

Significant variation (Appendix VI) showed due to different concentration of $GA_3$ treatment for stover yield of mustard represented in Table 8. The highest stover yield (2.76 t $ha^{-1}$) was found from $G_3$ (100 ppm) which was statistically different from others and the lowest stover yield (2.64 t $ha^{-1}$) from $G_1$ (Control i.e., 0 ppm) which was statistically different from others. From the statistical analysis, it was conducted that the stover yield of mustard was shown significant at 5 % level of significance due to the application of $GA_3$. The exogenous application of $GA_3$ increases the stover yield of mustard. The increase in the doses of $GA_3$ treatment straw yield was greater than the control. Similar result was found by Saini *et al.* (2017) that straw yield was increased with the increase of concentration up to certain level. Statistically significant plant straw yield was recorded in all the treatments over control. Sumi *et al.* (2021) findings that $GA_3$ significantly increases the stover yield of mustard.

**Table 8: Effect of $GA_3$ on stover yield (t $ha^{-1}$), biological yield (t $ha^{-1}$) and harvest index (%) of mustard**

| Doses of $GA_3$ (ppm) | Stover Yield (t $ha^{-1}$) | Biological Yield (t $ha^{-1}$) | Harvest Index (%) |
|---|---|---|---|
| $G_1$ | 2.64 b | 3.81 c | 30.51 b |
| $G_2$ | 2.71 ab | 3.98 b | 31.95 ab |
| $G_3$ | 2.76 a | 4.09 a | 32.33 a |
| $LSD_{(0.05)}$ | 0.0.095 | 0.088 | 1.5577 |
| CV (%) | 4.17 | 2.62 | 5.84 |
| LS | * | ** | * |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncan's Multiple Range Test
* = Significant at 5% level of significance   $G_1$ = 0 ppm (control)
** = Significant at 1% level of significance   $G_2$ = 50 ppm
LS = Level of significance   $G_3$ = 100 ppm
CV = Co- efficient of variance
LSD = Least Significant Difference

### 4.6.3 Interaction effect of mannitol and $GA_3$

Different concentrations of mannitol and $GA_3$ treatments showed significant variation on yield of stover due to the combination effect in (Table 9). The highest stover yield (2.90 t $ha^{-1}$) was attained from $M_4G_3$ (Mannitol 150 ppm with gibberellic acid 100 ppm) and the lowest stover yield (2.38 t $ha^{-1}$) from $M_1G_1$ (Control). It was conducted that the stover yield of mustard showed significant variation at 5 % level of probability.

**Table 9: Interaction effect of mannitol and $GA_3$ on the stover yield (t ha $^{-1}$), biological yield (t ha $^{-1}$) and harvest index (%) of mustard**

| Interaction of mannitol and $GA_3$ | | Stover Yield (t ha$^{-1}$) | Biological Yield (t ha$^{-1}$) | Harvest Index (%) |
|---|---|---|---|---|
| | $G_1$ | 2.38 f | 3.35 g | 28.74 d |
| $M_1$ | $G_2$ | 2.55 d-f | 3.61 f | 29.41 cd |
| | $G_3$ | 2.66 c-e | 3.78 ef | 29.44 cd |
| | $G_1$ | 2.52 ef | 3.65 f | 30.90 bcd |
| $M_2$ | $G_2$ | 2.71 b-d | 3.89 de | 30.27 bcd |
| | $G_3$ | 2.74 a-d | 3.97 cd | 30.98 bcd |
| | $G_1$ | 2.85 a-c | 4.07 bc | 29.88 bcd |
| $M_3$ | $G_2$ | 2.73 a-d | 4.06 bc | 32.76 ab |
| | $G_3$ | 2.74 a-d | 4.17 b | 34.32 a |
| | $G_1$ | 2.81 a-c | 4.16 b | 32.512 abc |
| $M_4$ | $G_2$ | 2.87 ab | 4.35 a | 34.16 a |
| | $G_3$ | 2.90 a | 4.43 a | 34.57 a |
| $LSD_{(0.05)}$ | | 0.0922 | 0.1759 | 3.1155 |
| CV (%) | | 4.17 | 2.62 | 5.84 |
| LS | | * | * | * |

In a column, figure bearing same, or no letter (s) do not differ significantly at 5% level of significance by Duncan's Multiple Range Test

* = Significant at 5% level of significance
** = Significant at 1% level of significance
LS = Level of significance
CV = Co- efficient of variance
LSD = Least Significant Difference

$M_1$ = 0 ppm (control)
$M_2$ = 50 ppm
$M_3$ = 100 ppm
$M_4$ = 150 ppm
$G_1$ = 0 ppm
$G_2$ = 50 ppm
$G_3$= 100 ppm

### 4.7 Biological yield (t ha$^{-1}$)

#### 4.7.1 Effect of mannitol

Due to varietal difference, there was significant variation on the biological yield of mustard (Table 7). It was observed that the highest biological yield of mustard (4.31 t ha$^{-1}$) was found to be from $M_4$ (150 ppm). On the other hand the lowest biological yield (3.58 t ha$^{-1}$) was observed from $M_1$ (Control). It was conducted that the seed yield of mustard showed significant variation at 1 % level of probability. Anjum *et al.* (2015) who obtained that foliar application of mannitol help plants to cope with various environmental stress and promote physiological processes such as photosynthesis and carbon assimilation resulting increase in biomass production.

#### 4.7.2 Effect of $GA_3$

Significant variation was recorded in respect of biological yield of mustard due to different concentration of $GA_3$. $G_3$ (100 ppm) produced the highest biological yield (4.09 t $ha^{-1}$) which was statistically equivalent with $G_2$ treatment, and the lowest biological yield (3.81 t $ha^{-1}$) was observed with $G_1$ (control) treatment (Table 8). It was concluded that the biological yield showed significant variation at 1 % level of probability. Corresponding to our findings, an improvement in yield and quality of groundnut was observed by the spray of $GA_3$ (Hasan and Ismail, 2018) and in mustard (Akter *et al.,* 2007).

#### 4.7.3 Interaction effect of mannitol and $GA_3$

Significant variation was recorded due to the combined effect of different mannitol and gibberellic acid on the biological yield of mustard (Table 9). It was observed that the treatment combination of $M_4G_3$ (Mannitol 150 ppm with 100 ppm) gave the highest (4.43 t $ha^{-1}$) biological yield which was statistically similar to $M_4G_2$. The lowest (3.35 t $ha^{-1}$) biological yield was attained from $M_1G_1$ (when no treatment was used) combination which was statistically different with the others. From the statistical analysis, the harvest index of mustard showed significant variation at 1 % level of probability.

### 4.8 Harvest index (%)

#### 4.8.1 Effect of mannitol

The harvest index **(%)** is the ratio of grain yield and straw yield. Due to the mannitol application statistically, significant variation was recorded for harvest index (Table 7). It was conducted that the highest (33.74 %) harvest index was produced from $M_4$ (150 ppm) while $M_1$ (0 ppm i.e., Control) produced the lowest (29.20 %) harvest index. From the statistical analysis, the harvest index of mustard showed significant variation at 1 % level of probability.

### 4.8.2 Effect of $GA_3$

Statistically significant variation was observed for harvest index due to the gibberellic acid treatment (Table 8). It was revealed that the highest harvest index (32.33 %) was obtained from $G_3$ (100 ppm) which was statistically different with other treatments and the lowest harvest index (30.51 %) was attained from $G_1$ (Control i.e. 0 ppm). It was concluded that the total stover yield showed significant variation at 5 % level of probability. Increasing the doses of $GA_3$ increases the harvest index of mustard. The higher harvest index indicated that, $GA_3$ application accelerated assimilate supply to sink and better utilization of the incoming assimilates by the reproductive sinks, which agrees with the results of Akter *et al.* (2007).

### 4.8.3 Interaction effect of mannitol and $GA_3$

Statistically significant variation was showed due to the combined effect of different mannitol and gibberellic acid in terms of harvest index Table 9. $M_4G_3$ (Mannitol 150 ppm with Gibberellic acid 100 ppm) produced the maximum harvest index (34.57 %) which was statistically similar with other combinations whereas the minimum harvest index (28.74 %) was observed from $M_1G_1$ (Control). From the statistical analysis, the harvest index of mustard showed significant variation at 1 % level of probability.

# CHAPTER V

# SUMMARY AND CONCLUSION

The experiment was carried out at the research field of Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200 during the period from November 2022 to March 2023 to study the effect of mannitol and gibberellic acid on yield and yield attributing characteristics of mustard. The experiment consists of two factors: (A) four levels of mannitol viz. $M_1$=0 ppm (control), $M_2$=50 ppm mannitol, $M_3$=100 ppm mannitol and $M_4$= 150 ppm mannitol and three levels of gibberellic acid viz. $G_1$= 0 ppm (control), $G_2$=50 ppm $G_3$= 100 ppm. It consisted of twelve different treatment combinations. The data on crop growth characters like plant height (cm), number of siliqua plant$^{-1}$ (no), number of seeds siliqua$^{-1}$ (no.), 1000-seeds weight (g), seed yield (t ha$^{-1}$), stover yield (t ha$^{-1}$), biological yield (t ha$^{-1}$) and Harvest index (%) were counted from 10 randomly selected plant of each plot. The collected data were analyzed statistically using ANOVA technique with the help of a computer package program MSTAT-C. Mean differences among the treatments were tested with the least significant difference (LSD) test at 1 % and 5 % level of significance respectively.

Considering the application of different doses of mannitol the increase of plant height was observed from 40 days after sowing to at harvest of growth stages which was the highest (60.78cm) in the $M_4$ (Mannitol-150 ppm) and smallest (55.55 cm) plant in $M_1$ (0 ppm, i.e., control) at harvest. The maximum siliqua number plant$^{-1}$ (57.24), number of seeds siliqua$^{-1}$ (34.22) and 1000-seeds weight (3.39 g) was obtained from $M_4$ (150 ppm) and the minimum number of siliqua plant$^{-1}$ (41.97), number of seeds siliqua$^{-1}$ (28.53) and 1000-seeds weight (2.93 g) was generated by $M_1$ (0 ppm that is Control). The maximum seed yield (1.45 t ha$^{-1}$) was generated by $M_4$ (150 ppm) and the minimum seed yield (1.04 t ha$^{-1}$) was produced by $M_1$ (0 ppm i.e., control) and also the maximum stover yield (2.86 t ha$^{-1}$) recorded in $M_4$ (150 ppm) while the minimum stover yield (2.53 t ha$^{-1}$) from $M_1$ (0 ppm). Among the different doses of mannitol, the highest biological yield (4.31 t ha$^{-1}$) and the highest harvest index (33.74 %) was recorded from $M_4$ (150 ppm) whereas the lowest biological yield (3.58 t ha$^{-1}$) and the lowest harvest index (29.20 %) found from $M_1$ (0 ppm).

Observing different level of gibberellic acid treatments $G_3$ (100 ppm) were generated tallest (62.07cm) plant and shortest (54.16 cm) was obtained from $G_1$ at harvesting stage in terms of as levels. The highest siliqua number plant$^{-1}$ (52.63), number of seeds siliqua$^{-1}$ (32.91) and 1000-seeds weight (3.37g) was generated from $G_3$ (100 ppm) whereas $G_1$ (0 ppm i.e, control) generated the minimum siliqua number plant$^{-1}$ (48.25), number of seeds siliqua$^{-1}$ (29.93) and 1000-seeds weight (3.13 g). The maximum seed yield (1.32 t ha$^{-1}$) recorded from $G_3$ (100 ppm) whereas control produced the minimum seed yield (1.16 t ha$^{-1}$) and $G_3$ (100 ppm) produced the highest stover yield (2.76 t ha$^{-1}$) and the lowest stover yield (2.64 t ha$^{-1}$) was observed from $G_{1.}$ The highest biological yield (4.09 t ha$^{-1}$) and harvest index (32.33 %) was recorded from $G_3$ (100ppm) and the lowest biological yield (3.81 t ha$^{-1}$) and harvest index (30.51 %) was attained from $G_1$ (control).

In combination of mannitol and gibberellic acid, tallest (64.66 cm) plant generated from $M_4G_3$ combination whereas $M_1G_1$ produced shortest (53.20 cm) plant at harvesting stage. In the interaction of $M_4G_3$ generated maximum siliqua number plant$^{-1}$ (58.06), number of seeds siliqua $^{-1}$ (35.33) and 1000-seed weight (3.51 g) whereas the minimum siliqua number plant$^{-1}$ (38.33), number of seeds siliqua$^{-1}$ (27.13) and 1000-seed weight (2.76 g) was produced from $M_1G_1$ treatment combination. $M_4G_3$ Combination generated maximum seed yield (1.53 t ha$^{-1}$) and stover yield (2.90 t ha$^{-1}$) but the minimum seed yield (0.96 t ha$^{-1}$) and stover yield (2.38 t ha$^{-1}$) recorded from $M_1G_1$ treatment combination. In combination treatments, the highest biological yield (4.43 t ha$^{-1}$) and harvest index (34.57 %) was recorded from $M_4G_3$ (Mannitol 150 ppm with Gibberellic acid 100 ppm) whereas the minimum biological yield (3.35 t ha$^{-1}$) and harvest index (28.74 %) was observed from $M_1G_1$ (Control) combination.

From the above result, it may conclude that different concentration of mannitol and gibberellic acid positively influenced the entire physiology, growth and yield of mustard. The treatment $M_4$ (150 ppm) produced the maximum yield which was statistically different from others. It was also observed that $G_3$ (100 ppm) showed maximum result in all growth and yield parameters. Among the combination $M_4G_3$ (Mannitol-150 ppm with Gibberellic acid-100 ppm) combination is suitable for maximum growth and yield of mustard.

**Recommendation**

From any experimental results obtained from a single year study is not sufficient to draw a valid conclusion for the performance of any biological entity. However to reach a specific recommendation, this trait could be replicated at different agro-ecological zones of Bangladesh for validating the present traits. Another doses of mannitol and $GA_3$ should be applied in another experiment.

# REFERENCES

Achakzai, A. K. K. and Z. A. Bazai. 2007. Effect of water stress on seedling growth of maize cultivars: In mannitol plus culture solution. Int. J. Biol. Biotech. 4(1): 37-42.

Afzal, M., K. Nawaz, K. Hussain, I. Iqbal, H. Riaz, Z. A. Rouf, M. Javeria, R. Akram, M. Khaliq, A. Attique, R. Zainab and Waqar-U-Nisa. 2023. Foliar application of mannitol as an effective approach to ameliorate the salt stress-induced toxicity in two varieties of maize (*Zea mays* L.). Pak. J. Bot., 55(2): 459-467.

Akram, H. M., M. Nadeem, A. Ali and A. Sattar. 2011. Influence of moisture stress and growth substances on germination and seedling growth of wheat (*Triticum aestivum* L.). Iranian J. Pl. Physiol. 1(4): 241-250.

Akter, A., E. Ali, M. M. Z. Islam, R. Karim and A. H. M. Razzaque. 2007. Effect of $GA_3$ on growth and yield of mustard. Int. J. Sustain. Crop Prod. 2(2): 16-20.

Alam, A. K. M. F. 2020. Rising trend in consumption of oils and fats in Bangladesh. *The Financial Express*. February *22*. https://thefinancialexpress.com.bd (Access date-05.05.2023).

Al-Hadithy, A. A. H. Ibrahim, Al-Hamdani and F. M. Ali. 2022. Effect of foliar different concentrations of boron and mannitol on the growth and yield of cauliflower. Intl. J. Agril. Stat. Sci. 18: 2303.

Anjum, S. A., M. Tanveer, S. Hussain, S. Babar, A. Umar, S. Fahad, W. Hassan, S. Jan, I. Khan, M. F. Saleem, A. A. Bajwa, L. Wang, A. Mahmood, R.A. Samad and S. A. Tung. 2016. Osmoregulation and antioxidant production in maize under cadmium and arsenic stress. Environ. Sci. Pollut. Res. 23(12): 11864-11875.

Arsad, M., N. Akbar, S. A. Anjum, M. U. Hameed, A. Raza, S. Nazeer, M. Sajjad. 2022. Effect of foliar application of mannitol on growth and yield of maize under different water regimes. Food Agric. Res. J. 01(1): 11-17.

BARI 2014. Bangladesh Agricultural Research Institute. Krishi Projukti Hatboi, 6th edition. BARI, Gazipur-1701. P-149.

BBS (Bangladesh Bureau of Statistics). 2016. Statistical Yearbook of Bangladesh 2015. Bangladesh Bureau of Statistics. Statistics Division, Ministry of Planning, Government of Bangladesh. p. 116.

BBS (Bangladesh Bureau of Statistics). 2024. Yearbook of Agricultural statistics 2023. Bangladesh Bureau of Statistics. Statistics Division, Ministry of Planning, Government of Bangladesh. p. 156.

BBS. 2019. Yearbook of Agricultural Statistics of Bangladesh. http://www.bbs.gov.bd/ site/page. Accessed 5th June 2020.

BBS. 2023. Bangladesh Bureau of Statistics. Yearbook of Agricultural Statistics of Bangladesh. Government of the People's Republic of Bangladesh. p. 122.

Bhauso, T. D., R. Thankappan, A. Kumar, G. P. Mishra, J. R. Dobaria and M. V. Rajam. 2014. Over-expression of bacterial'mtl D'gene confers enhanced tolerance to salt-stress and water-deficit stress in transgenic peanut (*Arachishypogaea*) through accumulation of mannitol. Aus. J. Crop Sci. 8(3): 413-432.

Borah, B., K. Pathak, J. Hazarika and G. Kataki. 2023. Enhancement of production and profitability of Flax by foliar application of plant growth regulating hormones. Current J. Appl. Sci. Tech. 42(27): 26-31.

Boultior, C. and D. G. Morgan. 1992. Development of oilseed rape buds, flowers and pods invitro. J. Exp. Bot. 43(253): 1089-1096.

Bousba, R., R. Bounar, N. Sedrati, R. Lekhal, C. Hamla and M. Rached-Kanouni. 2021. Effects of osmotic stress induced by polyethylene gly ethylene glycol (Peg) 6000 and eg) 6000 and mannitol on seed germination and seedling growth of durum wheat. J Biores Manag. 8(3): 57-66.

Buriro, K. A., N. S. Soomro, M. A. Siddiqui, M. S. Chang, J. K. Sootaher, G. M. Nangraj and N. A. Majeedano. 2022. Effects of foliar application of gibberellic-acid3 on the growth and yield of canola (*Brassica napus* L.) Genotypes. Bio. Scientific Review. 4(1): 12-25.

Chauhan, J. S., Y. K. Tomar, A. Badoni, N. I. Singh, S. Ali and L. Debarati. 2010. Morphology, germination and early seedling growth in *Phaseolus mungo* L. with reference to the influence of various plant growth substances. J. Amer. Sci. 6(1): 34-41.

Dawar, R., M. Giri, A. K. Meena, G. Patidar and S. Rathod. 2020. Effect of foliar application of gibberellic acid on growth, yield and economics of blackgram. J. Pharma phytochem. 9(4): 3184-3190.

Dawood, M. G., M. E. El-Awadi and I. M. El-Metwally. 2022. Physiological role of mannitol on Vicia Faba plants undergo sandy soil conditions. Egypt. J. Chem. 56(11): 499-507.

Elahi, N.N., S. Raza, M. S. Rizwan, B. F. A. Albalawi, M. Z. Ishaq, H. M. Ahmed, S. Mehmood, M. Imtiaz, U. Farooq, M. Rashid and A. Ditta. 2022. Foliar application of gibberellin alleviates adverse impacts of drought stress and improves growth, physiological and biochemical attributes of canola (*Brassica napus* L.). Sustainability. 15(1): 78.

El-Yazal, M. A. S., H. F. Eissa, S. M. A. E. Ahmed, S. M. Howladar, S. N. S. Zaki, and M. M. Rady. 2016. The mtlD gene-overexpressed transgenic wheat tolerates salt stress through accumulation of mannitol and sugars. Plant. 4(6): 78-90.

Emongor, V. 2007. Gibberellic Acid ($G_3$) influence on vegetative growth, nodulation and yield of cowpea (*Vigna unguiculata* (L.) Walp. J. Agron. 6: 509-517.

FAO. 2012. Statistical Yearbook, vol.73. FAO statistics series 119. pp. 152-154.

Gomez, K. A. and A. A. Gomez. 1984. Statistical procedure for agricultural research. Second edn. lhon Wiley and Sons. Inc. New York: 304- 307.

Habiba, U., S. Ali. M. Rizwan, M. Ibrahim, A. Hussain, M. R. Shahid, S. A. Alamri. M. N. Alyemeni and P. Ahmad. 2019. Alleviative role of exogenously applied mannitol in maize cultivars differing in chromium stress tolerance. Environ. Sci. Poll. Res. https://doi.org/10.1007/s11356-018-3970-2

Haifaa, M. D. and C. Moses. 2022. Effects of foliar and soil application of gibberellic acid (GA3) at different growth stages on agronomic traits and yield of rice (*Oryza sativa* L.). J. Agric. Sci. 14(6): 55.

Haque, M. A. 2018. Seed yield and quality of mungbean as affected by seed priming (Doctoral dissertation, Institute of seed Technology, Sher- E- Bangla Agricultural University-Dhaka 1207.

Harshitha, G., Ch. B. B. Rao, T. R. Prokash and S. A. Hussain. 2021. Effect of hormones on yield and economics of Mustard (*Brassica juncea* L.) under southern Telangana agro-climatic conditions. Intl. J. Environ. Climate Change. 11(7): 89-94.

Hasan, M. and B. S. Ismail. 2018. Effect of gibberellic acid on the growth and yield of groundnuts (*Arachis hypogaea* L.). Sains Malaysiana. 47(2): 221-225.

Holmberg, F. and G. Eduardo. 1991. Effect of growth retardants, (Chlormequat, triapentenol) under four nitrogen fertilization levels in spring rape (*Brassica napus* L. ssp. *oleifera*). p. 118.

Islam, S. and H. Mehraj. 2014. Growth and yield of wheat as influenced by $GA_3$ concentrations. Intl. J. Bus. Soc. Sci. Res. 2(1): 74-78.

Kaya, C., O. Sonmez, S. Aydemir, M Ashraf and M. Dikilitas. 2013. Exogenous application of mannitol and thiourea regulates plant growth and oxidative stress responses in salt-stressed maize (*Zea mays* L.). J. Plant Interactions. 8(3): 234-241.

Keykha, M., H. R. Ganjali and H. R. Mobasser. 2014. Effect of salicylic acid and gibberellic acid on some characteristics in mungbean (*Vigna Radiata*). Intl. J. Biosci. 5(11): 70-75.

Khan, M.A., M. Rahman, M. O. Kaisar, M. A. Siddiky and S. R. Haque. 2022. Effect of plant growth regulators on seed yield of mustard. Bangladesh J. Agric. Res. 47(1): 99-104.

Khan, N. A., M. Mobin and Samiullah. 2005. The influence of gibberellic acid and sulfur fertilization rate on growth and S-use efficiency of mustard (*Brassica juncea*). Plant soil. 270(1): 269-274.

Laboni, S. H., A. K. M. M. B. Chowdhury and M. M. Bahadur. 2024. Effect of different fertilizer combinations and gibberellic acid ($GA_3$) on yield attributing traits of mustard. J. Bd. Agril. Uni. 22(2): 185-192.

Lhungdim, J., T. Singh, K. N. Devi, N A. Singh, Y. S. Devi. 2018. Influence of seed priming methods on growth, yield attributes and seed yield of desi chickpea under acidic soils. Agril. Sci. Digest Res. J. 38 (3): 205-208.

Mazid, M. and F. Naz. 2017. Effect of macronutrients and gibberellic acid on photosynthetic machinery, nitrogen-fixation, cell metabolites and seed yield of chickpea (*Cicer arietinum* L.). J. Sci. 1(4): 24.

Nilanthi, D., P. C. D. Perera, and P. G. T. M. Gunarathna. 2015. Study the response of drought stress inducing by mannitol in germination to seedling stage of Mung Bean (*Vigna Radiata* L.) variety MI5 and variety Harsha. Intl. J. Sci. Res. 5(7): 1-4.

Nizamani, M. R., M. A. Ansari, M. A. Siddiqui G. S. Nizamani, F. Nizamani, M. Naz and M. Asad. 2018. Effect of gibberellic acid on yield and yield attributes of canola (*Brassica napus* L.) varieties. Indian J. Sci. Res. 6(8): 863-80.

Noor, F., F. Hossain and U. Ara. 2017. Effects of gibberellic acid ($GA_3$) on growth and yield parameters of French Bean (*Phaseolus vulgaris* L.). J. Asiat. Soc. Bangladesh Sci. 43(1): 49-60.

Patel, T. K. and J. D. Williamson. 2016. Mannitol in plants, fungi and plant-fungal interactions. Trends Plant Sci. 21: 486-497.

Pawar, V. and S. Laware. 2018. Seed priming a critical review. Intl. J. Sci. Res. Biol. Sci. 5: 94-101.

Prasad, N. S., P. K. Rai and A. Dayal. 2021. Effect of seed treatment with chemicals and plant growth regulators on growth and yield attributing traits of Indian mustard (*Brassica juncea L*.). Intl. J. Plant Soil Sci. 33(19): 170-176.

Rafique, M., M. Naveed, A. Mustafa, S. Akhtar, M. Munawar, S. Kaukab, H. M. Ali, M. H. Siddiqui and M. Z. Salem. 2021. The combined effects of gibberellic acid and rhizobium on growth, yield and nutritional status in chickpea (*Cicer arietinum* L.). Agron. J. 11(1): 105.

Rahman, M. A. 2015. Enhancement of drought tolerance in mungbean through osmo and hydro priming (Doctoral dissertation, Department of Agronomy).

Rahman, M. M., A. B. M. M. M. Khan, M. M. Hasan, L. A. Banu and M. H. K. Howlader. 2018. Effect of foliar application of gibberelic acid on different growth contributing characters of mungbean. Prog. Agric. 29(3): 233-238.

Rahman, M. S., M.A. Haque and M. G. Mostofa. 2015. Effect of $GA_3$ on biochemical attributes and yield of summer tomato. J. Biosci. Agril. Res. 03(2): 73-78.

Raj, V., R. Singh and T. Indu. 2022. Effect of plant growth regulators and zinc levels on yield and economics of Toria (*Brassica rapa* L.). Biol. Forum Intl. J. 14(1): 1582-1585.

Rashid, N. S. and M. F. Molesh. 2022. Effect of foliar spraying with boron and sugar alcohol (mannitol) on vegetative growth traits of pea (*Pisum sativum* L.). Euphrates J. Agril. Sci. 14 (4): 241-252.

Russell, D. F. 1986. MSTAT-C package programme. Dept. Crop Soil Sci. Michigian State Univ. USA. p. 59-60.

Saha, D., M. M. Rahman, M. A. Hossain, A. K. M. A. Prodhan, A. C. Das, M. Saha & M. M. Hasan. 2021. Yield performance of mustard using different concentrations of gibberellic acid ($G_3$). *American* J. Agril. Sci. Eng. Tech. 5(2): 488-495.

Saini, P. K., R. K. Yadav and M. Pratap. 2017. Effect of foliar application of $GA_3$, on yield and quality of indian mustard. Intl. J. Curr. Microbiol. App. Sci. 6(12): 4156-4159.

Saini, P. K., R. Yadav, and J. Bhati. 2021. Influence of $GA_3$ on yield and quality of indian mustard. Academia Letters. Article 1835. p. 2.

Saleh, F. F and I. A. Hamzah. 2021. Effect of mannitol and phenylalanine spray on the growth, yield and production of some active compounds of (*Brassica napus* L.). J. Edu. Sci. Stud. 17(3): 166-185.

Sampa, A. Y., F. Sarker, M. R. Rahman and R. Begum. 2020. Profitability and resource use efficiency of mustard cultivation. SAARC J. Agric. 18(2): 195-206.

Shakoor, B., S. M. Faheem, L. Ahmad, A. Sher, R. A. Iqbal, A. Shoukat, Z. Ahmad, M. Irfan, S. S. Hussain, N. Manzoor, M. S. Kamran, S. G. Vaseer, T. Hussain and S. Ahmad. 2024. Effect of exogenous application of mannitol on morphological, biochemical and yield trait of heat and stressed Mungbean. J. Liaaning Tech. Uni. Natural. Sci. 18(7): 27-40.

Sharma N., N. Nehal, M. Singh, P. Singh, P. Rajpoot, A. K. Pandey, A. H. Khan, A. K. Singh and R. K. Yadav. 2017. Effect of plant growth regulators on growth, biochemical changes and yield of mustard (*Brassica juncea* L.). Plant Arch. 17(1): 33-38.

Shirinzadeh, A., H. Soleimanzadeh and Z. Shirinzadeh. 2013. Effect of seed priming with plant growth promoting rhizobacteria (PGPS) on agronomic traits and yield of barley cultivars. World Appl. Sci. J. 21(5): 727-731.

Siddiqui, M.A., Z. H. Shah, S. Tunio and Q. Chacchar. 2016. Effect of different N P, fertilizer and plant growth regulators Gibberellic acid (GA3) and Indole-3acetic acid (IAA) on qualitative traits of Canola (*Brassica napus* L.) genotypes. Intl. J. Pure App. Biosci. 4(2): 238-244.

Soliman, A. S. 2019. Plant growth hormones. Intect Open. pp. 1-11.

Srivastava, A. K., N. K. Ramaswamy, P. Suprasanna and S. F. D'souza. 2010. Genome-wide analysis of thiourea-modulated salinity stress-responsive transcripts in seeds of *Brassica juncea*: identification of signalling and effector components of stress tolerance. Ann. Bot. 106(5): 663-674.

Sumi, P., S. C. Meena, R. H. Meena and J. Choudhary. 2021. Effect of gibberellic acid and sulphur on growth and yield of mustard (*Brassica juncea* L.). The Pharma Inn. J. 10(8): 1214-1217.

Tiwari, D. K., P. Pandey, S. P. Giri and J. L. Dwivedi. 2011. Effect $GA_3$ and other plant growth regulators on hybrid rice seed production. Asian J. Pl. Sci. 10(2): 133-139.

Uddin, M. M., A. Samad, M. R. Khan, S. Begum and M. A. Salam. 1986. Effect of sowing dates on the yield and some of its components of mustard and rapeseed. Bang. J. Sci. Indus. Res. 21(1-4): 160-165.

Ullah, I., K. Dawar, M. Tariq, M. Sharif, S. Fahad, M. Adnan, H. Illahi, T. Nawaz, M. Alam, A. Ullah and M. Arif. 2021. Gibberellic acid and urease inhibitor optimize nitrogen uptake and yield of maize at varying nitrogen levels under changing climate. Environ. Sci. Poll. Res. 29: 6568-6577.

Umair, A., S. Ali, R. Hayat, M. Ansar and M. J. Tareen. 2011. Evaluation of seed priming in mung bean (*Vigna Radiata*) for yield, nodulation and biological nitrogen fixation under rainfed conditions. African J. Biotech. 10(79): 18122-18129.

USDA (United States Department of Agriculture). 2022. Bangladesh: Oilseeds and Products Annual, USDA Foreign Agricultural Service. pp. 17. https://fas.usda.gov/data/bangladesh-oilseeds-and-products-annual-3 (Access date :17-03-2024).

Yamaguchi, S. 2008. Gibberellin metabolism and its regulation. Annu. Rev. Plant Biol. 59(1): 225-251.

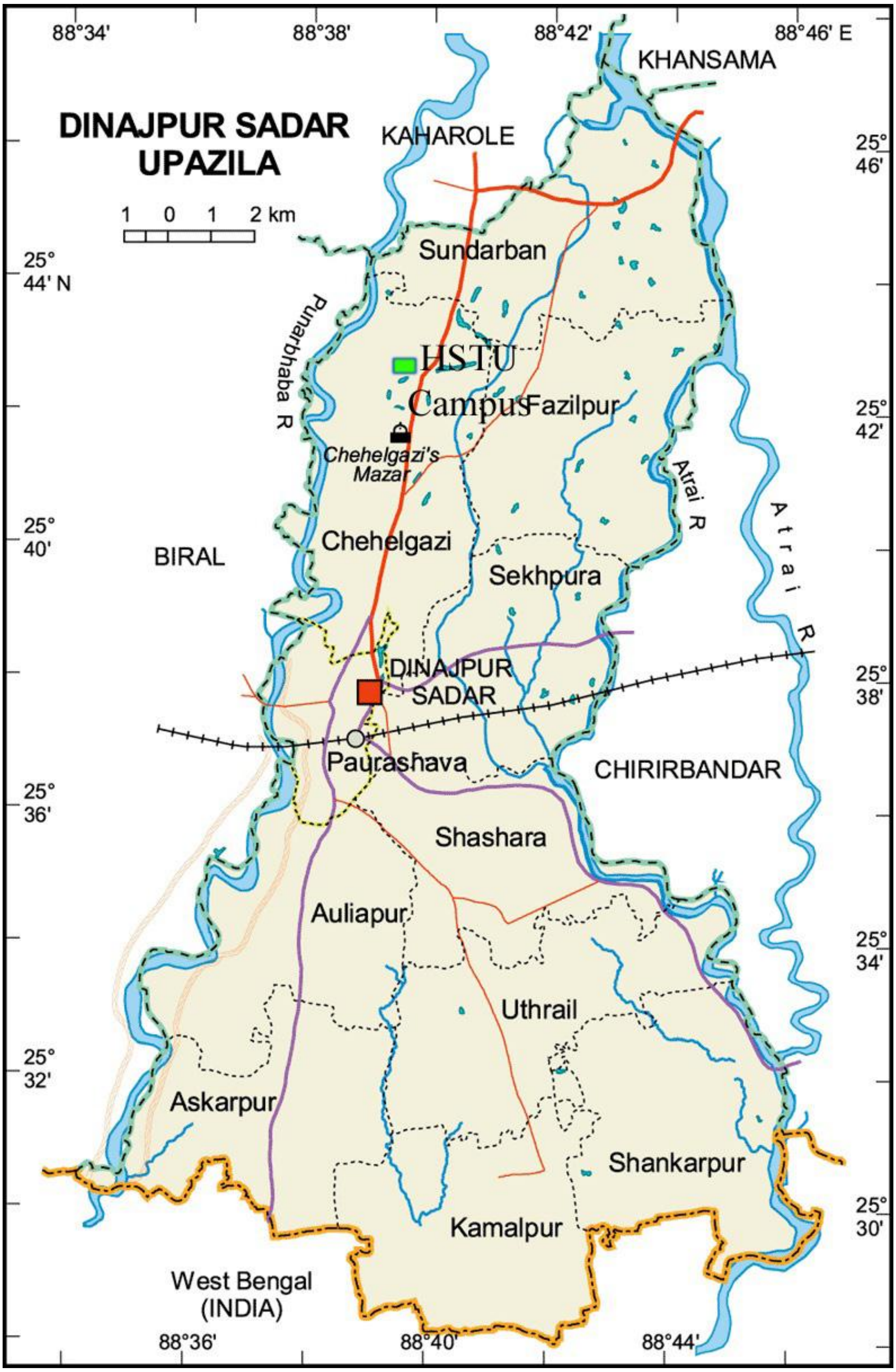
Yuan, L. and D. Q. Xu. 2011. The stimulation effect of gibberellic acid short-term treatment on leaf photosynthesis related to the increase in Rubisco content in broad bean and soybean. Photosynthesis Res. 68: 39-47.

Zaidi, S. T., A. K. Singh, A. K Pandey, A. C. Rai, K. Kumar and A. K. Singh. 2024. The Effect of mannitol and nano urea on terminal heat stress on wheat (*Triticum aestivum* L.). J. Adv. Biol. Biotech. 27(6): 327-335.

Zebarjadi, A., M. Kakaei and A. Mostafaie. 2011. Genetic variability of some traits in Rapeseed (*Brassica napus* L.) under drought stress and non-stress conditions. Biharean Biologist. 5(2): 127-31.

# APPENDICES

**Appendix I. Location of the experimental site (map of Dinajpur Sadar Upazila showing the research plot).**



**Appendix II: Morpho-physio-chemical properties of soil (collected before sowing of seeds) of the experimental field.**

**A. Morphological characteristics of the soil**

| Constituents | Characteristics |
|---|---|
| Location | Agronomy Research Field, Hajee Mohammad Danesh Science and Technology University, Dinajpur |
| Agro-ecological zone | Old Himalayan Piedmont Plain (AEZ-1) |
| Geographical position | 25° 38' N latitude and 88° 41' E longitude |
| General Soil type | Non-calcareous dark grey floodplain |
| Parent materials | Old Brahmaputra River borne deposit |
| Land type | Medium high land |
| Elevation | 37 meter above the mean sea level |
| Drainage | Well drained |
| Topography | Fairly level |
| Soil texture | Sandy loam |
| Soil Color | Dark grey |
| Flood level | Above flood level |

**B. Physical properties of the initial soil (0-15 cm depth)**

| Constituents | Results |
|---|---|
| Particle size analysis | |
| Sand (%) (0.2-0.002 mm) | 58 |
| Silt (%) (0.02-0.002 mm) | 28 |
| Clay (%) (<0.002mm) | 14 |
| Soil textural class | Sandy loam |

Source: Results obtained from the mechanical analysis of the initial soil sample

**C. Chemical composition of the initial soil (0-15 cm depth)**

| Characteristics | Value (%) |
|---|---|
| pH (Soil: water = 1: 1.25) | 5.41 |
| Organic matter | 1.48 |
| Organic carbon | 0.72 |
| Total N | 0.08 |
| Available P (ppm) | 11.20 |
| Exchangeable P (meq) | 0.10 |
| Exchangeable Ca (meq) | 2.48 |
| Exchangeable Mg (meq) | 2.29 |
| Available S (ppm) | 17.29 |
| Available B (ppm) | 0.13 |
| Available Zn (ppm) | 0.90 |
| Available Fe (ppm) | 51.90 |
| Available Mn (ppm) | 12.13 |

Source: Results obtained from the chemical analysis of the initial soil sample (SRDI, Dinajpur).

**Appendix III: Monthly recorded of air temperature, rainfall, relative humidity and sunshine at the experimental site**

| Months | Temperature (℃) | | Relative humidity (%) | Rainfall (mm) Total | Sunshine (hr) Total |
|---|---|---|---|---|---|
| | Minimum | Maximum | | | |
| November 2022 | 10.51 | 20.81 | 60.45 | 2.12 | 5.23 |
| December 2022 | 8.95 | 22.40 | 62.14 | 0.00 | 3.43 |
| January 2023 | 13.98 | 28.19 | 66.69 | 0.00 | 5.73 |
| February 2023 | 18.81 | 31.91 | 73.52 | 8.30 | 6.64 |
| March 2023 | 25.3 | 37.0 | 70.00 | 7.42 | 6.14 |

Source: Bangladesh Meteorological Department (Weather Research Station) Rajbati, Dinajpur

**Appendix IV. Mean square values for plant height at different days after sowing**

| Source of variation | df | PH (cm) | | | |
|---|---|---|---|---|---|
| | | 20 DAS | 40 DAS | 60 DAS | At harvest |
| Replication | 2 | 16.0655$^{NS}$ | 5.45068$^{NS}$ | 859.380$^{NS}$ | 505.637$^{NS}$ |
| Factor A | 3 | 0.1047$^{NS}$ | 0.10348$^{NS}$ | 62.509$^{**}$ | 52.767$^{*}$ |
| Factor B | 2 | 0.0980$^{NS}$ | 0.00340$^{NS}$ | 75.263$^{**}$ | 202.637$^{**}$ |
| Factor AB | 6 | 0.0656$^{NS}$ | 0.04042$^{NS}$ | 3.944$^{*}$ | 10.081$^{*}$ |
| Error | 22 | 0.0707 | 0.05914 | 3.242 | 11.355 |
| Total | 35 | | | | |

In a column, figure having common letters (s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
df= degrees of freedom, Factor A= Dose of mannitol, Factor B= Dose of $GA_3$, Factor AB= dose of mannitol × dose of $GA_3$
PH= Plant height
** = Significant at 1% level of probability
* = Significant at 5% level of probability
NS = Non-significant

**Appendix V. Mean square values for siliqua number, number of seed siliqua$^{-1}$ and 1000 seed weight of mustard.**

| Source of variation | df | Mean squire values | | |
|---|---|---|---|---|
| | | PN | SPP | TSW |
| Replication | 2 | 390.647$^{NS}$ | 14.7544$^{NS}$ | 0.07646$^{NS}$ |
| Factor A | 3 | 434.836$^{**}$ | 58.1256$^{**}$ | 0.41451$^{**}$ |
| Factor B | 2 | 60.762$^{**}$ | 27.4811$^{**}$ | 0.18521$^{**}$ |
| Factor AB | 6 | 2.791$^{*}$ | 1.0767$^{*}$ | 0.02354$^{*}$ |
| Error | 22 | 7.883 | 2.3920 | 0.02312 |
| Total | 35 | | | |

In a column, figure having common letters (s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.
Legend:
df= degrees of freedom, Factor A= Dose of mannitol, Factor B= Dose of $GA_3$, Factor AB= dose of mannitol × dose of $GA_3$
PN=Pod number, SSP= Seed per pod, TSW= Thousand seed weight
** = Significant at 1% level of probability
* = Significant at 5% level of probability
NS = Non-significant

**Appendix VI. Mean square values for seed yield, stover yield, biological yield, harvest index of mustard.**

| Source of variation | df | Mean squire values | | | |
|---|---|---|---|---|---|
| | | GY | SY | BY | HI |
| Replication | 2 | 0.11342$^{NS}$ | 0.05580$^{NS}$ | 0.25943$^{NS}$ | 27.2469$^{NS}$ |
| Factor A | 3 | 0.27987$^{**}$ | 0.18401$^{**}$ | 0.91209$^{**}$ | 34.8320$^{**}$ |
| Factor B | 2 | 0.08138$^{**}$ | 0.04272$^{NS}$ | 0.24161$^{**}$ | 10.1468$^{*}$ |
| Factor AB | 6 | 0.00223$^{*}$ | 0.02597$^{*}$ | 0.01737$^{*}$ | 3.1878$^{*}$ |
| Error | 22 | 0.00498 | 0.01274 | 0.01079 | 3.3851 |

In a column, figure having common letters (s) bearing same do not differ significantly at 5% level of significance by Duncan's Multiple Range Test.

Legend:

df= degrees of freedom, Factor A= Dose of mannitol, Factor B= Dose of $GA_3$, Factor AB= dose of mannitol × dose of $GA_3$

GY= Grain yield, SY= Stover yield, BY= Biological yield, HI= Harvest index.

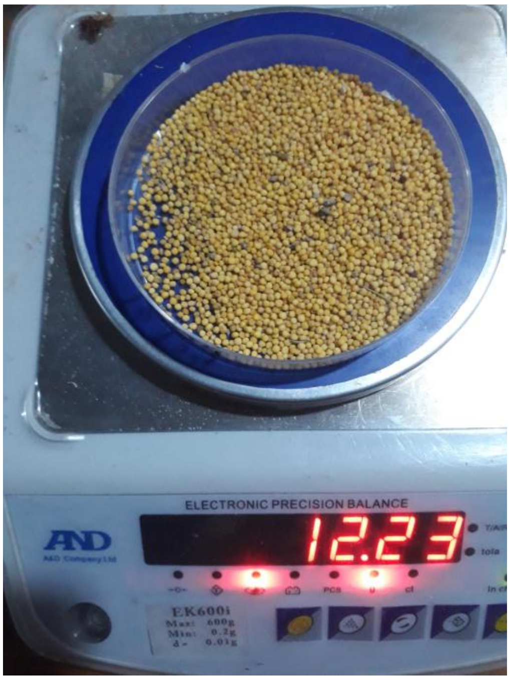
** = Significant at 1% level of probability

* = Significant at 5% level of probability

NS = Non-significant

## Appendix VII: Some photographs of my research works


ELECTRONIC PRECISION BALANCE
EK600i


ELECTRONIC PRECISION BALANCE
12.23
EK600i