YIELD AND YIELD ATTRIBUTES OF LENTIL AS INFLUENCED BY INDOLE-3-ACETIC ACID AND GIBBERELLIC ACID

A THESIS

BY

MARIOM AKTER MONISHA

Student ID: 1701149

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

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Submitted to the Department of Agronomy
Hajee Mohammad Danesh Science and Technology University, Dinajpur
In partial fulfillment of the requirements
For the degree

MASTER OF SCIENCE (M.S.)

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Approved as to style and contents by:

(Most. Mohoshena Aktar)
Assistant Professor
Supervisor

(Professor Dr. Md. Shafiqul Islam Sikdar)
Co-supervisor

(Professor Dr. Md. Mominur Rahman)
Chairman
Examination Committee
&
Chairman

DEPARTMENT OF AGRONNOMY

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

JUNE 2024

Dedicated

To my

Beloved Parents

ACKNOWLEDGEMENT

All praises are devoted to Almighty Allah, who the supreme authority of this universe, and who enable the author to complete the research work and submit the thesis for the degree of Master of Science (MS) in Agronomy.

*The Author would like to express her heartiest gratitude, sincere appreciation and immense indebtedness to her supervisor **Associate Professor Most. Mohoshena Aktar**, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh, for his scholastic guidance, planning, valuable suggestions, continuous encouragements and all kinds of support and help throughout the period of research work and preparation of this manuscript of thesis.*

*The author feels proud to acknowledge author's gratefulness, boundless gratitude and best regards to her respectable co-supervisor, **Professor Dr. Md. Shafiqul Islam Sikdar,** Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh, for his valuable advice, constructive criticism and factual comments in upgrading the research work.*

*It is a great pleasure and privilege to express her profound gratitude and sincere regards to **Professor Dr. Md. Mominur Rahman**, Chairman, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh, for his help, valuable advice, constructive criticism and facilities and supports needed to undertake this research work.*

*Special appreciation and warmest gratitude are extended to Author's esteemed teachers of her department of Agronomy, HSTU, Dinajpur, for their sincere guidance to learn and practice herself in scientific knowledge towards development agriculture. The author wants to know special thanks to **Assistant Professor Md. Obaidullah Shaddam**, Department of Agronomy for his co-operation and guidelines.*

The author is honored to express her gratefulness to the Department of Agronomy for extending their cooperation by allowing me to use the laboratory for the different analysis. She also wishes to give thanks to the staff of the Agronomy Laboratory for their valuable cooperation during the experimentation.

The author wants to say thanks, to all of her classmates and friends, for their active encouragement and inspiration. She also cannot but thank and appreciate to Imran Hossain and Mita Hossain for supplying necessary support and sacrificing a lot of time during the research period. The author is ever grateful to her beloved parents for their inspiration and blessings.

June, 2024 *The Authoress*

ABSTRACT

A field 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 yield and yield attributes of lentil as influenced by indole-3-acetic acid and gibberellic acid. The experiment comprised of two factors namely, Factor (A): doses of indole-3-acetic acid viz. I_1= 0 ppm (control), I_2= 25 ppm, I_3= 50 ppm and I_4= 75 ppm and Factor (B): doses of GA_3 viz. G_1=0 ppm (control), G_2= 50 ppm and G_3= 100 ppm. The experiment was laid out by randomized complete block design (RCBD) with three replications. It consisted of twelve different treatment combinations. Thus, there were 36-unit plots in this experiment. Among the doses of Indole Acetic Acid (IAA), the maximum number of pods plant^{-1} (38.82), pod length (0.96 cm), seeds pod^{-1} (1.83), 1000-seed weight (21.89 g), seed yield (1.29 t ha^{-1}), stover yield (2.69 t ha^{-1}), biological yield (4.00 t ha^{-1}) and harvest index (32.29 %) were recorded in I_3 treatment. The minimum number of pods plant^{-1} (35.72), pod length (0.83 cm), seeds pod^{-1} (1.62), 1000-seed weight (21.27 g), seed yield (1.03 t ha^{-1}), stover yield (2.43 t ha^{-1}), biological yield (3.47 t ha^{-1}) and harvest index (29.82 %) were observed in I_1 treatment, respectively. Among the doses of Gibberellic acid (GA_3), the maximum number of pods plant^{-1} (37.83), pod length (0.92 cm), seeds pod^{-1} (1.82), 1000-seed weight (21.75 g), seed yield (1.06 t ha^{-1}) and harvest index (31.62 %) were recorded in G_2 treatment respectively but stover yield (2.65 t ha^{-1}) and biological yield (3.84 t ha^{-1}) were highest at G_3 treatment. The minimum number of pods plant^{-1} (35.81), pod length (0.89 cm), seeds pod^{-1} (1.69), 1000-seed weight (21.33 g), seed yield (1.06 t ha^{-1}), stover yield (2.46 t ha^{-1}), biological yield (3.52 t ha^{-1}) and harvest index (29.86 %) were observed in G_1 treatment, respectively. In case of interaction effect of dose of IAA and GA_3, the maximum number of pods plant^{-1} (40.67), pod length (0.99 cm), seeds pod^{-1} (1.90), 1000-seed weight (22.30 g), seed yield (1.43 t ha^{-1}), stover yield (2.77 t ha^{-1}), biological yield (4.19 t ha^{-1}) and harvest index (34.06 %) were recorded in I_3G_2 treatment. The minimum number of pods plant^{-1} (35), pod length (0.80 cm) seeds pod^{-1} (1.60), 1000-seed weight (21.09 g), seed yield (1.43 t ha^{-1}), stover yield (2.77 t ha^{-1}), biological yield (3.29 t ha^{-1}) and harvest index (29.06 %) were observed in I_1G_1 treatment, respectively. Results indicated that doses of IAA and GA_3 had significant influence on most of the growth, yield and yield contributing characters of lentil. Thus, it concluded that medium range of IAA and GA_3 might aid in increasing production of lentil.

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LIST OFABBREVIATIONS

AEZ	= Agro-ecological Zone
ANOVA	= Analysis of variance
BARC	= Bangladesh Agricultural Researcher Council
BARI	= Bangladesh Agricultural Research Institute
BAU	= Bangladesh Agricultural University
BBS	= Bangladesh Bureau of Statistics
cm	= Centimeter
CV	= Co-efficient of Variation
DAS	= Days After Sowing
DMRT	= Duncan’s Multiple Range Test
et al.	= And other
FAO	= Food and Agriculture Organization
g	= Gram
ha^{-1}	= Per hectare
HI	= Harvest Index
IRRI	= International Rice Research Institute
kg	= Kilogram
LAI	= Leaf Area Index
LSD	= Least Significant Difference
meq	= Mili-equivalent
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
RBD	= Randomized Block Design
Viz.,	= Namely
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
ppm	= Parts per million
RARS	= Regional Agricultural Research Station
GA_3	= Gibberellic acid
IBA	= Indole-3-Butyric Acid
IAA	= Indole-3-Acetic Acid
BAP	= 6-benzyl aminopurine
PGRs	= Plant Growth Regulators

CHAPTER I
INTRODUCTION

Grain legumes, sometimes referred to as pulse crops, play a crucial role in world diets and agriculture. Considering global climate change, a second green revolution is required to provide food and nutritional security for the world's constantly expanding population. Legume crops had innate ability to fix nitrogen symbiotically and their inexpensive cost of production, grain legumes provide an unmatched answer to this issue. A wide variety of leguminous plants are grown for their dry, edible seeds, which is the main reason for their cultivation.

Pulses are essential to Bangladesh's agricultural diversity, as the country primarily grows rice. These are important in human nutrition among the food crops grown in Bangladesh. Pulses (grain legumes) are considered as cheapest source of protein for under privileged group of people who cannot afford to buy animal proteins and they enhance the soil fertility by symbiotic nitrogen fixation (Islam *et al.*, 2021). Overall, pulse crops are integral to food security, nutrition, and environmental sustainability worldwide.

Lentil is among the most significant pulse crops of Asia-Pasific region which covers about 53 % and produces 49 % of world's lentil (Thuc *et al.*, 2021). Renowned for its high protein content and nutritional value, lentil (*Lens culinaris*) is a pulse crop of global importance that plays a significant role in addressing global concerns related to food security (Bhargava *et al.*, 2019). Total production of lentil during 2022-23 in Bangladesh was around 196829.24 M tons from 334429.60 acre of land which reflecting a 2.83 % from the previous year (BBS, 2024). Lentil plays a vital role in human and animal nutrition and improvement of soil fertility. The primary product of lentil is the seed which has relatively higher contents of protein, carbohydrate, calories, dietary fibre, vitamin B, phophorus, iron, zinc, selenium. According to the US Department of Agriculture (USDA, 2022) nutrients data, raw lentil contains 24.6 % protein, 63.4 % carbohydrates, 1.1 % fat, and 2.7 % ash. It also contains a high concentration of essential amino acids like isoleucine and lysine and other nutrients like dietary fiber, folate, vitamin B_1 and minerals (Rozan *et al.*, 2001). Lentil provides an excellent replacement for meat in meals. Besides it has some health benefits such as reduces risk of certain chronic disease, supports the digestive system, improve heart health, helps to manage blood sugar levels, boost energy etc. Lentil is not only extremely beneficial for human consumption but also serves as valuable feed for animals, offering highly digestible protein, calcium and phosphorus compared to cereals crop residue. Husks, dried leaves, stems, fruit walls and bran (residues) can be fed to livestock. Due to its symbiotic N_2 fixation, lentil cultivation comprises a key crop of poor soils and rotation systems promoting amelioration of soil-quality and providing nutritious seeds (Liu *et al.,* 2019). Lentil enriches soil nutrient states by adding Nitrogen, Carbon and Organic matter. Lentils improve the physical properties of soils and increase the yield of succeeding cereal crops. Biological nitrogen fixation or other rotational effects could be the reason for higher yields after lentils. Hence it is proposed as a most suitable crop for sustainable agriculture and food safety in marginal lands (Sarker *et al*., 2018).

Plant growth regulators are the chemicals which influence the plant growth when applied in very minute quantities. PGRs are useful tools that can be used to increase agricultural production since they can control a variety of physiological processes in plants, such as growth, development, and yield creation. In the agricultural domain, a recent advancement focused on improving crop production involves the utilization of plant growth regulators (PGRs). These substances, naturally synthesized in plants, impact various physiological processes, and their synthetic counterparts activate numerous biochemical and physiological mechanisms associated with plant growth and development. There is proof that a variety of synthetic and natural growth regulators enhance many crops' seed germination and seedling vigor (Mohanty and Sahoo, 2006; Renugadevi and Vijayageetha, 2009). Plant hormones control how quickly plant cells divide and how they use their energy (Soliman *et al*., 2020). Among various PGRs, Indole-3-acetic (IAA) acid and Gibberellic acid (GA_3) are two important plant growth regulators.

The most prevalent auxin class hormone found in naturally occurring plants is indole-3-acetic acid (IAA, 3-IAA). It is the most well-known auxin, and plant physiologists have studied it in great detail (Simon and Petrasek, 2001). IAA is a monocarboxylic acid with the molecular formula $C_{10}H_9NO_2$, with a 1H-indol-3-yl group in place of one of the methyl hydrogens (Giri *et al*., 2020). Natural auxin IAA controls fruit development, stem elongation, and seed germination; gibberellin family member GA_3 is recognized for its function in stimulating stem elongation, flowering, and root initiation (Gupta *et al*., 2020). IAA plays a major role on regulation plant growth for example, it controls vascular tissue development, cell elongation, and apical dominance (Wang *et al*., 2001). Also, IAA stimulates cell elongation by modifying certain conditions like, increase in osmotic contents of the cell, increase in permeability of water in to cell, decrease in wall pressure, an increase in cell wall synthesis, protein synthesis and actively participates in adaptive responses of the plant to different stress factors (Yurekli *et al*., 2004).

Gibberellic acid (GA_3) is an important PGRs that is needed to accelerate plant growth and development. It enhances growth activities to plant, stimulates stem elongation and increases dry weight and yield. It significantly ($p<0.05$) increased the number of flowers per plant thereby increasing the number of pods per plant, seeds per pod and weight of seeds per plant (Thuc *et al*., 2021). Gibberellins play a special role in the early phases of plant growth by encouraging elongation in new shoots. It has a significant impact on the shift from vegetative to reproductive growth and is essential in establishing flowering time, they also control flowering in lentil plants. Sufficient quantities of gibberellin are necessary to guarantee timely and coordinated flowering. They also control cell division and the build-up of store reserves, which affects seed weight and size. Plant hormones, such as IAA, GA, ethylene, JA, ABA, and other hormones, are clearly and continuously changing in tandem with fruit growth and ripening biological processes (Cong *et al*., 2019; Fenn *et al*., 2021). The use of growth regulators, particularly in lentils, has received very little attention in our nation's research literature. Studies conducted in other nations have yielded valuable insights, but due to differences in weather and soil types, such findings might not be immediately applicable to our cultivars. Consequently, the present study was started with some valuable objectives.

Now the objectives of present study on application of Indole Acetic Acid (IAA) and Gibberellic acid (GA_3) on the growth and yield of lentil are given below**:**

- To know the optimum dose of Indole-3-acetic acid (IAA).
- To find out the suitable doses of Gibberellic acid (GA_3).
- To assess the interaction effect of Indole-3-acetic acid (IAA) and Gibberellic acid (GA_3) on the yield attributes and yield of lentil.

CHAPTER II
REVIEW OF LITERATURE

In Bangladesh, lentils are a significant pulse crop that can have a big impact on the econo my. Researchers have traditionally paid less attention to the crop in a number of areas since it typically develops without as much attention or management techniques. Many scientists are now studying the pattern of growth and development of plants applying different plant growth regulators. The goal of this chapter is to review the domestic and international data that is currently available on how differing GA_3 and IAA concentrations affect the performance of lentil cultivars.

Plant growth regulators are the compounds that control a plant's remarkable growth. Gibberellic acid (GA_3) is an important growth regulator which has many different modifying influences on growth, yield attributing characters and yield of leguminous crop. Indole-3-acetic acid (IAA) is a vital plant hormone responsible for various physiological processes, making it important in plant growth and development. Some of its key roles include stimulating cell elongation, promoting root development, and regulating responses to environmental stimuli such as light and gravity. Information of the regulatory effects of IAA and GA_3 on various crops have been reviewed below:

2.1 Role of IAA

2.1.1 Plant height (cm)

Any crop's total length, measured from the base to the tips of the leaves, is a reliable prediction of its general progress. Plant height can be altered by plant growth regulators like IAA.

Manpuhro *et al.* (2023) conducted a field experiment during kharif season of 2022 at Crop Research Farm (CRF), Department of Agronomy, SHUATS, Prayagraj (U.P) to evaluate the influence of IAA and boron on the growth and yield of maize. The treatment consisted of 3 levels of IAA (30 ppm, 60 ppm and 90ppm) and Boron (0.5 %, 1.0 %, and 1.5 %) both as foliar sprays and a control. The experiment was laid out in a Randomized Block Design with nine treatments and one control each replicated thrice. The results showed that treatment with foliar application of IAA (90 ppm), and boron (1.5 %) recorded higher growth and yield attribute viz. plant height (185.70 cm), more dry weight (182.15 g), the maximum number of cobs plant^{-1} (1.49), the maximum number of rows cob^{-1} (15.97), maximum number of grains row^{-1} (22.27), seed index (24.79 g), higher grain yield (4.99 t ha^{-1}), higher stover yield (10.20 t ha^{-1}), higher harvest index

(32.85 %), maximum gross return (1,98,470.00 INR ha^{-1}), net return (1,38,620.00 INR ha^{-1}) and B:C ratio (2.31).

Prosad *et al*. (2023) observed that the enhancement of plant growth, chlorophyll content, flowering, yield and seed protein content by plant growth regulators (triiodobenzoic acid, gibberellic acid, cytokinin, indole acetic acidand naphthaleneacetic acid) in DPL-62 lentil (*Lens culinaris* L. Medik) variety during two rabi seasons of 2019-20 and 2020-21. The results showed that the maximum plant height (38.12 & 38.15 cm at harvest) was obtained by 50 ppm GA_3 followed by 50 ppm IAA spray at all stages.

Kushwaha *et al*. (2021) consisted of an experiment on effect of growth regulators on yield of paddy (*Oryza sativa* L.) during the kharif season in 2012 and 2013 at Student's Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.). The experiment was setup in Randomized Block Design (RBD) with three replications and nine treatments. Growth regulators i.e. IAA (25 and 50 ppm), CCC (2000 and 4000 ppm), Alar (2000 and 3000 ppm) and Cytokinin (5 and 10 ppm) were applied on foliage at vegetative and milky stage of Rice (Var. PHB-71). All PGRs showed superior value in all the parameters of crop with respect to control. Plant Height (cm) was found to be superior with foliar application of IAA 50 ppm.

Al Haidary and Al Zubaidy (2019) conducted a study on the response of bread wheat crop to indol-3-acetic acid (IAA) at various growth stages during 2017-2018 using Randomized Complete Bock Design (RCBD) with split plot arrangement. Main plot contained four concentrations of 0, 50, 100 and 150 ppm of plant growth regulator (IAA), while sub-plot consisted of three critical growth stages namely, S_1 (tillering. ZGS:21) S_2 (booting. ZGS:45) S_3 (flowering. ZGS:69). The results showed that IAA at the concentration 100 ppm produced maximum plant height (92.36cm), chlorophyll content (51.04) SPAD, spike length (14.25 cm) number of spike m^{-2} (365.3), 1000-grain weight (36.50 g), grain yield (6.61 t ha^{-1}).

An investigation was carried out by Muthulakshmi and Pandiyarajan (2015) to examine the effects of IAA foliar spray on the physiological and biochemical components as well as the vegetative growth of *Chataranthus roseus* (L). Significant increase of vegetative growth characters such as shoot and root length, shoot and root fresh weights and dry weights, photosynthetic pigment, non-photosynthetic pigment composition and total soluble protein, total soluble glucose, free amino acid, starch, leaf nitrate and peroxidase activity were recorded after IAA treatment.

Mshelmbula *et al*. (2015) showed how drought-stricken sesame (*Sesamum indicum* L.) was affected by indole-3-acetic acid (IAA: 50 ppm and 100 ppm at 10-day intervals). The duplicate that had a weekly watering, but no IAA treatment did not, however, see a discernible rise in plant height. At the 50 ppm and 100 ppm concentrations used, IAA has an impact on the physiological and agronomic characteristics of sesame plants.

Abel and Theologis (2010) discovered through experimentation that auxin contributes to mitotic activity in sub-apical tissues, which in turn promotes plant development. Auxin and gibberellic acid boosted the vegetative development of linseed in a pot experiment conducted by Rastogi *et al*. (2013). It was observed that auxin at a level of 0.5 mg L^{-1} is advised to promote vegetative growth. On the other hand, it was found that IAA had greater promotory effects on vegetative growth expansion than GA_3. Auxin and gibberellin are two PGRs that are essential for controlling plant body growth Gou *et al.* (2010). Greater auxin concentrations restrict plant growth, but greater gibberellin concentrations promote it (Bora and Sarma, 2006), (Hussain *et al.*, 2010).

Quaderi *et al.* (2006) conducted a field experiment to evaluate the Influence of seed treatment with indole acetic acid on mungbean cultivation at Bangladesh Agricultural University, Mymensingh during the period from October 2000 to February 2001 to evaluate the influence of seed treatment with Indole Acetic Acid (IAA) by the concentration of 50 ppm, 100 ppm and 200 ppm on the growth, yield and yield contributing characters of two modern mungbean (*Vignara diata* L.) varieties viz. BARI moog-4 and BARI moog-5. The two-factor experiment was laid out by Randomized Complete Block Design (RCBD) with 3 replications. In the experimental, seed treatment with 100 ppm IAA resulted in the highest plant height.

2.1.2 Number of branches plant^{-1}

Khan *et al*. (2022) conducted an experiment which carried out from November 2019 to March 2021 at the research field of the Regional Agricultural Research Station (RARS), Bangladesh Agricultural Research Institute (BARI), Cumilla to determine the impact of two plant growth regulators (IAA and GA_3)on the yield attributes and yield of mustard (Var. BARI Sarisha-17). 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 were the seven treatments. Twice after seeding, on days 22 and 33, the mustard plant was sprayed with PGRs. Various doses of plant growth regulators had a substantial impact on plant height, branches plant^{-1}, siliqua plant^{-1}, 1000-seed weight, and seed yield ha^{-1}. Plant height, branches plant^{-1}, siliqua plant^{-1}, 1000-seed weight and seed yield ha^{-1} were influenced significantly by different levels of application of plant growth regulators. The highest plant height (115.9 cm), branches plant^{-1} (6.2), siliqua plant^{-1} (79.8), 1000-seed weight (4.1 g) and seed yield (1788.3 kg ha^{-1}) were obtained from T_5 (GA_3 - 75 ppm) treatment.

Khudhur and Omer (2015) studied on effect of NAA and IAA on stem cuttings of *Dalbergia sissoo* (Roxb). In this research, the treatments were prepared to include hormone of Naphthalene acetic acid in four levels (0, 100, 300 and 500 ppm) and Indole acetic acid in four levels (0, 100, 300 and 500 ppm) and the bottom part of the cutting was dipped into above solutions for 30 seconds. The results showed that the maximum percentage of the shoot cuttings, shoot length, number of main branches, diameter of main branches, leaf area, number and length of root, dry weight and biomass and dry matter of shoot, fresh and dry weight of root, biomass and dry matter of root and chlorophyll a belonged to IAA treatment with concentration of 500 ppm, NAA treatment with concentration of 500 ppm.

2.1.3 Number of pods plant^{-1}

Mshelmbula *et al.* (2020) conducted an experiment on the growth and yield characters of three varieties of cowpea (*Vigna unguiculata* L. walp.) in response to different concentrations of indole-3-acetic acid. This study was conducted to determine the response of Indole-3-acetic acid (IAA) on the agronomical and yield characters of three varieties of Cowpea (*Vigna unguiculata*) (SP6, SP9 and SP11) at four different concentrations of IAA; 250 mg L^{-1}, 500 mg L^{-1}, 750 mg L^{-1} and 1000 mg L^{-1}. Results showed that IAA at different concentrations had certain effects on the growth and yield parameters in the three varieties of cowpea. There was a general increase in the number of leaves of SP6, SP9 and SP11 with increased IAA concentration. Moderate concentrations of IAA (500 mg L^{-1} and 750 mg L^{-1}) enhanced the development of leaf area across the three varieties investigated. However, number of pods plant^{-1} increased on exposure to the least concentration (250 mg L^{-1}) of IAA, higher concentrations of IAA had no significant effect on the number of seeds. In Variety SP11 and SP6, no visible differences were observed in the number of days to germinate across all treatment levels including the control.

2.1.4 Length of pods (cm)

Hanna and Safaa (2019) conducted an experiment to study the response of bread wheat crop to indol-3-acetic acid (IAA) at various growth stages during 2017-2018 at agronomy research farm, College of Agriculture, University of AL. qasim Green, Babylon-Iraq. Main plot contained four concentration of 0, 50, 100 and 150 ppm of plant growth regulator (IAA), while sub-plot consisted of three critical growth stages of namely S_1 (tillering. ZGS:21) S_2 (booting. ZGS:45) S_3 (flowering. ZGS:69). The treatment of 100 ppm shows maximum spike length (14.25 cm), also revealed that various growth stage on spike length it was observed that various growth stage significantly affected spike length. The spike length of (13.11cm) was recorded in the S_2 (Booting). The interaction of wheat growth stage and IAA concentration was also highly significant of study. The treatment S_2 (Booting) ×100 ppm IAA produced maximum spike length (14.96 cm), while the lowest spike length (10.10 cm) was recorder in treatment 0 ppm IAA with S_1 (Tiller stage).

El-Saeid *et al.* (2010) showed the response of cowpea plants to IAA. The foliage of the plants were sprayed twice at 70 and 80 days from sowing with Indole acetic acid solutions (25, 50 and 100 mg L^{-1}) and the control plants were sprayed with distilled water. IAA treatments @ 25 and 50 mg L^{-1} increased number of leaves, shoot dry weight, number of produced flowers plant^{-1}, number and weight of pods and seeds plant^{-1}. Meanwhile, 50 and 100 mg IAA significantly decreased the number of flowers absorbed from cowpea plant.

2.1.5 Number of seeds pod^{-1}

Landge *et al*. (2023) used the research farm of the Agricultural Botany Section, College of Agriculture, Nagpur, to conduct a randomized block design experiment with three replications and eight treatments. The objective of the study was to assess the effects of foliar spraying IAA (40 ppm), kinetin (10 ppm), and boron (5000 ppm) on the morpho-physiological and yield-related parameters of chickpea. Based on the overall findings, it can be concluded that the best concentration and timing for boosting chickpea development and yield are foliar applications of IAA 40 ppm + kinetin 10 ppm + boron 5000 ppm at 20 and 40 DAS.

Yasin *et al.* (2023) carried out an experiment on efficacy of IAA for affecting nitrate reeducates activity and yield attributes of mash (*Vigna mungo* L.). The result showed that Indole Acetic Acid enhanced the number of grains, and increasing levels of Indole

Acetic Acid coincided with a steady increase in the number of grains. The maximum increase (15.02 %) was achieved with 125 mg L^{-1} of Indole Acetic Acid.

2.1.6 1000-seed weight (g)

Nourin (2021) corried out a field experiment at the research field of Sher-e-Bangla Agricultural University, Dhaka, during March to June 2020 to study the effect of foliar application of IAA and GA_3 on growth and yield of Mungbean (BARI Mung-6). The experiment consisted of two types of plant growth regulators, viz. i) Auxin (IAA-Indole acidic acid) and ii) Gibberellic acid (GA_3). Nine levels of foliar spray with IAA and GA_3 application viz. i) Control (T_0), ii) Spraying IAA @ 25 mg L^{-1} at 30 DAS (T_1), iii) Spraying IAA @ 50 mg L^{-1} at 30 DAS (T_2), iv) Spraying GA_3 @ 25 mg L^{-1} at 30 DAS (T_3), v) Spraying GA_3 @ 50 mg L^{-1} at 30 DAS (T_4), vi) Spraying IAA @ 25 mg L^{-1}+ GA_3 @ 25 mg L^{-1} at 30 DAS (T_5), vii) Spraying IAA@ 25 mg L^{-1}+ GA_3 @ 50 mg L^{-1} at 30 DAS (T_6), viii) Spraying IAA @ 50 mg L^{-1}+ GA_3 @ 25 mg L^{-1} at 30 DAS (T_7) and ix) Spraying IAA @ 50 mg L^{-1}+ GA_3 @ 50 mg L^{-1} at 30 DAS (T_8). The experiment was laid out in randomized complete block design (RCBD) with three replications weight of 1000-seeds (54.95 g), was higher in T_8 (IAA @ 50 mg L^{-1}+ GA_3 @ 50 mg L^{-1}) treatment. However, (T_0) untreated control (IAA 0.0 mg L^{-1}, GA_3 0.0 mg L^{-1}) showed the lowest performance.

2.1.7 Seed yield (t ha^{-1})

During the 2019 and 2020 seasons, Meleha *et al*. (2023) led an experiment at the Karada water requirements research station, Kafr El-Sheikh Governorate, Water Management Research Institute, National Water Research Center, Egypt to examine the effects of foliar spraying indole acetic acid (IAA) and skipping irrigations at different growth stages on the quantitative and qualitative characteristics of rice (Giza 179). They found that rice yield is most susceptible at the heading stage and that it progressively decreases as the season goes on. The sensitivity of rice yield to drought stress varies during growth stages. Foliar application of plant growth hormone (IAA) has better values of rice grain yield. The data concluded that the values of yield components obtained from foliar spraying of IAA were better than the values obtained from the control, it increased gradually with increasing the concentration of IAA.

Khan *et al.* (2022) conducted an experiment 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 PGRs were sprayed twice on mustard plants at 22 and 33 days after sowing. Plant height, branches plant^{-1}, siliqua plant^{-1}, 1000 -seed weight and seed yield ha^{-1} were influenced significantly by different levels of application of plant growth regulators. The highest seed yield (1788.3 kg ha^{-1}) was obtained from T_5 (GA_3-75 ppm) treatment. The lowest seed yield was obtained from the control treatments (T_7). Application of GA_3-50 ppm, GA_3-100 ppm, IAA-100 ppm, IAA-75 ppm, IAA 50 ppm gave statistical identical yield. 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.

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 early days to maturity was recorded under treatment of and 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}, siliqua plant^{-1} and 1000 seed weight were recorded under the treatment of 90N-45P-15 GA_3-15 IAA.

In 2014-2015, Talukdar *et al*. (2022) conducted a pot experiment to examine the effects of the cytokinin (6-benzyl aminopurine) (BAP) and the plant growth-promoting hormone auxin, (indole-3-acetic acid) (IAA), both separately and in combination, on the growth and oil quality of niger in lateritic soil. Sprays of 25, 50, 75, and 100 mg L^{-1} of IAA and BAP, 50, 75, and 100 mg L^{-1} of IAA + BAP, or water (control) were applied to the plants. The biomass production was highest when IAA or BAP were applied separately at a dose of 75 mg L^{-1} (I75B0 or I0B75). 2014 and 2015 saw notably high biomass (38 and 40 g plant^{-1}) and seed yield (13.24 and 12.67 g plant^{-1}) with the combination of IAA (50 mg L^{-1}) and BAP (100 mg L^{-1}; I50B100). These findings indicate that exogenous phytohormones can improve the seed yield and oil quality of niger seed plants in acid lateritic soil.

Kushwaha *et al*. (2021) conducted an experiment to know the effect of growth regulators on yield of paddy (*Oryza sativa* L.) during the kharif season in 2012 and 2013 at Student's Instructional Farm of Chandra Shekhar Azad University of Agriculture and

Technology, Kanpur (U.P.). The experiment was setup in Randomized Block Design (RBD) with three replications and nine treatments. Growth regulators i.e. IAA (25 and 50 ppm), CCC (2000 and 4000 ppm), Alar (2000 and 3000 ppm) and Cytokinin (5 and 10 ppm) were applied on foliage at vegetative and milky stage of Rice (Var. PHB-71). All PGRs showed superior value in all the parameters of crop with respect to control. Yield attributes viz. Number of panicles plant^{-1}, Number of grains panicle^{-1}, Grain weight plant^{-1} (g), Grain yield (kg ha^{-1}), Test weight (g), Harvest index (%) were also maximized with foliar application of IAA 50 ppm.

El Karamany *et al*. (2019) observed two field experiments which were carried out in Research and Production Station of National Research Centre, Al-Nubaria District, Al Behaira Governorate, Egypt to study the effect of indole acetic acid (IAA) and /or gibberellic acid (GA_3) on growth, photosynthetic pigments, yield, and chemical composition of mungbean seeds. Results indicated that all treatments caused significant increases in morphological criteria, biochemical parameters, and yield of mungbean plants. IAA or GA_3 with 50 mg L^{-1} concentration recorded the best values growth photosynthetic pigments, as well as, endogenous auxins, GA_3, and cytokinins. Interaction of IAA 50 mg L^{-1} + GA_3 50 mg L^{-1} gave the most effective treatment. The superiority of treatment IAA 50 mg L^{-1}, GA3 50 mg L^{-1} and interaction of IAA 50 mg L^{-1} + GA_3 50 mg L^{-1} recorded the same trend due to yield and yield components in characters' plant height, pods no. plant^{-1}, pods weight plant^{-1}, seeds pod^{-1}, seed yield, straw yield, biological yield, total carbohydrates, protein in seeds (%), and N in seeds (%).

El-Awadi *et al*. (2017) conducted an experiment and observed that IAA treatment at 1.0 mM and all melatonin treatments had the most positive effect on increasing seed yield and yield attributes of chickpea. It was observed that seed yield was increased by 113 %, 50.6 %, 117.6 % and 49.6 % under the use of 20 mg L^{-1} IAA, 0.25, 0.50- and 1.0-mM melatonin respectively over control.

Gupta *et al*. (2002) carried out an experiment on the effect of IAA and NAA (35 and 75 ppm, respectively, at 25 and 50 days after transplanting) and the micronutrients mixtures Multiplex and Humaur (2500 and 2000 ppm, respectively) on tomato cultivar Krishna at Karnataka, India during 1997-98 and 1998-99. The fruit size (length 6.32 cm and diameter 6.78 cm), dry matter, ash content, longest root length, and yield were all greatly enhanced by the application of auxins and micronutrients. The largest fruit size and yield were obtained with 75 ppm NAA + multiplex, while the highest dry matter and ash content were noted with 75 ppm NAA + Humaur.

2.1.8 Stover yield (t ha^{-1})

Yagum *et al*. (2023) conducted a field experiment at the research farm of Nagaland University's Medziphema campus to examine the effects of IAA (1 ppm, 2 ppm), GA_3 (200 ppm, 400 ppm), salicyclic acid (75 ppm), and 0.1 % Tebuconazole on the yield, quality parameters, and economics of linseed cultivation under rain-fed conditions in Nagaland during the rabi season. Stover yield was found to be significantly higher with application of IAA @ 2 ppm (2589.62 kg ha^{-1}) followed by GA_3 @ 200 ppm (2548.75 kg ha^{-1}).

Elshorbagi *et al*. (2008) consisted of an experiment and noticed the role of IAA on the anatomical characteristics, stover and fiber yield and quality of Flax. IAA and GA_3 had increased the stem thickness by increasing that of cortex, phloem fibers and xylem. Each had increased straw and fiber yield $plant^{-1}$, but the effect was more pronounced with GA_3 than IAA. The percentage of long fibers, strength and fineness increased significantly with GA_3. The latter two properties decreased with IAA.

2.1.9 Biological yield (t ha^{-1})

Sadak *et al*. (2013) discovered that the two fababean cultivars' seed yield $plant^{-1}$ (g), yield attributes (number of pods $plant^{-1}$, pods yield $plant^{-1}$ (g), 1000-seed weight (g), and biological yield $plant^{-1}$) significantly increased when the two cultivars were treated with IAA.

2.1.10 Harvest index (%)

At the C. S. Azad University of Agriculture & Technology's Student Instructional Farm in Kanpur, Shahi *et al*. (2023) worked on hybrid rice with the goal of determining how foliar application of plant growth regulators affected rice growth and yield in 2021 and 2022. A rigorous randomized block design was used in the experiment to assess different treatments, which included applying IAA (25 and 50 ppm), IBA (25 and 50 ppm), NAA (25 and 50 ppm), ascorbic acid (50 and 100 ppm), and kinetin (5 and 10 ppm) topically. When IAA at 50 ppm was applied, there were noticeable gains in growth parameters including total leaf area per plant and leaf and stem dry weights per plant. Additionally, there was a noticeable rise in the harvest index and grain output per plant.

In an experiment, Quaderi *et al*. (2006) discovered that treating the seeds with 200 ppm IAA produced the maximum yield, harvest index (38.48 %), crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR) of mungbean.

2.2 Role of GA_3

2.2.1 Plant height (cm)

Bista *et al.* (2022) conducted a field experiment at Horticulture Farm of Agriculture and Forestry University, Rampur, Chitwan, Nepal from 1 December to 30 April of 2018-19 to evaluate the effect of plant growth regulators on onion (*Alliumcepa* cv. Nasik-53). The experiment was laid out in a Randomized Complete Block Design (RCBD) with 13 treatments. Growth regulators including: GA_3 and NAA each at 75, 150 and 200 mg L^{-1} concentrations together with the combined forms were applied at 3 and 7 leaf stages of onion crop and the obtained data were compared with the control (distilled water spray) plants. Each treatment was replicated three times. The application of combination of 150 mg L^{-1} NAA at 3 leaf stage and 150 mg L^{-1} GA_3 at 7 leaf stage resulted in highest value for plant height (76.67 cm) while the control treatment resulted in the lowest value for plant height.

Raj *et al.* (2022) carried out an experiment at the Crop Research Farm, Department of Agronomy, SHUATS, Allahabad, during 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. The experiment used a Randomized Complete Block Design (RCBD) with 9 treatments and was repeated three times. The treatment of GA_3 90 ppm + Zn 15 kg ha^{-1} resulted in the highest plant height (126.50 cm) (treatment 9) recorded in the study.

Kumar and Kushwaha (2020) conducted a field experiment with nine treatments and three replications of each treatment to ascertain the effect of exogenously applied plant growth regulators on wheat morpho-physiological and biochemical attributes. Wheat plants were sprayed with growth regulators at tillering and before anthesis stage. The treatments were subjected to Indole 3 Acetic Acid (IAA) 25 ppm and 50 ppm, Gibberellins (GA_3) 20 ppm and 40 ppm, Cytokinin (Kinetin) 5 ppm and 10 ppm, Alar 1000 ppm and 2000 ppm. Application of GA_3 40 ppm at pre tillering and anthesis stage appreciated the plant height and relative growth rate of wheat crop while tiller number, leaf area, total dry weight and chlorophyll content improved by IAA 50 treatment.

Reja *et al*. (2020) carried out an experiment to evaluate the effect of gibberellic acid (GA_3) on morpho-physiological traits and yield performance of Chickpea (*Cicer arietinum* L.) at Research field and Laboratory of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during December, 2017 to April, 2018 with two factors: a) two growing conditions viz.; control and foliar application of GA_3 and b) four chickpea varieties viz.; Deshi, BARI Chola-3, BARI Chola-5 and BARI Chola-9. The experiment was laid out in Randomized Complete Block Design with three replications. The percentage of increasing in maximum plant height, leaf dry weight plant^{-1}, shoot dry weight plant^{-1} and root dry weight plant^{-1} were 6.21 %, 9.59 %, 12.00 % and 9.05 % in Deshi variety; 4.54 %, 3.06 %, 4.89 % and 4.76 % in BARI Chola-3; 5.21 %, 9.28 %, 8.25 % and 10.07 % in BARI Chola-5 and 8.31 %, 13.44 %, 9.80 % and 9.58 % in BARI Chola-9, respectively under foliar application of GA_3. BARI Chola-9 performed better compared to the other three varieties in relation to foliar application of gibberellic acid (GA_3).

Soomro *et al*. (2020) conducted an experiment in rice crop through foliar application of GA_3 at different intervals to evaluate their efficiency at different doses. Results revealed that there was no significant difference in crop maturity compared to control treatment. The highest plant height was recorded (121.2 cm) in 2017-18 experiment at T_3 Gibberellic acid @ 12 g acre^{-1} while minimum (96.2 cm) was in 2016-17 in T_7 Control.

Ujjwal *et al*. (2018) performed a field experiment during 2015-16, at the Horticulture Research Center of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut to find out the response of foliar application of GA_3 and NAA on vegetative and flowering attributes of tomato cv. Pusa Rohini. The two bio-regulators i.e. GA_3 and NAA ware used in different concentration i.e. GA_3 (20, 30, 40 and 50 ppm) and NAA (15, 20, 25 and 30 ppm) and Control (distilled water spray). Results revealed that the foliar application of GA_3 (50 ppm) registered significantly higher vegetative growth viz., plant height (101.45 cm) and internodes length (6.20 cm) and flowering parameters viz., minimum number of days to first flowering (24.60) and maximum number of flower plant^{-1} (50.13) as compared to other treatments.

Singh (2015) carried out an experiment at Gwalior during rabi season of 2012-13 to study the effect of mixture of GA_3 and NAA with four concentrations i.e. 0, 10, 15 and 20 ppm on growth, yield attributes and yield on cabbage varieties, namely Krishna (Hybrid). Kranti (Hybrid), Golden acre and Pride of India. Results revealed that 15 pm GA_3 + NAA was found to be the most effective growth regulators in increasing the growth, yield attributes and head yield (688.50 q ha^{-1}).

Gibberellic acid was found to have a continuous influence on the phenotypic of *Catharanthus roseus* L. plants in a previous experiment. Previous research has demonstrated that applying GA_3 as a foliar spray at 50, 100, and 500 g to transplanted cuttings of *Catharanthus roseus* L. lengthened the stems, which in turn enhanced plant height. In most plants, gibberellins accelerated the rate of cell elongation, resulting in longer shoots Shil *et al*. (2007).

2.2.2 Number of branch plant^{-1}

Danish *et al.* (2024) stated that the application of 0.8 mM MJ with 5 mg L^{-1} GA_3 significantly enhances shoot length (23.29 %), shoot dry weight (24.77 %), number of leaves plant^{-1} (24.93 %), number of flowering branches (26.11 %), chlorophyll a (31.44 %), chlorophyll b (20.28 %) and total chlorophyll (27.66 %) and shoot total soluble carbohydrates (22.53 %) over control.

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

2.2.3 Number of pods plant^{-1}

Dani *et al.* (2023) conducted an experiment to determine the effect of GA_3 on the seed production of peanuts. The experiment was arranged in a single factor randomized complete block design with GA_3 concentrations of 0, 75, 150, 225, and 300 ppm. The result showed that GA_3 at 126.80 ppm increased the number of harvested pods by 18.16 %.

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) were recorded under drought stress while the minimum were at control treatment.

Iqbal *et al.* (2022) conducted an experiment by considering the adverse impact of heavy metals on human health through consumption of crops. To alleviate the adverse effects of cadmium (Cd) toxicity foliar application of gibberellic acid, two varieties of *Brassica* including Indian mustard (*Brassica juncea* L.) commonly known as ‘Raya’ and rapeseed (*Brassica rapa* L.) as ‘Toria’ were studied. Foliar application of gibberellic acid (50 mg, 75 mg and 100 mg) positively influenced the growth parameter as siliqua plant^{-1} (88).

Hadiya *et al.* (2021) conducted an experiment at Agronomy Instructional Farm, S. D. Agricultural University, Sardarkrushinagar during kharif 2020 to examine the effect of different foliar spray of plant growth regulators viz., GA_3 (100 and 200 ppm), NAA (50 and 100 ppm), CCC (500 and 1000 ppm) and SA (500 and 1000 ppm) on seed yield and yield attributes of sesame variety (Gujarat Til 3). The research was laid out in randomized block design, with ten treatments in three replications under rainfed condition. The result showed that GA_3 @ 200 ppm significantly increased the number of capsule plant^{-1}.

2.2.4 Pod length (cm)

Sootaher *et al.* (2022) performed an experiment with four promising Canola genotypes in order to determine the impact of GA_3 foliar application on canola growth and outputs during 2017-18 in rabi season at the Nuclear Institute of Agriculture, Tandojam. The results showed that growth regulators levels significantly influenced the growth and yield of canola crops. It was observed that maximum siliqua length was 7.39 cm with the application of GA_3 5 g ha^{-1} in SURHRAN-2012.

Thakur *et al.* (2020) consisted of a study on effect of foliar application of GA_3 on flowering, fruiting, yield and seed quality parameters in okra [*Abelmoschus esculentus* (L.)] during kharif season of 2018-19. Various concentrations of growth regulator GA_3 i.e. 25, 50, 100 and 150 ppm were applied as foliar spray after 30, 45 and 60 days of germination on okra plants. The study showed that maximum number of fruits (14.47) and maximum fruit length (16.83 cm) obtained in treatment T_{11} i.e. with application of 150 ppm GA_3 at 45 days after germination.

2.2.5 Number of seeds pod^{-1}

Saha *et al.* (2021) observed the effect of gibberellic acid on yield performance and siliqua shattering of mustard (var. BINA shorisha-6) at the Crop Botany field Laboratory, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh during November 2007-March 2008. Four concentrations of Gibberellic acid (0, 25, 50 and 75 ppm) were sprayed on canopy at 30 days after sowing. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The result showed that GA_3 at 50 ppm significantly increased the number of seeds siliqua^{-1}.

Dawar *et al.* (2020) studied the effects of foliar application of gibberellic acid on growth, yield, and economics of blackgram (*Vigna mungo* L.) which was conducted during the Kharif season of 2018 at the research field of Pulses Research Unit, Washim Road, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Maharashtra). Eleven treatments including the management of gibberellic acid (applying 15, 30, 45 ppm GA_3 at flower and pod initiation phases and control) were studied in blackgram. The number of grains pods^{-1} was considerably higher with two administrations of 30 ppm GA_3 during the flower and pod initiation stages than with no application of GA_3.

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. The result showed that the highest number of seeds siliqua^{-1}under the concentration of GA_3 10 g ha^{-1} while the lowest under the control treatment.

Saini *et al.* (2017) conducted an experiment which entitled 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.)] under sodic soil 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). The results indicated that the number of seeds silique^{-1} (15.40) was found higher with foliar spray of GA_3 @ 125 ppm followed by foliar sprayed of 90 ppm, over rest of treatments including control.

2.2.6 1000-seedweight (g)

Hanum *et al*. (2024) examined the agronomic performance of various *Oryza sativa* L. rice cultivars grown at varying times for the application of GA_3. The study was carried out at Tanjung Morawa Subdistrict, Deli Serdang's Lengau Seprang Village. The rice types (Inpari 32, Ciherang, and Siporang) and the timing of gibberellic acid (GA_3) administration (0, 1, 2, and 3 applications) were the two treatment factors in this randomized complete block design investigation. It’s interesting to note that the measured parameters were mostly unaffected by the date of GA_3 application. In comparison to the other types, Siporang produced the least amount of grain per hill but had the greatest average values for plant height, panicle length, and flag leaf area. Conversely, Inpari 32 produced the largest grain weight.

Amri (2023) stated that three growth regulators were utilized to increase the physiological activity and production of cowpea plants. When compared to untreated control plants, seed presoaking in various concentrations of IAA, GA_3, and kinetin appeared to improve various yield parameters such as 1000 seeds weight and relative growth yield, pod weight, pod length number, and total amount of seeds pods^{-1} of cowpea plants.

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 1000 seeds ranged from 213.50 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 study of Tiwari *et al.* (2011) for rice.

2.2.7 Seed yield (t ha^{-1})

Laboni *et al*. (2024) conducted an experiment to know the effect of different fertilizer combinations and gibberellic acid (GA_3) on yield attributing traits of Mustard at the Research Field of the Department of 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 tons 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*. (2024) investigated the effects of different plant growth regulators on the yield and related traits of the PB-89 variety of pea (*Pisum sativum* L.) during the rabi seasons of 2021-22 at the Chamelti Agriculture Farm, MS Swaminathan School of Agriculture, Shoolini University of Biotechnology and Management Sciences, Solan, H.P., India. Nine treatments, including water soaking, varying concentrations of GA_3, and combinations with Cycocel at different concentrations, were used in the randomized block design trial. This study suggested that the application of GA_3 at 200 ppm followed by foliar spray of Cycocel at 200 ppm significantly improved pea yield attributes and overall yield, presenting a promising approach for enhancing pea productivity.

Sonia *et al*. (2024) conducted a field study under rainfed conditions to evaluate the response of foliar application of different PGRs such as hormonal-based gibberellic acid (20ppm); chemical-based thiourea (500 ppm); chemical-constituting structural component-based ortho-silicic acid (380 ppm); and control (water-sprayed) on sesame cultivars: Swethatil, GT-10, TKG-22, and JCSDT-26. GA_3 at 20 ppm was found most effective and may not only enhance the optimum productivity but also effective in improving the quality traits of sesame.

Islam *et al*. (2023) conducted an experiment at the Agronomy pocket House, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur to evaluate the growth promoting effect of foliage applied gibberellic acid (GA_3) at various spraying frequencies for mungbean crop. The employed treatments included four gibberellic acid levels (0, 100, 200, and 300 ppm) and two application frequencies (single spray at 30 days after sowing DAS, and two sprays at 30 and 40 DAS). When GA_3 200 ppm applied twice at pre-flowring stages it showed maximum grain yield plant^{-1} (4.57 g), and a minimum water saturation deficit.

Parveen *et al*. (2023) experimented on the mungbean plants which were treated with three levels of IAA (0, 30, and 60 mg L^{-1}) and GA_3 individually and/or in combination using a hydraulic sprayer. It was concluded that the 60 mg L^{-1} concentration of IAA and GA_3 led to significant changes in the growth and yield traits compared to non-treated plants.

At the C. S. Azad University of Agriculture and Technology's Student Instructional Farm in Kanpur, Shahi *et al*. (2023) worked on hybrid rice with the goal of determining how foliar application of plant growth regulators affected rice growth and yield in 2021 and 2022. A rigorous randomized block design was used in the experiment to assess different treatments, which included applying IAA (25 and 50 ppm), IBA (25 and 50 ppm), NAA (25 and 50 ppm), ascorbic acid (50 and 100 ppm), and kinetin (5 and 10 ppm) topically. When IAA at 50 ppm was applied, the highest results were shown.

Yagum *et al*. (2023) conducted a field experiment at the research farm of Nagaland University's Medziphema campus to examine the effects of IAA (1 ppm, 2 ppm), GA_3 (200 ppm, 400 ppm), salicyclic acid (75 ppm), and 0.1 % Tebuconazole on the yield, quality parameters, and economics of linseed cultivation under rainfed conditions in Nagaland during the rabi season. IAA @ 2 ppm among the PGR treatments recorded the highest seed yield of 1244.42 kg ha^{-1} than any other treatment. Tebuconazole, at 0.1 %, produced the lowest seed yield of 1013.47 kg ha^{-1}, excluding control.

Haifaa *et al.* (2022) conducted an experiment 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 MR 219. Two applications of GA_3 at 7 days interval had consistently given higher grain yield than single application. However, there was no significant difference in flag leaf characteristics, one thousand grain weight and milling qualities on different treatments. The study had clearly illustrated that foliar application of GA_3 at weekly interval at 10-30 % panicle heading stage, could increase rice grain yield significantly.

Shah *et al.* (2022) conducted an experiment to investigate the effect of gibberellic acid (GA_3) on the growth stages and yield of bitter gourd at Horticulture Research Farm, The University of Agriculture Peshawar, Pakistan during summer 2016. Gibberellic acid concentrations (GA_3) 0 ppm, 30 ppm, 60 ppm, and 90 ppm were applied at different leaf stages i.e., 2-4 leaves, 5-7 leaves, and 8-10 leaves. The result showed that 90 ppm GA_3 concentration improved the fruits yield $plot^{-1}$ (13.98 kg), and total yield (38.83 t ha^{-1}) respectively.

Islam *et al*. (2021) conducted an experiment at the Crop Museum, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh to evaluate the role of gibberellic acid [GA_3; (0, 100, 200, and 300 ppm)] in modulation of the growth, physiology, yield, and quality traits in two varieties (BARI Mung-6 and BARI Mung-8) of mungbean (*Vigna radiata* L.). The study compared the effects of foliar application of 200 ppm GA_3 on two varieties of *Vigna radiata* (BARI

Mung-6 and BARI Mung-8) in terms of growth, yield and quality traits. It was found that BARI Mung-8 exhibited significantly higher responses to the application of 200 ppm GA_3 compared to BARI Mung-6, particularly in terms of growth and yield attributes.

Tasnim *et al*. (2019) conducted a field experiment at the Agronomic Research Field, Hajee Mohammad Danesh Science and Technology University, Dinajpur during April to August 2018 in order to investigate the effect of GA_3 application time and different concentrations on morphophysiological, yield and yield contributing characters of mungbean cv. BARI mung-8. The experiment comprised three application times of GA_3 viz. 15, 30 and 45 DAS and three concentrations viz. 0, 100 and 200 ppm. The result showed that BARI mung-8 performed the best with the application of GA_3 @ 100 ppm at 30 DAS.

2.2.8 Stover yield (t ha^{-1})

Wesley and Dawson (2023) consisted of a study during Zaid season 2023 at CRF, (Crop Research Farm), Department of Agronomy, Naini Agricultural Institute, Sam Higgin bottom University of Agriculture, Technology and Sciences, Prayagraj during Zaid season of 2023. The purpose of this research was to study the influence of biofertilizers and gibberellic acid on growth and yield of Blackgram. From the observations, maximum stover yield (2.03 t ha^{-1}) was recorded with treatment 9 (PSB 10 g seeds kg^{-1} + Rhizobium 10 g seeds kg^{-1}+ Gibberellic acid at 150 ppm) while the minimum was recorded in treatment 10 (1.45 t ha^{-1}) with (Control NPK-20:40:20 kg ha^{-1}).

Sumi *et al.,* (2021) conducted a field experiment during the rabi season of 2020-21 at the research farm of Rajasthan College of Agriculture, Udaipur to investigate the effect of gibberellic acid and sulphur on growth and yield of mustard (*Brassica juncea* L.). The experiment consisted of four levels (control, 20, 40 and 60 kg ha^{-1}) of sulphur and four levels of gibberellic acid (control, 25, 50 and 75 ppm) there by making 16 treatment combinations, were laid out in Factorial Randomized Block Design and replicated three times. The significant increase in plant height (cm), dry weight (g), number of branches $plant^{-1}$, number of siliqua $plant^{-1}$, seed yield (g), stover yield (g) and biological yield (g) of mustard were observed with the application of 40 kg S ha^{-1} + 50 ppm GA_3, as compared to control.

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 g) was observed with the application of RDF + foliar spray of GA_3 @ 45 ppm 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 humic acid @ 1.5 % with 2 days interval at flowering (T_8) (5305 g).

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 by 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).

2.2.9 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 yield, 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.

Borra *et al.* (2021) carried out an experiment at CRE (Crop Research Farm) of Agronomy Department at SHUATS, Prayagraj with the objective to study performance of plant growth regulators and fertilizers effect on growth, yield and oil content of sunflower (*Helianthus annuus* L.) under Randomized Complete Block design (RCBD) comprising of 9 treatments with 2 different plant growth regulators from 3 different fertilizers. The result showed that the biological yield was maximum (4383.20 kg ha^{-1}) with application of NPK 100:50:50 + GA_3 200 ppm.

2.2.10 Harvest index (%)

Rakesh *et al*. (2024) revealed an experiment on the effect of plant growth regulators on economics and harvest index of Garlic (*Allium sativum* L.) under Terai region of West Bengal. The experiment conducted on various kinds of growth regulators (Gibberellic acid (GA_3) @ 50 ppm, GA_3 @ 100 ppm, GA_3 @ 150 ppm, Naphthalene acetic acid (NAA) @ 50 ppm, NAA@ 100 ppm, NAA @ 200 ppm, Kinetin@ 10 ppm, Kinetin @ 20 ppm, Kinetin@ 40 ppm and control (Distilled water) at the instructional and research farm of the Uttar Bangla Krishi Viswavidyalaya, Pundibari, Cooch Behar, India, during the autumn and winter seasons for two consecutive years. The result obtained that the highest harvest index obtained under the Knetin @ 20 ppm (71.53 %) and lowest HI obtained under treatment of GA_3 @ 100 ppm (62.59 %).

At the Crop Research Farm, Department of Agronomy, SHUATS, Allahabad, a field experiment was undertaken by Raj *et al.* (2022) 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 the 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 %). There was no significant difference between treatments (Ijaz *et al.* 2019).

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 2023 to March 2004 to study the effect of yield and yield attributes of lentil as influenced by Indole-3-acetic acid and gibberellic acid. The supplies and techniques used to carry out the experiment are included in this chapter and are listed below under the following headings:

3.1 Description of the experimental site

3.1.1 Experimental Location

The study was conducted at the research field of Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200. The geographical position of the area is between 25° 38' N latitude and 88° 41' E longitude and it is situated at elevation 37.50 meters above the sea level. The land of the experimental site was a medium high land belonging to the Agro-ecological Zone-1 (AEZ-1) which is named as Old Himalayan Piedmont Plain (UNDP and FAO, 1998) (Appendix I).

3.1.2 Soil of the experimental area

The soil of the experimental fields belongs to the Old Himalayan Piedmont Plain (Agro-ecological Zone-1). The soil of the experimental plot was sandy loam with good drainage capacity. Organic matter content was 1.48 % and soil PH was 5.8-6.0. The soil was moderately alkaline clays and low permeability.

3.1.3 Climate

The subtropical climate of the experimental location is characterized by three distinct seasons, the monsoon from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October. The weather data including maximum and minimum temperatures, rainfall and relative humidity for the study period were provided by the Bangladesh Meteorological Department (Weather Research Station) Rajbati, Dinajpur. The climate in Dinajpur has been presented in Appendix II.

3.2 Planting Material

The lentil variety BARI moshur-7 was used for the experiment. The seeds were healthy, pulpy, well matured and free from mixture of other seeds, weed seeds and extraneous materials.

3.2.1 Characteristics of BARI moshur-7

The BARI moshur-7 was developed in 2011 by the Pulses Research Centre located at Ishurdi, Pabna. BARI moshur-7 is a cultivar that grows tall with extensive branching and podding. The leaves have rudimentary tendrils and narrow, light- green leaflets. The mature pods, leaves and stems are a pale straw color, and the bloom is bluish-purple. Cotyledons are bright orange, and the seed coat is dark grey. Plant height 32-38 cm, pod number 55-60, 1000 grain weight 23-25 g. It lasts for 115-120 days. The average yield per hectare is 1800-2300 kg.

3.3 Treatments of the experiment

There are two factors in the proposed research and those were concentration of GA_3 and concentration of IAA. The treatments under investigation were as follows

Factor A: Indole-3-acetic (IAA) acid

I_0= Control
I_1= 25 ppm
I_2= 50 ppm
I_3= 75 ppm

Factor B: Gibberellic acid (GA_3)

GA_0= Control
GA_1= 50 ppm
GA_2= 100 ppm

Treatment combination:

I_1G_1= 0 ppm IAA + 0 ppm GA_3
I_1G_2= 0 ppm IAA + 50 ppm GA_3
I_1G_3= 0 ppm IAA + 100 ppm GA_3
I_2G_1= 25 ppm IAA + 0 ppm GA_3
I_2G_2= 25 ppm IAA + 50 ppm GA_3

I_2G_3= 25 ppm IAA + 100 ppm GA_3

I_3G_1= 50 ppm IAA + 0 ppm GA_3

I_3G_2= 50 ppm IAA + 50 ppm GA_3

I_3G_3= 50 ppm IAA + 100 ppm GA_3

I_4G_1= 75 ppm IAA + 0 ppm GA_3

I_4G_2= 75 ppm IAA + 50 ppm GA_3

I_4G_3= 75 ppm IAA + 100 ppm GA_3

3.4 Experimental design and layout

Three replications and a Randomized Complete Block Design (Factorial) were used to set up the experiment. The layout of the experiment was prepared for distributing the treatment. The area was divided into three equal blocks. Each block was divided into 12 plots where 12 treatments were allotted randomly. Therefore, the total number of experimental unit was 36 (12 x 3). Each plot dimension was 10 m^2 (2.5 m × 4 m). The layout of the experiment is shown in Figure 1.

R_1	R_2	R_3
I_2G_1	I_1G_1	I_4G_3
I_3G_1	I_2G_2	I_2G_1
I_4G_1	I_4G_2	I_3G_1
I_3G_3	I_1G_2	I_4G_1
I_1G_3	I_4G_3	I_3G_3
I_3G_2	I_2G_1	I_1G_3
I_2G_3	I_3G_1	I_3G_2
I_1G_1	I_4G_1	I_2G_3
I_2G_2	I_3G_3	I_1G_1
I_4G_2	I_1G_3	I_2G_2
I_1G_2	I_3G_2	I_4G_2
I_4G_3	I_2G_3	I_2G_2

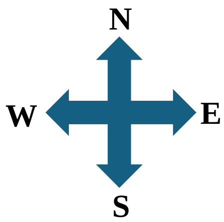

Figure 1. Field layout of the experiment

3.5 Growing of crops

3.5.1 Seed collection

The seeds of BARI moshur-7 type lentil were collected from the Bangladesh Agricultural Research Institute (BARI), Ishwardi, Pabna, regional station, on 19, October 2022. Healthy seeds were chosen for the experiment.

3.5.2 Land Preparation

On 20, November 2022 the experimental land was ploughed. Then it was exposed to the sunshine for 5/6 days prior to the next ploughing. Therefore, the land was brought into desirable tilth by 4 ploughing and cross-ploughing, harrowing and laddering to obtain good tilth, which was necessary to get better yield of this crop. The experimental field was cleared of weeds, stubble and crop wastes. The final ploughing was done on 26, November 2022. In accordance with the experiment's design, the experimental area was divided into 36-unit plots.

3.5.3 Fertilizer Application

The experimental plots were fertilized with Urea, TSP, MOP and Boric acid as the source of N, P, K and B at the rate of 40 kg, 80 kg, 40 kg and 12 k per hectare respectively according to the Bangladesh Agricultural Research Institute's (BARI) suggestion. All the fertilizers were collected from the farm of HSTU. During land preparation TSP, MOP and half of Urea used as basal dose, rest of urea applied in two splits. With the help of hand sprayer, the PGRs were applied three times at pre flowering stage (20 DAS), post flowering stage (40 DAS) and at last (60 DAS).

3.5.4 Sowing of seeds

The seeds of BARI moshur-7 were sown on 30, November 2022. Before sowing, the seeds were dried in the sun and then soaked into water for about 6 hours. The seeds were placed at about 2-3 cm depth from the soil surface. Row to row distance was 25 cm. About 90 % of seeds were germinated on the 5th day after sowing.

3.6 Application of IAA and GA_3

IAA of different doses (0 ppm, 25 ppm, 50 ppm and 75 ppm) were applied three times at 20 DAS, 40 DAS and 60 DAS, respectively. And GA_3 of different doses (0 ppm, 50 ppm and 100 ppm) were applied three times at 20 DAS, 40 DAS and 60 DAS, respectively.

3.7 Intercultural operations

3.7.1 Thinning

After the establishment of seedlings, it should be necessary to remove sick and lineless seedlings from the plot. The thinning procedure was carried out twice in order to obtain the optimal plant population. The first thinning was completed at 15 DAS and the second was at 30 DAS.

3.7.2 Weeding

To maintain weed-free plots and, eventually, improved growth and development, weeding was done. The experimental plots were weeded as needed after the initial 20 DAS.

3.7.3 Irrigation and drainage

Irrigation was completed according to specifications. Thirty DAS was the irrigation start time. Watering was kept up until the earth was saturated. During periods of intense rainfall, stagnant water was efficiently flushed away.

3.7.4 Plant protection measure

As a preventive measure of aphid, Ripcord 10 EC @ 1 ml L^{-1} was applied twice, one week apart. As the infection was severe, Bavistine 250 WP @ 2 g L^{-1} was also administrated twice, one week apart, to control the foot and root rot of the lentil disease.

3.7.5 Harvesting and threshing

On March 26, 2023, the crop was hand harvested from each plot after roughly 80 % of the pods reached maturity. The crop was spread out on the open threshing floor for three days to be sun dried. The bundles were beaten with bamboo sticks to extract the seeds from the plants. Each plot's harvested crop was packed individually, appropriately tagged, and transported to the threshing floor. The lentil seeds were threshed and harvested with care.

3.7.6 Drying, cleaning and weighing

After cleaning, the seeds that had been harvested were dried in the sun to maintain a constant amount of moisture percentage (12 %). Both the straw and the dried seeds were cleaned and weighed. The straw was additionally sun-dried, and the yields of grain and straw were measured and translated to hectares.

3.8 Sampling and recording data

Five randomly selected plant samples were gathered from each plot to gather data on the various lentil parameters. The data started recording on 30 DAS and continued until the crop's yield-contributing features were finished being documented after harvest. The experiment yielded the following data records:

3.8.1 Morphological parameters

1. Plant height (cm)
2. Number of branches plant^{-1}

3.8.2 Yield contributing characters

1. Number of pods plant^{-1}
2. Pod length (cm)
3. Number of seeds plant^{-1}
4. Weight of 1000 seeds (g)

3.8.3 Yield and harvest index data

1. Seed yield (t ha^{-1})
2. Stover yield (t ha^{-1})
3. Biological yield (t ha^{-1})
4. Harvest index (%)

3.9 Procedure of recording data

The following procedure was followed for data collection:

3.9.1 Plant height (cm)

The height of plant was recorded in centimeter (cm) at the time of 30, 60, 90 DAS (days after sowing) and at harvest. Data were recorded as the average of 5 plants selected at random from the inner rows of each plot. The height was measured from the ground level to the tip of the leaves.

3.9.2 Number of branches plant^{-1}

The number of branches per plant was counted from selected plants. It was done by counting the total number of branches of all sampled plants then the average number of branches plant^{-1} was determined.

3.9.3 Number of Pods Plant^{-1}

The number of total pods of five plants from each plot at the time of harvesting was noted and the mean number was expressed per plant basis.

3.9.4 Pod length plant^{-1} (cm)

The length of ten randomly selected pods from each of replication was measured and then divided by ten to get single pod length.

3.9.5 Number of seeds pod^{-1}

The seeds pod^{-1} was counted from 10 selected pods of plants and then the average seed number was calculated.

3.9.6 Weight of 1000 seeds (g)

One thousands cleaned and dried seeds were counted randomly from the seed stock obtained from the sample plants and weighed by using a digital electric balance and the mean weight was expressed in grams.

3.8.7 Seed yield (t ha^{-1})

The entire plot's plants were gathered in order to calculate the grain yield. After being removed from the plants, the grains were cleaned, dried, and weighed. The grain yield in kg plot^{-1} was converted to t ha^{-1} after being corrected for the grain's 12 % moisture content.

3.9.8 Stover yield (t ha^{-1})

The stover yield was calculated from the central portion of the plot. The stover of the harvested crop in each plot was sun dried to a constant weight. Then the stover's 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}.

3.9.9 Biological yield (t ha^{-1})

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

$$\text{Biological yield} = \text{Seed yield} + \text{Stover yield}$$

3.9.10 Harvest index (%)

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

$$\text{Harvest index (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

3.10 Statistical Analysis

The recorded data were analyzed statistically using the analysis of variance (ANOVA) technique with the help of computer- based programme MSTAT-C. The treatment means were compared using Duncan's Multiple Range Test (DMRT).

CHAPTER IV
RESULTS AND DISCUSSION

This chapter comprises presentation and discussion of the results obtained from a study to investigate the effect of IAA and GA_3 on the growth and yield of lentil variety cv. BARI moshur-7. The results of the experiment have been presented and discussed in this chapter in the form of different figures, tables along with adequate interpretations wherever needed. The results have been presented under the following headings:

4.1 Plant height (cm)

4.1.1 Effect of IAA

Plant height is one of the key growth factors for any crop plant. Application of IAA significantly influenced the plant height of lentil at different plant age after 20 DAS. However, the highest plant height (17.15 cm, 34.07 cm and 41.77 cm) was observed when IAA was applied at 60 DAS at all sampling dates (40, 60 DAS and at harvest) except 20 and 40 DAS (Table 1). The plant height was non-significant at 20 DAS and 40 DAS. The lowest plant height (16.82 cm, 25.69 cm and 34.85 cm) was attained at I_1 treatment (IAA applied at 20 DAS) at all sampling dates after IAA application (Table 1). The present results are in line with the findings of Manpuhro and Dawson (2023) who observed that foliar application of IAA (90 ppm) and boron (1.5 %) produced the maximum plant height (185.70 cm) in maize.

Table 1: Effect of IAA on plant height of lentil at different days after sowing

Doses of IAA	Plant height (cm) at different days after sowing			
	20 DAS	40 DAS	60 DAS	At harvest
I_1 (0 ppm)	7.07	16.82	25.69 d	34.85 c
I_2 (25 ppm)	7.08	17.04	30.42 c	37.34 bc
I_3 (50 ppm)	7.04	17.15	34.07 a	41.77 a
I_4 (75 ppm)	7.03	16.86	32.38 b	39.41 ab
CV (%)	1.55	1.71	4.38	7.08
LS	NS	NS	**	**
$LSD_{0.05}$	0.11	0.28	1.31	2.65

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

Legend:

*= 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
NS = Non significant

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA

4.1.2 Effect of GA_3

Different levels of gibberellic acid showed significant variation in plant height of lenti at different DAS (days after sowing) and harvest (Table 2). The tallest plant was recorded in 50 ppm of GA_3 with a value of 31.71 cm and 39.71 cm at 60 DAS and at harvest, respectively. On the other hand, the shortest plant height (29.32 cm and 37.25 cm) was found in the control treatment at 20, 40, 60 DAS, and at harvest, respectively. Gibberellic acid induced the cell division and cell enlargement as well as increased plant height. Similar growth stimulating effects were observed in field peas (Singh *et al.* 2015).

Table 2: Effect of GA_3 on plant height of lentil at different days after sowing

Doses of GA_3	Plant height (cm) at different days after sowing			
	20 DAS	40 DAS	60 DAS	At harvest
G_1 (0 ppm)	7.01	16.93	29.32 b	37.25 b
G_2 (50 ppm)	7.18	16.93	31.71 a	39.71 a
G_3 (100 ppm)	7.02	17.05	30.89 a	38.07 ab
CV (%)	1.55	1.71	4.38	7.08
LS	NS	NS	**	*
$LSD_{0.05}$	0.09	0.25	1.14	2.29

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

Legend:

*= 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
NS = Non significant

G_1 = 0 ppmGA_3 (Control)
G_2= 50 ppm GA_3
G_3 = 100 ppm GA_3

4.1.3 Interaction effect of IAA and GA_3

The application doses of indole acetic acid (IAA) and gibberellic acid substantially affected the plant height of lentil at all sampling dates (40 DAS, 60 DAS and at harvest) (Table 3). The highest plant height (35.42 cm and 44.00 cm) was observed from I_3G_2 treatment at all sampling dates (60 DAS and at harvest after IAA and GA_3 application). The lowest plant height (7.02 cm, 16.74 cm, 24.29 cm and 34.21 cm) was observed from I_1G_1 (0 ppm IAA and 0 ppm GA_3) treatment at 20 DAS, 40 DAS, 60 DAS and at harvest, respectively.

Table 3: Interaction effect of IAA and GA_3 on plant height of lentil at different days after sowing

Interaction of doses of IAA and GA_3		Plant Height (cm)			
		20 DAS	**40 DAS**	**60 DAS**	**At harvest**
	G_1	7.02	16.74	24.29 g	34.21 d
I_1	**G_2**	7.20	16.85	26.59 f	36.09 cd
	G_3	7.00	16.88	26.23 fg	34.26 d
	G_1	6.95	17.05	29.72 e	36.82 cd
I_2	**G_2**	7.18	16.85	31.53 cde	38.21 bcd
	G_3	7.09	17.22	30.39 de	37.00 cd
	G_1	6.95	17.08	32.46 bcd	39.64 abc
I_3	**G_2**	7.17	17.17	35.42 a	44.00 a
	G_3	6.99	17.21	34.33 ab	41.67 ab
	G_1	6.96	16.83	30.82 cde	38.33 bcd
I_4	**G_2**	7.15	16.85	33.67 ab	40.54 abc
	G_3	6.98	16.88	32.67 bc	39.36 bc
	CV (%)	1.55	1.71	4.38	7.08
	LS	NS	NS	*	*
	$LSD_{0.05}$	0.18	0.49	2.27	4.59

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
NS = Non significant

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA
G_1 = 0 ppmGA_3 (Control)
G_2= 50 ppm GA_3
G_3 = 100 ppm GA_3

4.2 Number of branches plant^{-1}

4.2.1 Effect of IAA

The number of branches plant^{-1} was significantly affected by the application of IAA in lentil (Table 4). The maximum number of branches plant^{-1} (5.9 and 6.87) was observed at T_2 treatment (IAA applied at 40 DAS and 60 DAS), whereas the minimum (3.23) was attained at T_1 treatment (IAA applied at 20 DAS) and this was statistically significant with other treatments. The finding of the study was coined with the observation of Prasad *et al*. (2023), where they noticed that number branches plant^{-1} was significantly enhanced by the application of IAA in lentil.

Table 4: Effect of IAA on number of branches plant^{-1} of lentil at different days after sowing

Doses of IAA	Number of branches plant^{-1}		
	20 DAS	40 DAS	60 DAS
I_1 (0 ppm)	3.23	5.07 b	6.04 b
I_2 (25 ppm)	3.23	5.61 ab	6.66 a
I_3 (50ppm)	3.36	5.90 a	6.87 a
I_4 (75 ppm)	3.23	5.48 ab	6.66 a
CV (%)	6.93	12.06	5.77
LS	NS	*	**
$LSD_{0.05}$	0.22	0.65	0.37

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
NS = Non significant

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA

4.2.2 Effect of GA_3

The number of branches plant^{-1} of lentil varied significantly due to gibberellic acid application. It was observed that T_2 treatments (IAA applied at 40 DAS and 60 DAS) produced highest number of branches (5.69, 6.78) (Table 5). It was observed that the lowest number of branches (3.24) at 20 DAS which was statistically similar with G_3 treatments (20 DAS). Different doses produced different numbers of branches on the basis of their genetic characteristics of lentil. From the statistical analysis, total branches plant^{-1} showed significant variation at 5 % level of probability.

Table 5: Effect of GA_3 on number of branches $plant^{-1}$ of lentil at different days after sowing

Doses of GA_3	Number of branches $plant^{-1}$		
	20 DAS	40 DAS	60 DAS
G_1	3.30	5.33	6.34 b
G_2	3.24	5.69	6.78 a
G_3	3.25	5.52	6.54 ab
CV (%)	6.93	12.06	5.77
LS	NS	NS	*
$LSD_{0.05}$	0.19	0.56	0.32

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
LS = Level of significance
CV = Co-efficient of variance
LSD = Least Significant Difference
NS = Non significant

G_1 = 0 ppmGA_3 (Control)
G_2= 50 ppm GA_3
G_3 = 100 ppm GA_3

4.2.3 Interaction effect of IAA and GA_3

Interaction of application of doses of indole acetic acid (IAA) and gibberellic acid (GA_3) showed a significant difference on number of branches $plant^{-1}$ of lentil (Table 6). The maximum number of branches $plant^{-1}$ (3.60 and 6.10) was observed from I_3G_1 treatment which is interaction of 50 ppm of indole acetic acid and 0 ppm of GA_3 applied at 20 and 40 days after sowing (DAS) and at 60 DAS, it showed the highest result in I_3G_2 treatments (7.23). The minimum number of branches $plant^{-1}$ (3.10) was observed from I_3G_3 treatments (at 20 days after sowing) (Table 6).

Table 6: Interaction effect of IAA and GA_3 on number of branches $plant^{-1}$ of lentil at different days after sowing (20, 40 and 60 respectively)

Interaction of doses of IAA and GA_3		Number of branches $plant^{-1}$		
		20 DAS	**40 DAS**	**60 DAS**
	G_1	3.20	4.70 b	5.93 d
I_1	**G_2**	3.20	5.41 ab	6.13 cd
	G_3	3.30	5.10 ab	6.07 d
	G_1	3.20	5.40 ab	6.37 bcd
I_2	**G_2**	3.20	5.70 ab	6.87 ab
	G_3	3.30	5.73 ab	6.73 abc
	G_1	3.60	6.10 a	6.57 bcd
I_3	**G_2**	3.37	5.87 a	7.23 a
	G_3	3.10	5.73 ab	6.80 ab
	G_1	3.20	5.13 ab	6.50 bcd
I_4	**G_2**	3.20	5.80 ab	6.90 ab
	G_3	3.30	4.50 ab	6.57 bcd
	CV (%)	6.93	12.05	5.77
	LS	NS	*	*
	$LSD_{0.05}$	0.38	1.13	0.64

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
NS = Non significant

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA
G_1 = 0 ppmGA_3 (Control
G_2= 50 ppm GA_3
G_3 = 100 ppm GA_3

4.3 Pod number

4.3.1 Effect of IAA

The number of pod plant^{-1} was significantly influenced by the application of different doses of IAA in lentil (Table 7). The maximum number of pods plant^{-1} (38.82) was observed at T_3 treatment (IAA applied at 50 ppm), while the minimum number of pods plant^{-1} (35.72) was attained at T_1 treatment (control) (Table 7) which was statistically similar with T_2 (25 ppm IAA) and T_4 (75 ppm IAA) treatments. The result of the present study was consistent with the findings of Prasad *et al*. (2023), where they mentioned that number of pods plant^{-1} was substantially increased by the application of IAA in lentil.

Table 7: Effect of IAA on pod number, pod length (cm), seeds pod^{-1}, thousand seed weight (g) of lentil

Doses of IAA	Pod number	Pod length (cm)	Seed pod^{-1}	Thousand seed weight (g)
I_1	35.72 b	0.83 c	1.62 b	21.27 b
I_2	36.87 b	0.89 b	1.78 a	21.56 ab
I_3	38.82 a	0.96 a	1.83 a	21.89 a
I_4	35.83 b	0.95 a	1.78 a	21.39 b
CV (%)	3.48	4.06	3.70	3.14
LS	**	**	**	*
$LSD_{0.05}$	1.25	0.04	0.64	0.45

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

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA

4.3.2 Effect of GA_3

The concentrations of GA_3 is an important yield contributing factor which affect on the number of pods plant^{-1}. Among the concentrations of GA_3 with the 50 ppm of GA_3 produced the highest number of pods plant^{-1} (37.83) where 0 ppm of GA_3 produced the lowest number of pods plant^{-1} (35.81) (Table 8). GA_3 @ 200 ppm produced the highest number of pods plant^{-1} in peas (Singh *et al.* 2015).

Table 8: Effect of GA_3 on pod number, pod length (cm), seeds pod^{-1}, thousand seed weight (g) of lentil

Doses of GA_3	Pod number	Pod length (cm)	Seeds pod^{-1}	Thousand seed weight (g)
G_1	35.81 b	0.89 b	1.69 b	21.33 b
G_2	37.83 a	0.92 a	1.82 a	21.75 a
G_3	36.79 ab	0.92 a	1.75 b	21.51 ab
CV (%)	3.48	4.06	3.70	3.14
LS	**	*	**	*
$LSD_{0.05}$	1.09	0.03	0.06	0.39

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

NS = Non significant

G_1 = 0 ppmGA_3 (Control)

G_2= 50 ppm GA_3

G_3 = 100 ppm GA_3

4.3.3 Interaction effect of IAA and GA_3

The number of pods $plant^{-1}$ was significantly affected by the interaction of application of doses of indole acetic acid (IAA) and gibberellic acid (GA_3) (Table 9). The maximum number of pods $plant^{-1}$ (40.67) was recorded at I_3G_2 treatment (50 ppm IAA with 50 ppm GA_3) which was statistically different from other treatments. The minimum number of pods $plant^{-1}$ (35.00) was recorded at I_1G_1 (0 ppm IAA and 0 ppm GA_3) treatment (Table 9) which was similarly significant with I_4G_1 treatment.

Table 9: Interaction effect of IAA and GA_3 on pod number, pod length (cm), seeds pod^{-1}, 1000-seed weight (g) of lentil

Interaction of doses of IAA and GA_3		Pod number	Pod length (cm)	Seed pod^{-1}	Thousand seed weight (g)
	G_1	35.00 d	0.80 g	1.60 e	21.09 c
I_1	**G_2**	36.33 cd	0.85 efg	1.67 de	21.40 bc
	G_3	35.83 cd	0.84 fg	1.60 e	21.33 bc
	G_1	36.10 cd	0.89 def	1.70 cde	21.46 bc
I_2	**G_2**	37.67 bc	0.90 c-f	1.87 ab	21.70 abc
	G_3	36.83 bcd	0.91 b-e	1.78 ab	21.50 bc
	G_1	37.13 bcd	0.94 abcd	1.77 bcd	21.43 bc
I_3	**G_2**	40.67 a	0.99 a	1.90 a	22.30 a
	G_3	38.67 ab	0.97 ab	1.83 ab	21.95 ab
	G_1	35.00 d	0.93 a-d	1.72 cd	21.34 bc
I_4	**G_2**	36.67 bcd	0.96 ab	1.83 ab	21.59 abc
	G_3	35.83 cd	0.95 abc	1.78 bc	21.25 bc
CV (%)		3.48	4.06	3.70	3.14
LS		*	*	*	*
$LSD_{0.05}$		2.17	0.06	0.11	0.78

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
NS = Non significant

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA
G_1 = 0 ppmGA_3 (Control)
G_2 = 50 ppm GA_3
G_3 = 100 ppm GA_3

4.4 Pod length

4.4.1 Effect of IAA on pod length of lentil

The length of the pod of lentil varies significantly due to IAA treatments. The longer pod length (0.96 cm) (Table 7) was obtained from I_3 (50 ppm IAA) and it was similarly significant with I_4 treatment (75 ppm IAA). On the other hand, the shorter pod length (0.83 cm) was obtained from control treatment. It was concluded that the pod length was showed significant variation at 1 % level of probability. Similar findings have been reported for bread wheat (Hanna and Safa, 2019).

4.4.2 Effect of GA_3 on pod length of lentil

The pod length was significantly differed with application of different concentration of GA_3 in this study (Table 8). Nevertheless, among the concentration of GA_3, the application of 50 ppm of GA_3 produced the longest pod (0.92 cm) whereas 0 ppm of GA_3 produced the shortest pod (0.89 cm). At 100 ppm GA_3 produced pod length 0.92 cm which provided statistically equivalent to 50 ppm GA_3. Spray of GA_3 significantly increased pod length in okra (Thakur *et al.* 2020).

4.4.3 Interaction effect of IAA and GA_3 on pod length of lentil

It was observed that the interaction effects of doses of IAA and GA_3 treatments were significant on pod length of lentil (Table 9). At I_3G_2 treatments (50 ppm IAA and 50 ppm GA_3) it showed the highest pod length (0.99 cm) and at I_1G_1 treatments (control), it showed the lowest pod length (0.80 cm) of lentil. Regarding all yield attributing characters, 50 ppm of IAA and 50 ppm of GA_3 produced the greatest results under all circumstances.

4.5 Seeds pod^{-1}

4.5.1 Effect of IAA on seeds pod^{-1} of lentil

Different doses of IAA significantly influenced the number of seeds pod^{-1} in lentil (Table 7). The highest number of seed pod^{-1} (1.83) was obtained with the application of 50 ppm IAA dose (I_3) which was similarly significant with 25 ppm and 75 ppm of IAA. The lowest number of seeds pod^{-1} (1.62) was produced by 0 ppm IAA dose (I_1). This finding was consistent with those reported for *Vigna mungo* (Yasin *et al.* 2023).

4.5.2 Effect of GA_3 on seeds pod^{-1} of lentil

Significant variation was evident in the number of seeds pod^{-1} of lentil with different doses of GA_3. The maximum number of seeds pod^{-1} (1.82) was found with 50 ppm of GA_3 treatment (Table 8). On the other hand, the minimum number of seeds pod^{-1} (1.69) was found in G_1 (0 ppm of GA_3) which was statistically significant with G_3 (100 ppm GA_3) treatment. The result agreed with the findings of Saha *et al*. (2021) who demonstrated that GA_3 increased the yield of mustard at 50 ppm.

4.5.3 Interaction effect of IAA and GA_3 on seeds pod^{-1} of lentil

The interaction effect of doses of IAA and GA_3 significantly impacted on number of seeds pod^{-1} (Table 9). The highest number of seeds pod^{-1} (1.90) was obtained from 50 ppm IAA and 50 ppm GA_3 (I_3G_2) and the lowest number of seeds pod^{-1} (1.60) was recorded in 0 ppm IAA and 0 ppm GA_3 (I_1G_1) (Table 9) which was similarly significant with I_1G_3 treatments.

4.6 1000-seed weight (g)

4.6.1 Effect of IAA on 1000-seed weight of lentil

Several doses of IAA significantly improved 1000-seed weight (Table 7). The highest 1000-seed weight (21.89 g) was observed by the application of 50 ppm IAA (I_3) and the lowest 1000-seed weight (21.27 g) was recorded by the application of 0 ppm IAA (I_1) (Table 7) which was similarly significant with 75 ppm IAA (I_4). The findings were in line with the findings of Saha *et al*. (1996), who reported that IAA applied at the beginning of the tillering stage in wheat increased 1000 grain weight. Similar results were also reported by Yan *et al*. (1995).

4.6.2 Effect of GA_3 on 1000-seed weight of lentil

The 1000-seeds weight increased with increasing the concentration of $GA_{3.}$ Application of GA_3 at 50 ppm showed the highest 1000-seeds weight (21.75 g) (Table 8), while 0 ppm of GA_3 exhibited the lowest 1000-seed weight (21.33 g). This was because increasing of application dose of GA_3 increases the 1000-seeds weight of lentil. Similar trends had been reported for rice (Hanum *et al*. 2024).

4.6.3 Interaction effect of IAA and GA_3 on 1000-seed weight of lentil

The 1000-seeds weight is an important yield contributing character which has a great effect on final yield. The interaction effect of doses of IAA and GA_3 application on lentil resulted in statistically significant change in terms of quantity of 1000-seed weight. The plant treated with 50 ppm IAA and 50 ppm of GA_3 (I_3G_2 combinations) produced maximum weight of 1000-seeds (22.30 g) (Table 9). Whereas the minimum weight of 1000-seeds weight was recorded on 0 ppm IAA and 0 ppm GA_3 (I_1G_1). And the minimum weight was 21.09 g which was statistically different from other treatment combinations. The results of the study were partially in agreement with Khan *et al.* (2022).

4.7 Seed yield (t ha^{-1})

4.7.1 Effect of IAA

The end outcome of all the factors favoring better development, which effectively increases the yield plant^{-1} and ultimately, the yield hectare^{-1}. IAA dose has a significant impact on lentil seed production (Figure 2). However, applying IAA @ 50 ppm to lentil resulted in the highest seed yield (1.29 t ha^{-1}) and was statistically distinct from other treatments. At the application of 0 ppm IAA, the lowest seed yield (1.03 t ha^{-1}) was recorded where no IAA was used (I_1). The high yield of lentil that IAA contributes to, together with the fact that yield varies at different doses, may be attributed to a combination of management techniques, genetic factors and environmental factors.

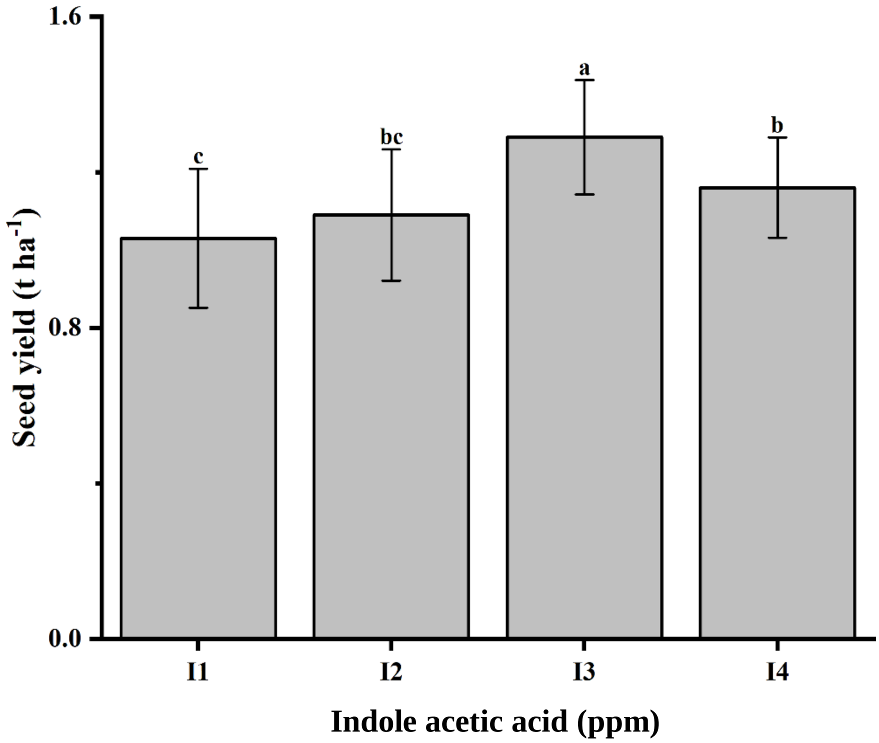

Figure 2: Effect of IAA on seed yield (t ha^{-1}) of lentil

4.7.2 Effect of GA_3

When GA_3 was applied at various doses, a significant difference in lentil seed production was seen (Figure 3). The results showed that G_2 @ 50 ppm had the highest seed yield (1.21 t ha^{-1}) and that G_1 had the lowest seed yield (1.06 t ha^{-1}) @ 0 ppm of GA_3. At 1 % level of probability, the statistical analysis showed a sizable variance in lentil seed yield.

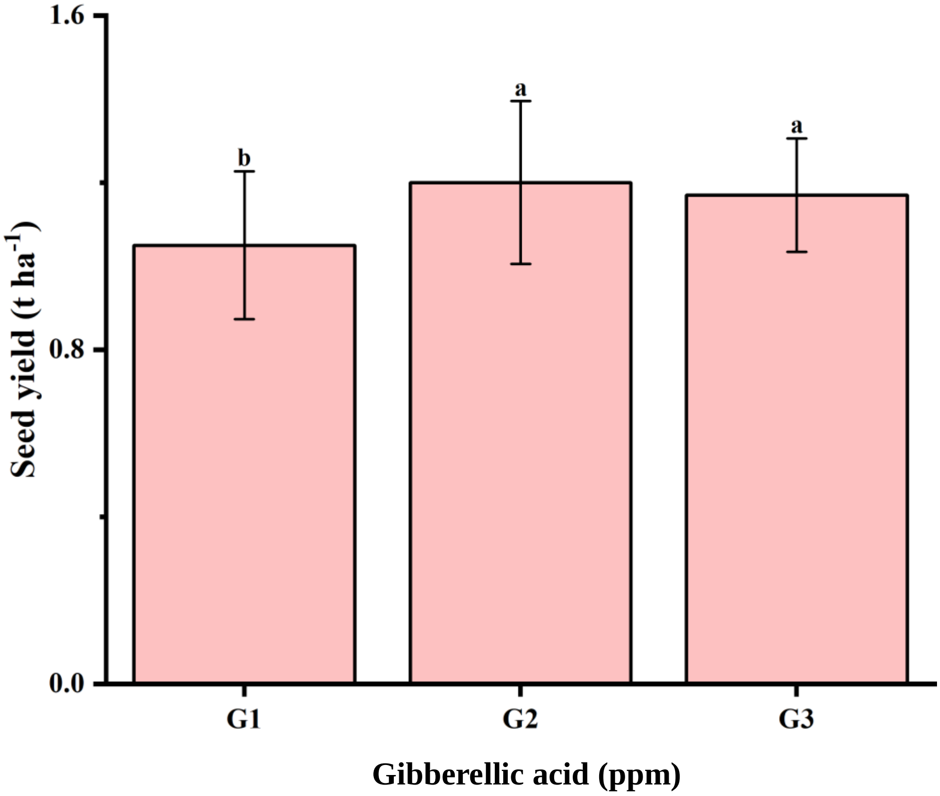

Figure 3: Effect of GA_3 on seed yield (t ha^{-1}) of lentil

4.7.3 Interaction effect of IAA and GA_3

When IAA and GA_3 were applied at various doses, a significant difference in lentil seed production was seen (Figure 4). The treatment combination I_3G_2 (50 ppm IAA and 50 ppm GA_3), which was statistically different from other treatment combinations, produced the highest seed production (1.43 t ha^{-1}). In contrast, the I_1G_1 treatment combination (without IAA and GA_3) yielded the lowest yield (0.96 t ha^{-1}).

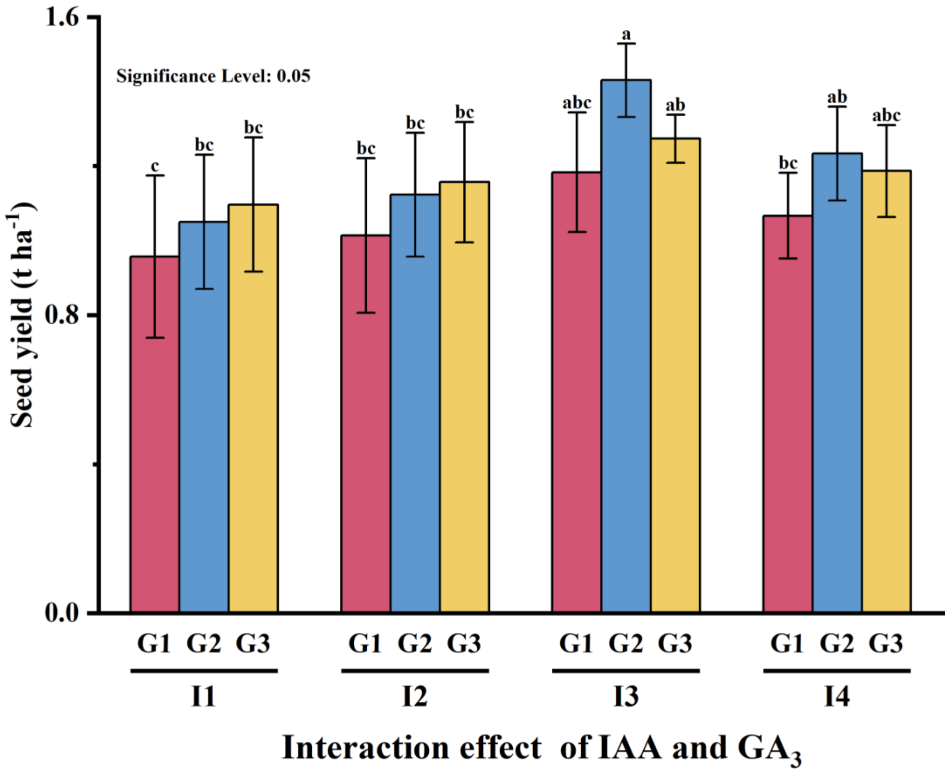

Figure 4: Interaction effect of IAA and GA_3 on seed yield (t ha^{-1}) of lentil

4.8 Stover yield (t ha^{-1})

4.8.1 Effect of IAA on Stover yield of lentil

A direct correlation exists between the growth in stover yield and the increase in vegetati ve development and, to a lesser extent, the reproductive component of the plants.

Different doses of IAA showed significant variation for stover yield of lentil demonstrated in Table 10. It was observed that the highest Stover yield (2.69 t ha^{-1}) was found at 50 ppm IAA (I_3 treatment) and the lowest one (2.43 t ha^{-1}) at 0 ppm IAA (I_1 treatment).

Table 10: Effect of IAA on stover yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index of lentil

Doses of IAA	Stover yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index (%)
I_1	2.43 c	3.47 c	29.82 b
I_2	2. 56 b	3.66 b	29.92 b
I_3	2.69 a	4.00 a	32.29 a
I_4	2.60 b	3.76 b	30.83 ab
CV (%)	4.70	4.48	7.67
LS	**	**	*
$LSD_{0.05}$	0.11	0.16	2.30

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

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA
NS = Non significant

4.8.2 Effect of GA_3 on stover yield of lentil

Stover production varies greatly due to different doses of GA_3 as seen in (Table 11). It was found that the highest stover yield (2.65 t ha^{-1}) was generated at 100 ppm GA_3 (G_3 treatment) and it was statistically similar with G_2 treatment (50 ppm GA_3). On the other hand, the lowest stover yield (2.46 t ha^{-1}) was generated at G_1 treatment (0 ppm GA_3). This may be because lower dose of GA_3 produces less branch, pod length etc. as a result decrease stover yield. Increased stover yield in mustard was also reported with the application of PGRs like GA_3 and Auxin (NAA) by Sumi *et al*. (2021).

Table 11: Effect of GA_3 on stover yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index of lentil

Doses of GA_3	Stover yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index (%)
G_1	2.46 b	3.52 b	29.86 a
G_2	2. 60 a	3.81 a	31.62 a
G_3	2.65 a	3.84 a	30.67 a
CV (%)	4.70	4.48	7.67
LS	**	**	NS
$LSD_{0.05}$	0.10	0.14	1.99

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

G_1 = 0 ppmGA_3 (Control)
G_2= 50 ppm GA_3
G_3 = 100 ppm GA_3
NS = Non significant

4.8.3 Interaction effect of IAA and GA_3 on stover yield of lentil

Due to diverse treatment combination of doses of IAA and GA_3, stover yield varied significantly (Table 12). The maximum stover yield (2.77 t ha^{-1}) was found to be produced by the treatment combination of I_3G_2 (50 ppm IAA and 50 ppm GA_3) which was statistically similar to I_3G_3 (2.73 t ha^{-1} @ 50 ppm IAA and 100 ppm GA_3) treatment combinations. The minimum (2.33 t ha^{-1}) stover yield was observed from I_1G (0 ppm IAA and 0 ppm GA_3) combination.

Table 12: Interaction effect of IAA and GA_3 on stover yield (t ha^{-1}), biological yield (t ha^{-1}) and harvest index of lentil

Interaction of doses of IAA and GA_3		Stover Yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index (%)
	G_1	2.33 e	3.29 g	29.06 b
I_1	G_2	2.43 de	3.48 efg	30.17 ab
	G_3	2.53 bcd	3.63 def	30.22 ab
	G_1	2.46 cd	3.47 fg	29.02 b
I_2	G_2	2.57 bc	3.69 cde	30.39 ab
	G_3	2.65 ab	3.81 bcd	30.34 ab
	G_1	2.57 a-e	3.75 cde	31.48 ab
I_3	G_2	2.77 a	4.19 a	34.06 a
	G_3	2.73 a	4.01 ab	31.34 ab
	G_1	2.50 c-f	3.57 def	29.88 b
I_4	G_2	2.63 a-e	3.87 bc	31.84 ab
	G_3	2.67 abc	3.85 bc	30.76 ab
	CV (%)	4.70	4.47	7.67
	LS	*	*	*
	$LSD_{0.05}$	0.20	0.28	3.99

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

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

I_1 = 0 ppm IAA (Control)
I_2 = 25 ppm IAA
I_3 = 50 ppm IAA
I_4 = 75 ppm IAA
G_1 = 0 ppmGA_3 (Control)
G_2= 50 ppm GA_3
G_3 = 100 ppm GA_3

4.9 Biological yield (t ha^{-1})

4.9.1 Effect of IAA on biological yield of lentil

Biological yield refers to the total biomass produced by a crop or a plant during its growth period. This includes all parts of the plant, such as stems, leaves, roots, and any other vegetative or reproductive structures. Biological yield was significantly influenced by IAA doses (Table 10). The highest biological yield (4.00 t ha^{-1}) was produced by 50 ppm IAA (I_3 treatment) which was significantly different from any other treatment. The lowest (3.47 t ha^{-1}) was observed at control (I_1 treatment) (Table 10). It was clear from this study that higher IAA dose gave higher biological yield. Similar results proved by Sadak *et al.* (2013) who reported that IAA treatments caused significant increases in biological yield $plant^{-1}$ of the two fababean cultivars.

4.9.2 Effect of GA_3 on biological yield of lentil

There was significant variation on the biological yield of lentil due to difference of GA_3 doses (Table 11). It was found that the highest biological yield of lentil (3.84 t ha^{-1}) was reported in G_3 (100 ppm GA_3) treatment, and it was statistically similar to G_2 (3.81 t ha^{-1} @ 50 ppm GA_3) treatment. On the contrary, the lowest biological yield (3.52 t ha^{-1}) was observed in the control treatment. From the statistical analysis, the seed yield of lentil showed significant variation at 1 % level of probability. Highest biological yield recorded (4383.20 kg ha^{-1} @ 200 ppm GA_3 from sunflower in the findings of Borra *et al.* (2021).

4.9.3 Interaction effect of IAA and GA_3 on biological yield of lentil

The interaction effect of application doses of IAA and GA_3 revealed significant variations on biological yield (Table 12). The highest biological yield (4.19 t ha^{-1}) was found from the interaction of 50 ppm of IAA applied and 50 ppm GA_3 (I_3G_2) and it was statistically different from any other treatment. The lowest biological yield (3.29 t ha^{-1}) was found from 0 ppm IAA dose applied and 0 ppm GA_3 (I_1G_1) (Table 12).

4.10 Harvest index (%)

The harvest index, which is reported to as a percentage, was determined from the seed yield to biological yield ratio.

4.10.1 Effect of IAA on harvest index of lentil

There was significant variation observed on harvest index on lentil for the effect of different doses of IAA treatments revealed that the highest harvest index (32.29 %) was recorded at I_3 treatment (100 ppm IAA) which was statistically dissimilar with other treatments (Table 10). On the other hand, the lowest harvest index (29.82 %) was attained at I_1 treatment (0 ppm IAA) and this was statistically similar (29.92 %) with I_2 treatment (25 ppm IAA).

4.10.2 Effect of GA_3 on harvest index of lentil

The doses of GA_3 did not have a significant impact on lentil harvest index (Table 11). The application of 50 ppm GA_3 to the BARI Moshur-7 resulted in the greatest harvest index (31.62 %), which was statistically significant with other treatments of GA_3 on lentil. The lowest harvest index was recorded (29.86 %) at no GA_3 treatment.

4.10.3 Interaction effect of IAA and GA_3 on harvest index of lentil

Use of IAA dose along with GA_3 dose significantly changed the harvest index (Table 12). The highest harvest index (34.06 %) was produced by the treatment combinations of I_3G_2 (50 ppm IAA and 50 ppm GA_3) and the lowest harvest index (29.02 %) was obtained from I_2G_1 (25 ppm IAA and 0 ppm GA_3) which was statistically similar to I_1G_1 (control) and I_3G_1 (50 ppm IAA and 0 ppm GA_3).

CHAPTER V
SUMMARY AND CONCLUSION

To evaluate the impact of yield and yield attributes of lentil as influenced by Indole-3-acetic acid and gibberellic acid, a field experiment was conducted at Agronomy research field of Hajee Mohammad Danesh Science and Technology University, during November 2023 to March 2024. The experiment was set up in randomized complete block design (RCBD) with three replications which comprised with four levels of Indole Acetic acid (D_1 = 0 ppm IAA (I_1= control, I_2 = 25 ppm IAA, I_3 = 50 ppm IAA, I_4 = 75 ppm IAA) and three levels of gibberellic acid (G_1 = control, G_2 = 50 ppm GA_3, G_3 = 100 ppm GA_3). There were 12 treatment combinations, such as- I_1G_1= 0 ppm IAA + 0 ppm GA_3, I_1G_2= 0 ppm IAA + 50 ppm GA_3, I_1G_3= 0 ppm IAA + 100 ppm GA_3, I_2G_1= 25 ppm IAA + 0 ppm GA_3, I_2G_2= 25 ppm IAA + 50 ppm GA_3, I_2G_3= 25 ppm IAA + 100 ppm GA_3, I_3G_1= 50 ppm IAA + 0 ppm GA_3, I_3G_2= 50 ppm IAA + 50 ppm GA_3, I_3G_3= 50 ppm IAA + 100 ppm GA_3, I_4G_1= 75 ppm IAA + 0 ppm GA_3, I_4G_2= 75 ppm IAA + 50 ppm GA_3, I_4G_3= 75 ppm IAA + 100 ppm GA_3.

Result revealed that the effect of doses of Indole-3-acetic acid significantly influenced the growth and yield parameters of lentil. For different application doses at 40, 60 days after sowing (DAS) and at harvest, the tallest plants (17.15, 34.07 and 41.77 cm) were recorded from I_3 (50 ppm IAA) treatment, while the shortest plants (16.82, 25.69 and 34.85 cm) were found from I_1 (control treatment) respectively but plant height at 20 DAS did not significant. At 40, 60 DAS and at harvest, the highest number of branches plant^{-1} were found from I_3 treatment (3.36, 5.90 and 6.86) whereas the lowest number of branches plant^{-1} was observed from I_1 (3.23, 5.07 and 6.04). The highest number of pod plant^{-1} was found from I_3 (38.82), whereas the lowest number of pod plant^{-1} was recorded from I_1 (35.72). The highest number of pod length was recorded from I_3 (0.96 cm) and the lowest one from I_1 (0.83 cm). The highest number of seeds pod^{-1} was recorded from I_3 (1.83), whereas the lowest number of seeds pod^{-1} was observed from I_1 (1.62) treatment. The highest weight of 1000-seeds was found from I_3 (21.89 g), while the lowest weight of 1000 of seeds was recorded from I_1 (21.27 g). The highest seed yield was recorded from I_3 (1.29 t ha^{-1}) and the lowest seed yield was observed from I_1 (1.03 t ha^{-1}). The highest stover yield was found from I_3 (2.69 t ha^{-1}), while the lowest stover yield was attained from I_1 (2.43 t ha^{-1}). The highest biological yield was observed from I_3 (4.00 t ha^{-1}), whereas the lowest biological yield was recorded from I_1 (2.43 t ha^{-1}). The highest harvest index was found from I_3 (32.29 %) and the lowest harvest index was observed from T_1 (29.82 %).

For different application doses of GA_3 at 60 days after sowing (DAS) and at harvest, the tallest plants (31.71 and 39.71 cm) were recorded from G_2 (50 ppm GA_3) treatment, while the shortest plants (29.32 and 37.25 cm) were found from G_1 (control treatment) respectively but plant height at 20 and 40 DAS did not significant. At harvest, the highest number of branches plant^{-1} were found from G_2 treatment (6.78) whereas the lowest number of branches plant^{-1} was observed from G_1 (6.34) but there were non-significant effects at 40 and 60 DAS. The highest number of pod plant^{-1} (37.83), pod length (0.92 cm), seeds pod^{-1} (1.82), weight of 1000-seeds (21.75 g), seed yield (1.21 t ha^{-1}) and harvest index (31.62 %) were recorded from G_2 (50 ppm GA_3) treatment except the highest stover yield (2.65 t ha^{-1}) and biological yield (3.84 t ha^{-1}) were found from G_3 (100 ppm GA_3). On the other hand, the lowest number of pod plant^{-1} (35.81), pod length (0.89 cm), seeds pod^{-1} (1.69), weight of 1000-seeds (21.33 g), seed yield (1.06 t ha^{-1}), stover yield (2.46 t ha^{-1}), biological yield (3.52 t ha^{-1}) and harvest index (29.86 %) were found from G_1 (0 ppm GA_3).

Due to combined effect of IAA dose and GA_3 dose on lentil at 60 DAS and at harvest, the tallest plants (35.42 and 44.00 cm) was observed from I_3G_2 (due to interaction of 50 ppm IAA applied with 50 ppm GA_3), while the shortest plants (24.29 and 34.21 cm) was found from I_1G_1 (due to interaction of 0 ppm IAA and 0 ppm GA_3) respectively but significant interaction effect did not found at 20 and 40 DAS. At 60 DAS, the highest number of branches plant^{-1} (6.10) was recorded from I_3G_1 (50 ppm IAA and 0 ppm GA_3) and at harvest it was recorded from I_3G_2 (7.23) which was the combination of 50 ppm IAA with 25 ppm GA_3. On the other hand, at 60 DAS, the lowest number of branches plant^{-1} (4.50) were recorded from I_4G_3 (75 ppm IAA and 50 ppm GA_3) and at harvest, the highest result (5.93) was found at I_1G_1 (0 ppm IAA and 0 ppm GA_3) but branch plant^{-1} at 40 DAS did not significant. The maximum results of pods plant^{-1} (40.67), pod length (0.99 cm), seeds pod^{-1} (1.90), weight of 1000-seeds (22.30 g), seed yield (1.43 t ha^{-1}), stover yield (2.77 t ha^{-1}), biological yield (4.19 t ha^{-1}) and harvest index (34.06 %) were recorded from I_3G_2 (50 ppm IAA and 50 ppm GA_3) treatment combination and gave the best result in some cases. On the other hand, the minimum results of pods plant^{-1} (35.00), pod length (0.0.80 cm), seeds pod^{-1} (1.60), weight of 1000-seeds (21.09 g), seed yield (0.96 t ha^{-1}), stover yield (2.33 t ha^{-1}), biological yield (3.29 t ha^{-1}) and harvest index (29.06 %) were found from I_1G_1 (0 ppm IAA and 0 ppm GA_3).

From the above findings it could be concluded as:

- For optimal yield, apply 50 ppm IAA on lentil.
- GA_3 @ 50 ppm can be effective for highest seed yield on lentil and for highest stover yield and biological yield, 100 ppm can be effective.
- The combination application of exogenous application of IAA @ 50 ppm and GA_3 @ 50 ppm (I_3G_2) can improve growth and production.

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APPENDICES

Appendix I: 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 II: 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 III: Analysis of variance (Mean square) of the data for plant height at different days after sowing (DAS) of lentil

Source of variation	Degree of freedom	Plant height (cm)			
		20 DAS	40 DAS	60 DAS	At harvest
Replication	2	5.003^{NS}	2.007^{NS}	27.175^{NS}	13.066^{NS}
Factor A	3	0.005^{NS}	0.214*	117.890**	78.171**
Factor B	2	0.139^{NS}	0.058^{NS}	17.629**	18.821*
Factor AB	6	0.004^{NS}	0.245^{NS}	0.471*	1.433*
Error	22	0.118	0.084	1.801	7.3629
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 IAA, Factor B= Dose of GA_3, Factor AB= dose of IAA× dose of GA_3
**= Significant at 1 % level of probability
*= Significant at 5 % level of probability
NS = Non-significant

Appendix IV: Analysis of variance (Mean square) of the data for number of branches plant^{-1} at different days after sowing (DAS) of lentil

Source of variation	Degree of freedom	Number of branches plant^{-1}		
		40 DAS	60 DAS	At harvest
Replication	2	0.0003^{NS}	2.124^{NS}	7.534^{NS}
Factor A	3	0.034^{NS}	1.074*	1.134**
Factor B	2	0.012^{NS}	0.389^{NS}	0.587*
Factor AB	6	0.069^{NS}	0.176^{NS}	0.042*
Error	22	0.051	0.443	0.143
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 IAA, Factor B= Dose of GA_3, Factor AB= dose of IAA× dose of GA_3
**= Significant at 1 % level of probability
*= Significant at 5 % level of probability
NS = Non-significant

Appendix V: Analysis of variance (Mean square) of the data for yield and other crop characters of lentil

Source of variation	Degree of freedom	Mean square values			
		Pod plant^{-1} (no)	Pod length (cm)	Seeds pod^{-1} (no)	1000- seed weight (g)
Replication	2	45.035^{NS}	0.215^{NS}	0.058^{NS}	0.073**
Factor A	3	18.568**	0.315**	0.075**	0.26**
Factor B	2	12.305**	0.004*	0.044**	0.123**
Factor AB	6	0.800*	0.0003*	0.002*	0.014*
Error	22	1.645	0.001	0.004	0.005
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 IAA, Factor B= Dose of GA_3, Factor AB= dose of IAA× dose of GA_3
**= Significant at 1 % level of probability
*= Significant at 5 % level of probability
NS = Non-significant

Appendix VI: Analysis of variance (Mean square) of the data for yield and other crop characters of lentil

Source of variation	Degree of freedom	Mean squire values			
		Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	0.173^{NS}	0.081^{NS}	0.032^{NS}	110.141^{NS}
Factor A	3	0.112**	0.102**	0.451**	11.824*
Factor B	2	0.079**	0.106**	0.373**	9.248^{NS}
Factor AB	6	0.007*	0.003*	0.015*	1.244*
Error	22	0.011	0.015	0.028	5.547
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 IAA, Factor B= Dose of GA_3, Factor AB= dose of IAA× dose of GA_3
**= Significant at 1 % level of probability
*= Significant at 5 % level of probability
NS = Non-significant

Appendix VII: Some pictorial views of my research work


সেন্ট্রাল ফার্ম